STANDARDS FOR TIME STUDIES FOR THE SOUTH AFRICAN FOREST INDUSTRY

First Edition

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Project team:

Pierre Ackerman

Elizabeth (Lise) Gleasure

Simon Ackerman

Brad Shuttleworth

Standard Summary

This South African Standard for Time-studies will provide a common and standard time-study methodology for the South African Forest Industry; a protocol that does not currently exist. Its implementation will serve the purpose of aligning the South African Forest Industry with international forest operations development and assist with the “modernisation” of the Industry’s forest operations. The concept of modernisation essentially includes updating forest operations in terms of both mechanisation and other modern systems improvements with the goal of improving wood/fibre yield, wood/fibre quality and reducing production costs to remain locally and internationally competitive.

The Standard has been compiled by those with specific expertise in work- and time-studies, particularly the statistical analysis component and machine costing. The Standard, with the inclusion of an internationally standardised Machine Costing Model, was developed based on accepted and validated international Time-study standards, protocols and literature. This Protocol is envisaged to be a state of the art model to benefit the South African Forest wood supply chain.

The Standard will be web-based and will guide the user step-by-step through the set up and execution of time studies and their application in Operations Research analysis. The standard deals with the setting of time-study objectives to ensure that time and resources are used efficiently and help to develop the desired results. Three types of studies, observational, experimental and modelling, are introduced. Different techniques are provided to control bias (i.e., systematic error) including randomisation and blocking.

The Standard contains sections on experimental study design, data collecting methodologies including sample size calculations; time study models; selecting an appropriate time study technique; statistical analysis and methods to best analyse the data collected; and ways to use and proceed with the results achieved through linkage with a machine costing model. The user will also be able to calculate machine availability, utilisation and systems efficiency ratios that are useful in determining systems efficiency. Background data forms, a terrain classification, templates to create data collection forms for the user’s study and a brief discussion on available time study software and equipment are also included

Included in the Standard is a Time-concepts model developed by the International Union of Forest Research Organisations (IUFRO) useful for the precise division of common time elements included in all work and production systems.

The Standard also describes in detail the six different scopes of time studies, ranging from wide to narrow. These studies are shift-level, plot level, cycle level, time and production count, working sampling and the element level. Each study has different strengths and weaknesses and requires a specific technique which is discussed. A statistical analysis manual is also in the drafting stages and will aid the user through conducting their analysis and interpreting the results.

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1.0 Introduction

The purpose of this protocol framework is to provide a standardised time study methodology for the South African forest industry. This manual has been developed to work in conjunction with the partner computer program to assist in work study development. This program is developed specifically as an extension of this manual and as a way to assist the user through navigating the concepts in the manual relevant to their study objective.

This manual will cover setting up a time study, selection of experimental design (2.0), time models and time concepts (3.0), time study methods (4.0), standardised, machine-specific time elements (5.0) and statistical analysis (6.0 – still to be completed). Tools included with this manual are the above-mentioned software, study forms – both generic and machine-specific, and a further reading list.

The outputs of time study analysis can then be inputted into a costing model developed by the European Union Cost Action 0902. This costing model has been developed by experts from around the globe, including South Africa, and provides an easy to use and internationally regarded way to cost forest operations (Figure 1). The model makes use of internationally accepted and current costing protocols and has been validated by an expert panel. The costing model can be found on the cost website at this link: [http://www.forestenergy.org/pages/costing-model---machine-cost-calculation/?PHPSESSID=68b81c040f0688cadc1a350adda16c9c.](http://www.forestenergy.org/pages/costing-model---machine-cost-calculation/?PHPSESSID=68b81c040f0688cadc1a350adda16c9c)

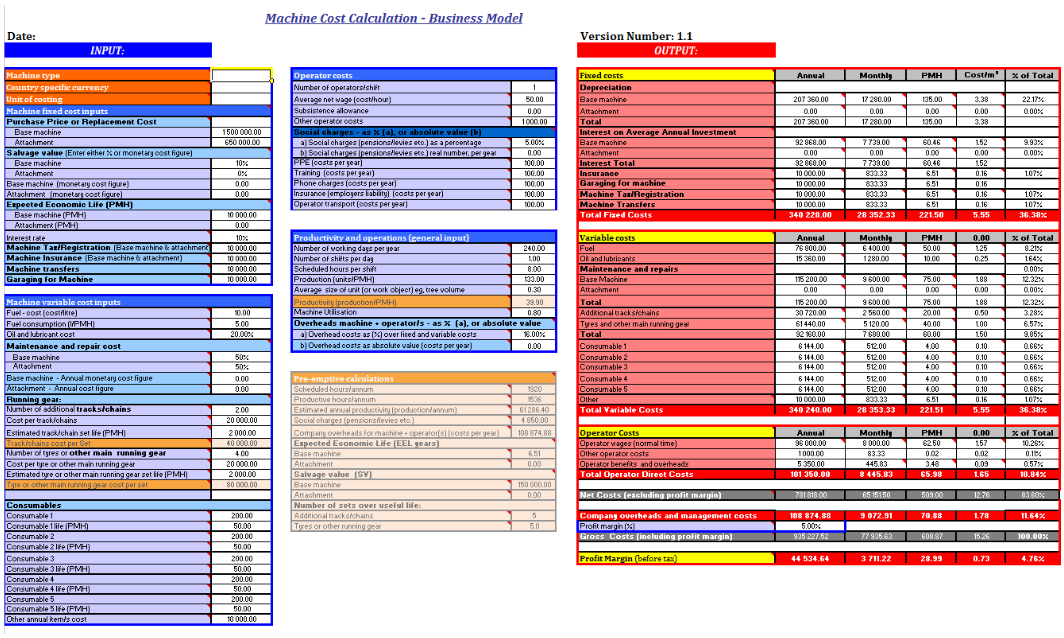

Figure 1: Screenshot of costing model developed by the European Union Cost Action 0902. A corresponding manual has been written to support the Microsoft Excel based model.

1.1 Background

Improving operations efficiency is an on-going need for all industries, including forestry. The South African forest industry faces unique challenges and addressing efficiency in this context is complex. A key tool to address the challenges of efficiency and productivity improvement comes from the discipline of work science; to study work and productivity. Work science is the study of work and its associated measurement including human elements, the machines and other equipment used for work, the organisation of work and the methods of work (Björheden and Thompson 1995).

Work science has a long history with forestry, having developed into an independent field as early as 1920. The origin of work science is often attributed to F.W. Taylor's (1895) paper titled "A piece-rate system being a partial solution of the labour problem" published in the Transactions of the American Society of Mechanical Engineers (Barnes, 1963). Taylor's emphasis on determining a standard amount of time for a task under certain conditions of measurement forms the basis for improving efficiency (Barnes, 1963). It is from this basis that work study methodologies developed.

Work study is the systematic examination of the methods of carrying on activities so as to improve the effective use of resources and to set up standards of performance for the activities being carried out (Kanawaty 1992). The aim of work study is to examine how activities are carried out to complete a task and the use this information to simplify or modify and then use the activity to reduce unnecessary or excess work (Kanawaty 1992).

1.2 From Work Study to Time Study

A work study is typically broken up into two parts, the method study and then the work measurement (Kanawaty 1992). A method study is normally the first step in order to determine what the optimal method for completing a task is. A method study is defined as a study where the task is systematically recorded and critically examined to find ways to make improvements to the task completion (Kanawaty 1992). An example of a change in method may be using three chokermen rather than two with the increased productivity making up for the increased cost of wages.

Once a method has been established, then the work measurement can begin. Most commonly, the time study is used to determine the standard time it should take to complete the task using the optimised method. Different time study techniques and scales of study exist; these are detailed in Section 4. The outcome of the time study is typically a measure of productivity per productive machine hour (i.e. 30 m^3 $hour^{-1}$). This output data is incredibly useful allowing for the creation of machine or operation standards, accurate inputs to pre-existing costing models, and potentially the creation of models to predict a machine or operations productivity given certain inputs.

2.0 Setting up a Time-study

The following section details the considerations before beginning a study and also walks the reader through different potential experimental designs. This section assumes the reader has already finalised the machine or operation's method. In this case finalised means that the method may or may not yet have been optimised; however, the vast majority of glitches have been identified and resolved and the reader is therefore ready to determine productive machine hours. At times, this section will likely be repetitive. This repetition was specifically done as this section, and this manual in general, is designed to be interpreted through the companion web-based application (in design). This web-based application will be used to help assist the user in designing their study methodology and selecting an appropriate study technique. As such, this section was not intended to be read as a whole, but rather the required segments would be presented to the user based on their inputs into the web-based application.

2.1 Developing a Study Goal and Objective

Before any study is undertaken, the objective needs to be determined. The development of a clear objective ensures that time and resources are used efficiently and help to develop the desired results. Examples of work study objectives are:

- Locate inefficiencies in a particular harvesting system
- Determine the productivity of a new operator
- Compare two harvesting systems' productivity
- Assess a machine's downtime and find reasons for downtime
- Develop a production model for a specific machine

Once an objective goal is set, a study can then be designed to achieve this objective.

2.2 Study Classification and Experimental Design

A sound experimental design makes it easier to achieve the objectives of the experiment, as has already been mentioned. The early establishment of experimental design makes it far easier to conduct an experiment, collect the required data, and conduct the statistical analysis required. Although an experimental design can be constructed to achieve most study objectives, for the purposes of simplification, this manual will divided into three study types: observational studies, experimental studies and modelling studies. Modelling studies in particular can be considered a sub-set of experimental studies and it can be argued that a modelling study can be obtained from both the observational and experimental studies and therefore is not an independent study type. However, the proposed division of study types allows for greater focus for the user of this manual to be spent on designing for the study's objective. This section is a guideline on how to design an experiment in the context of an operation time study.

2.2.1 What type of study do you need?

There are three types of studies that can be used, although they are not mutually exclusive. The first is the observational study. In an observational study, variables are not controlled (Magagnotti and Spinelli 2010 & Kanawaty 1992). This study type serves to describe the current state of a machine, operation or system. The second type of study is the experimental study. This type involves greater control of variables and produces results that are more statistically rigorous. The final classification is a modelling study. This type of study is done to create a model for a given machine, operation or system. Modelling differs mainly in the purpose of using the empirical information for modelling and later simulation (computer implemented modelling).However to keep things simple and for purposes of study, classification in this guideline will treat the three study types as separate entities.

Standard units of measure include (see Section 5.1 for standardised elements by machine with units described and defined): m^3, tonnes, tonnes/m^3 pmh^{-1}/smh^{-1}/amh^{-1}

2.2.2 Observational study

An observational study (not to be confused with activity sampling techniques and which are discussed in paragraph 4.6), also called descriptive study, is typically done to learn more about a specific machine, operator or system. This is the simplest study design as it does not require comparisons with other machines, operators or systems and where variables around the machine or systems function are not controlled. In essence an observational study draws inferences about the possible effect of a treatment on subjects, where the assignment of subjects into a treated group versus a control group is outside the control of the investigator. This is in contrast with experiments, such as randomised controlled trials, where each subject is randomly assigned to a treated group or a control group.

The treatment unit is the desired machine, operator or system. Different measurement methods can be used depending on the study's final objective.

Example of Study Objective

Determine the productivity of a feller-buncher.

What statistical analysis can be done?

Basic calculations include productivity and costs and are calculated using standard units (see Section 5.1) for the given machine, operator or system. Basic descriptive statistics (e.g., means, medians, minimum and maximum values and standard deviations). The confidence intervals can also be determined.

What are the strengths and weaknesses of this design type?

Strengths

- Analysis is relatively straightforward
- Likely to be quicker and easier to conduct than experimental and modelling classifications
- Matches “real life” situations quite well

Weaknesses

- Cannot be used to compare against other machines, operators, etc.
- Not statistically rigorous
- Gives a picture for one machine/operator in one set of conditions; results might be drastically different in other conditions

2.3 Experimental Study Designs

Experimental designs compare different variables in order to determine differences or establish cause and effect. Because more control of variation (such as slope, machine type, etc.) is required, these designs are usually more complex. Different techniques are used to control bias (i.e., systematic error) including randomisation and blocking. Bias refers to a tendency to over represent or under represent certain parts of the population (Ott, 1993). A factor (treatment) or factors are applied to see the effects.

Determining the effect of one factor is referred to as the “main effect” of the factor. For example, if one wanted to see how skidder type, cable or grapple, influences productivity, the main effect examined would be skidder type. When multiple factors are involved, the interaction between the factors may also become significant. For example, if one wanted to see how skidder type (cable or grapple) and skidder engine capacity (e.g., <130 kW of >130kW) influence productivity in combination, first the interaction between skidder type and engine size would be tested, as the hypothesis tested is that there is no factor interaction effects. If the interaction is not significant, the hypothesis can be rejected and therefore it is sufficient to test the main effects (Milton and Arnold 1999). To put it in simpler language, if the two (or more factors) do not interact statistically then the factors only need to be examined individually.

Another key concept to mention here is that of variance. Variance in layman's terms describes the spread of data around the mean (aka the average). For example, Table1 below shows two different sets of values. Both have the same mean of 2.75; however, the spread of values in set B is much wider than set A; therefore, set B has the larger variance of the two sets. Greater explanation of variance can be found in Section 6.0: Statistical Analysis.

Table 1: An example of variance; two sample sets can have the same mean but different variances.

Sample Set	Values	Mean	Variance
A	2, 2, 4, 3	2.75	0.92
B	1, 1, 3, 6	2.75	5.6

Experimental designs are described below and each is discussed in terms of factors and the bias control technique used as well as the strengths and weaknesses of each design. Three basic assumptions need to be adhered to in the analysis with standard linear statistics (i.e., t-test, ANOVA and ordinary linear regression): homoscedacity (statistically similar variances) and independence of data. Should these basic assumptions not be met, advanced statistical analysis is required. It is recommended that the user seek the guidance of a statistical professional in this case.

Care should also be taken to either use one operator across all treatments or use similar operators. A confounding factor can quite quickly develop if this factor is ignored. Confounding means that it becomes impossible to find out whether the relationship (or lack-there-of) is a result of the block or the treatments themselves) (Clewer and Scarisbrick 2001). Unless determining whether an operator is more effective than another operator, always ensure any differences between operators are minimal.

This section draws on the work of Pretzsch (2009) as well as Clewer and Scarisbrick (2001).

2.3.1 Mono-factorial Random Design

A mono-factorial random design involves testing (or comparing) one specific factor (Pretzsch, 2009). Bias is controlled through randomisation. This study is conducted to compare one factor under the condition that the study site conditions are homogenous (i.e.they do not vary drastically from each other).

Example of Design:

As an example, a study could be designed to compare productivity between a grapple and cable skidder. Operators have both been working for the same amount of time, have the same amount of training and can be considered similar. Alternatively, one can study the same operator on both machines to reduce the potential of differences between operators. Site and stand conditions are selected in a way that they do not differ for the two systems. The treatment is therefore skidder type (Cable vs Grapple).

What statistical analysis can be done?

Basic calculations include productivity and costs and are calculated using standard units for the given machine, operator or system. Basic descriptive statistics and confidence intervals can also be determined. Treatment effects are tested using an Analysis of Variance (ANOVA).

What are the strengths and weaknesses of this design type?

Strengths

- Relatively straightforward analysis
- Number of replications do not necessarily have to be equal

Weaknesses

- If sites are not entirely homogenous, results can be biased

2.3.2 Multi-factorial Random design

A multi-factorial random design involves testing two or more factors (Pretzsch, 2009). Bias is controlled through randomisation. This study is conducted to compare multiple factors and the study site conditions are homogenous (they do not vary drastically from each other) (Pretzsch, 2009).

Example of Design

One can design a study to examine the productivity of a cable skidder and a grapple skidder as well as how productivity varies between morning and afternoon shifts.

Cable Morning Shift	Grapple Afternoon shift
Grapple Morning Shift	Cable Afternoon shift

What statistical analysis can be done?

Basic calculations include productivity and costs and are calculated using standard units for the given machine, operator or system. Basic descriptive statistics and confidence intervals can also be determined. Treatment interactions as well as individual treatment effects are tested using factorial ANOVAs.

What are the strengths and weaknesses of this design type?

Strengths

- Allows for examination of different treatments and multiple interactions
- Can determine how (and if) multiple treatments interact

Weaknesses

- Analysis is slightly more complicated
- May be difficult to replicate all combinations

2.3.3 Mono-factorial Block Design

Mono-factorial block design involves testing (or comparing) one specific factor (Pretzsch, 2009). Block designs are used to reduce known systematic variation, (e.g. known changes in slope category, different shift times, etc.). This is done through the technique of blocking where treatments are grouped across the different categories (Cluwer and Scarisbrick 2001). Systematic bias is therefore controlled through a combination of the development of blocks and the remaining bias is controlled through randomly placing of treatments in blocks (Cluwer and Scarisbrick 2001). In other words it ensures that random effects are avoided that lead to a clustering of repetitions of the same treatment, which would lead to a bias in case of spatial correlations within the experimental site.

Example of Design

A study is designed to compare the productivity of three operators (the treatment factor is therefore operator), Abe, Bob and Carl. The sites vary depending on slope and we split the experiment into two blocks (aka, blocking): slope less than 10% and slope greater than or equal to 10%. Abe, Bob and Carl will be studied in both blocks and randomly allocated to sites in each block.

Block	Operator		
Slope < 10%:	Bob	Abe	Carl
Slope ≥ 10%:	Carl	Bob	Abe

What statistical analysis can be done?

Similar to the mono-factorial random design, basic calculations include productivity, costs and are calculated using standard units for the given machine, operator or system. Basic descriptive statistics and confidence intervals can also be determined. Treatment effects are tested using an Analysis of Variance (ANOVA) controlling for block error.

What are the strengths and weaknesses of this design type?

Strengths

- Reduces systematic experimental error (accounts for variation in site quality)
- Sampling can be done block by block

Weaknesses

- May be difficult to replicate all treatments across all blocks
- If sites are homogenous, less efficient than random sampling
- Large number of treatments may make it difficult to find an appropriate number of blocks

2.3.4 Multi-factorial Block design

A multi-factorial block design involves testing two or more factors (Pretzsch, 2009). Block designs are used to reduce known systematic variation, (e.g. known changes in slope category, different shift times, etc.). This is done through the technique of blocking where treatments are grouped across the different categories (Clewer and Scarisbrick 2001). Systematic bias is therefore controlled through a combination of the development of blocks (aka blocking) and the remaining bias is controlled through random treatment placement in the block (Pretzsch, 2009).

Example of Design

A study is designed to examine productivity of two operators (one of the treatment factors is operator), Abe and Bob, and the use of a cable skidder or grapple skidder (the second treatment factor). The site varies depending on gradient and the experiment is split into two blocks: gradient less than 10% and gradient greater than or equal to 10%. Abe and Bob operating each machine will be studied in both blocks and randomly allocated to sites in each block.

Block:	Machine and Operator			
Slope < 10%	Cable Abe	Grapple Bob	Cable Bob	Grapple Abe
Slope ≥ 10%	Grapple Bob	Grapple Abe	Cable Abe	Cable Bob

What statistical analysis can be done?

Basic calculations include productivity, costs and are calculated using standard units for the given machine, operator or system. Basic descriptive statistics and confidence intervals can also be determined. Treatment interactions as well as individual treatment effects are tested using factorial ANOVAs controlling for block effects.

What are the strengths and weaknesses of this design type?

Strengths

- Allows for treatment interactions to be determined and controls for block error

Weaknesses

- Analysis becomes more complicated
- May be difficult replicating all the necessary treatments and blocks
- If sites are homogenous, extremely inefficient as the design blocks what could otherwise be a simple random design

2.3.5 Mono-factorial Latin Square design

A mono-factorial Latin square design involves testing (or comparing) one factor or treatment (Pretzsch, 2009). The site however varies in two or more ways and this error is controlled through square (or rectangular) blocking (Clewer and Scarisbrick 2001). Block designs are used to reduce known systematic variation, (e.g. known changes in slope category, different shift times, etc.). This is done through the technique of blocking where treatments are grouped across the different categories (Clewer and Scarisbrick 2001). Blocks in a Latin Square design can be thought of as moving in rows and columns (Pretzsch, 2009).

Example of Design

A study is designed to compare the productivity of three operators, Abe, Bob and Carl (the treatment factor is therefore operator). The sites vary depending on slope and soil type. The experiment is therefore split into two rows (blocks) for slope less than 10% and slope greater than or equal 10%. The experiment will also be split into two columns (blocks) for clay type soil and sand type soil. Abe, Bob and Carl will be studied in both blocks and randomly allocated to sites in each block.

Blocks:	Clay Soil			Sand Soil		
Slope < 10%	Abe	Carl	Bob	Bob	Carl	Abe
Slope ≥ 10%	Carl	Bob	Abe	Carl	Abe	Bob

What statistical analysis can be done?

Similar to the mono-factorial block design, basic calculations include productivity, costs and are calculated using standard units for the given machine, operator or system. Basic descriptive statistics and confidence intervals can also be determined. Treatment effects are tested using an Analysis of Variance (ANOVA) controlling for block error both for rows and columns.

What are the strengths and weaknesses of this design type?

Strengths

- Relatively easy to control for two differences in site type

Weaknesses

- Number of replications can very quickly become too large to manage
- Analysis is complicated
- Analysis is not valid if there is interaction between the blocking factors and the treatment

2.3.6 Multi-factorial Latin Square Design

A multi-factorial Latin square design involves testing (or comparing) two or more factors or treatments (Pretzsch, 2009). The site however varies in two or more ways and this error is controlled through square (or rectangular) blocking. Block designs are used to reduce known systematic variation, (e.g. known changes in slope category, different shift times, etc.). This is done through the technique of blocking where treatments are grouped across the different categories (Clewer and Scarisbrick 2001). In a Latin Square design, blocks can be thought of as moving in rows and columns (Pretzsch, 2009).

Example of Design

A study is designed to compare the productivity of three operators, Abe, Bob and Carl (the first treatment factor) and two skidder types, Cable and Grapple (the second treatment factor). The site varies in terms of gradient and average tree size. Two blocks will be formed for slope (less than 10% and greater than or equal to 10%) and two blocks for tree size (less than 1 m^3 and greater than or equal to 1 m^3). Operators will be tested on both machines and operators-machine combinations will be randomly distributed across all blocks.

The first letter in the site refers to the Operator (A,B and C) and the second letter refers to the machine type (C for cable and G for grapple).

Blocks:	Average Tree Size Less than $1m^3$						Average Tree Size Greater than/Equal $1m^3$					
Slope < 10%	CC	AC	CG	BG	AG	BC	BG	BC	CC	AG	AC	CG
Slope ≥ 10%	AG	CC	AC	BC	BG	CG	CG	AC	BC	CC	BG	AG

What statistical analysis can be done?

Similar to the mono-factorial block design, basic calculations include productivity, costs and are calculated using standard units for the given machine, operator or system. Basic descriptive statistics and confidence intervals can also be determined. Treatment interactions as well as individual treatment effects are tested using factorial ANOVAs controlling for block error in both rows and columns.

Caution must be noted because, for this design, the number of replications can rapidly become very large (Clewer and Scarisbrick 2001). For a solid design, every treatment must be replicated across all blocks, otherwise confounding effects can occur. Confounding can seriously diminish the strength of an experiment and should be approached with caution.

What are the strengths of this design?

Strengths

- Allows for control of two or more site factors through blocking
- Allows for assessment of both treatment interactions and individual factor effects

Weaknesses

- Number of replications can very quickly becomes too large to manage
- Analysis is complicated
- Analysis is not valid if there is interaction between the blocking factors and the treatment
- If all treatments are not replicated, then confounding becomes a problem

2.3.7 Split-plot designs

Split plot or split block designs are used in multi-factorial experiments when one treatment can be applied on a large scale and the other treatment can be applied on a small scale (Clewer and Scarisbrick 2001).

Example of Design

As an example, a study is designed to assess the effects of average tree volume (less than 1 m^3 or greater than or equal to $1m^3$) and skidder type (cable or grapple) across three Pine species. Since tree volume is fixed by compartment, half the compartment is skidded with a cable skidder and the other half with a grapple skidder. The plot is therefore organised by average tree volume and then split by skidder type.

Pinus elliotti	**Tree Vol. $<1m^3$**	**Tree Vol. $\geq 1m^3$**
	Cable	Grapple
	Grapple	Cable
Pinus patula	**Tree Vol. $\geq 1m^3$**	**Tree Vol. $<1m^3$**
	Grapple	Cable
	Cable	Grapple
Pinus taeda	**Tree Vol. $<1m^3$**	**Tree Vol. $\geq 1m^3$**
	Grapple	Cable
	Cable	Grapple

What statistical analysis can be done?

Beyond basic statistics and calculations, factorial ANOVAs would be used, although output of interactions and main effects becomes difficult to interpret.

What are the strengths of this design?

Strengths

- Allows for greater freedom in Block design

Weaknesses

- Analysis is much less precise
- Analysis is more complicated than factorial designs
- May be difficult to find enough sites for each block

It is highly recommended that for studies which require this type of experimental design, a statistician should be consulted.

2.4 Modelling Studies

Similar to observation studies, modelling studies are done to observe machines, operators, or systems and create a production or cost model based on a series on input factors. These input factors must be measurable and preferably are continuous, meaning they are quantitative and within a range any number can exist. Examples of continuous variables include DBH, slope (%), speed, etc.

Example of Design

Develop a production model for a skidder in an operation. Inputs for this model include slope (%), cycle time, choking time, dechoking time, travel empty and loaded time, speed (loaded and unloaded), extraction distance etc. Some basic assumptions that need to be adhered to are homoscedacity and independence of data (see above).

What statistical analysis can be done?

Productivity and cost must be calculated in some way in order to develop the model. This can be done using regression methods, including multiple regression, or analysis of covariance.

What are the strengths and weaknesses of this method?

Strengths

- Development of predictive models that can be used to describe the relationship between the response variable and the independent variables

Weaknesses

- May be difficult to control for variation from qualitative sources

2.5 Sample size calculations

It is essential that you have enough samples within your treatments and enough replications to allow for differences (or lack there-of) to be determinable. The difficulty that results is that in order to know the margin of error your sample will produce, you need to know the within-treatment variation (σ^2). The generic formula for sample size calculation is shown in Equation 1.

$$n = \frac{t^2 \cdot \sigma_x^2}{t \cdot \sigma_x^2} \tag{1}$$

Where:

n = the minimum sample size
t = the t-value, as provided from a t-table, usually selected with an error probability 0.05 (confidence level of 0.95
σ_x^2 = the variance

It is obvious from Equation 1 that apart from the confidence level, information about the variation in the population is also needed.

One way of determining this variation is to run a pilot study beforehand. Such a pilot study allows a quick assessment of the variation (σ^2). From this variation, the full study sample size can be better approximated.

2.5.1 Pilot Studies

If running a pilot study is not feasible, sample size can also be approximated from similar studies. However, the pilot study is the preferable option as it gives a more accurate picture of the variation.

Once the pilot study has been completed, sample size for the study can be calculated by using Equation 2 below. This formula calculates sample size using a 95.45 confidence level and a margin of error of ± 5% (Kanawaty 1992).

$$n = \left(\frac{40\sqrt{n' \sum x^2 - (\sum x)^2}}{\sum x}\right)^2 \tag{2}$$

Where:

n = sample size for study
n' = number of readings taken in the pilot study
x = observed value
Σ = sum of values (i.e.: sum of observed values)

It is important to note that if the minimum sample size determined is more than the sample size of the pilot study, one cannot simple “top up” the pilot study by sampling the difference of n and n'. Rather, n samples must be determined again (Kanawaty 1992).

2.5.2 Approximating Sample Size

Cochran (1977) developed an equation for approximating sample sizes from a large population based on proportions. Given that the number of cycles a machine works can be considered a large sample, this formula can be used. The proportions referred to are the approximate time the machine is working (p) and the approximate time the machine is not working (1-p). Equation 3 below details the formula.

$$n = \left(\frac{Z}{ME}\right)^2 pq \quad (3)$$

Where:

Z = Associated Z value for required accuracy (ie: 95%)
ME = Maximum allowable error (ie: 10%)
p = Estimated proportion of time machine is active and working
q = Estimated proportion of time machine is not active (aka 1 – p)

This method is not as ideal as the above mentioned pilot study method as it relies on an estimate of machine availability rather than the actual variance in shifts, cycles, or elements. As a general rule of thumb, for cycles which are 1 minute in duration, at least 30 samples are needed. This number increases exponentially as cycle time decreases (Kanawaty 1992).

3.0 Time Models

Time is a key element of production and is a crucial resource which must be managed. Several models are in use and work to describe how forestry activities use time. This standard will use the model and definitions proposed by the International Union of Forest Research Organisations (IUFRO).

The IUFRO model (Figure 2) divides Total Time (TT) into Non-Workplace Time (NW) and Workplace Time (WP). Workplace time is further subdivided into Non-Work Time (NT) and Work Time (WT). Work time is then divided into either Productive Work Time (PW) or Supportive Work Time (SW). Productive work time includes Main Work Time (MW) and Complementary Work Time (CW). Productive work time is where the work elements would be considered. Elements will be discussed further in Section 5.

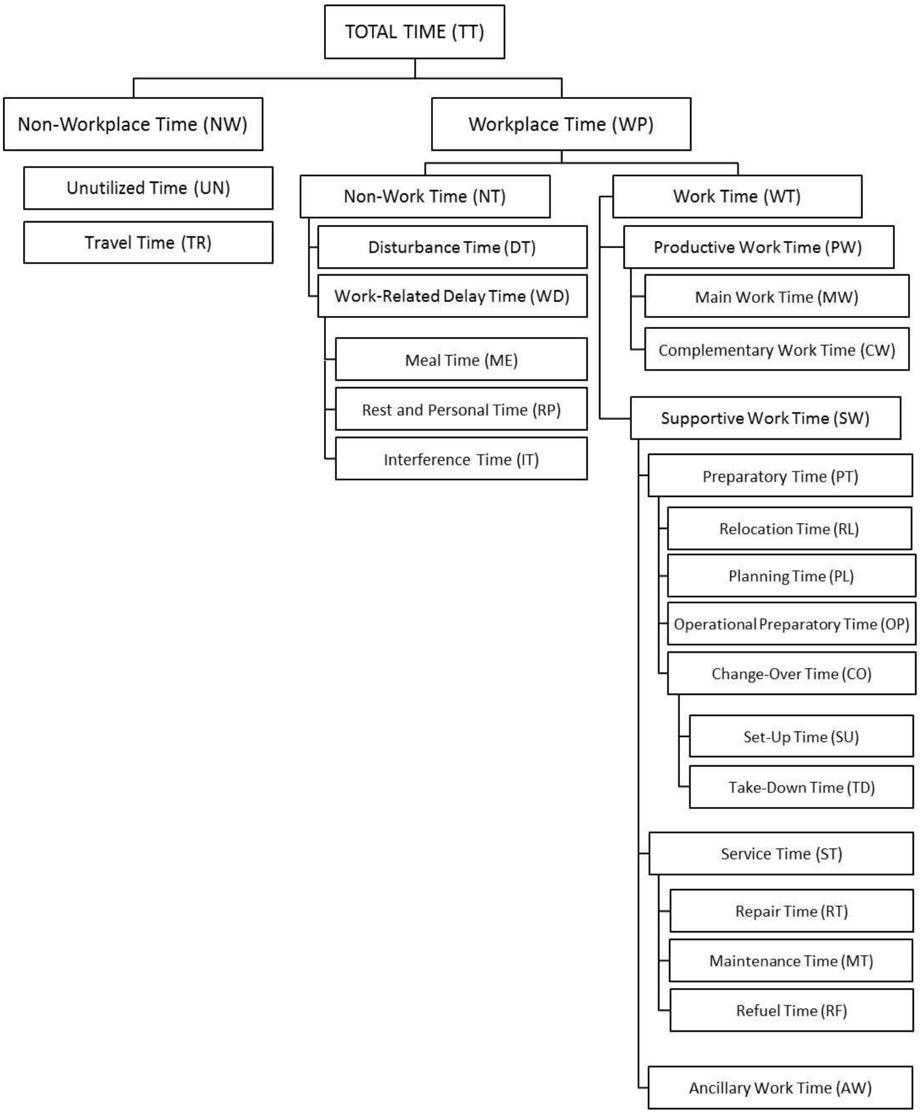

Figure 2: IUFRO time concepts structure (Björheden and Thompson 1995) including abbreviations for time components.

Supportive work time is further split into Preparatory Time (PT), Service Time (ST) and Ancillary Work Time (AW). From a time study perspective, the main objective is typically to determine the productive machine hours (PMH). These hours are what the IUFRO model refers to as Productive Work Time (PW). They are the portion of time where the machine, or operator, is engaged in their primary work function. For example, the productive machine hours for a chainsaw operator refer to the time he is actively felling trees, including the time to walk from tree to tree as this is fundamental to the felling process. In Section 5, detailed elements which demonstrate the machine/operations productive work cycle are described. From the time model, time can be divided up and used to calculate ratios which are essential for accurate costing. These ratios are: mechanical availability, machine utilisation and capacity utilisation.

The ratios are calculated using time intervals developed from the IUFRO time concepts structure. These are detailed below (Table 2).

Table 2: Description of time concepts used to calculate usage ratios.

Term	Calculation	Description
Scheduled machine hours (**SMH**)	$SMH = Work\ Time$	This is the portion of the total time that an operation or part of an operation is engaged at a specific work task. The normal shift time (e.g., a 9 hour shift per day). Referred to as Work Time (WT) in the IUFRO model.
Available machine hours (**AMH**)	$AMH = Work\ Time - Service\ Time$	Available machine hours refers to the portion of time that a machine is available to work. This is the shift time minus time spent on routine maintenance (i.e. fuelling). For example, 1 hour out of a 9 hour scheduled shift.
Productive machine hours (**PMH**)	$PMH = Productive\ Work\ Time$ **Or:** $PMH = SMH - Service\ Time - Other\ Delays$	The potion of work time that is spent contributing directly to the completion of a specific work task. Referred to as Productive Work Time (PW) in the IUFRO Model.

3.1 Ratio Calculations

3.1.1 Mechanical Availability

Mechanical availability refers to the portion of the workplace time (WP) during which a machine is mechanically fit and able to conduct productive work (Björheden and Thompson 1995). Availability is dependent on machine required maintenance, either preventative or otherwise (Pulkki 2001). Equations 3 and 4 below detail the formulas for calculating mechanical availability.

$$Mechanical\ Availability\ (\%) = \frac{Workplace\ Time\ (WP) - Service\ Time\ (ST)}{Workplace\ Time\ (WP)} \times 100 \tag{3}$$

Or alternatively,

$$Mechanical\ Availability\ (\%) = \frac{Available\ Machine\ Hours\ (AMH)}{Scheduled\ Machine\ Hours\ (SMH)} \times 100 \tag{4}$$

(Both equations taken from Pulkki (2001)).

3.1.2 Machine Utilisation

Machine utilisation refers to the portion of workplace time when a machine is used to conduct the function intended for the machine (Björheden and Thompson 1995). It is dependent on the mechanical availability of the machine as well as on the effectiveness of the operating method (Pulkki 2001). Equations 5 and 6 below detail the formulas for calculating machine utilisation).

$$Machine\ Utilisation\ (\%) = \frac{Productive\ Work\ Time\ (PW)}{Workplace\ Time\ (WP)} \times 100 \tag{5}$$

Or alternatively,

$$Machine\ Utilisation\ (\%) = \frac{Productive\ Machine\ Hours\ (PMH)}{Scheduled\ Machine\ Hours\ (SMH)} \times 100 \tag{6}$$

(Both equations taken from Pulkki (2001)).

3.1.3 Capacity Utilisation

Machine capacity utilisation refers to a measure of the extent of total time (TT) that the machine is used for work. This includes all delay times, supportive work time along with the actual productive work time (Pulkki 2001). Equation 7 below details the formula for capacity utilisation.

$$Capacity\ Utilisation\ (\%) = \frac{Workplace\ Time\ (WP)}{Total\ Time\ (TT)} \times 100 \tag{7}$$

(Equation taken from Pulkki (2001)).

3.1.4 Visualisation of Time Concepts

Figure 3 below shows a diagram illustrating how the time concepts come together for use in ratio calculations.

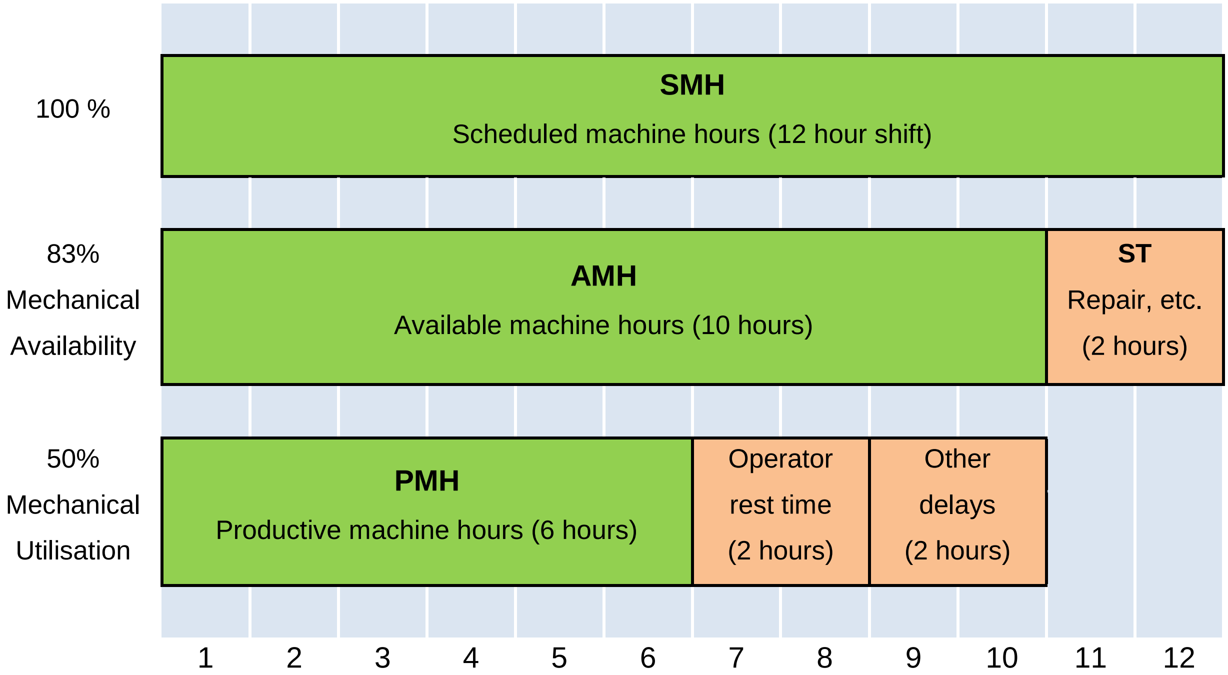

Figure 3: Time concepts visualisation for a machine operating over a 12 hour shift. 2 hours are spent on service time (ST), giving this particular machine a mechanical availability of 83%, 2 hours of shift are spent on operator rest time and another 2 hours are spent on other delays, such as answering personal cell phone calls. The mechanical utilisation of this operation is therefore 50%.

4.0 Time Study Techniques and Methodologies

Once an objective and appropriate experimental design have been decided, the study technique can be finalised. Study technique will be highly objective specific. There are six different types of time study techniques that are commonly used (Table 3). Each technique varies in its scope and duration. Cost of conducting a study also varies depending on how much time and resources it takes to conduct.

Table 3: Comparison of the six time study techniques and their typical degree of scope and duration.

Study Type	Scope	Observation Unit	Duration
Shift level study	Wide	Shift	Weeks – Months
Plot Level study	Wide	Plot	Weeks
Cycle Level	Medium	Cycle	Days
Time and Production Count	Narrow	Cycle or Shift	Hours
Work Sampling	Narrow	Element	Hours – Days
Element Level	Narrow	Element	Hours - Days

Before discussing the individual study types, it is important to discuss delays. As shown above in the IUFRO model, Workplace time (WP) is divided into Work time (WT) and Non-work time (NT). A delay is considered any time that is Non-work time (NT). Delays can then be further classified depending on whether they are work related (WD) or Disturbance (DT).

The literature tends to handle delays in differing ways, and the suggestion is often made that only delays greater than 15 minutes be recorded (Brown et al. 2010). We instead propose that any delay greater than 30 seconds be recorded and classified appropriately. Whether or not it is included in the analysis will depend on study length and sample size (a 20 minute delay on a one-day study may be unrepresentative but several 2 minute delays every day for a week could be) but it is felt it is important to at least have an understanding of where and when the delays occur. Whatever protocol is used, it is important that the person doing the study clearly states which route was followed so that comparison studies in the future become potentially possible.

4.1 Shift Level Study

A shift level study examines production of a machine, operator or system with the observational measurement being a fully completed work shift. This technique is generally used for long-term observation, monitoring or follow-up studies (Magagnotti and Spinelli 2010).

4.1.1 Data acquisition methods

Data for a shift level study can be acquired either manually or automatically if the equipment is available. Manual shift-level studies involve giving a foreman or shift supervisor a sheet on which to record their team's performance every shift. Specific data recorded should include:

- Shift start and end time
- Record of crew working
- Production in appropriate unit
- Job type
- Delays and causes of delays
- Fuel consumption
- Etc.

Some of this data may be collected automatically with on-board data logging software connected to appropriate sensors.

4.1.2 Advantages and Drawbacks

The major drawback to a shift-level study is that it requires on-going data management, particularly if done manually, and that it lacks the finer elemental detail. Furthermore, shift supervisors need to support the study and understand their role in the study's success is crucial. Nevertheless, it is a powerful tool and the analysis tends to be more straightforward, particularly when combined with a simpler experimental design.

4.2 Plot Level Study

A plot level study examines production of a machine operator or system with the observational unit being a fully completed plot. A plot can be designed specifically to meet the study's objectives. An example of a plot would be 4 rows of 30 trees with consistent tree species, diameter, height and spacing. The unit therefore is a completed plot and time is cumulative for the entire plot (i.e. how long does it take Operator A to complete a plot versus Operator B).

4.2.1 Data acquisition methods

Data acquisition for a plot level study can be done manually or automatically depending on how the plot is defined and on the technology available. If a plot is smaller and contiguous with the next plot, it may not be possible to differentiate one plot from the next using data logging. If; however, plots are easy to separate then automatic acquisition is possible.

For manual acquisition, the time study observer can time the duration of the plot and record the respective production figures. Other information to specifically include would be:

- Detailed definition of the plot
- Machine used, make and model
- Operator
- Species
- Etc.

4.2.2 Advantages and Drawbacks

The major drawback to a plot level study is it becomes difficult to compare a plot level study to other studies that do not use the same plot composition. Additionally, as timing focuses on the plot completion alone, delays and elemental data are not acquired. Furthermore, performance in a plot may be specific to the plot itself and may not be able to be applied outside.

Nevertheless, the advantage of a plot level study is it is a very good way to quickly compare two very similar types of machinery or operators. Depending on the plot composition, it may also be easier to design an experiment for other study techniques.

4.3 Cycle Level Study

A cycle level study examines production on the cycle level and the observational unit is a completed cycle. A work cycle is defined as a sequence of tasks that perform a job or produce a unit of production (Kanawaty 1992). A completed cycle can be anything from felling a tree to trucking a round trip with a load. Cycle level studies can be conducted manually or using automatic data acquisition depending on the objective of the study and the equipment available.

4.3.1 Data acquisition methods

For manual acquisition, an observer in field would record time consumed per cycle and note the relevant production figures. Delays should also be recorded and classified. Data loggers may also provide an alternative if appropriate sensors can be attached to the desired inputs (might be more difficult for chainsaws but feasible for forwarders).

4.3.2 Advantages and drawbacks

The major drawback of a cycle level study is that it lacks the elemental detail of the work process. The advantages are that it provides a quick way of seeing the variability in the work process and allows delay information to be captured. It is less intensive than an elemental study. Overall, cycle level studies are not recommended.

4.4 Time and Production Count

One of the simplest techniques for time and work study is time and production count. The observation level is variable and can be anything from a cycle, series of cycles or a shift. Time and Production Counts are designed to be very quick and typically are done manually with an observer in the field over a few hours.

4.4.1 Data acquisition

Data collection is usually collected over a short period of time (i.e. few hours) and is done through recording productive time and production in the preferred unit (e.g. logs, volume, tonnes, etc.). Any delays should be recorded and excluded from productive time. By dividing production by time, one can find a quick estimate of performance. To calculate productivity, one of the following formulae should be used:

$$Productivity = \frac{Number\ of\ trees \times average\ tree\ size}{Productive\ time} \tag{8}$$

Or alternatively,

$$Productivity = \frac{Number\ of\ loads \times average\ load\ size}{Productive\ size} \tag{9}$$

Equations 8 and 9 taken from Brown *et al*. (2010).

It is helpful to record comments on any special situation during study time (delays, work methods, etc.) as well as background information on the study conditions such as tree size, stocking, slope, etc.

4.4.2 Advantages and Drawbacks

The advantages of this technique are that it is quick and simple but the disadvantages are that the result only reflects the performance for a relatively short period of time and for a specific condition. In addition, it is difficult to identify inefficiencies because of the lack of detail.

4.5 Element Study

An element study breaks down the work cycle of a machine or system into individual functional steps called elements (Magagnotti and Spinelli 2010). For the purposes of standardisation, elements have already been defined by machine type and are described in-depth in section 5.0.

An elemental study is typically conducted manually and tools can range from basic clipboard and stopwatch to complex handheld personal computers with detailed time study software to video recording. Particularly when individual elements are very short in duration, computer software and video recording can make capturing these elements easier.

4.5.1 Data acquisition

Elemental timing can be recorded using two different timing techniques: snap back timing or continuous timing (Magagnotti and Spinelli 2010). In snap-back timing, the clock is reset back to 0 at the end of every element. This can be done using the lap feature of a stopwatch. The major benefit of snap back timing is that recording the amount of time per element is very easy. A disadvantage is that it requires a watch that has a lap function or the observer to reset the clock every time which can increase the risk of timing mistakes.

Continuous timing means that the time is recorded for every break point (transition between elements) and time per element is then calculated after the fact. Continuous timing is made simpler by the use of decimal time watches which convert minutes into decimal minutes allowing for simpler math.

For elements that are extremely short, a handheld computer program which can change elements with one click can help to record very quick changes. The fastest elements though will require video-taping and element times are established through multiple replays after the fact (Magagnotti and Spinelli 2010).

Other data recorded includes:

- Any delay greater than 30 seconds and cause of delay
- Production unit
- Comments per cycle or element

4.5.2 Advantages and Drawbacks

The main advantage of an element study is the fine level of detail regarding the work process it provides. Element studies allow for greater understanding of the functional steps and can help directly pin down inefficiencies. The major drawback of elemental studies is they are time consuming and can become costly for acquiring large data sets. Experimental design has to be done to minimise replications and keep the overall number of observations feasible. Furthermore, element studies require the observer to be well versed in the element breaks and understand what they are specifically looking for.

4.6 Work Sampling (Instantaneous Observation, and/or Activity Sampling)

While not a true time study technique per say, work sampling is an important method of work measurement and is therefore recorded here. Similar to an element study, Work Sampling also records element-level data. Unlike time study; however, work sampling determines the relative frequency of the elements over the total time observed. During Work Sampling, a series of instantaneous readings of an activity are taken over a period of time. Ideally, the readings are not taken in time with the cycle as irregular sampling intervals.

4.6.1 Data acquisition

The observer collects data by sampling at either a fixed or random interval. Fixed intervals (e.g. two minutes) should be used in conditions when the duration of work activities are random. When the duration of activities are more systematic or when there is uncertainty regarding the duration of activities, sampling should be done at random interval in order to avoid bias. With this technique, the relative times of work activities are determined by assuming that the percentage of observations recorded for each activity approximates the percentage of each activity within the total time.

Each activity that occurs during each sampling interval is tallied and tallies are excluded from delays. To calculate the percentage of a particular activity within a work cycle, divide the total tally for that element by the total tally of the study.

4.6.2 Advantages and Drawbacks

Work sampling is a simple and inexpensive way to conduct time and work study, requiring only a wristwatch or stopwatch and a clipboard for equipment. No special training or expertise is needed to conduct a study using this technique and an observer may collect data on several pieces of equipment or operators at the same time. This technique provides a general time distribution and highlights efficiencies of a work cycle. However, it is difficult to apply to other conditions because of its lack of detail.

A work sampling study is most effective when used for an operation where a number of activities are happening at once to complete a task. For example, a merchandising operation at roadside where multiple workers are cross cutting logs would be a good candidate for work sampling. Work sampling studies can also be used to assist in method determination or to help the data collector become familiar with a new machine or operation.

One suggested use of work sampling is to couple it with an element study. The data collector performs work sampling for the first hour or so of the study and then switches to the element study. This first hour provides the benefit of allowing the workers to become accustomed to the data collector's presence as well as provides a small work sampling dataset without any additional effort.

5.0 Machine Element Standardisation

A review was conducted to determine the machines commonly used in the South African forest industry. From this survey, elements in a normal machine cycle have been established. An element breaks down to a basic, functional step which can be measured throughout the duration of a normal work cycle. The pages below list the standardised elements and data collection requirements for commonly used harvesting machines in South Africa.

5.1 Standardised Element Lists by Machine

Please note the following:

- Any amount of additional detail can be added within each broad elements described below. A proviso is that the timekeeper has to be able to record the duration of each additional element, all associated attributes are recorded and described, that the additional detail fits into the fixed elements as listed in the tables below, and that any additional breakpoints are properly described and recorded within the elements.
- If need be, one or more of the listed elements can be omitted for a study such as; e.g., with chainsaw felling the element "consideration". Or it may be necessary to group "consideration "and "clear site"; or leave them out altogether. If two elements are grouped the recorder must make sure the breakpoints for start and end include the start for the first element and the end of the second element. However the timekeeper should consider the implication of this action before doing so as it can seriously affect the integrity of the study to be undertaken.
- The column "detail required" outlines the minimum required data and these range from time and distance to single tree dimensions. It is important in single tree operations that individual cycles' match a specific tree data. If in doubt rather measure to smallest individual unit; e.g., single tree, log etc.
- It is important to become conversant with the "Time Model" described in section 3.0 for correct allocation of delays and systems operations. This is particularly important in the calculation of machine availability, machine utilisation and systems efficiency. Each delay must be adequately described and recorded.

Chainsaw:

Elements	Break points	Detail required
Change position (walk to) to next tree to be felled	From when **final cut** on the previous tree (completed previous cycle) to **start of consideration phase** (when operator arrives at the next tree)	Time (t) and distance (d) for walking to next tree to be felled
Consideration (assess felling direction and potential inherent dangers).	From when **arriving** at the tree to be felled to when **saw touches material to be cleared**	Time (t) for considerations
Clear site around stump and create escape route	From when saw **touches material to be cleared** to when saw **touches stem for felling process**	Time (t) taken to clear obstacles and creating escape route
Felling tree	From when **saw touches** stem for first cut to when **tree hits the ground**	Time (t) taken to fell. Required: single tree dimensions
Tree length -> **delimbing** Cut to length -> **delimbing and cross—cutting** combined	From when **tree hits the ground** to when **last branch, last log, or topping cut is complete** (can include cutting the butt end square)	Time (t) taken to cross-cut, debranch, top. Record individual log data when practicing CTL
Delays		
Refuel time	From when **saw stops** due to fuel starvation (or needs fuel top-up) to when the **current operation resumes** (whatever the operation was previously)	Time (t) for refuelling (RF) - refer Time Models
Repair time	From when **saw stops** for repair to when current operation **resumes**	Time (t) for repairs (RT) - refer Time Models
Maintenance time	From when **saw stops** for maintenance to when current operation **resumes** (whatever the operation was previously)	Time (t) for maintenance (MT) - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when **work stops** due to delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays - refer Time Models

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance**: Estimate the distance the operator moves from one task to the next. An approximate distance can be estimated in un-thinned stands by using tree spacing**.** Otherwise the number of paces the operator takes can be used for good measure. If more accurate data is required use a tape measure. A GPS mounted to the operator could also provide a means of determining distances travelled between tasks.
- **Single standing tree dimension:** Number each tree to be felled in the study and pair this unique number to its associated dimensions. Also record other tree attributes; e.g., form etc. (refer to background information forms). Measure DBH (1.3m above ground level) and height of each tree. Use the Schumacher and Hall model (South African Forestry Handbook, 2012) to determine the volume of each tree. To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000).
- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) and tape measure or logging tape. For measuring methodology refer to South African Forestry Handbook (2000 & 2012).
- **Individual log data:** Record number of logs, and their dimensions (diameter – thin and thick-end - and length) cross-cut from each tree, if of interest.
- **Refer to IUFRO Time-models**

Harvester

Elements	Break points	Detail required
Travel	Begins when machine starts to move to new position and ends when the boom starts to swing towards the next tree ti be felled	Time (t) and distance (d) for travel
Boom-out (positioning head to cut)	Begins when the **boom starts to swing** towards a tree to be felled and ends with the **head resting in position on the tree** for the felling cut to commence	Time (t) and distance (d) for boom movement[1]
Felling	Begins when the **head is resting in position** on the tree and ends when the **tree starts to fall.**	Time (t) for felling.
Boom-in	Begins when the **tree is falling** and the boom starts to swing towards and stops in front of the base machine. The element ends when the **feed rollers start to turn** in the processing area at the machine front.	Time (t) and distance (d) for boom movement
Processing (i.e., delimbing, debarking, cross-cutting	Begins when the **feed rollers start to turn** and ends when the harvester begins to move to a new position	Time (t).
Delays		
Clearing (clearing of disturbed undergrowth and processing of un-merchantable trees or pieces of trees	Starts from the **end of a particular function** (e.g., processing – see above) and ends with the end **function in boom-in**	Time (t) for clearing (refer Time Models)
Moving tops and branches (slash)	Starts from the **end of a particular function** (e.g., processing – see above; and **ends when operation resumes again**	Time (t) for moving logs, tops and branches (refer Time Models)
Stacking logs	Starts from the end of a particular function (e.g., processing – see above); and ends when operations resumes again	Time(t)
Refuel time (in-shift)	From when harvester **stops** due to fuel shortage to when the current operation **resumes**	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when the harvester **stops** for repair to when the current operation **resumes**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when the harvester **stops** for maintenance to when current operation **resumes**	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when harvester **stops** for the particular delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance**: Estimate the distance the machine moves between stops of tasks. An approximate distance can be estimated in un-thinned stands by using tree spacing. Otherwise the number of rotations of the wheels/tracks can be used for good measure (mark a point on the wheel/track as reference point). Average speed for the move can be calculated as the quotient of distance and time for the move. GPS/OBC/CanBus system is a good alternative, if available.
- **Boom movement:** If machine has the ability to measure boom movement distance i.e. CanBus system, recover this data, otherwise exclude.

- **Single tree attributes:** Number each tree to be felled in the study and pair this unique number to its associated dimensions and record. Also record other tree attributes; e.g., form (refer background information forms). Measure DBH (1.3m above ground level) and height of each tree. Use the Schumacher and Hall model (South African Forestry Handbook, 2012) to determine the volume of each tree. To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000).
- **Individual log data:** Record number of logs, and their dimensions (diameter – thin and thick-end - and length) cross-cut from each tree. Calculate log size (m^3/tonnes) from Huber, Samlain or Newton's equations (South African Forestry Handbook 2012 & 2000). To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000).
- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) tape measure of logging tape. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Feller-buncher:

Elements	Break points	Detail required
Move to next tree	From where the previous **accumulated bunch is dropped** to when the **saw** (i.e., disc, chainsaw or shears**) touches** the next tree to be felled for next accumulated load	Time (t) and distance (d) required for moving from previous operation
Felling	From when **saw touches tree** to when the cut tree is **firmly gripped within the accumulating arms** of the feller-buncher	Time (t) required to fell each tree
Move to next tree (or swing to next tree)	From when the tree is **firmly in the accumulating arms** to when the saw touches the next tree for felling	Time (t) and distance (d) required to drive (or swing) between trees
Dump to stack	From when the **last tree** to be accumulated is **firmly gripped within the accumulating arms** to when the **machine releases** the accumulated bunch on to the ground (bunch hits ground)	Time (t), distance (d) and number of trees per accumulation
	Delays	
Refuel time (in-shift)	From when **machine stops** work due to fuel shortage to when the **current operation resumes** (whatever the operation was previously)	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when the machine **stops** for repair to when the current operation **resumes** (whatever the operation was previously)	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when the machine **stops** for maintenance begins to when current operation **resumes** (whatever the operation was previously)	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when the machine **stops** for the delay to when operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance:** Estimate the distance the machine moves. An approximate distance can be estimated in un-thinned stands by using tree spacing. Otherwise the number of rotations of the wheels/tracks or another good approximation can be used for good measure (mark a point on the wheel/track as reference point). Average speed for the move can be calculated as the quotient of distance and time for the move. GPS/OBC/CanBus systems are good alternatives, if available.
- **Tree data:** As single tree dimensions (DBH specifically) do not affect time for felling operations greatly, single tree dimensions are not required provided the individual tree dimensions are relatively uniform throughout the work area. Use average tree volume/tonnes as a measure. To gain average tree volume, sample the compartment following the methodology outlined in the South African Forestry Handbook (2012 & 2000). To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000). To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000).
- **Record the number of trees dumped:** This will provide an estimate of the bunch size (number of trees and volume) for the extraction operation. Use average tree volume/tonnes as a measure. To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000).
- **Measuring equipment:** Callipers (digital or manual) vertex (or other simple hypsometers - Suuntu) and tape measure or logging tape. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Skidder/agricultural tractor with winch or drawbar (a-frame or other):

Elements	Break points	Detail required
Travel unloaded along a forest road (if applicable)	From when the skidder **starts** to travel back to stump site after dropping its previous load to when it **enters** the compartment	Time (t) and distance (d) for travel along the road unloaded
Travel unloaded, off-road	From when the skidder **enters** the compartment to when it **stops** in a final position to start choking process	Time (t) and distance (d) for travel in the compartment unloaded
Choking	From when the skidder has **stopped** to start the choking process to when it **starts to move** off with its complete/full load after it has been winched in	Time (t) required to accumulate the load and number of trees in load
Travel loaded, off-road	From when the skidder **starts** to move fully loaded to when it **enters** the forest road	Time (t) and distance (d) for travel in the compartment loaded
Travel loaded along **forest road** towards the landing	From when the skidder **enters** the forest road to when the load (once the winch has been released) **makes contact with the landing surface**	Time (t) and distance (d) for travel along the road loaded
De-choking at landing	From when the load **makes contact with the landing surface** after release of the winch cable to when the skidder **starts to move off** to collect the next load	Time (t) required to release the skidder from its load and to load all available choker chains/cable – record number of stems/trees/logs that made up the final load that reached to landing. Record single tree dimensions (dbh, length, and species). Dbh recorded in experimental design since the operation is a single stem system
Delays		
Refuel time (in-shift)	From when skidder **stops** due to fuel shortage to when the current operation **resumes** (whatever the operation was previously)	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when the skidder **stops** for repair to when current operation **resumes** (whatever the operation was previously)	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when the skidder **stops** for maintenance to when **current** operation **resumes** (whatever the operation was previously)	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when the skidder **stops** for the delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance:** Estimate the distance the machine moves along the forest road and/or from stump site to roadside landing (m). A close approximate distance can be estimated by staking the road/skid trail with pegs (e.g., 20 m to 50 m apart) as reference points. GPS/OBC/CanBus system is a good alternative, if available. Average speed for both the loaded and unloaded can be calculated as the quotient of distance and time for the move.
- **Tree/load data:** Record number of pieces contained in load dropped at the landing. To determine load size (m^3/tonnes) multiply average tree/log volume/tonnes with number of pieces. Calculate piece volume for logs and for longer lengths using Huber, Smalian or Newton's equations (South African Forestry Handbook 2012 & 2000). Another option for longer lengths is to clearly mark DBH on the stem so that it is visible on arrival at roadside. Then record this DBH and the length of the tree and applying the Schumacher and Hall model (South African Forestry Handbook, 2012) for longer lengths or tree-lengths. To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000). It may not be possible to measure each piece in high production operations. In this case determine a sample size

(refer to protocol manual). Failing that a good estimate can be gained by measuring at least 30 pieces per day or per study and calculating volume/tonnes using the equations mentioned above.

- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) and tape measure or logging tape. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Skidder (grapple):

Elements	Break points	Detail required
Travel unloaded on forest road	From when the skidder has **dropped** its previous load (load touches the ground) to when it **enters** the compartment	Time (t) and distance (d) for travel along the road unloaded
Travel unloaded off-road	From when the skidder **enters** the compartment to when the skidders grapple **touches** the first trees/logs that will comprise the next load	Time (t) and distance (d) for travel in the compartment unloaded
Loading	From when the skidders grapple **touches** the bunched load to when the skidder starts to **move** with its final load is secured	Time (t) required to accumulate the load
Travel loaded, off-road	From when the skidder starts to **move** with full load to when it **enters** the forest road	Time (t) and distance (d) for travel in the compartment loaded
Travel loaded, on forest road	From when the skidder **enters** the road to when the load **makes contact** with the landing surface after release from skidder grapple	Time (t) and distance (d) for travel along the road loaded
Dropping load at landing	From when the load **makes contact** with the landing surface after release of the grapple to when the skidder **move off** for next load	Time (t) required to release the skidder from its load
	Delays	
Refuel time (in-shift)	From when skidder **stops** due to fuel shortage to when the current operation **resumes** (whatever the operation was previously)	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when skidder **stops** for repair to when current operation **resumes**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when skidder **stops** for maintenance to when current operation **resumes** (whatever the operation was previously)	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when skidder **stops** for the particular delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance:** Estimate the distance the machine moves along the forest road and/or from stump site to roadside landing (m). A close approximate distance can be estimated by staking the road/skid trail with pegs (e.g., 20 m to 50 m apart) as reference points. GPS/OBC/CamBus system is a good alternative, if available. Average speed for both the loaded and unloaded can be calculated as the quotient of distance and time for the move.
- **Tree data**: Record number of pieces contained in load dropped at the landing. To determine load size (m^3/tonnes) multiply average tree/log volume/tonnes with number of pieces. Calculate piece volume for logs and longer lengths using Huber, Smalian or Newton's equations (South African Forestry Handbook 2012 & 2000). Another option for longer lengths is to clearly mark DBH on the stem so that it is visible on arrival at roadside. Then record this DBH and the length of the tree and applying the Schumacher and Hall model (South African Forestry Handbook, 2012) for longer lengths or tree-lengths. To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000). It may not be possible to measure each piece in high production operations. In this case determine a sample size (refer to protocol manual). Failing that a good estimate can be gained by measuring at least 30 pieces per day or per study and calculating volume/tonnes using the equations mentioned above.
- **Measuring equipment:** Callipers (digital or manual) and vertex (or other simple hypsometers - Suuntu). For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Forwarder:

Elements	Break points	Detail required
Travel unloaded on forest road	From when the forwarder starts to **move** after it has unloaded its load (crane secured) to when it **enters** the compartment	Time (t) and distance (d) for travel along the road unloaded
Travel unloaded in-field	From when the forwarder **enters** the compartment to when the forwarder grapple begins to **move** from its position on the forwarder bunk to start the loading of the forwarder	Time (t) and distance (d) for travel in the compartment unloaded
Loading The loading element can be divided into sub-elements for more detailed analysis if necessary: • Reaching to the stack • Dropping load into the forwarder bunk • Sorting and handling logs on the ground • Sorting and handling the logs on the forwarder bunk	Begins from when the forwarder grapple **starts** to move from the forwarder bunk to when the forwarder grapple **come to rest** on the bunk after the last grapple load is loaded into the bunk	Time (t) and number of logs loaded per grapple and in total. Stack number should also be recorded. Log specific dimensions required to determine individual log volume and load volume
Driving while loading (between loading stops)	Begins when the forwarder **starts** to move to the next stack/pile and ends when the forwarder **stops** at the next stack/pile to begin loading from the next loading stop	Time (t) and distance (d)
Travel loaded in-field	Begins when the forwarder grapple **comes to rest** on the forwarder bunk after the last grapple load of the last loading stop and the forwarder bunk is full to when it **enters** the forest road	Time (t) and distance (d) for travel in the compartment unloaded
Travel loaded on forest road	Begins when the forwarder **enters** the forest road to when the grapple loader starts to **move** for unloading phase of the operation	Time (t) and distance (d) for travel along the road unloaded
Unloading at landing: The unloading element can be divided into sub-elements for more detailed analysis if necessary: • Lifting the grapple load onto the landing pile • Moving the empty grapple loader back onto the bunk • Sorting and handling logs in the bunk • Sorting and handling the logs on the landing pile	Begins when the grapple starts to **move** to start the unloading phase and ends when the empty forwarder starts to **move** to return to the field	Time (t) and if the forwarder moved during unloading the distance between stops. If forwarder moved between stops record number of logs unloaded per grapple and per stop
Delays		
Refuel time (in-shift)	From when forwarder **stops** due to fuel shortage to when the current operation **resumes**	Time (t) for refuelling (RF - refer Time Models)

Repair time (in-shift)	From when the forwarder **stops** for repair to when the current operation **resumes**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when the forwarder **stops** for maintenance to when current operation **resumes**	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when forwarder **stops** for the particular delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance:** Estimate the distance the machine moves along the machine trail (m). A close approximate distance can be estimated by staking the road with pegs (e.g., 20 m to 50 m apart) along the road as reference points. In this case a GPS is a good alternative, if available. Average speed for the move can be calculated as the quotient of distance and time for the move. GPS/OBC/CanBus system is a good alternative, if available. Average speed for both the loaded and unloaded can be calculated as the quotient of distance and time for the move.
- **Tree data** Record number of pieces contained in each grapple load. To determine load size (m^3/tonnes) use an estimation of average tree/log volume/tonnes by using Huber, Smalian or Newton's equations (South African Forestry Handbook 2012 & 2000). Also record the number of grapple loads to complete the loading of the forwarder. Total load size can be estimated by multiplying the total number of logs in the full load with the average piece size. To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000).
- It may however not be possible to measure each piece loaded that makes up the total load. In this case a sample of logs must be measured to determine an average log size and used throughout the study (if piece size remains uniform). Determine the minimum sample size needed using the sample size calculator outlined in the Protocol manual. Failing that a good estimate can be gained by measuring at least 30 pieces per day or per study and calculating volume/tonnes using the equations mentioned above.
- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) tape measure of logging tape. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Loader (either tracked or wheeled)

Elements	Break points	Detail required
Moving from one loading position to next loading position on landing	From when loader **starts moving** to new position and ends with **crane starting to swing** to stack/pile of logs/trees	Time (t) and distance (d) for travel
Load The loading element can be divided into sub-elements for more detailed analysis if necessary: • Reaching to the stack/pile (grab empty) • Boom from stack/pile to truck (grab loaded) • Dropping grab load into the truck bunk • Sorting and handling logs on the ground • Sorting and handling the logs on the truck bunk	From when **crane and grapple starting to swing** to stack/pile and ends when the **last logs/tree assortments are in place** on truck and crane and grapple is stationary in resting position	Time (t) and number of grapple loads and number of logs per grapple of total number to fill truck. Log specific dimensions required to determine individual log volume and load volume
Delays		
Refuel time (in-shift)	From when loader **stops** due to fuel shortage to when the current operation **resumes**	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when the loader **stops** for repair to when the current operation **resumes**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when the loader **stops** for maintenance to when current operation **resumes**	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when loader **stops** for the particular delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance:** Estimate the distance the machine moves along the machine trail (m). A close approximate distance can be estimated by staking the road with pegs (e.g., 20 m to 50 m apart) along the road as reference points. In this case a GPS is a good alternative, if available. Average speed for the move can be calculated as the quotient of distance and time for the move. GPS/OBC/CanBus system is a good alternative, if available. Average speed for both the loaded and unloaded can be calculated as the quotient of distance and time for the move.
- **Tree data** Record number of pieces contained in each grapple load. To determine grapple load size (m^3/tonnes) use an estimation of average tree/log volume/tonnes by applying Huber, Smalian or Newton's equations (South African Forestry Handbook 2012 & 2000). Also record the number of grapple loads required to complete the loading of the vehicle. Total load can be estimated by multiplying the total number of logs in the full load with the average piece size. To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000).
- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) and tape measure or logging tape. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Processor

Elements	Break points	Detail required
Travel (relocating) and positioning	Begins with the **first movement of the processor** and ends with **boom starting its swing** to stack/pile for first processing	Time (t) and distance (d)
Boom-out (positioning head to grab tree or tree section)	Begins when the **boom swings out** to stack/pile and ends when it has **grip on the stem**	Time (t) and distance of boom movement (d)[1]
Boom-in	Begins once it has a **grip on the stem** and then moves to front of base machine. Element ends when the **feed rollers start to turn**.	Time (t) and distance (d)[1] for boom movement
Processing (debranching (debarking), and/or cross-cutting and stacking)	From when the **feed rollers start to turn** and ends when either the completed tree-length or the **last** log cross-cut is **placed on a stack**	Time (t)
Delays		
Refuel time (in-shift)	From when processor **stops** due to fuel shortage to when the current operation **resumes**	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when the processor **stops** for repair to when the current operation **resumes**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when the processor **stops** for maintenance to when current operation **resumes**	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when processor **stops** for the particular delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance:** Estimate the distance the machine moves along the machine trail (m). A close approximate distance can be estimated by staking the road with pegs (e.g., 20 m to 50 m apart) along the road as reference points. In this case a GPS is a good alternative, if available. Average speed for the move can be calculated as the quotient of distance and time for the move. GPS/OBC/CamBus system is a good alternative, if available. Average speed for both the loaded and unloaded can be calculated as the quotient of distance and time for the move.
- **Boom movements:** If the machine has the ability to measure boom movement distance, recover this data, i.e. CanBus, OBC etc., otherwise exclude.
- **Tree data:** Record number of logs produced from each processing event. Do not separate debarking from cross-cutting as it is very difficult to define each operation separately. If possible record passes with eucalyptus debarking if finite
- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) and tape measure of logging tape. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Truck (timber transport)

Elements	Break points	Detail required
Travel Unloaded	From when the **truck moves off** after unloading and ends when it **stops to be loaded** at loading site	Time (t) and distance (d)*
Loading Operation	From when truck **stops** at position to load and ends when last load of assortments have been **loaded** onto the truck load body	Time (t) and number of assortments or total mass of assortments. If number of logs are recorded; record log dimensions for volume determination of load
Load control and fixing load	From when **last load** of assortments have been loaded and ends when the truck **starts to move** on transport route towards the off-loading point	Time (t)
Travel Loaded	From when truck **starts to move** on transport route towards the offloading point the and ends when the truck **stops** and is in position waiting to be unloaded with load securing undone	Time (t) and distance (d)
Unloading	Element starts when the truck **stops** and is in position waiting to be unloaded and ends when the empty truck **moves** off top return to loading site	Time (t)
	Delays	
Refuel time (in-shift)	From when truck **stops** due to fuel shortage to when the current operation **resumes**	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when the truck **stops** for repair to when the current operation **resumes**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when the truck **stops** for maintenance to when current operation **resumes**	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as Waiting to be Loaded or Unloaded etc.	From when truck **stops** for the particular delay to when current operation **resumes** (whatever the operation was previously)	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distance:** Record distance travelled (km) either from speedometer of by means of GPS data.
- **Road class:** Road class can be added and recorded if desired; otherwise, note on background information form.
- **Tree data** Record load size by recording then number of logs loaded multiplied with average tree/log volume/tonnes Determine log volume/tonnes using Huber, Smalian or Newton's equations (South African Forestry Handbook 2012 & 2000). To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000). An alternative to determine load size is to use recorded by the truck scales
- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) and tape measure or logging tape. A GPS is another useful tool for truck distance measurement, particularly when longer distances are being studied. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Yarder

Elements	Break points	Detail required
Yarder set-up	From when **yarder arrives** at landing site and end when the carriage first **starts to move** on the skyline	Time (t) for set-up
Carriage out	From when the carriage **starts to run out** and ends when it **stops/clamped** in its designated position	Time (t) and distance (d)**
Mainline out	From when carriage is **clamped** (or stationary) ready to take on load and ends when the **main-line reaches the first assortments** to be choked	Time (t) and distance (d)
Choking	From when the **main-line reaches the first assortments** to be choked and ends when the choker-setter are in the clear and **the signal has been given** that the choked load/turn can be hauled to the carriage	Time (t)
Mainline in	From when the choker-setter are in the **clear signal** and ends when the **carriage unlocks** from the skyline	Time (t)
Carriage Return	From when **carriage unlocks** from the skyline in the infield position and ends when the carriage stops at the landing and **the load reaches the ground on the deck**	Time (t) and distance (d)
De-choking	From when the **load reaches the deck** and ends when the **carriage starts moving** to return to the filed	Time (t) and volume/tonnes of the load
Yarder dismantling	Starts with **the last assortment load being de-choked** and ends when the **dismantled yarder leaves** the deck.	Time (t)
	Delays	
Refuel time (in-shift)	From when processor **stops due to fuel shortage** to when the operation **starts again**	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when need for **repair begins** (breakdown) to when operation **starts again**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when need **for maintenance begins** to when operation **starts again**	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when need the **delay begins** to when operation **starts again**	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distances:** Estimate the distance the carriage moves on the skyline loaded (m). A close approximate distance can be estimated by staking the corridor with pegs (e.g., 20 m to 50 m apart as reference points. GPS can also be used. Average speed of the carriage return process can be calculated as the quotient of distance and time for the move.
- **Tree data** Record number of pieces contained in load dropped at the landing. To determine load size (m^3/tonnes) use an estimation of average tree volume/tonnes using Schumacher and Hall model (South African Forestry Handbook, 2012) or Huber, Smalian or Newton's equations for logs (South African Forestry Handbook 2012 & 2000). To convert to mass (tonnes) refer to the South African Forestry Handbook (2012 & 2000). It may not be possible to measure each piece in high production operations. In this case determine the minimum sample size needed to produce an

acceptable estimate (refer to protocol manual for sample size calculator). Failing that a good estimate can be gained by measuring at least 30 pieces per day or per study and calculating volume/tonnes using the equations mentioned above

- **Measuring equipment:** Callipers (digital or manual), vertex (or other simple hypsometers - Suuntu) and tape measure or logging tape. For measuring methodology refer to South African Forestry Handbook (2012 & 2000).
- **Refer to IUFRO Time-models**

Mulchers and Destumpers

Elements	Break points	Detail required
Move to next stump	From the time the machine **completes a stump and starts moving** to the time it **starts destumping**	Time (t) and distance (d) required for moving between stumps (dependant on compartment spacing)
Mulch / destump	From when machine **arrives at a stump and starts mulching / destump starts** to when it **stops mulching / destumping**	Time (t) required to mulch each stump
Turn	From the time the **last stump is completed** to the time **destumping / mulching of the first stump in the new line starts**	Time (t) and distance (d) required to drive
Delays		
Refuel time (in-shift)	From when processor **stops due to fuel shortage** to when the operation **starts again**	Time (t) for refuelling (RF - refer Time Models)
Repair time (in-shift)	From when need for **repair begins** (breakdown) to when operation **starts again**	Time (t) for repairs (RT - refer Time Models)
Maintenance time (in-shift)	From when need **for maintenance begins** to when operation **starts again**	Time (t) for maintenance (MT - refer Time Models
Other workplace time (refer to Time Model) delays such as planning, rests, work preparations etc.	From when need the **delay begins** to when operation **starts again**	Time and reason (t) for delays (refer Time Models)

Specific time-study information required

- **Time:** Measure time in minutes and centi-minutes – i.e. hundredths of a minute.
- **Distances:** Use a measuring wheel to measure distance. This can be done afterwards if a starting point, the rows and the end point are marked. Distance between stumps can be calculated using the compartment spacing.
- **Stump data:** single stump dimensions (height and diameter) are not required provided the individual stump dimensions are relatively uniform throughout the work area. Use average stump dimension as a measure.
- **Record the number of stumps treated**
- **Refer to IUFRO Time-models**

5.2. User-defined elements

The user is strongly encouraged to use these pre-defined elements for both convenience and the purposes of industry standardisation; however, in certain cases, developing new elements may be required (e.g. the user is examining a machine which is not on the list below). All elements are basic, functional steps that occur during the work process, whether they contribute to the successful completion of work or not (delays).

When defining elements, a key consideration is defining element breakpoints. Breakpoints refer to the exact start and exact end time of an element. For example, a re-fuelling time element for a chainsaw begins when the saw stops due to lack of fuel or fuel top up and resumes when the saw starts to continue the operation. Elements also need to have defined measurement standards. This may be just the length of time the element takes to complete but it may also have other data requirements, such as the volume of load. When new elements are used, the user is kindly asked to define these steps and forward this information along to FESA in order to continue improving this protocol.

6.0 Statistical Analysis

This section is still in progress.

7.0 References

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