HANDBOOK FOR OX SKIDDING RESEARCHES

Martti Saarilahti & Paula Isoaho

The Finnish Forest Research Institute
Forestry Training Programme

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The handbook is aimed at research and field officers interested in developing at the animal timber transport. Time and work study techniques are presented and basic statistical methods are described. A theoretical frame of reference is developed for ox skidding and eight ox skidding studies are analyzed. In order to homogenisize the research carried out on different areas soil and terrain classification scheme are presented. Some methods for analyzing the socio-economic and environmental effects of animal skidding are referred.

Keywords: Ox, animal terrain transport, skidding, animal power, work study, productivity

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FOREWORD

This manual is based partially on Saarilahti´s lecture notes on Forest Engineering at Sokoine University of Agriculture, Morogoro, Tanzania. Data on oxen skidding production were compiled from Chamba (1984:I), Solberg & Skaar (1986:III), Rodriguez (1986:IV), Isoaho (1992:V), and Cordero (1988:VI). Additional data on load size were also compiled from FAO (1974:II), Cornelius & Broadley (1974:VII) and Heding & Ole-Meiludie (1979:VIII). Ms. Paula Isoaho studied oxen skidding in Zambia for her M.Sc. thesis.

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FWET is a project under the SIDA special programme for development and methodology. The project started in 1988 with the task to prepare a three-year special programme concerning working environment and techniques in forestry in developing countries. The first document produced in the project was a survey of activities and literature on the subject prepared by Jonas Cedergren and published by Department of Operational Efficiency, Swedish University of Agricultural Sciences in Garpenberg (Uppsatser och Resultat 140, 1989).

Country projects have been prepared by country representatives from Lao PDR, Nicaragua and Tanzania and preparatory field activities have started during the budget year 1990/91. The overall objective of the project is to contribute for improved working environment, techniques and efficiency in forestry operations in developing countries.

Within the framework of the FWET-project it is the intention to publish technical reports as a mean to disseminate interesting results from the project and elsewhere.

Bengt Frykman
FWET Project Coordinator

Jari Parviainen
FFRI, Research Director

Earlier issues of FWET Technical Report:

FWET Technical Report 1: The use of draught animals in forestry - a survey of literature by Lars Hedman, SUAS/IRDC Working Paper 166, 1991.

FWET Technical Report 2: Preconditions for improvement of working and living conditions in forestry work in developing countries by Bo Ohlsson, SUAS/IRDC Working Paper 180, 1991.

FWET Technical Report 3: Checklist for better working environment and safety in small and mobile sawmills by Rolf Almqvist, SUAS/IRDC Working Paper 205, 1992.

1. INTRODUCTION

Labour-intensive primary transport methods which use manual or animal traction are widely recommended for different conditions in forestry at developing countries. Mechanised methods, however, are often preferred to labour-intensive ones. One reason is that labour intensive methods are not used to their full advantage and the planning and supervision are neglected. This results in low productivity and high costs, giving the advantage to machines. Good planning is based on reliable methods for target setting. Time and work studies are used in improving productivity by evaluating the factors affecting productivity. Traditionally, comprehensive work studies are substituted by narrower time studies, and not all the advantages are made use of. This paper aims at improving the research methods in animal primary transport in order to obtain more reliable data for decision making.

This manual is aimed both at research officers involved in large development projects and forest officers interested in improving the productivity of their everyday activities. The need for this kind of manual is evident. The principles of work and time studies will be adopted during professional studies, but most of the details will be forgotten thereafter. On the other hand, teaching at colleges and universities is seldom detailed enough to permit the development of comprehensive research concepts for specific research projects, such as animal primary transport, for example. There are different types of research reports and manuals for time studies and statistical analysis, but these are not readily available on a forest camp. Therefore different types and levels of data have been compiled. Results from other studies are also analysed, so that the data from this study can be evaluated and compared with existing data.

2. WORK STUDY METHOD

In manual and animal primary transport the energy is produced by a living organism. Therefore the system becomes more complicated as different physiological and psychological processes regulate the output, not only the position of the acceleration lever as in motorised work. The basic task of forest work science is to analyse the relations between mutable working conditions and the performance corresponding to these conditions, using generally accepted statistical methods. One of the most important means of work science is the work study. This can be defined as a generic term for those techniques which are used in the systematic examination of human work in all its contexts and all the factors affecting its efficiency and economy in order to effect improvement. Work science includes the social, psychological and physiological aspects of a worker at work, as well as the technical working conditions. Its purpose is to develop both existing methods and new improved ones, to gain information and knowledge on the time consumption and performance at work and to improve working conditions. The time study is one of the most common practices of work measurement used to determine the input of time in the production process.

Operational efficiency and ergonomic conditions in forestry are closely linked. Logging operations are heavy, often so heavy that the physical work capacity of the workers puts a practical limit on the work output. Ergonomics aims at "fitting the job to the worker", or better, at "optimising man-task-systems" in order to promote the worker's health, well-being, and efficiency. The work science methods are thus directly applicable into manual work, but the broad principles can be applied to animal work as well.

21. Time studies

The time study is a form of work study aimed at the assessment of time consumption. Two broad types of work study techniques are generally recognised:

- time study or detailed time study
- gross data analysis or shift level time study

In the detailed time study the work is segregated into small elements and the time and the production registered by elements, usually by observing an individual. In gross data analysis only the total time spent on the work site is observed and the total production is recorded, usually observing the whole crew at a time. Gross data analysis is often neglected and considered less scientific. However, a thorough analysis of long-term production statistics will provide reliable information in the factors affecting production on real working conditions. The detailed time study, with short time observations, is applicable when developing methods and theories, while the shift level time study, with long time observations, can be applied for developing organisation and for testing models. It is not always necessary to examine the whole working cycle if only part of the operation is under investigation, e.g. loading.

211. Timing methods

The manual timing methods used in forestry can be classified as follows:

a) Continuous (cumulative) timing
The time is recorded continuously and the elements are the difference between recorded times. Continuous timing is an easy method to adopt for long cycle times. No special watches are needed (an ordinary digital wrist watch is enough), and it is possible to monitor errors.

b) Repetitive (snap-back) timing
Recording of very short elementary times is possible only when using snap back timing. The stop-watch is snapped back to 0 at the end of each time element. Each of the recorded times gives the time of each element directly. Snap-back timing is a recommended timing method mainly for an experienced measurer. Repetitive timing is applicable for recording short work elements, and a special stopwatch is needed. In

animal skidding research, repetitive timing is not necessary, except for some special studies.

In addition, **automatic time registration** is used, especially for machine work. The simplest forms are instruments which record the time the machine is running, or standing still, by means of vibration. Other instruments record the driving speed, the power, the rpm, etc. with respect to time.

212. Time concepts

The terminology associated with time studies in forestry has been reasonably well standardised. The Nordic Forest Work Study Council (NSR 1978) has published a nomenclature for application to forest work studies. The structure of basic time concepts used in forestry is presented in Appendix 1.

Work place time (WPT) is the time spent in performing a task at a working place. It is divided into **productive** (effective) time and **delay** times.

Productive time is usually considered to be composed of two kinds of activities.

> Direct time (main-time) is the time of the work element which directly changes a work object in form, position or state. (E.g. loading in oxen skidding.)
>
> Indirect time (by-time) is the time for the work element which only indirectly changes the work object. (E.g. opening the skidding trail in oxen skidding.)

Delay time (non-productive time) is defined as an interruption that interferes with the continuity of a performance. The delay time can be divided into:

> Unavoidable (necessary) delay which is an inevitable interruption due to the nature of work and its continuity on rational lines. (E.g. hitting an obstacle which could not have been avoided.)
>
> Avoidable (unnecessary) delay which is unnecessary in rational work or working methods, and which can be avoided. (E.g. hitting an obstacle due to a steering mistake.)

22 .Two schools of work study techniques

There are two schools in forest work studies. The influence of teams (workers) can be taken into account (or be eliminated) in different ways according to the school of forest work science. The schools differ in their approach to eliminating the influence of teams on production rates, called:

- performance rating, and
- comparative time study schools.

The first one, directly employing the time and motion study technique developed for industrial needs, is widely used in Central Europe (for example in the U.K.). The latter is developed for more varying conditions, and is mainly used in the Nordic countries.

Performance rating

Concept of rating

In the performance rating method the variation between workers is eliminated using a performance rating, which is a classification system to assess workers according to their work pace. When using the same method, different men produce different outputs, and most men's rate of output will vary at different times of the day. With time studies both those changes due to the operator as well as those due to the method must be considered. This is done by means of a rating.

Standard time

Standard times are set for skilled and accustomed workers using the right method and motivated to apply themselves to their work. It follows that time studies are not carried out on workers unless they have become skilled in the job under review and are working under some satisfactory incentive scheme. This reduces the range of variation considerably, but variations in output are still found. These variations in output can be due to variations in method, differing degrees of control over actions, or different rates of working. So these allowances in output are called the rating. There are different rating methods, but the principle is as follows:

A standard rating of 100 (normal rate) is used, and different corrections are made for rating and effort and rating and fatigue.

> *Rating and effort*: the rating is based on speed of movement, but assessment should be made relative to what the speed would be at the 100 rating. This will depend on weight carried, etc. and is therefore not always the same velocity.
>
> *Rating and fatigue*: in order to be able to maintain a constant pace over long periods, the compensation for fatigue is given in relaxation allowance. Relaxation allowance is defined as **an addition to the basic time** intended to provide the worker with the opportunity to recover from the physiological and psychological effects of carrying out specific work.

In addition to the relaxation allowance, the ILO (1979) handbook enumerates the following allowances to be added to the net times (effective times):

- contingency allowance
- policy allowance
- special allowance
- learning allowance

The principle of adding allowances to the net times is described in Chapter 42.

Basic time
Basic time is calculated from observed time recorded during the studies and the rating is as follows:

$$\text{Basic time} = \text{Observed time} * \frac{\text{Rating}}{100} \qquad (2.1)$$

Comparative time study

The basic statement in comparative time studies is that the relative time consumption between different working methods and conditions is constant and independent of the worker. The comparative time study is based on relative time consumption and is aimed to compare different working methods or conditions. There is no "standard", but a kind of standard is nevertheless set either by negotiation (between employer and employees), or collecting a wider range of data using productivity studies, etc.

23. Measuring force, work and power

The SI-system is already widely accepted, but units other than SI units are used in research reports. It is recommended that more emphasis should be put on using standardised SI-units. Some of the most common conversion factors are given in Appendix 2.

The SI-unit for ***force*** is the **Newton (N)**. It is the force needed to accelerate a mass of 1 kg to a velocity of 1 m/s in one second. The most common force is gravity which accelerates a mass of 1 kg to the velocity of 9.81 m/s in one second. When lifting a body with a mass of 1 kg a force of 9.81 N must be generated[1].

Forces can be measured using a sprung weight or load cells. Weighing a mass with a sprung weight is nothing but measuring the gravity force acting on it. If the mass is lying on a horizontal surface and the sprung weight is parallel to the surface, the frictional force is measured (see Fig. 1).

[1] For practical applications, 1 kg mass equals 10 N gravity force (weight) can be used; the error is <2%

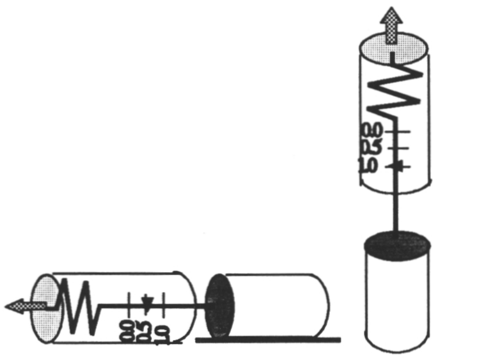


Figure 1. Measurement of forces by sprung scale.

A sprung scale is practical for smaller applications and static work measurements. In skidding, the changes in force are rapid and ocular reading of a dial is difficult. Therefore a sprung weight has a reduced field of application. The advantage is that it is cheap and readily available. It is an accurate enough method to measure the forces encountered in oxen skidding. A maximum reading indicator is useful for some applications.

An electronic measuring system consists of different types of transducers which convert the changes of some physical quantity into changes in electric current. A strain gauge is a typical transducer. Stress due to a certain force tends to strain a piece of metal, reducing its surface area. According to Ohm's law the resistance of a metal body depends on its length and surface area. In a strain gauge a thin metal film is glued to the surface of a metal rod and the variations in resistance in this metal film due to minor strains in the metal rod are measured and converted into the corresponding force (Fig. 2).

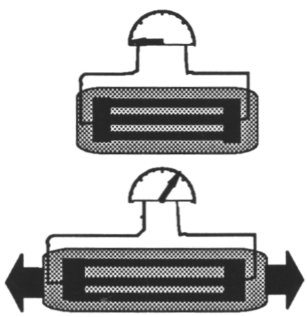


Figure 2. Principle of the strain gauge.

For more advanced research an electronic force recording system can be used. The principle is as presented in Fig. 3. The cost of (outdoor) computers, dataloggers, A/D-cards and programs varies largely, but prices are coming down and systems improving all the time. Continuous recording offers some advantages, especially for comprehensive work studies as the variation in the phenomenon can be recorded and analysed later. It is therefore advisable to study the possibility of developing electronic measuring systems for larger development projects.

The SI-unit for ***work*** is the **Joule (J)**. One Joule is equivalent to the force of 1 N acting over a distance of 1 m, J is thus distance multiplied by force, or Nm. One joule is equivalent to a mass of 1/9.81 kg being lifted to a height of 1 m. The Joule is also used for energy, and the old unit of energy, calorie (cal), is to be disregarded. Work can be measured by measuring force and distance separately.

The SI-unit for ***power*** is the **Watt (W)**. It describes the rate of doing work and is measured as the work done in a unit of time. 1 W is one joule per second. If a mass of 1/9.81 kg is lifted to a height of 1 m in one second then the power has been 1 W. Power is force times velocity (P=F*v), and can be measured by recording force, distance and time.

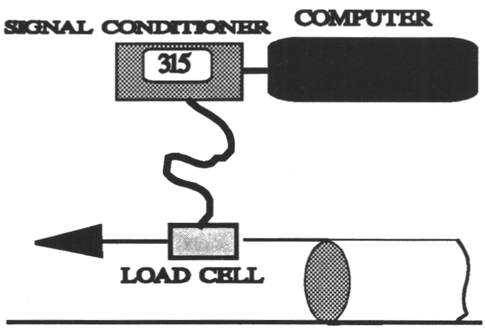


Figure 3. Electronic force recording system.

The SI-unit for ***time*** is the **second (s)**. In time studies the minute (min) and the centiminute, (cmin = min/100) (min.cmin)[2] can also be used even though they are not SI-units. It should be considered, if times are to be converted into seconds before data analysis, especially in cases where time has been recorded in minutes and seconds (min:s) using a normal digital wristwatch. It will ease the data processing, especially if power is being studied. When writing the report, some important times can be converted back into minutes in order to make them more easily adaptable for practical applications. **Day (d)** is a 24 h period, and can be used in production rates. **Month (mo)** is useful in reports aimed at practical applications. Note the abbreviation for **year** is **a** (annum), not yr.

The basic SI-unit for ***distance*** is the **metre (m). mm** and **km** are multiplication's of SI-units of distance and recommended SI-units should always be used in work studies. Log diameters may be recorded in centimetres, but for calculations it is more rational to convert them into metres or millimetres before data processing.

Volume is best converted into $\mathbf{m^3}$. Litre (L)[3] is recommended for liquids only, but can be used for volumes, specially when loads consist of small logs.

24. Basic geometry

A mathematical approach is useful when modelling physical phenomena. In oxen skidding studies, for example, the division of active forces into components is essential. This division can be calculated by means of the following trigonometric functions (Fig. 4).

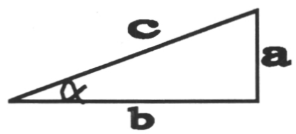


Figure 4. Trigonometry.

$$\sin\alpha = \frac{a}{c} \qquad \cos\alpha = \frac{b}{c}$$

$$\tan\alpha = \frac{a}{b} \qquad \cot\alpha = \frac{b}{a}$$

where

α	is the angle between two sides of a triangle
a,b, and c	are lengths of the sides of a triangle

---

[2] In order to avoid confusion note that times recorded in minutes and centiminutes are expressed as min.cmin (2.75). Time recorded in minutes and seconds is expressed in min:s (2:45)

[3]ASAE recommends the abbreviation "L" instead of "l"

25. Regression analysis

Regression analysis is a statistical procedure useful for fitting a mathematical equation to a set of observed data. Just as important as data collection is its analysis. Results of the analysis are used to estimate production rates and skidding costs and factors affecting them. However, some pitfalls of regression analysis should be avoided:

- the linearity of the model should be checked using residual analysis. If the residuals seem biased, **non-linear models** should be tested,
- if independent variables are **intercorrelated**, the validity of the model worsens,
- **additive** or **multiplicative** models must be predetermined based on a logical frame of reference,
- **extrapolation** of the model beyond the data range may lead to wrong decisions.

An example of calculating a simple regression equation without a computer is presented in Appendix 3.

Linearity

The linearity can often be determined. For example, if the velocity is constant, then the time is a linear function of distance. If the linear time model seems to be biased, then there must be a reason why the velocity changes during skidding. But as the production rate is of the form $\frac{1}{a+b*d}$ it cannot be analysed by linear models.

There are advanced commercial regression analysis packages which include tests for the residuals. They can be used, but it is often sufficient to plot residuals and observe the distribution visually. If there seems to be no bias, the model is acceptable (Fig. 5). If there is a noticeable bias (residuals are not randomly distributed on both sides of 0 on the X axis) a non-linear model must be developed (Fig. 6). It can be done either by transformation or by adding X^2 and/or X^3 terms.

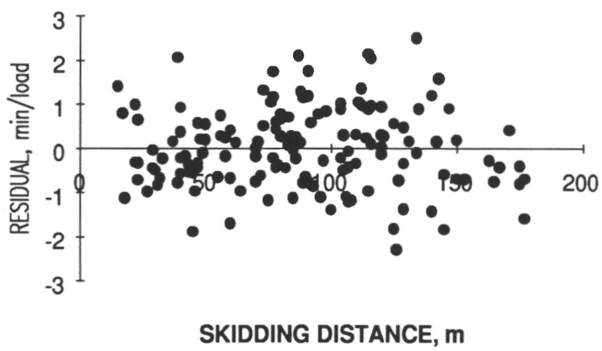


Figure 5. Residuals of skidding cycle time against skidding distance; linear model acceptable.

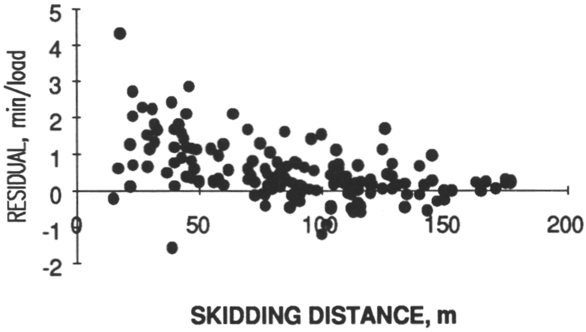


Figure 6. Residuals of a non-linear phenomenon after testing a linear model. Linear model not acceptable.

Common transformations of regression models are:

<u>ln transformation</u> (Fig. 7):

- if the increase in Y seems to be smaller for grater values of X (degressive function) tending to have a horizontal asymptotic value, a **ln**(Y) transformation can be attempted. Instead of using Y as an independent variable, it is replaced by **ln**(Y). The model becomes

$$Y = \mathbf{exp}^{a+b*X} \qquad (2.2)$$

- if the increase of Y seems to be greater for grater values of X (progressive function) tending to have a vertical asymptotic value, a **ln**(X) transformation can be attempted. The model becomes

$$Y = a + b*\mathbf{ln}(X) \qquad (2.3)$$

- in some cases the ln-ln transformation yields the least bias; both X and Y are replaced by their logarithms, **ln(Y)**, **ln**(X).

$$Y = \exp^{a*x^{b}} \qquad (2.4)$$

- if the form of the function seems to have both horizontal and vertical asymptotes then a $\frac{1}{X}$ transformation can be attempted. The model becomes

$$Y = a + \frac{b}{X} \qquad (2.5)$$

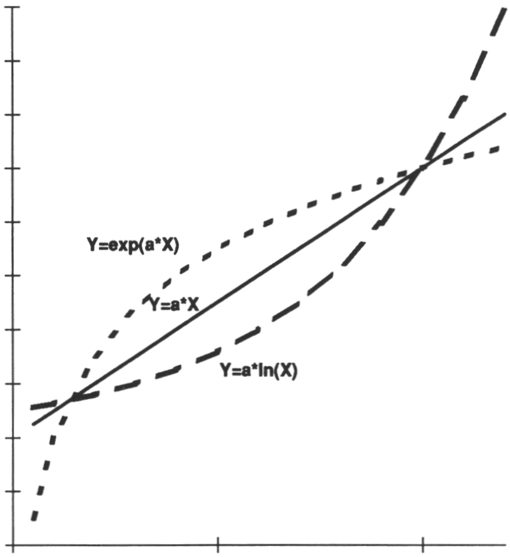


Figure 7. General form of different functions.

Intercorrelation:
If there is intercorrelation between independent variables the conclusions may be erroneous. If the load size, for example, is smaller on steeper slopes the influence of slope and load cannot be distinguished, only their intercorrelation. In work studies, designed to analyse the influence of each factor normal work is not the best data source, rather a deliberately arranged sample with large and small loads on steep and gradual slopes over short and long distances.

Extrapolation:
Extrapolation of a model beyond the data range may lead to wrong decisions, even if the model fits well with the data. This is especially true when linear black-box models are fitted into a non-linear phenomena using a narrow data range. For example, Solberg & Skaar (1986) give the following return time model for an area where the distance varied from 60 to 125 m ($\overline{x}$=87):

$$t_R = -764 + 14.89*d \qquad (2.6)$$

where

t_R is return time, cmin
d is return distance, m

The model gives negative times for short distances < 50 m and cannot be extrapolated for distances under about 60 m.

26. Modelling

The principles in the construction of models for forest work are classified as follows:

- Black-box modelling follows the tradition of natural sciences. A large amount of empirical data is collected, and the statistical dependencies between different variables are studied. The model is constructed based on main dependencies.

- Mathematical modelling is generally used in physics and engineering. First a model is developed. The missing elements, some constants, are determined empirically, and/or the whole model is only tested against empirical data.

When working out models it is essential to distinguish between additive and multiplicative models.

Let us consider loading as an example of an **additive model**. A certain time, ***b*** seconds, is needed to collect one piece of timber for a load. The total time for collecting a load is ***b**n*** seconds if the number of pieces is n. After collecting an adequate number of logs, the load is attached to the chain. Assuming that the time depends on the load size (a heavier load is more difficult to handle), then the hooking time is ***c**V*** where ***c*** is the time to handle 1 m• of timber and V is the load size. Generally some fixed preparatory time, ***a*** seconds, is needed for handling oxen at the stump site, for example. The loading time model consists of different independent parts which can be added up:

$$t = a + b*X_1 + c*X_2 \quad (2.7)$$

In a **multiplicative model** the influence of different independent variables (load, distance, slope, etc.) cannot be separated independently as they depend on each other. For example, velocity can be dependent on slope and load volume. Let us assume a simplified situation where velocity is linearly dependent on slope or volume. If the velocity is kept constant, then the black-box time model (Y is time and X_1 is distance) is:

$$Y = a + b*X_1 \quad (2.8)$$

where

a is a certain fixed time

b is the slope angle, $\frac{1}{v}$

Assuming that the slope angle ***b*** (inverse of velocity) depends linearly on the load size (X_2) we obtain the following model for the slope angle

$$b = a_1 + b_1 * X_2 \quad (2.9)$$ [4]

[4] Note that a_1 may be 0

If we combine eq. (2.9) with eq. (2.8) we obtain:

$$Y = a + (a_1 + b_1 * X_2) * X_1 \tag{2.10}$$

or

$$Y = a + a_1 * X_1 + b_1 * X_2 * X_1 \tag{2.11}$$

27. Introduction to mathematical modelling

The principles of constructing a production rate model are enlightened by developing a simple oxen skidding model on level ground. The production rate in oxen skidding can be described by the following model

$$P = \frac{1}{t} * L_{vol} \tag{2.12}$$

where

P	is production rate, m^3/s
t	is cycle time, s
L_{vol}	is load size, m^3

The production rate can be determined if the cycle time and the load size are known. Obviously the model can be composed of two submodels, a cycle time model and a load size model. In many studies modelling of the load size is neglected and it is replaced by an empirically observed (average) load size.

Cycle time model

Term $\frac{1}{t}$ is the number of loads per time unit. If the production rate is expressed as m^3 per hour and the cycle time has been recorded in seconds, the term becomes $\frac{3600}{t}$. If the cycle time is recorded in minutes (and centiminutes), the term becomes $\frac{60}{t}$.

The cycle time is the sum of elementary times. The breakdown in its simplest form is as follows:

$$t = t_R + t_L + t_S + t_U + t_D \tag{2.13}$$

where

t	is cycle time, s
t_R	is return empty time, s
t_L	is loading time, s
t_S	is skidding time, s
t_U	is unloading time, s
t_D	is delay time, s

Elementary times can be assessed from time studies, surveys of literature, or by theoretical models. Principles for constructing more realistic elementary time models are discussed in Chapter 34.

Return time (t_R)
From experience[5] we know that the walking velocity of an ox is 3 km/h (0.83 m/s). By definition,

$$v = \frac{d}{t} \tag{2.14}$$

where
- v is velocity, m/s
- d is distance, m
- t is time, s

Solving time from eq. (2.14), and applying it for t_R, produces the following general model for return time:

$$t_R = \frac{d}{v_R} \tag{2.15}$$

where
- t_R is return time, s
- d is distance, m
- v_R is return velocity, m/s

Skidding time (t_S)
The same principle applies for skidding:

$$t_S = \frac{d}{v_S} \tag{2.16}$$

Loading time (t_L)
Loading time is difficult to guess. In Chamba's (1984) study[6] the average loading time was from 4 to 5 minutes (240-300 s).

$$t_L = 240 \tag{2.17}$$

Unloading time (t_U)
Let us allow 1 minute[7] (60 s) for unloading.

$$t_U = 60 \tag{2.18}$$

---

[5] Example of empirical data.
[6] Example of literature survey.
[7] Example of educated guess.

Other times
Let us add 15 s contingency allowance for each element.

Cycle time (t)
Adding eq. (2.15) ... (2.18) and letting v=0.833, the following cycle time can be calculated

$$t = (\frac{d}{0.833}+15) + 255 + (\frac{d}{0.833}+15) + 75 \qquad (2.19)$$

and further

$$t = 360 + 2.4*d \qquad (2.20)$$

where

- t is cycle time, s
- d is distance, m

Load size model

Load size is largely dependent on the pull of the oxen and the slope. Load size can be estimated based on work studies, surveys of literature, or theoretical models. Load size models are discussed in Chapter 343. As an example the principles are presented for constructing a simple load size model. In order to keep the log moving on the ground, the pull generated by the oxen must be equal to the resisting forces due to log/soil friction.

$$F_O = F_R \qquad (2.21)$$

where

- F_O is pull, tractive effort, N
- F_R is resistance, N

The load size model contains two components, the oxen pull model and the resisting force model.

Oxen pull model
An old rule of thumb states that an animal can exert a continuous pull of about 1/5 of its gravity, mathematically described by eq. (2.22)

$$F_O = \frac{1}{5} * m_O * g \qquad (2.22)$$

where

- F_O is pull generated by an ox, N
- m_O is mass of oxen, kg
- g is gravity (9.81 m/s^2)

A pair of 500 kg oxen can generate a pull of about 2000 N.

Resisting force model

Applying the law of friction (eq. (2.23)), the resisting force of a log on a soil surface can be determined if the friction coefficient (dragging resistance coefficient) is known. The dragging resistance coefficient is analogue to the friction coefficient, and lies generally between 0.6 and 0.7 (Saarilahti 1986a).

$$F_R = \mu_L * W \tag{2.23}$$

or

$$F_R = \mu_L * m_L * g$$

where

F_R	is resisting force, N
W	is weight of load, N
g	is gravity, 9.81 m/s^2
μ_L	is dragging resistance coefficient (friction coefficient)
m_L	is mass of load, kg

Load size model for a horizontal plane

Combining eq. (2.22) and (2.23),

$$0.2 * m_O * g = \mu_L * m_L * g \tag{2.24}$$

and solving m_L, the following load size model can be developed:

$$m_L = 0.2 * \frac{m_o}{\mu_L} \tag{2.25}$$

where

m_L	is load size, kg
μ_L	is skidding resistance coefficient
m_O	is mass of oxen, kg

A pair of oxen, mass per animal being 500 kg and pull 2000 N, is able to skid a load of 3000 N if the skidding resistance coefficient is 0.65. A load of 3000 N corresponds to a load of about 300 kg or 0.30 m^3, if the green density of wood is 1000 kg/m^3.

Production rate model for a pair of oxen

By combining the cycle time model and the load size model, the following oxen production model can be constructed:

$$P = \left(\frac{3600}{360+2.4*d}\right) * \left(0.2 * \frac{m_O}{\mu_L}\right) \qquad (2.26)$$

Substituting

m_O =1000 kg
μ_L = 0.65

the hourly production model for an oxen team becomes

$$P = \frac{1107692}{360+2.4*d} \qquad (2.27)$$

where

P	is production rate, kg/effective hour
d	is skidding distance, m

Testing the production rate model

When a theoretical frame of reference or time/production model is developed it must be validated and compared with reality. If there is any discrepancy between the theoretical model and reality, the model is either erroneous, or the basic assumptions are not correct. For example, if we use the theoretical maximum load but in practice only one small log is systematically attached to the chain, there is a discrepancy between the theoretical and the observed production. If there are solid grounds for justifying larger loads (animals apparently underworking) the reality can be changed by applying larger loads.

In order to validate the model (2.27), it is compared with empirically measured daily production over different skidding distances (FAO 1974, p. 118). As the FAO report gives the daily production, the model (2.27) is converted into a daily production model. The **daily production rate** model becomes

$$P_d = h * \frac{1107692}{360+2.4*d} * \left(1-\frac{D}{100}\right) \qquad (2.28)$$

where

P_d	is daily production, kg/d
h	is the number of effective hours in a day
d	is distance, m
D	is delay time percentage, %

Allowing 20% for different delays (D=20) and 0.5 h for daily fixed time (h = 7.5) the following simple daily (8 h) production model is developed

$$P_d = \frac{6646152}{360+2.4*d} \qquad (2.29)$$

In Fig. 8 the model is tested against the FAO (1974, p. 118) production rate. It can be seen that the theoretical model is fairly close to reality, and the oxen model developed is applicable in practice. It also shows that there is no imminent need for changing the skidding practice, the loads studied have been close to the capacity of oxen.

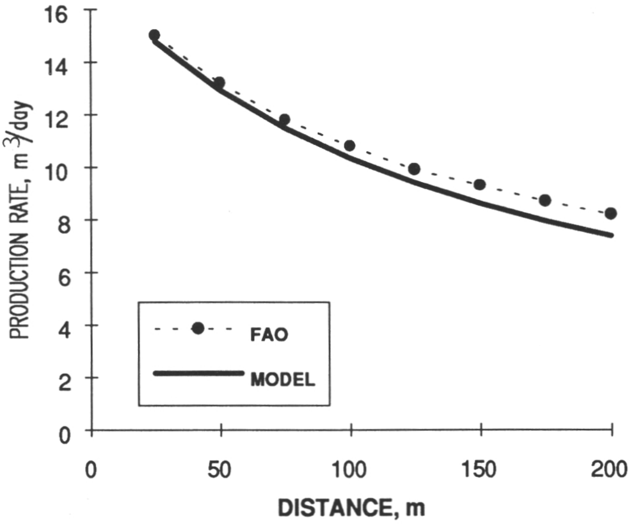


Figure 8. Oxen skidding model (2.29) compared to observed production rate (FAO 1974, Chart 9).

28. Statistics in the time study method

Statistical programs have adequate inbuilt statistical tests. For some field applications knowing the most common methods is adequate, and therefore these are presented. Many pocket calculators also have statistical functions for use in statistical tests. It should be borne in mind that even if the model is statistically highly significant, it may be wrong if the theory behind the model is wrong. Small differences, even if statistically significant, may also be neglected in practical applications if their importance is negligible. Tests are intended to help the researcher in his/her decision making, but they may mislead if not correctly applied. Low correlation is low correlation and even it may be highly significant.

281. Correlation coefficient

The correlation coefficient is defined as a measure of the strength of the relationship between two or more variables. Given n pairs of observations (x_i,y_i), we can compute the sample correlation coefficient r as

$$r = \frac{S_{xy}}{\sqrt{S_{xx}S_{yy}}} \tag{2.30}$$

It can be shown that r must lie within the interval -1 ... ρ ... +1. Several misinterpretations of the coefficient of correlation should be noted. Firstly, a coefficient of correlation equal to 0.5 does not mean that the strength of the relationship between y and x is "halfway" between no correlation and perfect correlation. If we designate $s_{yy} = \sum(y-\bar{y})^2$ as the total variability of the y values about their sample mean, it can be shown that an amount equal to r^2 of this total variability can be explained by the variable x. The more closely x and y are linearly related, the more variability in the y values can be explained by variability in the x values and the closer r^2 will be to 1. If r = 0.5, the independent variable x accounts for $r^2 = 0.25$ of the total variation in the y values and 25% of the variation is explained by the model. The quantity r^2 is called a **coefficient of determination**. It indicates the share of variation explained by the linear model of the total variation of the sample. A computational example of determining the coefficient of determination is presented in Appendix 3.

Secondly, y and x could be perfectly related in some manner other than a linear one, when r is close to 0. Finally, note that we cannot add correlation. If simple linear correlation between y and x_1, x_2, and x_3 are 0.1, 0.3 and 0.2 respectively, it does **not** follow that x_1, x_2, and x_3 account for $r_1^2 + r_2^2 + r_3^2$ of the variability of the y values about their sample mean.

282. Sample size

In order that conclusions may be drawn from the study with a certain degree of statistical validity, a sufficiently large number of observations must be timed. For practical reasons, it is impossible to study the whole phenomenon.

A sample is defined as a subset of measurements selected from a population. The sample should be representative enough, and the measurements as reliable as possible. The sample must be large enough for the effect of different variables on the results to be explained. Conversely, observations cost money. If the sample is too large, time and talent are wasted. From the sample it is possible to estimate certain parameters which characterise the whole population. There is always uncertainty inherent in the results, due to sampling.

The sample size can be determined in two ways:

- Based on deliberation or experiences. This is a common procedure in forest work study, in which the sample size is often small for practical reasons.

- By probability calculations based on an estimate of the variation of the variables and desired level of significance.

If the variance of the population (s^2) is known, and the mean value of a certain parameter is unknown, the sample size required for a reliable estimate on the average can be defined as follows (based on the so-called central limit theorem):

$$n = \frac{z^2 s^2}{E^2} \qquad (2.31)$$

where

n	is sample size, number of observations
z	is the value from the normal distribution table (Appendix 4) for the desired confidence interval (e.g. z = 1.96 for a 95% confidence interval, and z = 2.58 for a 99% confidence interval, see Appendix 4)
s^2	is variance of the population
E	is tolerance error for the confidence interval

Example 1
A forester wants to estimate the mean loading time of pine sawlogs. A preliminary survey suggests that the time can be as short as 0.54 min per load and as long as 5.95 min per load. The forester wishes the estimate to be within 30 s of the mean loading time, using a 95% confidence interval. How many loadings should be timed?

Solution The tolerance error for the confidence interval is E = 0.5 min. Before using the equation for n, we must estimate the population variance s^2. We do so using a range estimate of s. Since the range of loading times is 5.41 min (5.95 -0.41), an estimate of s is

$$s = \frac{\text{range}}{4} = \frac{5.95\text{-}0.54}{4} = 1.4$$

Then an approximate sample size can be found by substituting 1.4^2 for s^2 in the equation for n. Substituting z = 1.96 and s = 1.4, we have

$$n = \frac{1.96^2 * 1.4^2}{0.5^2} = 16$$

Thus the forester would have to sample 16 loads to estimate the mean loading time using a 95% confidence interval in the form x $\pm$ 30 s (= 0.5 min).

283. Confidence interval

Estimation procedures can be classified into two categories: *point estimation* and *interval estimation.* The sample mean $\overline{x}$ is a logical point estimate of the population mean μ. We can also use the point estimate to form an interval estimate for the population mean μ. When the sample size (n) is reasonably large (n>30), the sampling distribution for σ^8 will be approximately normal with mean μ and standard error (deviation) σ^8. Thus the interval $(\mu \pm 2\sigma_{\overline{x}})$, or, more precisely, $(\mu \pm 1.96\sigma_{\overline{x}})$, includes 95% of the $\overline{x}$s in repeated sampling.

The confidence interval for μ can be computed as follows (σ known):

$$\overline{x} \pm z\sigma_{\overline{x}} \qquad (2.32)$$

where

$$\sigma_{\overline{x}} = \frac{\sigma}{\sqrt{n}} \qquad (2.33)$$

The values of z for α 90%, α 95% or α 99% confidence interval for μ are 1.645, 1.96 or 2.58 respectively.

Example 2

A forester is studying the loading time in skidding. A sample of 112 loads are examined, and the sample mean and standard deviation are found to be $\overline{x}$ = 132.6 s and s = 77.4 s. We are now estimating μ, the average loading time, using a 95% confidence limit.

Solution The appropriate 95% confidence interval is computed by using the formula $(\overline{x} \pm 1.96\sigma_{\overline{x}})$. Although σ is unknown, we can substitute the sample standard deviation s for σ in the formula for $\sigma_{\overline{x}}$, since n>30. The lower point for the confidence interval, called the *lower confidence limit,* is (eq.(2.32))

$$132.6 - 1.96\left(\frac{77.4}{\sqrt{112}}\right) = 132.6 - 14.33 = 118.3$$

Similarly, the *upper confidence limit* is

$$132.6 + 1.96\left(\frac{77.4}{\sqrt{112}}\right) = 132.6 + 14.33 = 146.9$$

Then the 95% confidence interval for the mean loading time is 118.3 to 146.9.

[8] Notation for standard deviation of a sample, s is also used (see Appendix 3.2)

284. Level of significance

The level of significance refers to the outcome of a specific statistical test of a hypothesis (for example, a regression equation for skidding time). The level of significance of the test is the probability of drawing a value of the test statistic that contradicts the null hypothesis.

Many statistical tests are such that the observed significance level cannot be computed without computer programs. Unless there are statistical programs available, the level of significance can be estimated with the help of statistical tables with a reasonable degree of accuracy. When using statistical tables, the level of significance is fixed beforehand at a certain value. The hypothesis is rejected if the test value, calculated from the sample, exceeds the table value (critical value) corresponding to the desired significance level.

When a hypothesis has been developed, the confidence level tells how big a risk is involved in rejecting the theory. When the risk is known, one can decide what kind of attitude to adopt towards the hypothesis. The most common levels of significance presented in statistical tables are 0.001, 0.01, 0.05 and 0.1. For example, a significance level of 0.05 indicates that with a probability of 95 % the hypothesis is acceptable, i.e. the risk involved in rejecting the hypothesis is 5 %.

285. Statistical tests≠

A statistical test is a procedure for making an inference about one or more population parameters by using information from sample data. The procedure is based on the concept of proof by contradiction. In this chapter, two simple statistical tests are presented, that can be performed without computers.

Test 1: Comparison of averages (t-test)

We can run a statistical test on the difference between two population means. As with any test procedure, we begin by specifying the null and alternative hypothesis. If we let μ_1 and μ_2 denote the means for populations 1 and 2 respectively, the null and alternative hypotheses for a two-tailed test are

$$H_0 : \mu_1 = \mu_2$$
$$H_a : \mu_1 \neq\neq \mu_2$$

When the population variances are unknown but not necessarily equal, the test statistic is

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (2.34)$$

where

$\bar{x}_1, \bar{x}_2$	are sample means
n_1, n_2	are sample sizes
s_1^2, s_2^2	are sample variances[9]

The degree of freedom (df) can be computed from the following equation:

$$\frac{1}{df} = \frac{c^2}{n_1 - 1} + \frac{(1-c)^2}{n_2 - 1} \quad (2.35)$$

where

$$c = \frac{\frac{s_1^2}{n_1}}{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \quad (2.36)$$

Example 3 (Point estimation)
An experiment was conducted to investigate the difference in average skidding velocities in thinning and clearfelling. We are now trying to determine if the data presented in Table 1 indicates a difference between the average skidding velocities in thinning and clearfelling.

Table 1. The data for example 3.

	Thinning	**Clearfelling**
Sample mean ($\bar{x}$), m/s	0.942	0.831
Sample st. deviation (s), m/s	0.308	0.266
Sample variance (s^2)	0.095	0.071
Sample size, (n)	100	112

Solution: Inserting the data from Table 1 into eq.(2.34) gives

$$t = \frac{0.942 - 0.831}{\sqrt{\frac{0.095}{100} + \frac{0.071}{112}}} = 2.71$$

For computing the degree of freedom, c is solved from eq. (2.36):

[9] For calculating of the variance and standard deviation see Appendix 3.2

$$c = \frac{\frac{0.095}{100}}{\frac{0.095}{100} + \frac{0.071}{112}} = 0.5998,$$ and placed into eq. (2.35)

$$\frac{1}{df} = \frac{0.5998^2}{100 - 1} + \frac{(1-0.5998)^2}{112 - 1} = 0.0051$$

The degree of freedom (df) is the inverse of 0.0051 = 196.1

The rejection region for $\alpha = 0.05$ utilises a t value corresponding to $\alpha = 0.025$ and df = 196. The t value for df = 196 is not listed in the t-table of Appendix 4 but taking the labelled value for the nearest df (df = 120) we have t = 1.980. Thus we reject the null hypothesis if the computed value of t is greater than 1.980 or less than - 1.980. Noting that the computed value of t, t = 2.71, falls in the rejection region, we conclude that there is sufficient evidence to indicate a difference in the mean skidding velocities for the two skidding methods.

Example 4. (Interval estimation)
Confidence limits can be used for comparing two means in place of t-test (ref. example 3). Average skidding velocities in thinning and clearfelling are to be compared.

Solution Average skidding velocities are the same as in Table 1, in thinning 0.942 m/s and in clearfelling 0.831 m/s. Standard deviations (s) are 0.308 m/s and 0.266 m/s respectively. $N_1 = 100$ and $n_2 = 112$. 95% confidence intervals are computed (see Chapter 283) both for thinning and clearfelling by using eq. (2.32). Confidence intervals are as follows:

Thinning: $0.942 \pm 0.019 = 0.932 \ldots 0.961$
Clearfelling: $0.831 \pm 0.007 = 0.824 \ldots 0.838$

Since the confidence limits do not meet, it can be concluded that there is a difference between mean skidding velocities in thinning and clearfelling. The results of the comparison of two (or more) averages can be presented in graphic form as well (Fig. 9).

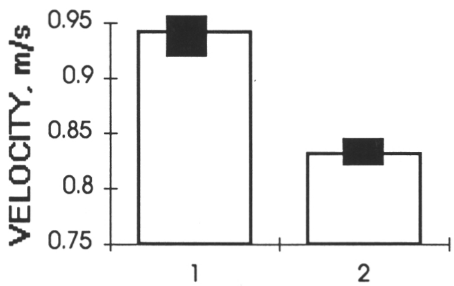


Figure 9. Comparison of the average velocities in thinning (1) and clearfelling (2) with confidence limits.

Test 2: Analysing count data (chi-square tests)

A problem that arises frequently in statistical work is the testing of the compatibility of a set of observed and theoretical frequencies. Many experiments yield count data (enumerative data), i.e. data that can be counted. Many such problems are analysed by means of a chi-square statistic. The test statistic used in the χ^2 tests is

$$\chi^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i} \qquad (2.37)$$

where

o_i	is the observed frequency
e_i	is the expected frequency
k	is number of possible outcomes

We will illustrate with the following two examples the use of this method for quality of fit tests and for an important group of problems involving the investigation of the dependence (or independence) of two methods of data classification.

Limitations of the χ^2 test:

Since the χ^2 distribution is only an approximation to the exact distribution of the test statistic (eq. (2.37)), care must be taken that the χ^2 test is used only when the approximation is good. Experience and theoretical investigations indicate that the approximation is usually satisfactory, provided that the sample size is such that not more than 20% of the expected frequencies is less than 5, and all the expected frequencies are more than 1.

a) The chi-square quality of fit test

Example 5

A researcher examines the occurrence of delays in oxen skidding. The number of interruptions (unavoidable or avoidable) per skidding cycle was registered and divided into five classes as follows:

1) No delays
2) One delay per cycle
3) Two delays per cycle
4) Three delays per cycle
5) Four or more delays per cycle.

A sample of 277 loads was studied. It was hypothesised that the probabilities of delay occurrence in classes 1 ... 5 were 35%, 30%, 20%, 10% and 5% respectively.

Now we will test the hypothesis that the cell probabilities for delay occurrence classes do not differ from the hypothesis, using $\alpha = 0.05$.

Solution This experiment possesses the characteristics of a multinominal experiment with n = 277 trials and k = 5 outcomes.

Outcome 1: No delays, with a probability of 35%
Outcome 2: One delay per cycle, with a probability of 30%
Outcome 3: Two delays per cycle, with a probability of 20%
Outcome 4: Three delays per cycle, with a probability of 10%
Outcome 5: Four or more delays per cycle, with a probability of 5%.

The test statistic is

$$\chi = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i}$$

Table 2. Observed and expected cell counts for example 5.

Class	o_i	e_i	$(o_i - e_i)$	$(o_i - e_i)^2$	$\frac{(o_i-e_i)^2}{e_i}$
1	76	96.95	-20.95	438.90	4.53
2	81	83.10	-2.10	4.41	0.05
3	67	55.40	11.60	134.56	2.43
4	34	27.70	6.30	39.69	1.43
5	19	13.85	5.15	26.52	1.91
Total	277	277.00			10.35

The tabulated value of chi-square for a = 0.05, with k - 1 = 5 -1 = 4 df, is 9.49 (Appendix 4). Since the observed value of chi-square exceeds 9.49, we have sufficient evidence to indicate that the cell probabilities differ from the hypothesised probabilities.

b) The chi-square test of independence

Example 6
A total of 277 oxen skidding cycles (n = 277) were timed, 152 loads in clearfelling and 125 in thinning. The number of delays was registered and divided into classes as explained in example 5. The number of observations appearing in each category is presented in Table 3. This two-way classification of data is called a contingency table. The researcher wants to determine whether the number of delay occurrences is dependent upon the logging type. Test the null hypothesis that these two classifications are independent of one another (that is, the number of delay occurrences does not depend on the logging type). Use $\alpha = 0.10$.

Table 3. Delay occurrence results.

Type of logging	Delay occurrence class 1	2	3	4	5	Total
Clearfelling	52	47	33	15	5	152
Thinning	24	34	34	19	14	125
Total	76	81	67	34	19	277

Solution Before calculating chi-square, we must first obtain the expected cell counts, using the row and column totals of Table 3 and the additive property of the expected cell counts. The remaining expected cell counts shown in Table 4 were obtained using the additive property. Note that the expected cell counts satisfy the requirements that no more than 20% are less than 5, and that none is less than 1.

$$\text{Clearfelling, no delays} = \frac{(152)(76)}{277} = 41.7$$

$$\text{Clearfelling, 1 delay/cycle} = \frac{(152)(81)}{277} = 44.4$$

Table 4. Expected values for the data of example 4.

Type of logging	Delay occurrence class 1	2	3	4	5	Total
Clearfelling	41.7	44.4	36.8	18.7	10.4	152
Thinning	34.3	36.6	30.2	15.3	8.6	125
Total	76.0	81.0	67.0	34.0	19.0	277

Now we compute the test statistic

$$\chi = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i}$$

and obtain

$$\chi^2 = \frac{(52\text{-}41.7)^2}{41.7} + \frac{(47\text{-}44.4)^2}{44.4} + \dots\dots\dots + \frac{(14\text{-}8.6)^2}{8.6} = 17.2$$

The rejection region for this test can be located by using Table A4.2 in Appendix 4, with $\alpha = 0.10$ and df = (r-1)(c-1) = (1)(4) = 4. This tabulated value is 7.78. Since the observed value of χ^2 exceeds the tabulated value, we reject the null hypothesis of the independence of the classifications and conclude that the number of delays does seem to be related to the type of logging. In this case thinning is "more difficult" as the number of delay occurrences is higher in many occurrence classes.

286. Validity and reliability problem

The internal reliability of the data describes how reliable the observations in the sample are. The ***reliability*** of the observations indicates how well the systematic variation has been measured. The reliability of the sample is lowered by the random measurement errors. The ***validity*** of the observations indicates how well the variable measures the topic of study (e.g. pulse rate in studies of work strain). The validity of the sample is lowered by both random and systematic measurement errors.

In comparative time studies the reliability is of primary importance. The process is considered to contain a certain variation and it is assumed that it can be statistically assessed when the model is good enough for application. For example, the variation between men is considered as background noise and the variation in comparative time studies is eliminated using relative times. If applied to the population of all the forest workers, the workers studied must be a statistical sample of the population. If the relation between working capacity and work output is known, the model can be applied to any work site where the workers' capacity distribution is known. Therefore it might be rational to add validity. It means that in stead of studying normal work arranged work is studied.

3. THEORETICAL FRAME OF REFERENCE FOR OX MODEL

31. Ox as a prime mover

311. Pull

The pull of an ox depends on race, sex, weight, age, training, gait and character. Long term development programmes could envisage the breeding aspect because it permits long-term improvements. The pulling effort may also depend on the harnessing, how efficiently the animal's muscles are loaded. In a test a 500 kg carabao[10] generated 3.5 kN maximum pull (70%) when using a harness, but only 2.5 kN (50%) when using a traditional yoke. Therefore basic development should aim at improving the pull of existing herds by improving harnessing and training.

According to Goe (1983, p. 3) an ox can generate a continuous pull of 10 ... 14% of its body weight. Over shorter distances the effort is higher and in skidding (up to 500 m) a constant of 20% of body weight can be applied. In Appendix 5 the most common draught animals are presented.

A pull coefficient (c_{pull}) 0.10 ... 0.15 can be used for continuous pull such as ploughing. If the pull and rest periods are successive as in skidding, a 0.15 ... 0.20 pull coefficient can be used. The maximum pull coefficient is 0.6, and a momentary peak value may even be as high as 0.6 ... 1.1.

---

[10] The name carabao is used for water buffalo in the Philippines

When an ox is working uphill on a slope[11], part of its power is used to move the animal itself against gravity, and less power remains for pulling the load. On favourable slopes, the gravity pulls the oxen, but after a certain slope the ox must begin to brake the velocity, and **concentric work** (muscle retracts when working) changes to **eccentric work** (muscle lengthens to try to brake the movement). It is assumed that the pull of an ox is at its maximum on a -10% slope, and is 50% +25% and -45% slopes, following the model shown below:

$$F_S = F_0 * (1 - \frac{2*(\mathbf{ABS}(S+10)-10)}{100}) \qquad (3.1)$$

where

F_S is pull on slope, N

F_0 is pull on level ground, N

The model is tested with the pull based on data from sources I-VIII. A skidding coefficient of 0.65 is used. The pull coefficient, the calculated pull divided by oxen team weight, is compared with the theoretical model in Fig. 10. The pull coefficient seems to be somewhat higher than 0.2, but as the skidding resistance coefficient is only an estimate no conclusions can be drawn.

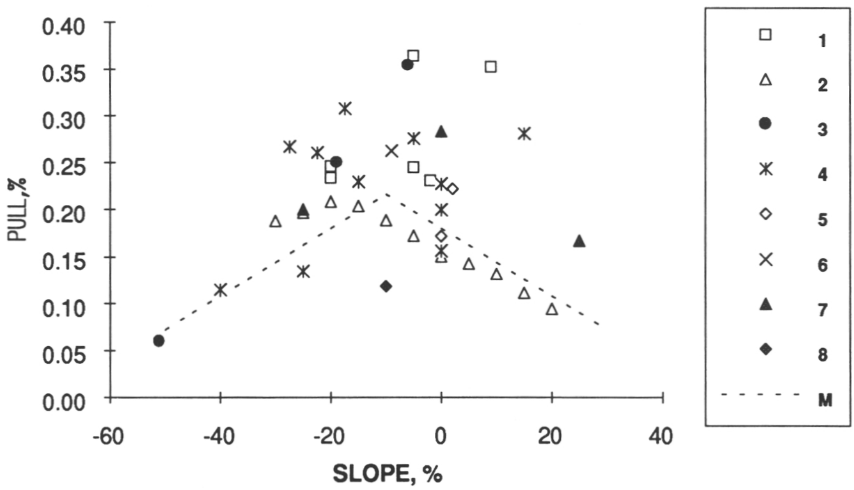


Figure 10. Pull coefficient based on model (3.1) compared to pull coefficient estimated based on sources I-VIII.

[11] Pull as a function of slope is poorly described in literature. The proposed model is to be developed further.

312. Power

The optimum velocity, the velocity an ox uses naturally, seems to be 0.8 ... 1.1 m/s. This yields net power of about 2 W/kg on a horizontal plane, and the power of an ox is around 1 kW.

The calculated (net) power from different sources is depicted in Fig. 11. In source III power seems to decrease linearly as a function of slope. In source IV the power decreases on a steep favourable slope (<-30) but stays rather constant (about 1 W/kg) for other slopes. In source I the power seems to increase slightly as a function of slope. It is evident that on steep favourable slopes the power of the animal is no longer the governing factor, but log size and the difficulty in handling larger loads dictate the load size. It is evident that comprehensive studies are needed in measuring the power of oxen in different terrain conditions.

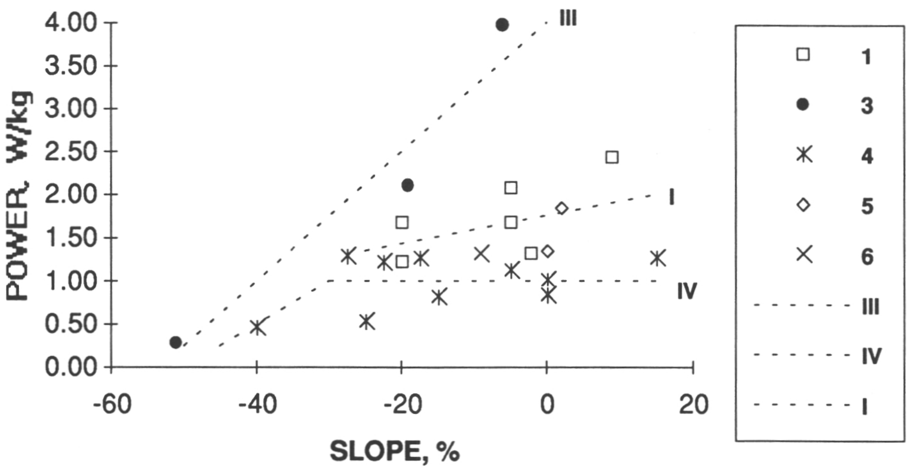


Figure 11. Power as a function of slope.

313. Pull and power in team work

If two or more animals are harnessed together, it results in a relative loss of efficiency of each animal. The loss compared with a single animal's pulling effort is 7.5% for two animals (Goe 1983), and the team efficiency coefficient becomes 0.925. The pull of a team can be estimated using the following model:

$$F = c_{pull} * 9.81 * c_{eff}^{n-1} * \sum m_i \qquad (3.2)$$

where

F	is pull of a team of oxen, N
c_{pull}	is pull coefficient (0.15 ... 0.20)
c_{eff}	is team efficiency coefficient (0.925)
n	is number of animals in the team
m	is mass of an animal, kg

The loss in power is somewhat greater since regulating the velocities between oxen increases the variation. In practical time studies, an approximate 10% decrease in power can be assumed, i.e. $c_{eff} = 0.9$.

314. Velocity

When developing return and skidding time models, the concept of velocity plays an important role. When carrying out time studies the breakpoint between elements is somewhat arbitrary. Generally, the breakpoint is when the ox handler has stopped unloading or loading phases, and begins to command the ox to move. Some fixed time (independent of distance) is therefore evident, and there might be some fixed time at the end of the move as well. During the move, there might be some minor stopping or lowering of the velocity due to surface conditions (obstacle resistance), but they cannot be timed separately as delay time. Oxen may also have some short rest breaks, which may be included or excluded from (effective) travel time. The moving time model becomes

$$t = \boldsymbol{a} + \boldsymbol{b} * d \qquad (3.3)$$

$$\boldsymbol{b} = \frac{1}{v} \qquad (3.4)$$

where

t	is cycle time, s
a	is fixed (contingency) time, s
b	is inverse of velocity
v	is ground velocity, m/s

For analysis, two concepts of velocity need to be defined:

- <u>Average velocity</u> ($v_{(a)}$) is calculated by dividing (average) distance by (average) time. It is calculated using models found in references letting (average) load size and (average) slope in models.

$$v_{(a)} = \frac{d}{\boldsymbol{a} + \boldsymbol{b} * d + \boldsymbol{c} * X_2 + \boldsymbol{d} * X_3 \ldots} \qquad (3.5)$$

Average velocity is dependent on distance.

- <u>Apparent velocity</u> ($v_{(b)}$) is the slope angle velocity (ground velocity) measured by timing the moving animal.

$$v_{(b)} = \frac{1}{b} \tag{3.6}$$

$$v_{(b)} = \frac{d_2 - d_1}{t_2 - t_1} \tag{3.7}$$

Apparent velocity is independent of distance.

The velocity of a walking ox ($v_{(b)}$) is 0.8 ... 1.0 m/s. In forest work, however, the velocity ($v_{(a)}$) is usually lower, 0.5 ... 0.7 m/s as the short rest breaks are included. The factors affecting the velocity are discussed in Chapter 342.

When timing a moving animal it is important to indicate how accurate the segregation between travel time (effective time) and rest and other breaks (delay time) has been. Velocity $v_{(a)}$ generally includes all the short (< 60 s) breaks as it is based on observing the element as a whole. Velocity $v_{(b)}$ may be observed by following the animal during the walk and observing the time in sections, either in constant distances (e.g. 25 m) or in homogenous sections (e.g. 0% slope, + 5 % etc.). If the delay times (rest breaks) are segregated, then higher apparent velocities are obtained. If short breaks(< 60 s) are included then lower apparent velocities are evident. For the purpose of the study both timings are acceptable.

3.1.5 Estimating the body weight of an ox

Estimating the live mass of draught animals without the use of scales is of obvious importance as a practical field technique. The body mass of the draught animal is needed when estimating its tractive effort. The following general eq. (3.8) gives a rough estimate of the body mass of an ox (see Fig. 12):

$$m_O = \frac{g_c^{\,2} * l_b}{10\,000} \tag{3.8}$$

where

- m_O is live mass of the body, kg
- g_c is chest girth, taken from the height of the heart, cm
- l_b is length of the body, cm

Spencer and Eckert (1988) have presented the following linear equation (3.9) for estimating the live weight of a Gambian male bovine:

$$m_O = -363.79 + 4.27 * g_c \tag{3.9}$$

where

- m_O is live mass of the body, kg
- g_c is chest girth, taken from the height of the heart, cm

In Appendix 5 an equation for estimating the live weight of a horse is presented.

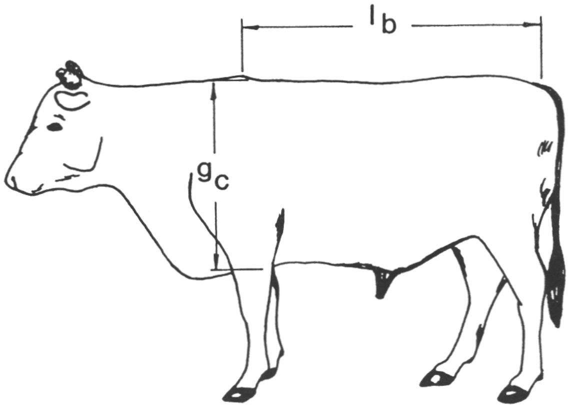


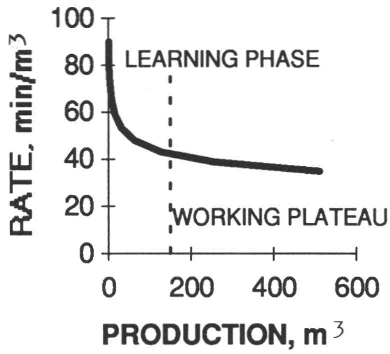
Figure 12. Dimensions needed in estimating the live weight of an ox.

316. Learning curve

When carrying out time or work studies it is assumed that the animals are working at a standard rate and are used to the work. Often when starting up projects, well trained animals are not available, so plans must be based on data obtained using animals in training. The future production can be estimated by applying learning curve theories (Wright 1936, Yelle 1979) to oxen skidding.

The learning curve theory postulates that the time required to produce a fixed quantity of output (measured, for example as the average time required to skid 1 m^3 of timber) will be continuously reduced at a constant rate for some time while a worker, or animal, learns, until eventually a "working plateau" is reached, beyond which essentially no further improvement can be made without additional investment (such as new equipment, or training in improved skidding methods). Typical learning curves are illustrated in Figs. 13a and 13b.

In developing the learning curve theory, it was assumed that the learning rate is essentially constant during the learning phase. The theory has proved to be a reliable method for predicting future production rates during the learning phase (Dykstra 1983). For example, supposing that the learning rate for oxen skidding is 85%. This means that if a total of N m^3 of timber has been skidded by a particular crew, the amount of time required by that team to skid the Nth cubic metre is approximately equal to 85% of the time required by the crew to skid N/2 m^3. As a more concrete example, suppose that the 5th m^3 of timber skidded by the crew required 23.0 minutes. Then, at an 85% learning rate, we would expect that the time required to skid the 10th m^3 of timber would be only 23.0 * 0.85 = 19.6 minutes, the 20th m^3 16.7 min, etc.



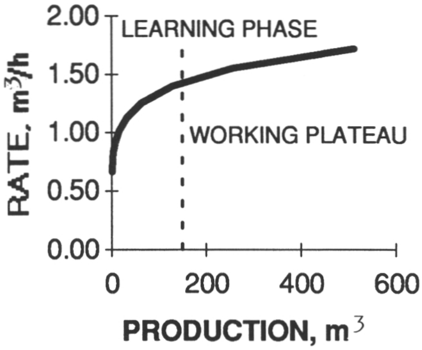


Figure 13a. A hypothetical learning curve showing the time required to carry out a specific task as a function of the cumulative number of repetitions performed by an individual worker.

Figure 13b. A hypothetical productivity improvement curve showing the shape of the learning phenomenon curve.

The training of oxen usually starts when animals are 2.5 a old and lasts for 0.5 a. The animal is considered to be completely trained as it reaches maturity at approximately 5 a old. In Malawi the daily production of an oxen team as a function of age is as given in Table 5.

Table 5. Average daily production in oxen skidding as a function of experience, m•/d for a team of 2 oxen (after The use of.... 1980).

			Age, a			
2.25	2.5	2.75	3	3.5	4	5
			Production, m^3/d			
2.8	3.3	4.0	4.7	5.6	10.0	12.7

In Fig. 14 the data is fitted with a theoretical learning curve at a 0.6 learning rate, which includes both the increase in body mass, force and experience. It seems that the 0.6 learning rate can be used for young animals.

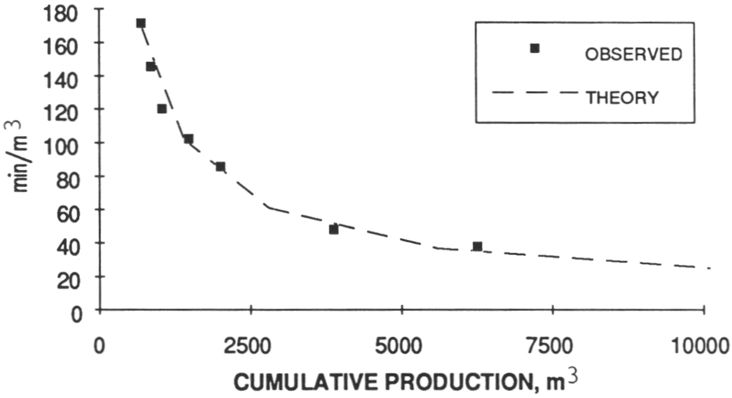


Figure 14. Observed production (Table 5) compared with the learning curve theory when a learning rate of 0.6 is applied.

32. Log-soil interaction

321. Theoretical frame of reference

Dynamic and static friction coefficient

In physics there is a distinction between static and dynamic friction coefficients. The friction coefficient is higher at the beginning of the pull and drops to a lower level when the body is on the move. Usually static friction is 10% higher than dynamic friction, but it depends on the materials. The same type of phenomena is also found when studying the log-soil interface. At the beginning the measured resisting force is greater than immediately afterwards because of static friction[12]. The static resistance may be high in clayey soil due to cohesive bounding which develops between the soil and log (or implement) interface. In Tervo's (1986) study the ratio between static and dynamic resistance coefficients varied between 1.25 and 1.38.

As an animal can develop a high short-duration pull-peak, static friction can be omitted from studies, and the recorded coefficients should refer to dynamic resistance force measurements, when the log is moving at a constant velocity.

Resisting forces in moving a log at constant velocity are of different types, such as:

- Skin friction (surface friction) is the friction between the soil surface and the bark of the log.

---

[12] Accelerating the log to a constant velocity increases the total resistance as well.

- Drag resistance (gouging resistance) is due to the energy needed to deform the soil and tear the roots of vegetation. The log presses the soil surface, causing a small sinkage. The log end (and limb stubs) push soil particles forward.
- Obstacle resistance can be described as a force needed to change the direction of the move of the log in order to overcome obstacles on the ground.

For practical reasons, all the resisting forces are measured and analysed together, and defined as a skidding resistance (or dragging resistance) coefficient. The influence of a few large obstacles can be ignored, but the influence of frequent small obstacles can be included in the (average) resistance. The skidding resistance coefficient is the ratio between the tangential force needed to move the log, and log weight (Fig. 15). On a horizontal plane, the tractive pull is (Fiske & Fridley 1975):

$$T = (1-k)*\mu_L*W \qquad (3.10)$$

where

T	is tractive pull (tangential force), N
k	is load transfer coefficient
μ_L	is skidding resistance coefficient
W	is log weight, N

From Fig. 15 it can be seen that line pull, the force a pair of oxen must generate, depends on the lift component and skidding resistance,

$$L = \sqrt{T^2 + N^2} \qquad (3.11)$$

where

L	is line pull, dynamometer reading, N
T	is tractive effort, horizontal force component, N
N	is lift component, vertical component, N

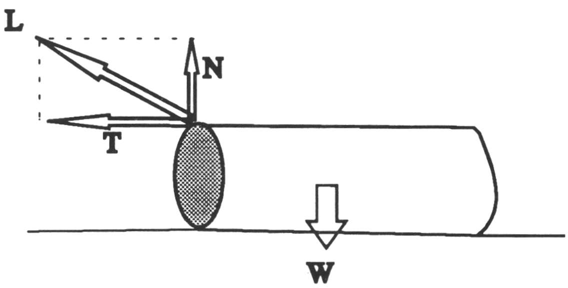


Figure 15. Log-soil interaction.

When studying oxen, a small systematic error is introduced if the dynamometer reading (line pull) is used directly in calculating skidding resistance instead of its horizontal component (skidding resistance) (Fig. 16). A more accurate skidding resistance coefficient can be calculated using model (3.12).

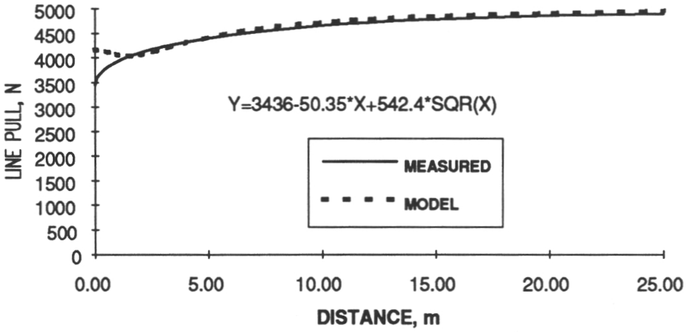


Figure 16. Line pull as a function of distance in winching a 0.74 m^3 load. The height of the pulley is 1.70 m (Tervo 1986).

$$\mu_L = \frac{L * \cos\beta}{W - L * \sin\beta} \tag{3.12}$$

where

μ_L	is skidding resistance coefficient (tangential force coefficient)
L	is dynamometer reading (line pull), N
β	is skidding chain angle, °
W	is log weight, N

As the chain angle in oxen skidding stays fairly constant, the following model can be applied on a horizontal plane (Fig. 17):

$$\mu_L = \frac{L * \frac{\sqrt{l^2 - h^2}}{l}}{W - L * \frac{h}{l}} \tag{3.13}$$

where

μ_L	is skidding resistance coefficient (tangential force coefficient)
L	is dynamometer reading, line pull, N
h	is height of yoke, m
l	is length of chain, m
W	is log weight, N

The load transfer coefficient, the share of log weight supported by the prime mover, in chain skidding is generally 0.0 ... 0.2 (Table 6)[13]. In case of a yoke height of 1.5 m and chain length of 5.0 m, the load transfer coefficient is k= 0.17.

---

[13] An approximation for load transfer coefficient (k) is $k \approx \mu_L * \sin\beta$

where

k	is load transfer coefficient
μ_L	is skidding resistance coefficient
β	is line angle

Table 6. Load transfer coefficient.

Skidding type	Load transfer coefficient
Chain skidding	0.0 - 0.2
Ground skidding	0.2 - 0.3
Arch skidding of long thin stems, butt first	0.4
Arch skidding of short logs	0.5

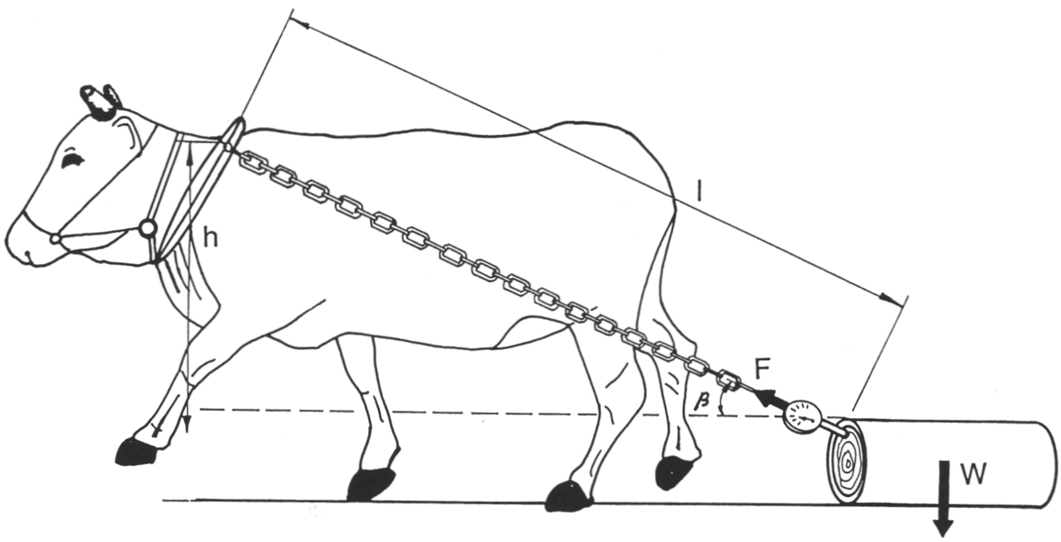


Figure 17. Ox skidding geometry.

On slopes, the effect of changes in co-ordinates and slope resistance must be included (Fig. 18).

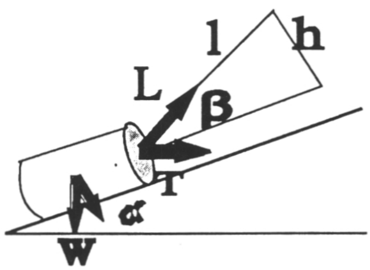


Figure 18. Forces acting on skidding on slope.

On a slope, the perpendicular component to the soil changes as a function of slope.

$$N = k*W*\cos\alpha \tag{3.14}$$

where

N	is lift component, horizontal force, N
k	is load transfer coefficient
W	is log weight, N
α	is slope angle, °

Tractive pull on slopes must be calculated as the horizontal component of line pull, eq. (3.15) (Fiske & Fridley 1975):

$$T = (1-k)*\mu_L*W*\cos\alpha + W*\sin\alpha \tag{3.15}$$

where

T	is tractive pull, tangential force, N
k	is load transfer coefficient
μ_L	is skidding resistance coefficient
W	is load weight, N
α	is slope angle, °

The skidding resistance coefficient on a slope can be calculated from line pull using eq. (3.16).

$$\mu_L = \frac{\cos\beta*(L - W*\sin\alpha)}{\cos\alpha*(W - L*\sin\beta)} \tag{3.16}$$

where

μ_L	is skidding resistance coefficient
L	is line pull, dynamometer reading, N
W	is load weight, N
α	is slope angle, °
β	is line angle, °

322. Empirically measured skidding resistance coefficients

Line pull or skidding resistance measurements are hardly made in oxen skidding, as studies have been concentrated on measuring of time only. To a certain extent, the measurements carried out in tractor skidding can also be applied to animal logging. The skidding resistance coefficient depends on soil properties, soil moisture, vegetation and microrelief. As a rule the dragging and skidding resistance coefficient lowers if the soil moisture increases. Generally the skin friction on moist clayey soils is lower than on granular friction soils. In Table 7 some indicative skidding coefficients are given.

Table 7. Resistance coefficients

Soil moisture, %	Dragging resistance coefficient (Saarilahti 1986a)	Skidding resistance coefficient (FAO 1976)
15	0.65	
20	0.62	0.50
30	0.60	0.45
40	-	0.40
45	0.56	-
50	-	0.35
60	-	0.30

323. Implements

The dragging resistance coefficient is high, at 0.6 ... 0.7 compared to the gliding resistance (friction between steel/soil) of 0.25 ... 0.35 or the rolling resistance of a wheel at 0.1 ... 0.2. As the pull of the animals stays fairly constant the load size may increase if the resisting forces are reduced by using some implements which reduce log/soil resistance. The gross load size using sledges with steel runners may be 1.5 ... 3 times higher than in chain skidding and the use of carts may increase the load 3 ... 4 times. The inconvenience of using implements is that they increase the total weight, reducing net load and they must be transported back to the stump site empty. Loading time may also be higher when using sledges, carts and trailers, even if various rapid locking devices speed up the loading operation. In many reports a remarkable increase in productivity has been shown when using appropriate implements. Daily production with carabao primary transportation in the Philippines using different implements is given in Table 8. Heding & Ole-Meiludie (1979) recorded an average load of 0.18 m^3 (100%) in chain skidding, 0.21 m^3 (116%) when using a skidding pan and 0.52 m^3 (289%) when using a skidding pan and sulky. Tervo (1986) recorded the following resistance coefficients on a firm sandy forest floor for different implements (Table 9).

Table 8. Daily output with selected variants of carabao skidding (after Implementation ... 1982).

Alternative	Load, m^3	Skidding distance, m		
		100	500	800
		Daily production, m^3		
Yoke and traditional sledge	0.21	6.14	2.83	2.02
Yoke and skidding pan	0.34	9.82	4.07	2.83
Yoke and imported wheeled sledge	0.31	7.93	4.23	3.22
Harness and local two-wheel cart	0.58	7.51	5.36	3.59
Harness and four-wheel trailer	1.38	15.46	10.94	8.97
Harness and skidding pan	0.34	10.56	4.77	3.39
Harness and imported wheeled sledge	0.31	8.24	4.81	3.66

Terrain limits the use of certain implements. Wheeled trailers are preferred on bearing friction soils with a fairly smooth surface and a gradual (favourable) slope over long skidding distances. Carts are well suited to friction soils over shorter distances. Skidding pans are suited for moist cohesion soils and on rugged surfaces. The optimum working range for each implement can be found from work studies. The recommended terminology for the different implements is given in Appendix 10.

Table 9. Skidding resistance coefficient for different implements (after Tervo 1986).

Implement	Resistance coefficient
Three-pronged tongs	0.45
Plastic cone	0.40
Skidding sledge, I	0.35
Skidding cart	0.28
Skidding sledge, II	0.35

Cones and squaring of the log end smoothen the angle of attack of the log end and reduce obstacle and gouging resistance, offering some advantages on rugged surface (stones, hummocks, roots) (Fig. 19). The horizontal pull generates the lifting moment needed to lift the log end over an obstacle. The horizontal component in generating an adequate lift (obstacle resistance) is

$$T = 0.5*W*\tan\beta \qquad (3.17)$$

where

- T is obstacle resistance, N
- W is log weight, N
- β is angle of attack, °

For a straight angle **tan**90=∞; there is no lift component and the log tends to pull the obstacle forward. For a milder angle of attack the value of the tangent is smaller and the log is pulled over the obstacle. The inconvenience is that a cone increases the weight and must be transported back to the stump site, and squaring the log end demands extra work.

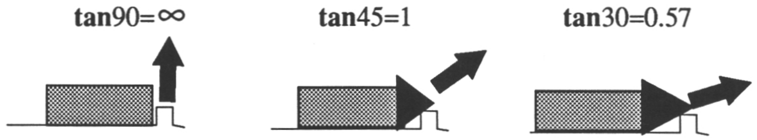


Figure 19. Influence of skidding cone on obstacle resistance.

33. Load size model

Theoretically the load size depends on the pull (and/or power) of the oxen and the resisting forces (eq. (2.24)). In practice, the load size may be determined by the ox handler's decision, and/or may be dependent on the size of available logs. Evidently the optimum situation in skidding is obtained, if the load size corresponds to the capacity of the oxen. The tree size (thinning/clear cut) and utilisation (pulpwood/sawlog with predetermined diameter and length) may dictate that the optimum load is difficult to arrange. It is therefore important to analyse the factors affecting the load size, and not to accept the hypothesis that the empirically observed load size is "correct" or optimal.

The load size for an oxen team on different slopes can be estimated by combining equations (3.1), (3.2) and (3.10) and solving the load size.

$$m_L = \frac{c_{pull} * c_{eff}^{\,n-1} * \sum m_i * \left(1 - \frac{2 * (\mathbf{ABS}(S+10) - 10)}{100}\right)}{\mu_L \frac{S}{100}} \qquad (3.18)^{14}$$

where

m_L	is load size, kg
c_{pull}	is pull coefficient (0.15 ... 0.20)
c_{eff}	is team efficiency coefficient (0.925)
n	is number of animals in the team
m	is mass of one animal, kg
S	is slope, %
μ_L	is skidding resistance coefficient

The calculated load size is compared to loads found in literature using the skidding resistance coefficient 0.65 in Fig. 20. The model seems to give somewhat conservative results.

---

[14] More accurate model for slopes **ABS**(S)>20

$$m_L = \frac{c_{pull} * c_{eff}^{\,n-1} * \sum m_i * \left(1 - \frac{2 * (ABS(S+10}{}\right.}{}$$

$$m_L = \frac{c_{pull} * c_{eff}^{\,n-1} * \sum m_i * \left(1 - \frac{2 * (\mathbf{ABS}(S+10) - 10)}{100}\right)}{\cos\alpha * \mu_L + \sin\alpha}$$

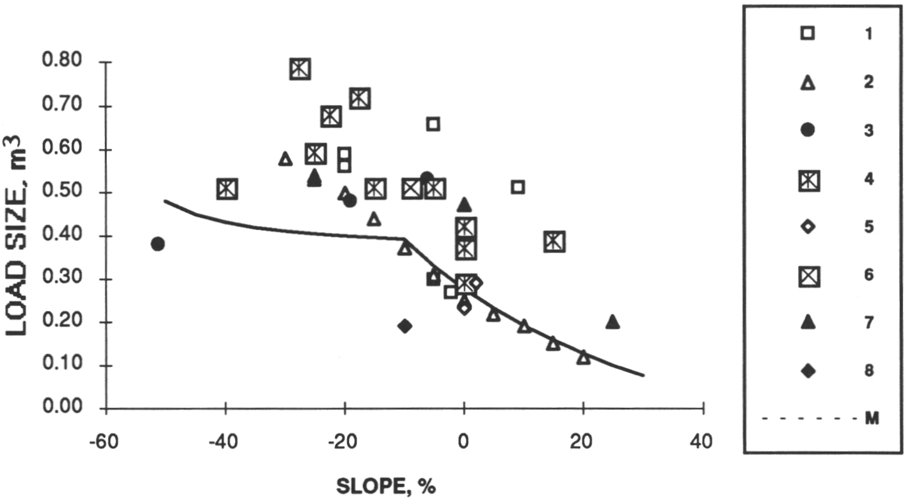


Figure 20. Recorded load size as a function of slope compared to the load size model.

The preceding model is only the first stage in the development of a load size model for oxen skidding. Instead of a culmination point (Fig. 20), there may instead be a break-down area where the load size stays more or less constant when concentric work changes to eccentric work (Chapter 311). Thus it is recommended that both theory development and empirical model research should be initiated [15].

34. Empirical oxen skidding models

341. Cycle time models

Work cycle consists of four base elements

- **return**: moving from landing to stump site without load
- **loading**: attaching the load into the prime mover
- **skidding**: moving from stump site to landing with load
- **unloading**: detaching the load from the prime mover

Different delay times occur randomly during the different elements.

$$t = t_R + t_L + t_S + t_U + t_D \qquad (3.19)$$

where

t	is cycle time, s
t_R	is return empty time, s

[15]WARNING: Theoretically logs keep moving by gravity if $\cos\alpha * \mu_L < \sin\alpha$ or about $\mu_L < \frac{S}{100}$. It means that on steeper favourable slopes the logs may overrun the oxen. The limiting factor is not the pull of the animals but the capacity to handle logs safely on steep slopes.

t_L is loading time, s
t_S is skidding time, s
t_U is unloading time, s
t_D is delay time, s

Return time

Return time consists of a certain fixed time needed for commanding oxen and of the distance/velocity variable component.

Fixed time ***a*** may depend on the slope and the following fixed times can be used for estimates:

- +20 ... 0 slope (in skidding direction) ***a*** = 20 s
- 0 ... -20 slope (in skidding direction) ***a*** = 40 s
- -20 ... -40 slope (in skidding direction) ***a*** = 60 s

The distance-dependent time component depends on return velocity. Return velocity $v_{(b)}$ seemed to depend on the slope[16] (Fig. 21) and the return velocity model became:

$$v_{r(b)} = 1.08 + 0.016*S \tag{3.20}$$

where
$v_{r(b)}$ is return velocity, m/s
S is slope in skidding direction, %

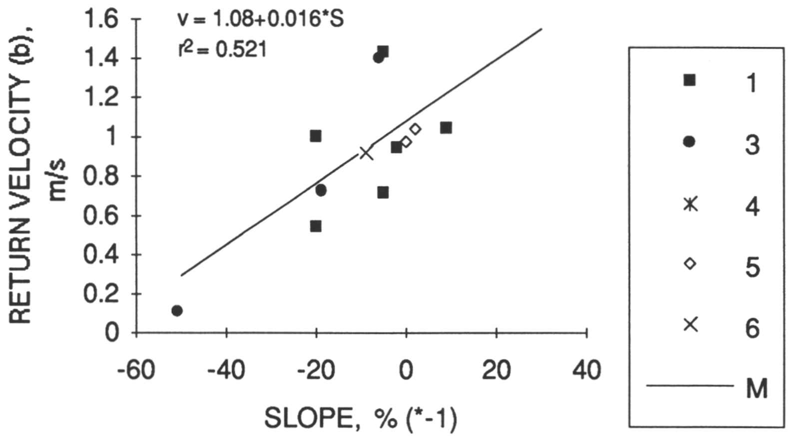


Figure 21. Return velocity $v_{(b)}$ as a function of slope (in skidding direction).

[16] Adverse slopes are scarcely present and the model applies only to moderate adverse to favourable slopes.

Loading time

Loading time consists of different elements: bunching a load, manoeuvring the oxen and attaching the chain to the load. Bunching and manoeuvring may take place simultaneously; the helper prepares the load and the driver positions the oxen. It is pointless to try to develop a detailed frame of reference for loading because most of the times are independent of outside factors. As work on a steep slope is usually more strenuous, the slope is considered to enter into the models.

There is quite a large difference between loading times in the data, the shortest time being 34 s (IV) and the longest 384 s (I). The average loading time is 179 s. Loading time is dependent on the number of logs and the load size, the number of logs entered into the model in eight cases and the number of logs and load size in three cases of the 11 models studied. The correlation coefficient was generally low, between 0.2 ... 0.4.

The loading time model developed from the data is

$$t_L = 19 + 14 * v_L * \mathbf{ABS}(S) + 20 * n_{LOG} \qquad R^2=0.86 \qquad (3.21)$$

where

t_L	is loading time, s
v_L	is load size, m^3
S	is slope, %
n_{LOG}	is number of logs

The contingency time is about 19 s and the time taken to handle one piece of log is 20 s.

The productivity in loading seems to be related to the slope, and a simple black-box model seems adequate enough for estimating loading time (Fig. 22).

$$t_L = (262 + 12.4 * \mathbf{ABS}(S)) * v_L \qquad (3.22)$$

where

t_L	is loading time, s
S	is slope, %
v_L	is load size, m^3

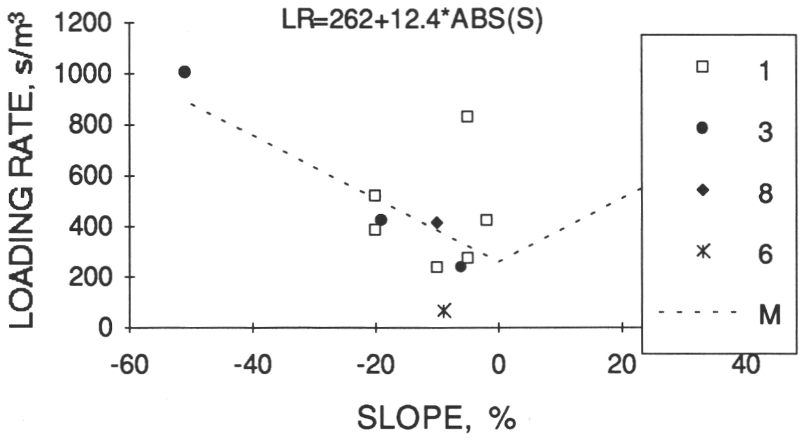


Figure 22. Loading rate as a function of slope, s/m^3.

Skidding time

Skidding time is generally analysed using different additive black box models of the type t = f (distance, load size, slope, ...) (Heding & Ole-Meiludie 1979, Chamba 1984, Solberg & Skaar 1986, Cordero 1988). This leads to the skidding time model

$$t_s = \boldsymbol{a} + \boldsymbol{b}*d + \boldsymbol{c}*L + \boldsymbol{d}*S \;.... \qquad (3.23)$$

where

t_S	is skidding time, s
a,b,c,d	are coefficients found from regression analysis
d	is distance, m
v_L	is load size, m^3
S	is slope, %

Theoretical frame of reference

If the aim of the study is to analyse the work of an ox, a more scientific frame of reference should be developed. Based on the assumption that an ox (or a pair of oxen) tends to work at constant power[17] we can write

$$v = \frac{P}{F_R} \qquad (3.24)$$

where

v	is velocity, m/s
P	is power generated by a prime mover, W
F_R	is resisting forces, N

[17] It is also possible that the (net) power is dependent on the slope as both pull and velocity seem to be slope-dependent. In that case constant power (P) in the model should be replaced by power model.

If the skidding velocity is kept constant during the cycle and some contingency time is added, the following skidding time model applies

$$t_s = \boldsymbol{a} + \frac{1}{v} * d \qquad (3.25)$$

where

t_S	is skidding time, s
$\boldsymbol{a}$	is constant time, contingency time, s
v	is velocity, m/s
d	is skidding distance

By combining eq. (3.24) and (3.25), the following time model is obtained for constant power:

$$t_S = \boldsymbol{a} + \frac{F_R}{P} * d \qquad (3.26)$$

The resisting forces, total tractive effort, consist of log soil interaction and of grade resistance (Saarilahti 1991, p. 69)

$$F_T = m_L * g * (\mathbf{cos}\alpha * \mu_L + \mathbf{sin}\alpha) \qquad (3.27)$$

On moderate slopes (-25 ... +25%) a simpler approximation can be used

$$F_T = m_L * g * (\mu_L + \frac{S}{100}) \qquad (3.28)$$

where

F_T	is tractive effort, N
m_L	is load size, kg
g	is gravity acceleration, 9.81 m/s^2
α	s slope angle, °
μ_L	is log skidding resistance coefficient
S	is slope, %

By combining eq. (3.26) and (3.28), the following skidding time model[18] is obtained

$$t_s = \boldsymbol{a} + \frac{m_L * g}{P} * (\mu_L + \frac{S}{100}) * d \qquad (3.29)$$

where

t_S	is skidding time, s
$\boldsymbol{a}$	is constant time, contingency time, s
m_L	is load size, kg

[18]Applicable for 0 ... ±20% slopes

g is gravity acceleration, 9.81 m/s^2
P is power of the oxen, W
μ_L is log skidding resistance coefficient
S is slope, %
d is skidding distance, m

For the purposes of regression analysis, eq. (3.29) can be rearranged

$$t_s = \boldsymbol{a} + \frac{\mu_L * g}{P} * m_L * d + \frac{g}{100 * P} * S * m_L * d \tag{3.30}$$

For the same pair of oxen (P is constant) working on the same trail (μ_L is constant) the member X_1 becomes the product m_L*d and the member X_2 becomes the product S*m_L*d, the model being multiplicative.

On slopes an ox uses part of its power to move its mass against gravity and evidently the net power depends on the slope. On the other hand, the slope effect is not linear and therefore it is rational to analyse the data in narrow slope classes also.

Empirical models

As mentioned before, none of the skidding time models were multiplicative. Distance alone figured in one model, distance and load size in nine models and distance, load and slope in two models of the 12 models studied.

The average fixed time, constant ***a***, was independent of the slope at 30 s. Constant ***a*** can also be estimated from the load size. Skidding velocity, $v_{(b)}$, seemed to depend on the slope (Fig. 23), but the number of observations is inadequate for further analysis. The following two models fit best with the empirical data (eq. 3.31 and 3.32):

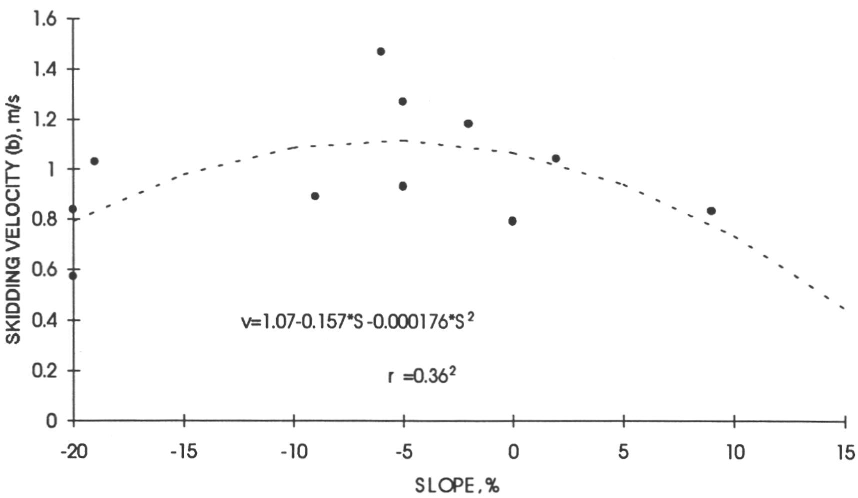


Figure 23. Skidding velocity, $v_{(b)}$ as a function of slope.

$t_S = 30 + (1.07 - 0.157*S - 0.000176*S^2)*d$ (3.31)

$t_S = 98*v_L + (1.07 - 0.157*S - 0.000176*S^2)*d$ (3.32)

where

t_S is skidding time, s
v_L is load size, m^3
S is slope, %
d is skidding distance, m

Unloading time

Unloading time varied from 18 to 67 s, the average unloading time being 45 s. In some cases loading time includes piling time. Unloading time can be regarded as more or less constant and independent of terrain. It depends more on stock arrangements than load properties. A constant unloading time

$t_U = 45$ (3.33)

can be used in average calculations. If unhooking of logs only takes place 30 s unloading time can be used. Unhooking and piling of pulpwood may take 60 s.

Other times

Other times consist of necessary delay time and of unnecessary delay time. Often they are expressed as a percentage of effective time, or of main time if elementary delay times are analysed.

Necessary delay time varied from 2 to 16% of effective time, the average necessary time being 7%. Necessary delay time lies normally between 5 and 10% of the effective cycle time.

Unnecessary delay time varied widely from 1 to 163% of the effective time. In Chamba's (1984) study of Pine cutting the oxen had to wait for the crosscutting team; the reason for high unnecessary times (35 ... 163%) was thus poor logging organisation. In the same study unnecessary delay time in well organised eucalyptus skidding was only 1%. In the other studies the unnecessary delay time varied from 3 ... 15% of effective time, the average being 10%. As a rule unnecessary time exceeding 10% indicates a poorly managed operation and a training programme should be proposed.

Total cycle time

Total cycle time depends on distance and therefore total cycle time is expressed in different reports in equation form t = ***a*** + ***b****d (3.34)

where

t	is cycle time, s
a	is fixed time, s
b	is velocity-dependent constant, (2*s/m))
d	is one way distance, m

Constants ***a*** and ***b*** are given in Table 10. Fixed time varied from (erroneous) -541 s to 869 s (in a tropical high forest). In pine plantations constant time varied from 120 to 540 seconds, the average being 256±64 s. In most reports fixed time seems to decrease as a function of increasing slope, and the lowest constant times are found on adverse slopes (Fig. 24). No final conclusions can be drawn, however. As the load size tends to decrease on steeper slopes the fixed time 539±107 s/m^3 reduces the variation somewhat. The average two-way velocity is 0.71 m/s, yielding ***b*** = 0.0592 (Table 10). For a two-way velocity model see eq. (3.36).

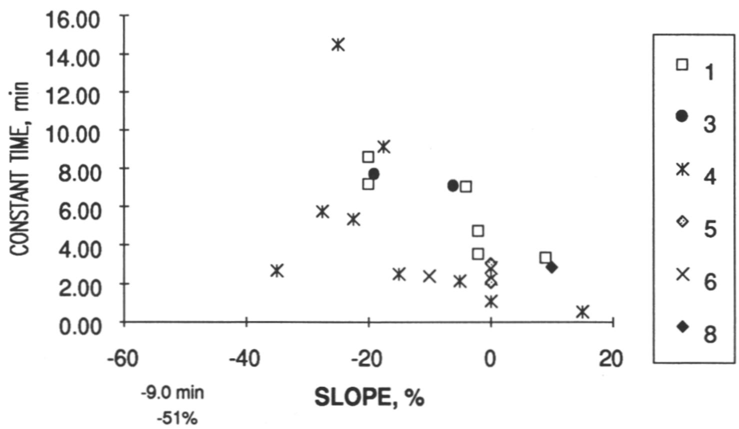


Figure 24. Constant time in different total time models.

Table 10. Coefficients for the cycle time model[19] from different sources.

Source	Cut 1)	Slope %	Load m^3	Constant *a*	Constant *b*	Two-way velocity, m/s 2)
I	E1	-4	0.24	422	1.662	1.20
I	E1	-2	0.27	212	2.292	0.87
I	S2	-20	0.56	430	3.840	0.52
I	S3	9	0.51	199	2.448	0.82
I	S4	-20	0.58	517	2.598	0.77
I	S5	-2	0.66	283	2.514	0.77
III	S3	-19	0.48	463	2.832	0.71
III e)	S2	-51	0.38	-542	19.152	0.10
III	S5	-6	0.53	425	2.832	0.71
IV	S5	-27.5	0.79	346	4.542	0.44
IV	S5	-22.5	0.68	321	4.704	0.42
IV	S5	-17.5	0.72	550	3.366	0.59
IV	S5	15	0.39	32	6.702	0.30
IV	P5	-35	0.51	160	3.678	0.54
IV	P5	-15	0.51	151	3.522	0.57
IV	P5	-5	0.51	129	3.444	0.58
IV	S5	0	0.42	65	4.092	0.49
IV	P5	0	0.37	134	2.364	0.84
IV	P3	0	0.29	169	2.310	0.87
IV e)	N	-25	1.19	870	3.084	0.65
V	S5	0	0.29	182	1.920	1.04
V	S3	0	0.23	122	2.280	0.88
VI	S4	-10	0.51	143	2.214	0.90
VIII	S3	10	0.18	172	2.460	0.81
Average		**-8**	**0.49**	**255**	**3.120**	**0.71**
STD		**13**	**0.22**	**152**	**1.158**	**0.22**

1) Eucalyptus; S pine, sawlog; P pine, pulpwood; N tropical high forest
2) Average skidding and return velocity, $v_{(b)}$
e) Excluded from average

342. Velocity models

Return velocity

The average return velocity $v_{(a)}$ was strongly dependent on the slope (Fig. 25)

$$v_{r(a)} = 0.762 + 0.0089*S \tag{3.35}$$

where

$v_{r(a)}$ is average return velocity, m/s
S is slope in skidding direction, %

[19] Cycle time is converted into seconds.

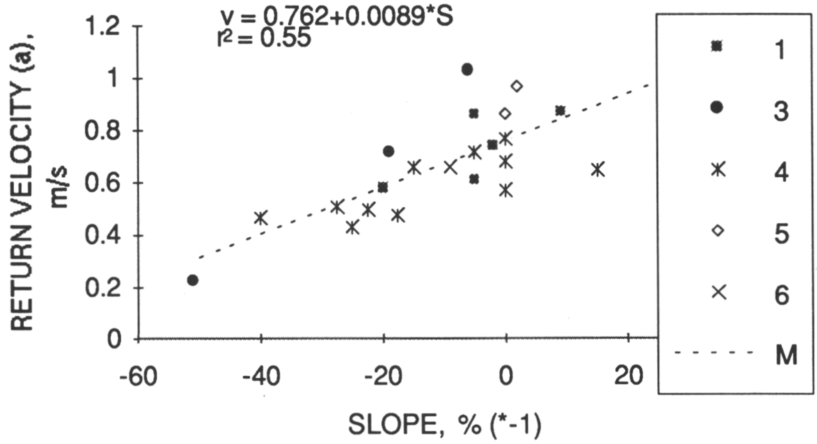


Figure 25. Average return velocity $v_{(a)}$ as a function of slope.

Skidding velocity

Skidding velocity, $v_{(a)}$ was fairly constant, independent of the slope, in Rodriguez (1986) about 0.5 m/s and in Chamba (1984) about 0.6 m/s (Fig. 26). In Solberg & Skaar (1986) there was a strong correlation between slope and velocity.

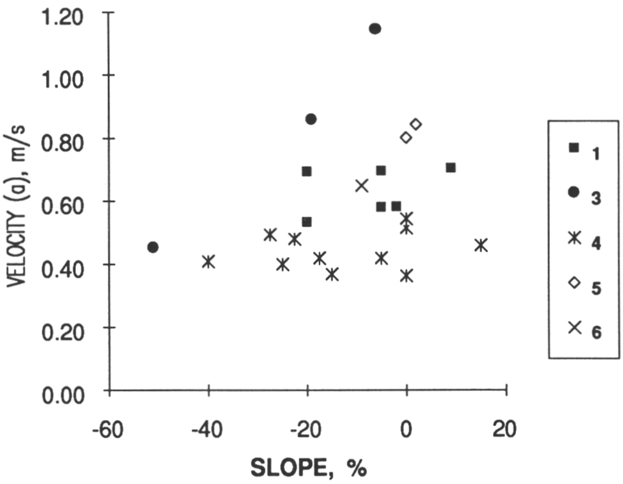


Figure 26. Average skidding velocity, $v_{(a)}$, on different slopes.

Average return and skidding velocity (two-way velocity)

In the cases studied, the loaded skidding velocity $v_{(b)}$ was strongly correlated with the empty return velocity $v_{(b)}$ (Fig. 27). However, it should be noted that no adverse slope skidding is included in the data and that all the skidding time models are additive, which reduces the validity of the data.

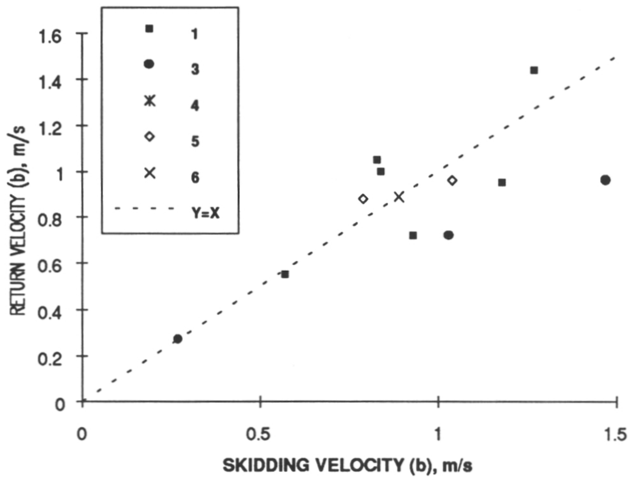


Figure 27. Skidding velocity, $v_{(b)}$, compared to return velocity, $v_{(b)}$.

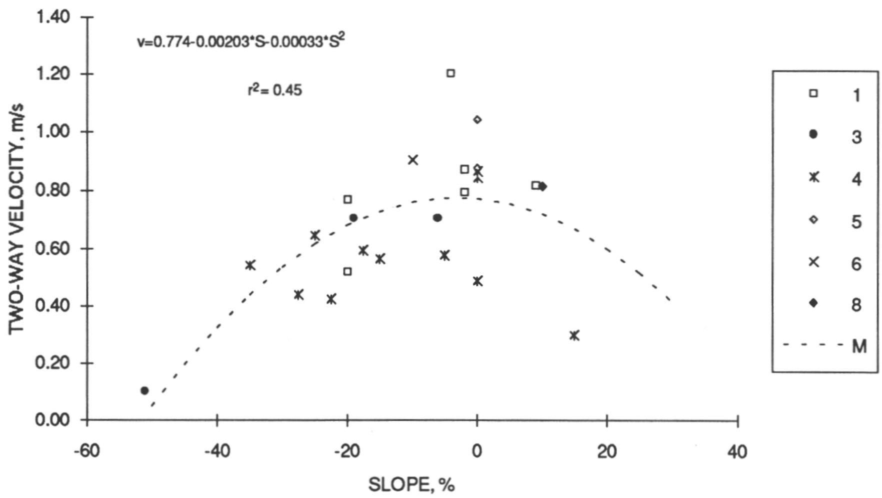


Figure 28. Two-way velocity (average return and skidding velocity), $v_{(b)}$, as a function of slope.

As the return and skidding distances are usually of equal length, an average skidding and return velocity, (two-way velocity), can be used for general cycle time and production rate models. Return and skidding velocities were correlated, even the direction of the slope changes to its inverse. Two-way velocity, average return and skidding velocity in different reports are presented in Table 10[20] and in Fig. 28. The following black-box model explains nearly half of the variation in the two-way velocity (eq.(3.36)).

$$v_{rs(b)} = 0.774 - 0.00203*S - 0.00033*S^2 \quad R^2=0.45 \qquad (3.36)$$

where

$v_{rs(b)}$ is two-way velocity, average skidding and return velocity, $v_{(b)}$, m/s
S is slope in the skidding direction, %

343. Load size models

No load size model was presented in the reports referred to. In FAO (1974) a graphical load size/slope dependence is presented. The average load size is 0.45 m^3, the minimum being 0.18 m^3 and the maximum 1.15 m^3, the maximum load being recorded in a tropical high forest. There are many factors affecting the load size, and therefore estimating the realistic load size for different conditions is of primary importance. It seems that the load size increases as a function of tree size (Table 11), although the slope is also a major influence.

Table 11. Load size in different logging.

Cutting	Load size, m^3
1st thinning, eucalyptus	0.27 ... 0.33
2-3 thinning, pine	0.38 ... 0.56
4th thinning, pine	0.59
Clear cutting, pine	0.53 ... 0.66
Tropical hardwood	1.19[1)]

1) Work sharing with two oxen teams

A model for load size was developed in Chapter 33. It seems that the model is applicable to practical planning purposes until better models are developed. Tree size and permitted log dimensions may mean that the optimum load is difficult to arrange.

344. Skidding distance

Skidding distances were generally short as most of the studies took place in pine plantations. In Chamba's (1984) study the average distance varied between 41 and

20 NOTE: If used in cycle time and/or productivity models the distance is the sum of the skidding and return distances , or $d = 2*d_s$.

166 m. Solberg & Skaar (1986) recorded somewhat longer (average) distances, between 81 and 194 m. Longer distances, around 450 m, are recorded in tropical high forests by Rodriguez (1986).

4. PRODUCTION RATE

Productivity is defined as the ratio of output to a particular input. The productivity may be given in quantity per unit input, such as a volume per working hour (m^3/h), volume per unit of energy (m^3/kWh), etc. Performance measures output in relation to the input actually employed. It is the result achieved during the production period. The performance is usually lower than the productivity due to interruptions during the production period. The performance can be given as a quantity per time unit, e.g. m^3/h. In this report the term production rate is used to express the output per time input and depending on the time concept it corresponds to the productivity or performance.

41. Effective time

Effective time is defined as the time required to perform a specified work element which directly or indirectly changes the work object in respect of its form, position or state. Effective time may be divided into:

- Main time, which is the part of the effective time which directly changes the working object with regard to its form, position or state. The main time is always variable in relation to the quantity produced or to the length of the working period.

- By-time, which is the part of the effective time which indirectly changes the work object. By-times are sometimes fixed and sometimes variable in relation to the quantity produced or the length of the working period.

42. Allowances

In comparative time studies the recorded by-times are usually regarded as "ground truth", and added into the model. When observing well trained men using correct working methods, the approach is acceptable. When studying methods still under development, the delay times may be too long, and better work organisation will change drastically the total work place time. In this case, the approach of the rating method is more appropriate: the observed (rated) effective times are used as "true" times and by-times are added using standard allowances. In this method, production rate elementary times and load size can be calculated using the effective time models that have been developed (Chapter 34). Different allowances are based on the ILO (1979) handbook, which enumerates the following allowances

- relaxation allowance
- contingency allowance
- policy allowance
- special allowance
- learning allowance

The **relaxation allowance** provides the opportunity to recover from the physiological and psychological effects of carrying out a specified job. For **personal needs** about 5 ... 7% is added. The **basic fatigue** allowance is 4 %. If the average work load stays low, a 10% relaxation allowance is adequate. In case of an extreme work pace, the allowance must be larger, but evidently the oxen are seldom overcharged. Therefore a 10% relaxation and basic fatigue allowance is recommended.

Two to three rest pauses of 15 minutes are needed for drinking, especially in warmer conditions. When estimating the daily production rate, 45 min should be added as a fixed daily time. This means that in an 8 h day there is at maximum 435 min (26 100 s) available for other times. Different animals may need extra rest pauses, and therefore the effective time per day may vary greatly. Variations in climatic conditions may result in a variation in effective day length for draught animals.

Contingency allowance is a short time to cover different irregularities observed during the work. Contingency allowance is usually < 5% of standard time. Different delay times and constants in time equations usually include a contingency allowance, but still 5% contingency may be added to standard times.

Contingency time should be added in models based on effective times and $v_{(b)}$ velocities. If snap-back timing is used, and different delay times are clearly segregated, then adding contingency time is of primary importance. If effective times contain hidden delay times, as in the case of continuous timing, the need to add contingency times should be reconsidered.

Policy allowance is an increment applied to standard time to provide a satisfactory level of performance under exceptional circumstances. This additional time can be added to standard time in order to make the use of standard times more flexible.

This time can be negotiable, and reduce the need for continuous changes in tariffs. It might be greater for example in areas where some increase in salary is needed. Then common standard times can be used in all the forests, but a differentiation in earnings between forests can be obtained using different policy allowances.

Special allowances contain different times which are usually specified as different times outside the work cycle, such as shut-down, cleaning and tool allowance times. Some 15 to 30 minutes per day is needed for starting the job and for maintaining the equipment etc. These special allowances can be determined from time studies which cover the whole day.

A **learning allowance** is used for trainees as their work pace does not match the pace of skilled workers. It is important to note the learning process when carrying time studies at early phases of implementing new methods (Chapter 316). Standard time should be shorter than time measured when observing non-skilled workers. Learning allowance can be estimated by applying learning curve theories to the work studies carried out successively at certain time intervals.

43. Load size

Load size is dependent on the logging type, terrain conditions, skidding method etc. For example, loads are generally bigger in clearfelling than in thinning due to the larger stem size, and thus the production rate in clearfelling tends to exceed the production rate in thinning. In comparisons of time study results, the differences in the previously mentioned factors should be taken into account.

44. Hourly and daily production rate

The number of working hours per day varies from one country to another; seasonal variation is also obvious. Detailed time studies are usually performed in somewhat controlled conditions and the production rate is expressed in m^3/h. For practical applications, a knowledge of daily, monthly or annual production is more important. Literature provides, however, rather scantily information about real production. It is therefore important to combine shift level studies where day length and daily production are the prime aims. The number of effective hours per day in skidding is often only around 5 h.

45. Monthly and annual production

The number of working days in a month varies greatly between countries, depending where there are of 5 or 6 working days per week and the number of holidays. Generally 22 ... 25 working days can be reckoned for a month. This corresponds to about 175 ... 200 hours in a month. When comparing older monthly production records with recent ones, it should be noted that the number of working days in a week has reduced in most countries, and in many cases the number of hours per day may also have dropped. On the other hand, better supervision and improvements in working techniques may have had a compensating effect.

Animals need rest, and therefore the number of effective days per month may be less than in manual or machine work. Monthly production is also reduced by accidents. With mules, for example, about 1/3 of the animals are resting at any time or the number of annual working days of elephants is only about 160. Shift level time studies are needed to increase the knowledge of effective monthly production for different animals in different conditions.

The hourly production model (eq. (2.28)) can be extended to the monthly production model by multiplying it by the number of working hours in a month

$$P_{mo} = h*\frac{1107692}{360+2.4*d}*(1-\frac{D}{100})*N_{DAY} \qquad (4.1)$$

where

P_{mo} is monthly production, kg/month
h is number of effective hours in day (about 8 h)
d is distance, m
D is delay time percentage, % (about 20%)
N_{DAY} is number of working days in a month (about 22 d)

For an average distance of 100 m, the model (4.1) yields 260 000 kg equalling about 260 m^3 in a month of 22 working days. In Malawi, the monthly production of "hard working" teams is over 300 m^3 and less than 300 m^3 for teams classified as "lazy" (Chamba 1984, p. 44). Model (4.1) seems to yield rather realistic estimates.

46. Effect of climate on production

461. Temperature

Temperature has an important effect on the physical ability of a forest worker to work steadily. Humidity is almost as important. In high ranges both are enervating. As they rise so does the need for extending rest periods during the working day. The effect of these environmental parameters on animal skidding productivity has not been studied at all. It is assumed that the heat stress decreases the production rate of animal skidding even more than with men.

The duration and frequency of rest periods during the working day depends on the ambient temperature and humidity and the work load. In Canada, for example, the following decrease in production rate in timber cutting as a function of air temperature has been recorded (see Fig. 29).

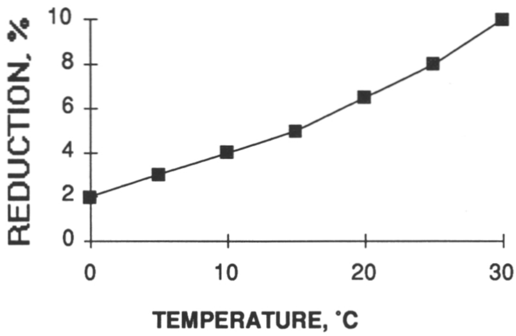


Figure 29. Decrease in production rate in timber cutting as a function of atmospheric temperature in Eastern Canada (after FAO 1976).

462. Precipitation

The effect of precipitation on production is an unresearched field in forest work studies. Rain increases soil moisture, and the skidding resistance coefficient decreases. Animal mobility is less sensitive to changes in terrain conditions, and thus increased soil moisture probably increases the production rate to a certain extent.

On the other hand, knowing the frequency and intensity of the rains helps in planning forestry operations. Rainy seasons affect the number of annual working days, and thus also the annual production.

47. Empirical production rate models

Most of the production rate models presented in literature are effective hourly productivity models. Empirically observed production rates are presented in Fig. 30. The effect of size of the ox or slope are not compensated for, and the slope range extends from -51 to +15 % and ox size from 450 to 600 kg. As the production rate can be calculated based on an average fixed time 255±61 s/cycle or 540±104 s/m^3 and on the two-way velocity model (eq. (3.36)) closer analysis in this context is unnecessary. Table 10 also provides some data for production rate estimates.

Large variations in productivity are evident and therefore more research is needed to develop more reliable models for oxen skidding. The slope seems to be one of the governing factors, and with a skidding distance of 100 m, for example, the slope explains about 30% of the variation in hourly productivity (Fig. 31).

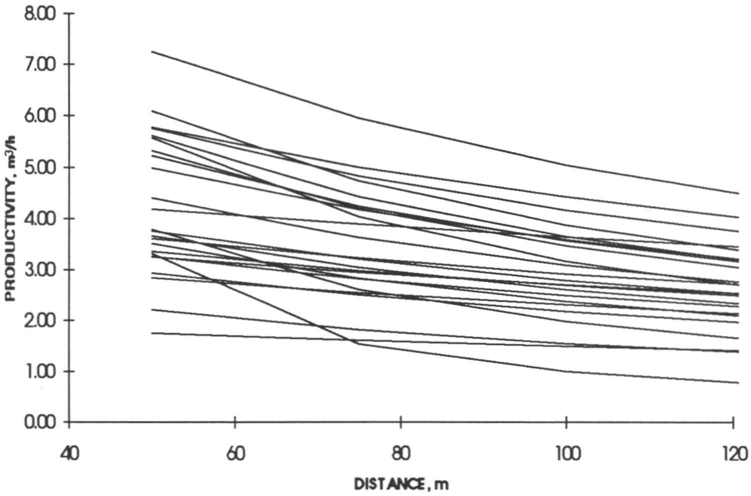


Figure 30. Empirically observed production rates in m^3 per effective hour as a function of distance.

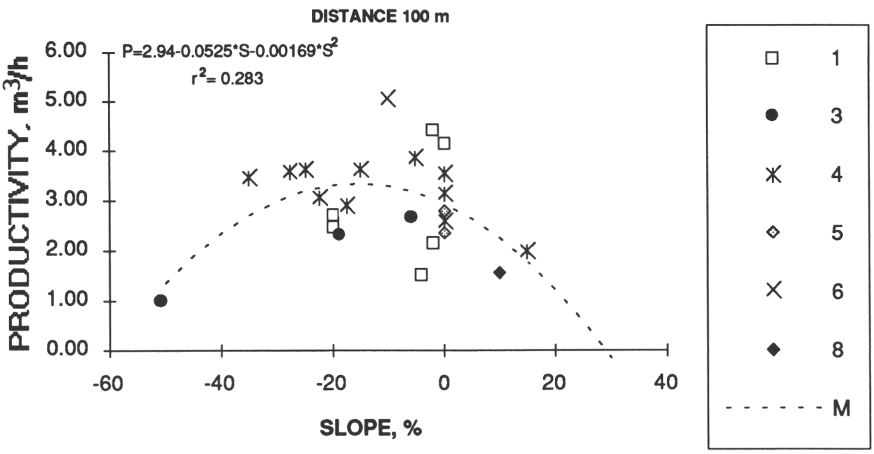


Figure 31. Productivity for 100 m distance in oxen skidding, m^3/effective hour, as a function of slope.

5. WORK STUDY PROCEDURE

51. Recording work conditions

511. Load size

The load size is easiest to record in m^3 by measuring the logs piece by piece. Either the average of top and butt diameters or the middle diameter must be recorded using a calliper (1 cm graduation), and the length measured using a tape (0.1 m graduation). The volume expressed in m^3 can be estimated by using some of the following simple equations:

A basic formula:

$$V = \frac{\pi * d_m^{2} * l}{4} \qquad (5.1)$$

or:

$$V = \frac{\pi * d_a^{2} * l}{4} \qquad (5.2)$$

where

V	is volume of a piece of timber, m^3
π	is pi (3.14)
d_m	is middle diameter, m
d_a	is average of the butt and top diameters, m
l	is log length, m

512. Load weight

Load weight (or mass) is calculated by determining the average density of the wood. A certain number of logs are weighed in order to find the density. This can be done in connection with the skidding resistance measurements. Log weight can be determined with a sprung weight or load cell (Fig. 32). As lifting the whole log manually may be strenuous, or if the weight exceeds the capacity of the scale, logs can be weighed by lifting at first the top end and then the butt end and adding the two readings. It also allows the centre of gravity to be located, when special studies on skidding resistance are carried out. The mass of the log is calculated by dividing the weight by g (9.81 m/s^2).

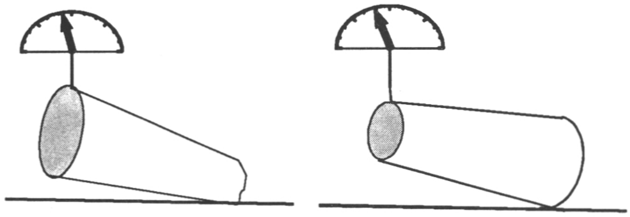


Figure 32. Measuring log weight by a sprung scale.

513. Skidding resistance coefficient

Excluding special skidding resistance coefficient and other terramechanical studies, it is adequate to measure the skidding resistance on different parts of trails at random. A small-size log (l=2 ... 3 m, d=0.1 ... 0.2 m)[21] can simply be pulled manually along the ground for about 5 ... 10 m, and the resisting force recorded. The log is weighed and the slope determined. The dragging resistance coefficient is calculated from the measured line pull using eq. (3.12) or (3.16). Soil and moisture classes are identified (Appendix 6).

If implements are used, measuring the resistance coefficient is somewhat more complicated. The recommended terminology for different types of resistance is given in Appendix 10.

The average skidding resistance coefficient should be assessed for different soil and moisture conditions. It is important to monitor the seasonal variations in the skidding resistance coefficient.

514. Soil Classification

A soil description is necessary in order to make the results comparable with studies carried out in other countries. The USDA (United States Department of Agriculture) soil classification system is widely recognized and can be used for describing soils.

[21] d=0.2 m and l=3.0 yields about 100 L (100 kg). Thus a small sprung weight with 1000 N capacity is adequate.

Soil moisture should be estimated using a simple visual/finger test, or determined using the gravimeter method.

Some soil classification methods are presented in Appendix 6.

515. Terrain classification

The following three factors should be described in terrain classification:

Macrorelief
Macrorelief is described using two slope variables: average slope and average maximal slope. For each trail the average slope from stump site to landing (difference in altitude divided by distance) and average maximal slope are recorded. The slope can best be determined with a clinometer. If no clinometer is available, the eye can be practised using spirit level and tape.

Microrelief
Microrelief describes the evenness of the surface pattern, the most common patterns being even, rolling or terraced.

Surface roughness
The surface roughness classification is based on the number and height of obstacles on average trail areas.

Appendix 7 contains more information on common terrain classifications.

516. Recording environmental temperature

Because of the complexity of environmental heat exchange, various types of heat stress indices have been developed. Wet-bulb globe temperature (WBGT) is one of the most common of them. It is simple and suitable for outdoor work. WBGT is defined as follows:

$$WBGT = 0.7*t_{wn} + 0.2*t_g + 0.1*t_d \qquad (5.3)$$

where

t_{wn} is wet-bulb temperature
t_d is dry-bulb temperature
t_g is globe temperature

The dry-bulb temperature can be measured with a normal mercury thermometer in the shade. The wet-bulb temperature is measured with a normal thermometer as well, with a wet cotton lining around the bulb. The lining is kept wet by inserting one of its ends into a water reservoir. The globe thermometer consists of a normal thermometer, whose bulb is placed in the middle of a blackened 150 mm hollow tin cylinder. It is placed so that it registers the radiation that the workers and animals are subjected to.

52. Time breakdown

The time breakdown recommended for oxen skidding research is presented in Fig. 33. See also the basic time concepts in Appendix 1.

6. SOCIO-ECONOMIC STUDIES

61. Workers

It is important to record the work experience of workers. The following general classification can be used for describing the experience of the workers:

1. **Unskilled workers**: workers who have had little or no training and have been working less than one year in the work studied.

2. **Semi-skilled workers**: workers who have had a certain amount of on-the-job training and experience. Work experience over one year.

3. **Skilled workers**: Good vocational training and certain work experience. Workers without vocational training must have over five years work experience.

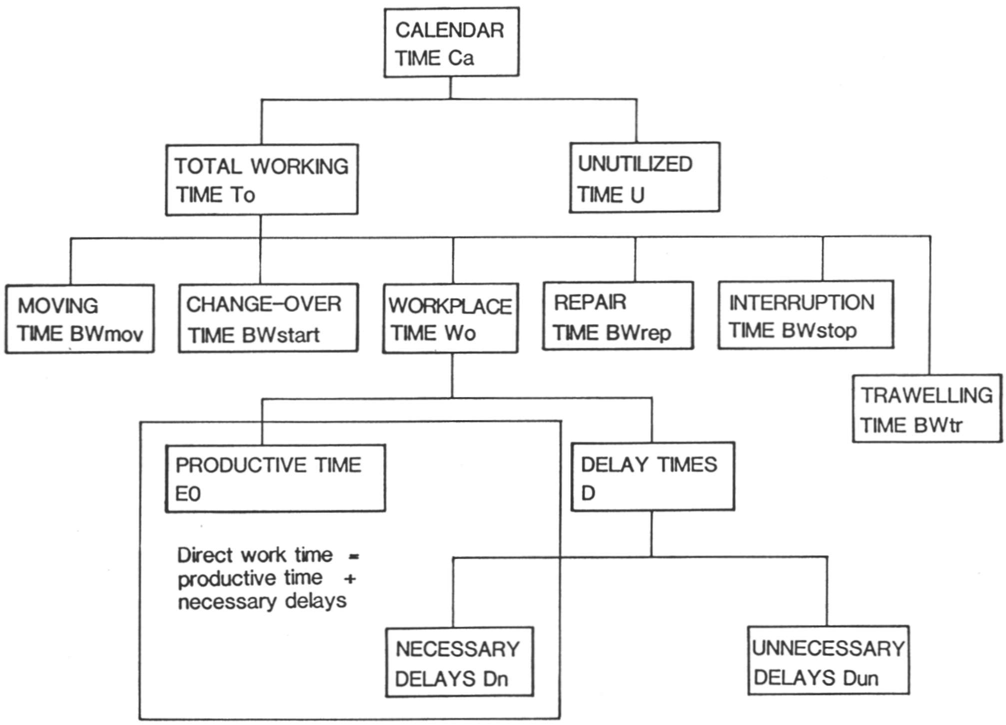


Figure 33. Time breakdown in oxen skidding.

611. Working capacity of workers

In animal skidding the physical fitness of the workers is hardly the minimum factor, as the natural walking velocity of oxen (0.8 m/s) is lower than the natural walking velocity of men (1.0 m/s) (Saarilahti 1992), and the lifting phases during loading and unloading are short. However, the motivation and work pace of the men influence productivity, and therefore a short description of the human team is needed.

For minimum data on the fitness of the ox handlers and helpers the following should be recorded:
- age, sex, weight and height
- work experience, training, worker status (permanent, skilled, seasonal labour)
- a subjective estimation of the fitness (in good/poor health)
- other relevant information on motivation and working conditions (payment system, work organisation, supervision)

In more exhaustive socio-economic studies the physical fitness of the workers should be assessed using some generally adopted test, such as
- step test
- bicycle ergometer or
- walk test.

612. Assessing the work load

The work load of the oxen handler and helper can be assessed based on their heart rates. For a simple test, palpate the wrist artery and count the pulses during 30 s a few times during the work cycle. The work load can be assessed more accurately using Sport Tester or other heart rate recording devices. The heart rate can be measured separately for different work phases or an average pulse over the cycle can be calculated.

As the work load in animal skidding usually stays low, more comprehensive studies are not needed. Some random heart rate recordings are adequate. The work load can be assessed directly based on the heart rate (Table 12), or the Work Load Index (WLI) can be calculated (eq. (6.1)) (Mälkiä 1973, 1974):

$$WLI = \frac{HR_{WORK} - HR_{REST}}{HR_{MAX} - HR_{REST}} * 100 \qquad (6.1)$$

where

WLI	is work load index, %
HR_{WORK}	is observed heart rate during the work element, P/min
HR_{REST}	is rest pulse, P/min
HR_{MAX}	is maximum pulse, P/min

Arstila (1972) defines the approximate maximum pulse rate as follows:

$$HR_{max} = 200.1 - 0.685 * \text{age in years} \quad (6.2)$$

WLI 50 is considered an acceptable work load limit.

Apud et al. (1989, after Christensen 1953) proposed the scale presented in Table 12 for grading the physiological load on the basis of heart-rate determinations.

Table 12. Physiological load on the basis of heart-rate determinations.

Heart rate, P/min	Physiological workload
<75	Very low
75 - 100	Low
100 - 125	Moderate
125 - 150	High
150 - 175	Very high
>175	Extremely high

613. Working postures

Men at work need to perform a variety of movements. These are achieved by means of different levers formed by the skeletal system and powered by muscles. Therefore, the skeleton might be looked upon as the frame for body motion. From the ergonomic point of view, the main interest is concentrated in the four systems of levers, the arms and the legs, as well as in the support represented by the spinal column.

In skidding work, very serious injuries of the spine may occur due to inadequate lifting and carrying methods during the loading and unloading phases. The intervertebral discs tend to degenerate with advancing age and become fragile. Therefore, any sudden stress, such as lifting of weights, will easily damage these structures, leading to lumbago or hernial discs. Therefore, from the ergonomic point of view, it is very important to prevent the occurrence of such damage.

The OWAS (1992)[22] method is developed for charting the working postures in order to improve working conditions and working methods in a more ergonomic direction. The basic survey is aimed at demonstrating the following items:

- the types of working postures used and their relative proportions
- the part of the work in which the postures occur
- concentration of working postures on various parts of the body
- the strain caused by the weight or force affecting the posture
- classification of measures for improving the postures (no measures, non-urgent measures, urgent measures)

The basic working postures are illustrated in Appendix 8.

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[22] Ovako Working Posture Analysing System

62. Animals

621. Recording of animals' characteristics

As the productivity in animal skidding is strongly dependent on the characteristics of the prime mover, the main features of the oxen used should be recorded. Every study should contain at least (the estimated) weight of the oxen, their age and training. It is also recommended that the breed is mentioned. Gait (slow ... fast) and character (calm ... nervous) can also be assessed and used as variables for increasing the validity of models.

622. Nutrition studies

For economic analysis the cost of the animal is needed. Even if oxen are usually fed on pasture, additional feeding is necessary in order to guarantee good animal health. Long-term nutrition studies are needed for determining optimum strategies in oxen husbandry. These studies should be carried out in co-operation with a specialist in veterinary sciences. Usually the studies are related to shift work studies and an analysis of variations in long-term in productivity.

623. Other studies

A special version of Sport Tester is used for monitoring the heart rate of race horses under training. Evidently the same device is suitable for monitoring the heart rate of oxen as well. It gives reliable data on the pull/strain relation and makes it possible to evaluate the power of oxen in different conditions.

If only short-term productivity is being considered, and over-strict norms are applied, it might lead to more injuries and more frequent immobilisation of animals due to sickness. It is therefore important to carry out long-term shift level studies where the health of the animals, the length of day, production and injuries are recorded. A thorough scientific analysis of past records makes it possible to detect changes in productivity, day length or the number of injuries. As an example, Sohlberg & Skaar (1986, p. 40) analysed the accident records of Dedza and found that the absence rate due to sick and injured animals was between 0 and 7% when working under a time-based payment system, but the rate went as high as 20 to 48% when a piece work rate was applied. Evidently the expectation of higher income caused the animals´ working capacity to be exceeded.

63. Accident records

631. Near accident analysis

The risk of individuals being involved in accidents in developing countries is found to be higher than, for example, in Finland. The reasons for this can be classified as follows:

- the physical environment
- facts due to the labourer
- technology
- organisation of work and safety

Risk analysis is designed to improve the safety at work, as well as teach safe working methods (Mäkijärvi & Ihonen 1986). By means of risk analysis it is possible to observe either the direct or indirect dangers of machines, work objects or the environment for the labourer. Video recording can be used for risk analysis. If there are no facilities for video taping available, visual observations can be made. Due to the subjectiveness of these observations, and the uniqueness of a working event, it is recommended that two persons should be involved in observations.

In risk analysis the work is divided into elements. The safest way to carry out these work phases is determined, and a checklist for aberrations from the recommendable procedure is made. The reason for the dangerous situation is recorded, as well as the gravity of it. The number of risk situations is expressed as the number of occurrences per time unit (e.g. per minute).

632. Accident statistics

Reliable long-term accident statistics are a useful tool in evaluating the development of overall efficiency and the response of the organisation in terms of training. It is therefore important to initiate the collection of comprehensive accident statistics, and the work study officers should also encourage this activity. The accident statistics should cover both men and animals if animal transport is used on site.

The accident statistics should contain at least the following information: time, place, type of work and accident and days lost.

The standardised accident indices calculated from the raw data are (ILO 1971):

$$\text{FREQUENCY RATE} = \frac{\text{Total number of accidents} * 1{,}000{,}000}{\text{Total number of man} - \text{hours worked}} \qquad (6.3)$$

$$\text{SEVERITY RATE} = \frac{\text{Total number of days lost} * 1{,}000{,}000}{\text{Total number of man} - \text{hours of exposure}} \qquad (6.4)$$

64. Assessing the ecological impact

Labour-intensive methods are generally considered ecologically less destructive than mechanised ones. This should also be proved scientifically and therefore inventories of damages to the remaining vegetation and the soil are needed. The importance of ecological damage depends largely on the forest type and the cutting. Most damage to remaining trees is caused by felling and usually only a small number of trees along trails sustain minor bark and root injury from skidding. In clearfelling damages to remaining trees is of no significance. In thinning it is rational to select one or two trails and study more closely the number of affected trees and the extent of the damage.

641. Evaluation of damage to remaining trees

In developing countries, there are no standards for evaluating the damages to the remaining trees. The evaluation can be performed by adapting the Scandinavian method as follows:

Damages to remaining trees are divided into the following two categories:

- Stem damage: the bark is damaged as far as the inner bark (*phloem*), and the damage is located above stump height. Resin flows are not classified as damage.

- Root collar damage: Damage located below stump height, within a radius of 70 cm from the stem. In order for a tree to be classified as damaged the minimum diameter of a damaged root is 20 mm.

In Finland, damage classification is based on studies on the effects of damage to timber quality. Damage is classified in two groups according to the extent of the damage: damage of less than 100 cm^2 and damage of more than 100 cm^2 (badly damaged). If there is more than one damage to a tree, it is classified as badly damaged, regardless of the sizes of the damage.

Damage evaluation can take place either after skidding operations, or whilst skidding is in progress. In the first case, for example, the officer systematically measures located sample plots, the number of which depends on the area to be inventoried. Utilising the skidding trails, if uniformly located, is useful in sampling. The total number of damaged trees per hectare is obtained by multiplying the average number of damages per sample plot by the area of the sample plot. The degree of damage is often given as a percentage of damaged trees of the total number of remaining trees. If the damage is inventoried after skidding, in some cases (especially in mechanised skidding) it might be difficult to distinguish between damages due to felling and damage due to skidding.

If possible, damage can also be recorded while examining the skidding operation. Care must be taken that the same damage is recorded only once.

642. Evaluation of soil damage

Soil damage consists of
- soil compaction
- soil disturbance
- exposure to erosion

As the loads in oxen skidding are relatively small, soil compaction is not a real problem. Soil compaction can be analysed, if the need arises, by taking soil samples and weighting them moist and dry. The volume of the soil sample can be determined by inserting a thin plastic film into the cavity and filling it with water up to the soil surface. The volume of water is determined by weighing. The other method is to record the infiltration rate by inserting tubes 250 mm high 100 mm in diameter into the soil. The tubes are filled with water to a certain height, and observing the sinkage of water level as a function of time, the relative densities of soils on and off trails can be compared.

Soil disturbance is analysed by estimating the length and average width of the trails as a percentage of the total surface. As a second variable the severity of soil disturbance can be estimated bye eye: light, medium, severe.

Exposure to erosion is an analysis of the possible consequences of the operation for the course of surface water. On longer slopes, deeply gouged skidding trails might collect surface water during heavy rain into rills which initiate a continuous gully erosion. It is therefore important to evaluate the possible erosion risks and record them in the study report. Notes on necessary erosion control operations[23] should be included in the recommendations of the study report.

7. ECONOMIC STUDIES

The objective of the engineering economy is the quantitative evaluation of engineering proposals in terms of costs and benefits before they are undertaken. The engineer's responsibility is to ensure that the engineering proposal is both technically and economically sound before it is recommended for adoption.

The most common field of application in forest engineering is the selection of timber harvesting technology by comparing various alternatives.

71. Costing

Hourly cost calculations are needed in estimating the skidding unit costs. For accounting purposes the costs of an engineering proposal are often divided into two broad categories: **fixed** costs and **variable** costs.

Fixed costs do not vary significantly with the level of the utilisation of the oxen. Generally they are related to the ownership of the oxen. In oxen skidding, interest payments, depreciation, normal feed and medicaments are considered as fixed costs.

Variable costs depend directly on the level of utilisation of the oxen. They are running costs, including special feed.

Labour costs in most cases are fixed costs, and only the bonus can be considered as a variable part. The following equations can be used for estimating hourly depreciation and interest (both for oxen and the equipment used in skidding):

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[23] Such as smoothing the trails, building water diversion banks over trails, vegetatative erosion control, etc.

$$\text{Depreciation (D)} = \frac{P-S}{n*E_h} \quad (7.1)$$

$$\text{Interest (I)} = \frac{(\frac{P+S}{2})*i}{E_h} \quad (7.2)$$

where

P	is purchase price
S	is salvage value (slaughter value for the oxen)
i	is rate of interest, %
E_h	is estimated working hours per a year
n	is useful life of oxen/equipment, a

The running of a skidding operation necessitates different kinds of extra costs which are charged to the administration, etc. In addition to the above-mentioned cost categories, some overhead costs must be added to the total hourly cost, depending on many factors. The level of overhead costs is usually between 20 and 30% of the total costs.

72. Shadow pricing

Many countries have difficulties in balancing their external trade. Due to limited foreign currency resources, the imported goods cannot directly be compared to local goods and services. Shadow pricing is a tool in decision making, making it possible to quantify some intangible benefits.

The main purpose of shadow pricing in planning logging operations is to discourage proposals that will involve a loss in foreign exchange and encourage those which will enable a project to save foreign exchange. Shadow pricing is based on the use of a shadow pricing factor, a multiplier by which all the foreign currency components are multiplied. Economists have various methods for assessing the shadow pricing factor. Saarilahti (1986b) recommends values between 1.5 and 3 for use in forest engineering economies. The foreign currency component of hourly oxen skidding costs varies. The figures presented in Table 13 can be used as a rough estimate of the division of hourly oxen skidding costs into foreign and local components.

Table 13. Foreign and local currency components of the total hourly oxen skidding costs for shadow pricing.

Item	**Foreign component, %**	**Local component, %**
Labour cost	0	100
Depreciation[24]	20	80
Interest	0	100
Fodder	0	100
Medicaments	100	0

[24] If the skidding device contains some imported components, otherwise 0:100.

8. REPORTING THE RESULTS

The main aim in reporting forestry work study results is to communicate them to the primary customers of the research worker. The results should be presented in such a form and in such a language that can be interpreted correctly and put into practice. Including the following facts in the study report is one of the basic requirements for publications in the field of forest work science:

- The name of the publication (short and illustrative)
- The author's name and employer
- The topic of the study
- Objective
- Study method and technique
- Data collection
- The time of data collection
- Location of the study area
- Description of the work studied (the work method, the division of the work into elements and the method of payment)
- Information on the working conditions
- Description of the workers' job and their skill
- Description of the oxen and equipment

The following basic content of a study report is widely used:

> title, abstract and/or summary[25], keywords, list of contents, acknowledgements, introduction, literature survey, materials and methods used, data analysis, results, discussion, conclusions, recommendations, literature references and appendices.

The results of the study should be presented as recommended earlier in this paper. The most important part of the report is the conclusion as it interprets the results of the study. Based on the reliability estimates of the results and a comparison with earlier knowledge, a recommendation for the application of the results should be given.

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[25] If an extended summary (in another language than the report) is written it may be placed at the end, between the recommendations and literature references.

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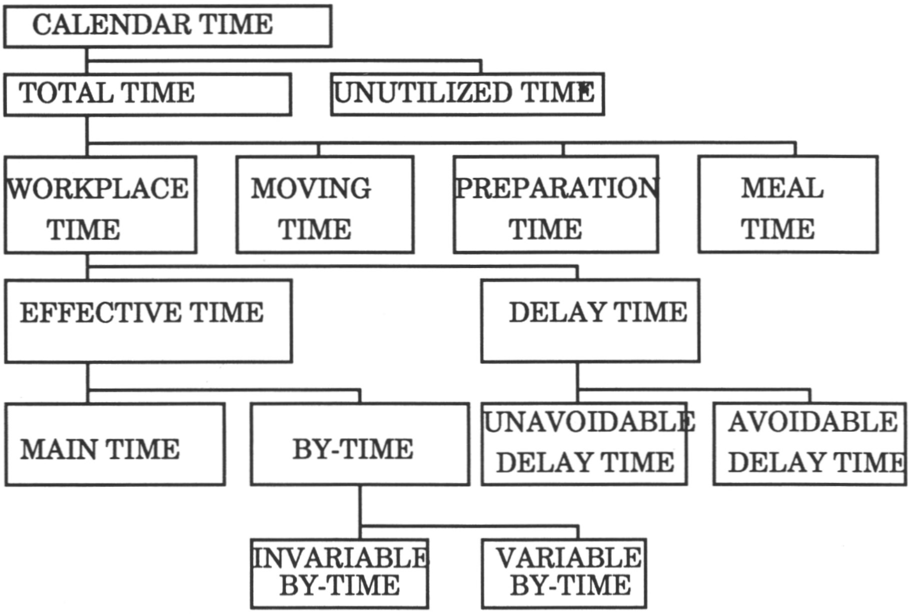
APPENDIX 1. The structure of basic time concept used in forestry (after NSR 1978).



* Note that in larger socio-economic and ergonomic studies also unutilized time should be studied as oxen may be used for other work outside working hours.

APPENDIX 2. Conversion factors

Length

1 inch	=	2.54 cm (=25.40 mm, =0.0254 m)
1 foot (ft.)	=	0.3048 m
1 mile (m)	=	1609 m

Mass

1 ounce (oz.)	=	28.35 g (1 g =0.001 kg)
1 pound (lb)	=	0.4536 kg

Work, energy

1 calorie (cal)	=	4.1868 J
1 horse power (hp)	=	735.5 W

Velocity

1 km/h	=	0.28 m/s

Pressure

1 lb/sq.ft	=	47.9 N/m^2 = 47.9 Pa
1 lb/sq.in	=	6.895 kPa

Table A2.1. SI abbreviations for multipliers.

Prefix	Abbreviation	Multiplier	Prefix	Abbreviation	Multipli
exa	E	10^{18}	deci [1)]	d [1)]	10^{-1}
peta	P	10^{15}	centi [1)]	c [1)]	10^{-2}
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	µ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}
hecto [1)]	h [1)]	10^{2}	femto	f	10^{-15}
deca [1)]	da [1)]	10^{1}	atto	a	10^{-18}

[1)] not recommended for use

APPENDIX 3

A3.1 Regression analysis of time study data

A computational example

Suppose we have conducted a time study of an oxen skidding operation. We have hypothesised that there is a functional relationship between total skidding time per load and skidding distance. Thus, in conducting the time study we have measured not only skidding time per load (the dependent variable) but also the skidding distance for each load (the independent variable). Data for the 18 loads are summarised in Table A3.1.

Table A3.1. The data for the regression analysis example.

Load no.	Skidding distance, m	Total skidding time, min/load
1	23	0.42
2	29	0.49
3	40	1.10
4	45	1.16
5	55	1.12
6	60	1.45
7	70	1.49
8	80	2.14
9	90	2.06
10	95	2.29
11	111	2.60
12	121	2.50
13	134	1.80
14	140	1.94
15	150	2.42
16	165	2.73
17	175	3.10
18	179	4.03

Note that presenting the data in order of increasing skidding distance is not necessary. The only requirement is that a particular load corresponds to the skidding time for that load. The total skidding times in the above table are productive times only.

(1) A useful first step in any regression analysis is to **plot the data** in order to visualise the type of functional relationship that may exist between the independent and dependent variables (Fig. A3.1). The data points in Fig. A3.1 do not all lie on a smooth curve, due to some random influences in the skidding operation. However, it is clear that there is a linear relationship between skidding distance and skidding time

per load. From the plot we would therefore hypothesise the following simple linear model:

y = ***a*** + ***b***x

where y = skidding time in min/load; x = skidding distance in m; ***a*** = a constant (to be established by the regression analysis) representing the fixed times (such as choker setting and unhooking of logs at the landing) for the skidding cycle; ***b*** = a constant representing the change in skidding time associated with any change in skidding distance. Note that for the equality to hold the units of a must be minutes per load, and the units of ***b*** must be minutes per metre.

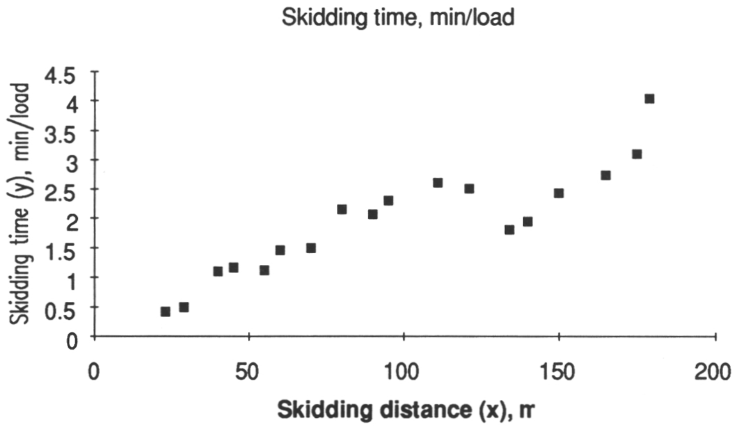


Figure A3.1. Plot of observed skidding times vs. skidding distance.

(2) **Compute the regression**: The second step in the regression analysis is to make the regression calculations. A convenient way to do this is illustrated in Table A3.2. The notation x_i means "the observation of x at load i", where for this study it goes from 1 to 15. A similar interpretation may be made for y_i; $\overline{x}$ and $\overline{y}$ represent the

mean values of x and y. That is, $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and $\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$
where n = the number of observations in the sample (n = 18).

Having made the calculations summarised in the table, we can easily calculate the regression coefficients a and b:

$$b = \frac{\sum(x_i - \overline{x})(y_i - \overline{y})}{\sum(x_i - \overline{x})^2} = \frac{717.89;44}{473.78} = 0.0161$$

$$a = \overline{y} - b\overline{x} = 1.94 - (0.0161)(97.89) = 0.3640$$

Table A3.2. Regression calculations for the skidding data.

i	x_i	y_i	$x_i - \bar{x}$	$y_i - \bar{y}$	$(x_i-\bar{x})(y_i-\bar{y})$	$(x_i-\bar{x})^2$
1	23	0.42	-74.89	-1.52	113.83	5608.51
2	29	0.49	-68.89	-1.45	99.89	4745.83
3	40	1.10	-57.89	-0.84	48.63	3351.25
4	45	1.16	-52.89	-0.78	41.25	2797.35
5	55	1.12	-42.89	-0.82	35.17	1839.55
6	60	1.45	-37.89	-0.49	18.57	1435.63
7	70	1.49	-27.89	-0.45	12.55	777.85
8	80	2.14	-17.89	0.20	-3.58	320.05
9	90	2.06	-7.89	0.12	-0.95	62.25
10	95	2.29	-2.89	0.35	-1.01	8.35
11	111	2.60	13.11	0.66	8.65	171.87
12	121	2.50	23.11	0.56	12.94	534.07
13	134	1.80	36.11	-0.14	-5.06	1303.93
14	140	1.94	42.11	0.00	0.00	1773.25
15	150	2.42	52.11	0.48	25.01	2715.45
16	165	2.73	67.11	0.79	53.02	4503.75
17	175	3.10	77.11	1.16	89.45	5945.95
18	179	4.03	81.11	2.09	169.52	6578.83
Sums:	1762	34.84	0*	0*	717.89	44,473.78
Means:	97.89	1.94	--	--	--	--

* These do not exactly total to zero because of rounding errors; however, the sums should be very close to zero. This is a useful check to ensure that no major computational errors have been made in these columns.

The regression equation can thus be written as follows:

$$y = 0.364 + 0.0161x$$ [1]

Fig. A3.2 verifies that this equation provides a good fit through the data points.

(3) **Check the quality of fit**. The most commonly used statistic for this purpose is called the *coefficient of determination*, and it is designated by the symbol r^2. The coefficient of determination measures the fraction of variance in the observed values of the dependent variable which is explained by the regression equation. There is some fraction of variance in the data that has not been explained by the regression line.

[1] Note that inverse of 0.0161 is 62.11, which means that the velocity has been 62.11 m/min corresponding to 1.03 m/s velocity(b)

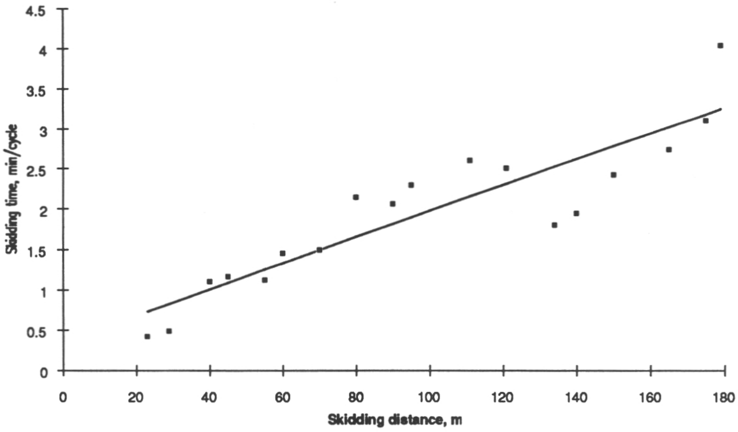


Figure A3.2. Observed data points and the estimated regression line.

The coefficient of determination is calculated as follows:

$$r^2 = \frac{SSR}{SST}$$

where

SSR is the regression sum of squares = $\Sigma (\hat{y}_i - y)^2$
is the estimate of total skidding time computed by the regression equation using the skidding distance associated with observation i.

SST is the total sum of squares $\Sigma (y_i - y)^2$

Again, it is convenient to develop a table of calculations (Table A3.3).

Then $r^2 = \frac{11.53}{14.36} = 0.80$

R^2 tells us that approximately 80% of the variance in the observed skidding times is explained by the regression equation. A "good fit" will always have an r^2 value close to 1.0.

For this example approximately 20% of the variance in skidding time is unexplained by the regression equation. It is assumed that this portion of total variance is due to random influences. However, there may also be non-random factors at work which account for part of the unexplained variance; for example the number of logs skidded per load. It is possible to test for the influence of more than one independent variable by using multiple regression analysis. We might hypothesise that skidding time is affected by both skidding distance and the number of logs per load, as follows:

$y = a + b_1x_1 + b_2x_2$
or
$y = a + b*x_1*x_2$

where

y = skidding time, min/load
x_1 = skidding distance, m
x_2 = number of logs skidded/load

Table A3.3. Calculations for determining SSR and SST for the skidding data when the regression equation is given by y = 0.3640 + 0.0161x.

i	x_i	y_i	$\bar{y}_i$	$\hat{y}_i - y$	$(\hat{y}_i - y)^2$	$y_i-\bar{y}$	$(y_i-y)^2$
1	23	0.42	0.73	-1.21	1.45	-1.52	2.31
2	29	0.49	0.83	-1.11	1.23	-1.45	2.10
3	40	1.10	1.01	-0.93	0.87	-0.84	0.71
4	45	1.16	1.09	-0.85	0.73	-0.78	0.61
5	55	1.12	1.25	-0.69	0.48	-0.82	0.67
6	60	1.45	1.33	-0.61	0.37	-0.49	0.24
7	70	1.49	1.49	-0.45	0.20	-0.45	0.20
8	80	2.14	1.65	-0.29	0.08	0.20	0.04
9	90	2.06	1.81	-0.13	0.02	0.12	0.01
10	95	2.29	1.89	-0.05	0.00	0.35	0.12
11	111	2.60	2.15	0.21	0.04	0.66	0.44
12	121	2.50	2.31	0.37	0.14	0.56	0.31
13	134	1.80	2.52	0.58	0.34	-0.14	0.02
14	140	1.94	2.62	0.68	0.46	0.00	0.00
15	150	2.42	2.78	0.84	0.70	0.48	0.23
16	165	2.73	3.02	1.08	1.17	0.79	0.62
17	175	3.10	3.18	1.24	1.54	1.16	1.35
18	179	4.03	3.25	1.31	1.71	2.09	4.37
				SSR	=11.53	SST	=14.36

Note: $\bar{y}$ = 1.94 (Table A3.2). Also note that the last column but one can be taken from Table A3.2.

The calculations to determine the values of a, b_1 and b_2 are considerably more complicated to calculate without computer programs than those for simple regression analysis with only one independent variable. Many statistical programs have facilities for testing the significance of each slope coefficient, i.e. the programs calculate the t-statistics for each coefficient.

A3.2 Standard deviation

Standard deviation[2] (s, STD) and variance are the most important statistical parameters. The population variance (σ^2) and sample variance (s^2) are defined as follows:

[2] Name Standard error ir also used

$$\sigma^2 = \frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N} \tag{A3.1}$$

$$s^2 = \frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{n-1} \tag{A3.2}$$

where

σ^2	is population variance
s^2	is population variance
x_i	is value of observation
$\bar{x}$	is population or sample mean
N	is number of observations in the population
n	is number of observations in the sample

For pocket calculator operations eq. (A3.2) can be rearranged

$$s^2 = \frac{\sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}}{n-1} \tag{A3.3}$$

The standard deviation is square root of the variance

$$s = \sqrt{s^2} \quad \text{A3.4)}$$

Example A1
Standard deviation for a sample of five loading times is calculated in Table A3.4.

Table A3.4 Loading time (min) of a sample consisting of five observations.

Observation	x_i	x_i^2
1	1.25	1.5625
2	0.92	0.8464
3	0.98	0.9604
4	1.37	1.8769
5	1.11	1.2321
*	5.63	6.4783

$$\text{Variance } s^2 = \frac{6.4783 - \frac{5.63^2}{5}}{5-1} = 0.03473$$

Standard deviation (s, STD) = $\sqrt{0.03473}$ = 0.18 (min)

APPENDIX 4

Table A4.1. **Critical values of *t*.**

d.f.	$t_{.100}$	$t_{.050}$	$t_{.025}$	$t_{.010}$	$t_{.005}$	d.f.
1	3.078	6.314	12.706	31.821	63.657	**1**
2	1.886	2.920	4.303	6.965	9.925	**2**
3	1.638	2.353	3.182	4.541	5.841	**3**
4	1.533	2.132	2.776	3.747	4.604	**4**
5	1.476	2.015	2.571	3.365	4.032	**5**
6	1.440	1.943	2.447	3.143	3.707	**6**
7	1.415	1.895	2.365	2.998	3.499	**7**
8	1.397	1.860	2.306	2.896	3.355	**8**
9	1.383	1.833	2.262	2.821	3.250	**9**
10	1.372	1.812	2.228	2.764	3.169	**10**
11	1.363	1.796	2.201	2.718	3.106	**11**
12	1.356	1.782	2.179	2.681	3.055	**12**
13	1.350	1.771	2.160	2.650	3.012	**13**
14	1.345	1.761	2.145	2.624	2.977	**14**
15	1.341	1.753	2.131	2.602	2.947	**15**
16	1.337	1.746	2.120	2.583	2.921	**16**
17	1.333	1.740	2.110	2.567	2.898	**17**
18	1.330	1.743	2.101	2.552	2.878	**18**
19	1.328	1.729	2.093	2.539	2.861	**19**
20	1.325	1.725	2.086	2.528	2.845	**20**
21	1.323	1.721	2.080	2.518	2.831	**21**
22	1.321	1.717	2.074	2.508	2.819	**22**
23	1.319	1.714	2.069	2.500	2.807	**23**
24	1.318	1.711	2.064	2.492	2.797	**24**
25	1.316	1.708	2.060	2.485	2.787	**25**
26	1.315	1.706	2.056	2.479	2.779	**26**
27	1.314	1.703	2.052	2.473	2.771	**27**
28	1.313	1.701	2.048	2.467	2.763	**28**
29	1.311	1.699	2.045	2.462	2.756	**29**
inf.	1.282	1.645	1.960	2.326	2.576	**inf.**

Table A4.2. **Critical values of χ^2**

df	α=0.1	α=0.05	α=0.010	α=0.005	df
1	2.706	3.841	6.635	7.879	**1**
2	4.605	5.991	9.210	10.597	**2**
3	6.251	7.814	11.345	12.838	**3**
4	7.779	9.488	13.277	14.860	**4**
5	9.236	11.071	15.086	16.750	**5**
6	10.645	12.592	16.812	18.548	**6**
7	12.017	14.067	18.475	20.278	**7**
8	13.362	15.507	20.090	21.955	**8**
9	14.684	16.919	21.666	23.589	**9**
10	15.987	18.307	23.209	25.188	**10**
11	17.275	19.675	24.725	26.757	**11**
12	18.549	21.026	26.217	28.300	**12**
13	19.812	22.362	27.688	29.819	**13**
14	21.064	23.685	29.141	31.319	**14**
15	22.307	24.996	30.578	32.801	**15**
16	23.542	26.296	32.000	34.267	**16**
17	24.769	27.587	33.409	35.719	**17**
18	25.989	28.869	34.805	37.156	**18**
19	27.204	30.144	36.191	38.582	**19**
20	28.412	31.410	37.566	39.997	**20**
21	29.615	32.671	38.932	41.401	**21**
22	30.813	33.924	40.289	42.796	**22**
23	32.007	35.173	41.638	44.181	**23**
24	33.196	36.415	42.980	45.558	**24**
25	34.382	37.653	40.314	46.928	**25**
26	35.563	38.885	45.642	48.290	**26**
27	36.741	40.113	46.963	49.645	**27**
28	37.916	41.337	48.278	50.993	**28**
29	39.088	42.557	49.588	52.336	**29**
30	40.256	43.773	50.892	53.672	**30**
40	51.805	55.786	63.691	66.766	**40**
50	63.167	67.505	76.154	79.490	**50**
60	74.397	79.082	88.379	91.952	**60**
70	85.527	90.531	100.425	104.215	**70**
80	96.578	101.879	112.329	116.321	**80**
90	107.565	113.145	124.116	128.299	**90**
100	118.498	124.342	135.807	140.169	**100**

APPENDIX 5. List of the most common draught animals

The characteristics of the most common draught animals are given in Table A5.1.

Table A5.1. The most common draught animals (after Goe 1983), except for work hours (after Saarilahti 1986a).

Power source	Mature weight, kg	Tractive effort, N	Average speed, m/s	Power, kW	Work hours, h/d
Horse					6-10
Light	385	39	1.1	0.43	
Medium	500	50	1.1	0.55	
Heavy	850	85	1.1	0.94	
Mule					8
Light	200	20	1.1	0.22	
Heavy	600	60	1.1	0.66	
Donkey					3-4
Light	120	14	1.1	0.15	
Medium	200	24	1.1	0.27	
Heavy	300	36	1.1	0.39	
Ox					5-6
Light	210	21	1.1	0.23	
Medium	450	45	1.1	0.50	
Heavy	900	90	1.1	0.99	
Cow					-
Light	200	16	1.0	0.15	
Heavy	575	48	1.0	0.46	
Buffalo					5-6
Light	400	40	0.9	0.35	
Medium	650	65	0.9	0.57	
Heavy	900	90	0.9	0.80	
Camel					9-13
Light	370	37	1.1	0.41	
Heavy	600	60	1.1	0.66	
Elephant					5-6
Light	2900	-	-	-	
Heavy	3600	-	-	-	

Pull and power of horses

Horses were commonly used as traction animals in Scandinavia until the late 1960's when the breakthrough of mechanised primary transport took place. The average power of oxen and horses in Scandinavia has been estimated at 0.25 ... 0.36 kW per animal (Sundberg 1990, p. 85).

The drawbar pull of a horse over long distances is 15 ... 20% of the body weight (c_{pull}= 0.15 ... 0.20) but on a very short effort the pull may attain 70 ... 110 % of body weight (Jansson 1972, p. 48). The mass varies largely depending on race. The average body mass of work animals in Scandinavia is about 550 kg. The rest pulse is about 30 ... 40 P/min and the maximal pulse close to 160 (Fig A5.1). The average heart rate at different pulls is as given in Table A5.2.

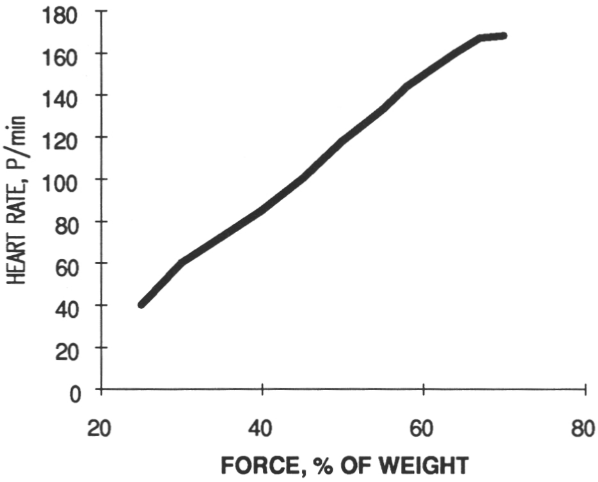


Figure A5.1. Heart rate of a horse as a function of relative pull (Jansson 1972).

Table A5.2. Heart rate of work horses (after Krüger 1957 cit. Jansson 1972, p. 38).

Fitness	Rest pulse	1200 N pull	1500 N pull	Maximal pull
Good	22-41	41-67	48-78	97-109
Medium	27-41	42-72	51-84	71-106
Poor	24-40	60-72	63-84	62-108

The velocity on maximal pull on a 50 m track is about 1.8 m/s up to about 50 ... 60% pull (Fig. A5.2) corresponding to the maximum power range (Fig. A5.3). The maximum power on a short-duration (>30 s) effort is about 9 W/kg of body weight.

Body mass can be estimated using eq. (A5.1).

$$m_H = 100 * c^2 * l - 30 \qquad \text{(A5.1)}$$

where

- m_H is body mass of a horse, kg
- c is circumference of thorax, m
- l is body length, m

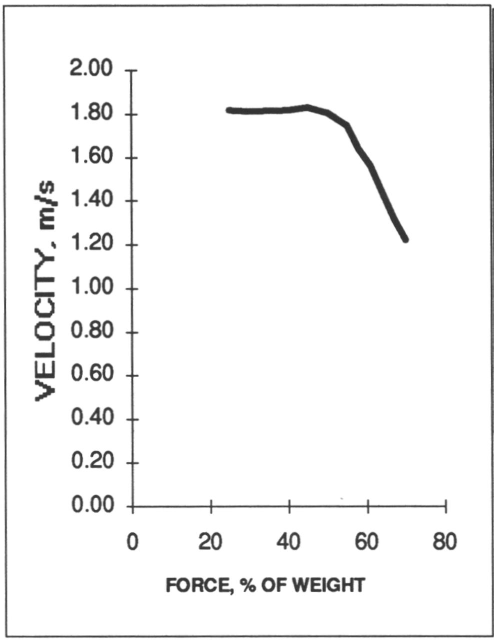


Figure A5.2. Velocity as a function of relative pull (after Jansson 1972).

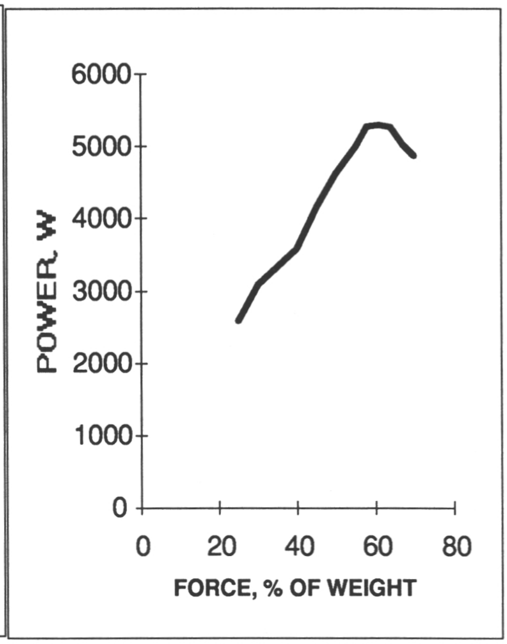


Figure A5.3. Power as a function of relative pull (after Jansson 1972).

Elephant as a prime mover
(After Corvanich 1979 and 1991)

Elephant logging has been practiced for more than a century in Thailand and Burma. The mass of an elephant is around 4,000 kg. The pull of an elephant on a short-duration effort is about 50% of its weight, or about 20 kN. The walking velocity is about 1.1 m/s. A male elephant with ful grown tusks can lift a log up to 700 kg, while non-tusked females can lift less.

In hauling, elephants need a long pause after hauling for about 500 m. (Corvanich 1991, p. 45). The number of effective hours in a day is 6 h, from 6:00 to noon. The animals are rested for the whole afternoon. Elephants need frequent rest. Their working schedule is three consecutive days for work and two for rest. In summer (March to May) they are allowed a long rest. In a working year elephants perform 160 6-h working days (960 h/a).

The annual production of an elephant is around 450 ... 600 m^3 on easy terrain, in average conditions 300 ... 450 m^3 and 150 ... 300 m^3 on rough terrain during the eight month logging season at an average logging distance of 1 km.

The daily consumption of a working elephant is 250 kg of fodder.

APPENDIX 6. Classification of soils

1. Soil classification

The basic classification is to distinguish between sediment soil and moraines. Moraines are found only in the Northern hemisphere.

Simple field methods have been developed for the identification of soils in place of expensive laboratory methods. If correctly applied, they give accurate enough results for forest engineering purposes. The most common field methods are briefly described below (after Troedsson & Nykvist 1973).

Rolling test: Despite the fact that soil types are seldom dry, the rolling test is the most common soil type determination method. The soil sample is dampened and rolled till the rolled band bursts. The diameter of the band indicates how fine the soil structure is. Achieving the right water content in the sample is a problem. If the soil is too dry, the band bursts too early, and when too wet, it becomes too thin. The right moisture content can be achieved by dampening the sample so that the soil is gluey and by kneading it till the glueyness disappears.

Finger test: The plane surface of a soil sample is stroked with a finger. The particles which come off the soil surface are observed.

Grooving test: The surface of a soil sample is made even, and a groove is drawn on the soil surface with a rounded stick made of glass, etc. The groove formation is observed.

Both rolling, finger, and grooving tests are based on soil cohesion. The setting takes place on particle surfaces. The smaller the particle is, the more cohesion surface available, and thus the force that keeps the particles together is stronger.

2. Soil condition classification

The skidding resistance coefficient is largely dependent on variations in soil moisture. Therefore the soil surface moisture must be assessed. The gravimeter method should be used for base studies in order to permit the use of soil engineering theories in analysing skidding resistance. The gravimeter method is tedious and therefore not recommended for everyday use. A simple visual/finger test should be carried out daily on each track in order to classify the soil surface moisture. The results are easily applicable for everyday use, as the same classification can be used for payment systems.

The soil surface moisture is determined by taking a small amount of soil between the fingers and pressing it between thumb and forefinger and by observing the wheel and log tracks. The classifications are as given in Table A6.2. In large projects the average soil moisture by soil moisture classification can be assessed using the gravimeter method. It is, however, possible that the moisture in different classifications changes during the year.

Table A6.1. Field definitions of mineral soils (after Eriksson et. al. 1978).

Soil type	Rolling test, ϕ mm	Finger test	Grooving test	Remarks	Particle size, mm
Stones				No fine material between stones	>20
Gravel	Cannot be rolled	Does not hang together	Cannot be formed		2-20
Coarse sand	Cannot be rolled	Does not hang together	Forms only weakly		0.6-2
Sand	Cannot be rolled	Does not hang together			0.2-0.6
Fine sand	Cannot be rolled	Very loose, scatters	Forms only weakly	Particles visible to naked eye. Single grain structure	0.06-0.2
Fine fine-sand	4-6	Sprinkles very strongly. Coarse powder	Very deep furrow. Weak consistency	Grains hard to see with naked aye. Forms lumps in dry condition	0.02-0.06
Silt	3-4	Sprinkles very strongly. Mealy powder	Very deep furrow. Rather good consistency	Forms lumps in dry condition. Sticky in wet condition	0.002-0.02
Loamy soils	3	Sprinkles strongly-very strongly	Deep and broad mat furrow		
Clayey soils	1-2	Sprinkles weakly, does not sprinkle	Mat or gleaming furrow		

Table A6.2. Soil surface moisture classification.

Moisture class	Description
Dry	Dust when working on it, provides hard surface
Moist	Gives cold feeling on contact with skin, does not give dust when working on it
Wet	Can be rolled into small threads when squeezed between forefinger and thumb. Plastic, forming permanent deformation when pressed. Gives slippery surface
Very wet	Much mud on trails

APPENDIX 7

Terrain classification

1. Macrorelief

On each trail the average slope (a-b in Fig. A7.1 and A7.2) and the mean maximal slope on < 5 m sections (c-d in Fig. A7.1 and A7.2) must be assessed using a clinometer. If no clinometer is available but good maps are available the average slope can be estimated based on contour lines. In case there is no clinometer a spirit level can be used for measuring the slope (Fig. A7.1). Place it on a 1.5 m (- height of balance) stake and balance the bubble. Aim along the surface at the terrain and measure the distance l. The slope percent is

$$S = 100 * \frac{h}{\sqrt{l^2 - h^2}} \qquad \text{(A7.1)}$$

where

S	is slope, %
l	is ground distance to aiming point, m
h	is height of aim line, m

Trained officers can estimate the slope by eye, as in most cases 5 % accuracy is adequate. It is important that the slope of every trail is assessed.

The slope is indicated as **loaded direction**, from the stump site towards the landing
- adverse slope, uphill direction, (+)
- favourable slope, downhill direction (-)

NOTE: The return slope has the same slope value as the skidding slope, but the model seems "illogical" at first sight. It is easier to use only one slope value for all operations.

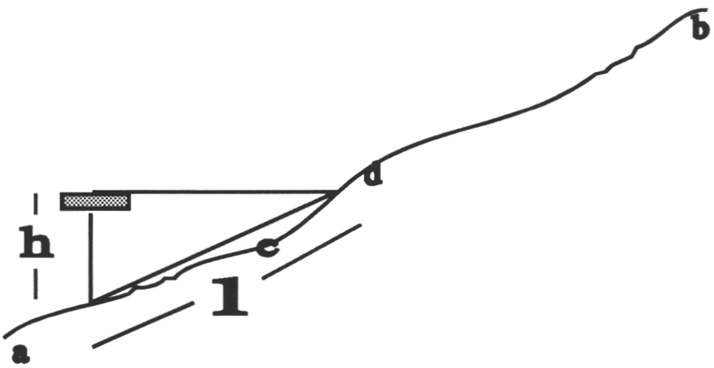


Figure A7.1. Measurement of slope.

Staaf & Wiksten (1984) divide the slope into five classes as in Table A7.1.

Table A7.1. Slope steepness classes.

Class	Percent	Degrees	Designation
1	0 - 10	0 - 6	Level
2	10 - 20	6 - 11	Gentle
3	20 - 33	11 - 18	Moderate
4	33 - 50	18 - 27	Steep
5	50 -	27 -	Very steep

2. Microrelief

Microrelief describes the variation in ground surface height at 1 ... 5 m sections, as variations under 1 m are classified as obstacles and over 5 m as mean slopes.

The microrelief can be described such as "rolling" or "undulating" if the microrelief is broken, e.g. if there are many remarkable short uphills **and** downhills on the trail. Microrelief can be described as "terraced" if there are several short uphills **or** downhills on the trail (Fig A7.2).

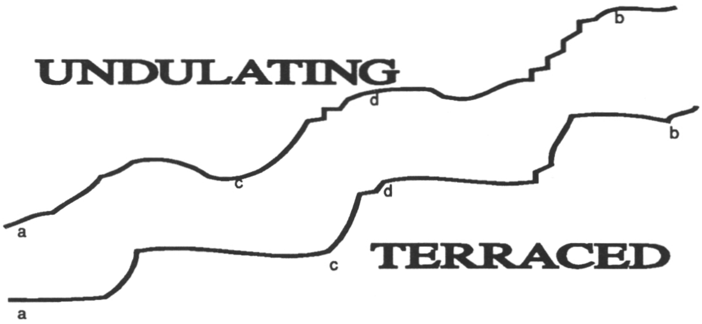


Figure A7.2. Assessment of microrelief.

3. Surface roughness

Surface roughness classification is based on the number and height of obstacles on average trail areas. The classification may be verbal, such as "very even" or "rather even" if the surface seemingly has only minor effect on skidding. If there are several hummocks, stones or stumps a more detailed description is needed. The obstacle frequency may be numeric (Nb/ha) or the following verbal classification can be used (Table A7.2).

Table A7.2. Obstacle frequency (after Sutton 1979).

Class	Spacing, m	Nb per hectare
Isolated	16-50	4-40
Infrequent	5-16	40-400
Moderately frequent	1.6-5	400-4000
Frequent	<1,6	>4000

As an example the Canadian terrain classification is presented in Table A7.3. Originally it was designed for wheeled tractor logging and therefore it is somewhat too coarse for oxen. For a more detailed terrain classification see Eriksson et al. (1978), Löffler (1979), Sutton (1979), Tsay (1979).

Table A7.3. Surface roughness classification (after Terrain Classification ... 1980).

Roughness description	Roughness class	Obstacle height or depth, m	Number of obstacles per 100 m^2
Very even	1	0.1-0.3	0-4
Slightly uneven	2	0.1-0.3	>4
		0.3-0.5	1-4
Uneven	3	0.1-0.3	>4
		0.3-0.5	5-40
		0.5-0.7	1-4
Rough	4	0.1-0.3	>4
		0.3-0.5	5-40
		0.5-0.7	1-4
		0.7-0.9	1-4
Very rough	**5**	More severe than Class 4	

APPENDIX 8. The OWAS method

The work is observed at constant intervals either every 30 or 60 seconds. The working posture and the load weight are observed and the classified to different working posture classes (see Fig. A8.1 ... A8.3). The posture evaluation is a four class classification based on the strain on different body elements. In Fig. A8.1 ... A8.3 the series of numbers refers to the apparent load:

first number, weight or force less than 100 N (10 kg)
second number, weight or force over 100 but under 200 N (>10>20 kg)
third number, weight of force over 200 N (20 kg)

The interpretation of the classes is as follows:

- in Class 1 the posture is normal and the strain is acceptable
- in Class 2 the load has a certain influence on the strain and the working may cause healthy problems. Better working postures should be developed in near future
- in Class 3 strain is evident and better working method with improved posture to be developed in immediate future
- in Class 4 the train is excessive and better work postures are to developed at once

If the work consists of posture classes 1 and 2 it is evident that there is no need for developing better working techniques. If classes 3 and 4 are often present then the working technique must be improved as the strain on body exceeds the ergonomic recommendations.

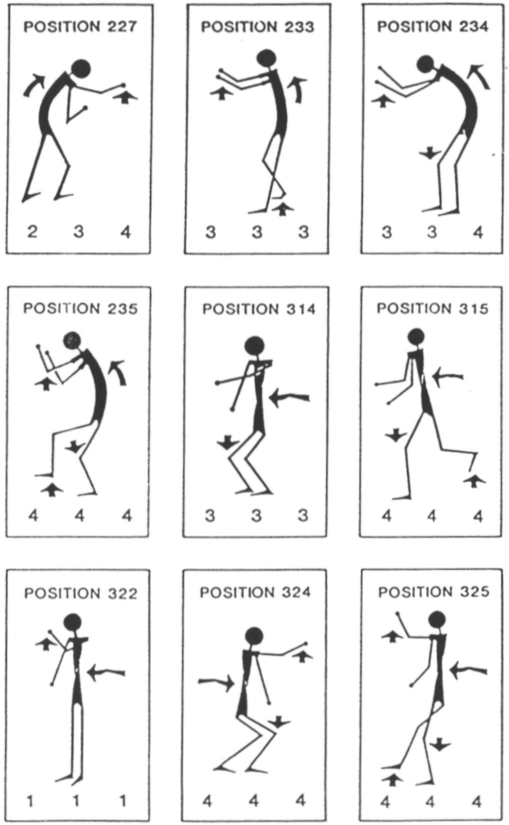


Figure 8A1.

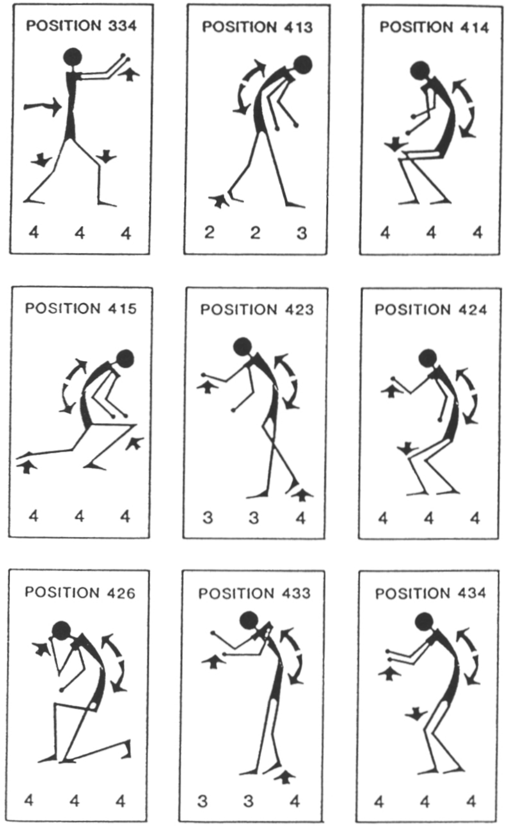


Figure 8A2.

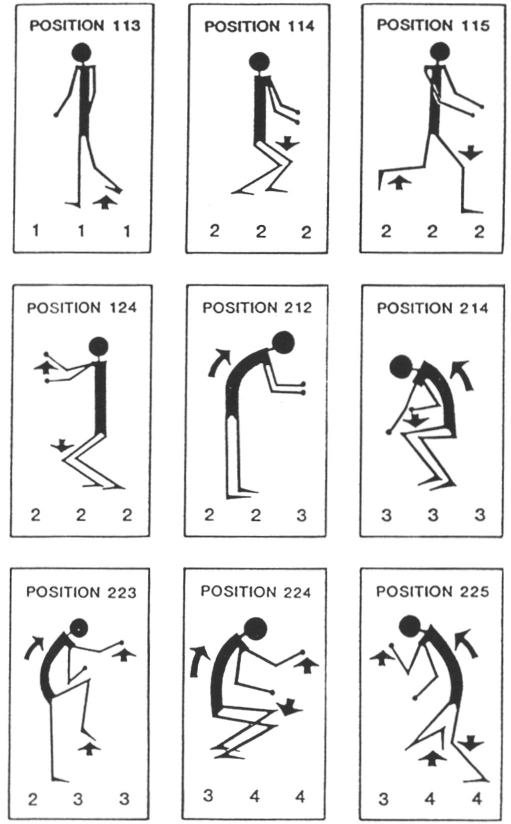


Figure 8A3.

APPENDIX 9. A list of recommended literature

Forest work study:

Adamowich, L.L. Engineering fundamentals for forest engineers, Part I - Engineering mechanics. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science. University of Dar es Salaam, Morogoro, Tanzania. 151 p.

ILO 1979. Introduction to Work Study, 3rd edition. Geneva.

Wittering, W.O. 1973. Work Study in Forestry. Forestry Commission Bulletin 47. Her Majesty's Stationery Office, London. 99 p.

Ergonomics:

ILO 1989. Guidelines on ergonomic study in forestry. Geneva.

Handbooks on statistics :

Hoel, P.G. 1984. Introduction to Mathematical Statistics. Fifth Edition. John Wiley & Sons, Singapore. 435 p. ISBN 0-471-80530-0.

Ott, L. & Mendenhall, W. 1984. Understanding Statistics. Duxbury Press, Boston. 493 p. ISBN 0-87150-855-9.

APPENDIX 10. Recommended terminology for comparing different implements

In animal primary transport the following terminology is recommended if different implements are to be compared (Fig. A10.1).

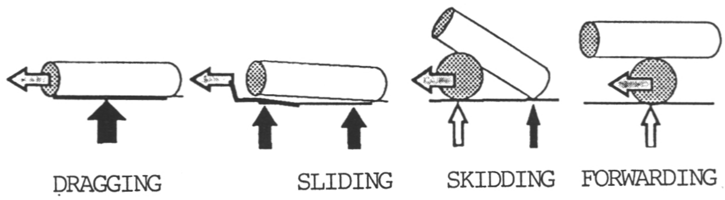


Figure A10.1. Different log/soil and wheel/soil resistance combinations in animal primary transport when using different implements.

Dragging resistance consists of log/soil interaction only. No implement is used, and the load is directly attached to the chain.

In **skidding** part of the resistance is due to log/soil interaction and part to wheel/soil interaction. Different types of skidding carts or sulkies are used. If a metal or plastic pan or cone is used the term **sliding resistance** should be used instead of skidding resistance.

In **forwarding** the load is totally supported by a wheeled cart or trailer and the resistance is due to wheel/soil interaction.

In this study mainly dragging is analysed and most of the formulas are best applicable to chain skidding. In skidding the load transfer coefficient between log/soil and wheel/soil depends on the slope and some systematic error may occur.

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