Evaluating Operator-Machine Interactions in Comparative Time Studies

T. Gullberg
Swedish University of Agricultural Sciences
Garpenberg, Sweden

ABSTRACT

Comparative experimental studies offer possibilities for reducing the uncontrolled variation in time studies of forest work. However, the factor "Operator" has often been found to be very difficult to keep constant when working with different machines. Analysis of variance often indicates that an interaction between operator and machine reduces opportunities to make generalizations.

The objective of this study was to develop and test a method for analysing and correcting for operator-machine interaction effects in comparative time studies encompassing few operators.

A new variable "Adaptation" was introduced to describe differences in the operators' degree of adaptation to various machines. In the present study the numeric value of the variable was estimated from *(a) previous experience, (b) the subjective feeling of adaptation by the operator, and (c) a standardized time study of loading from a pile.*

Analysis of variance showed that differences in adaptation could explain the interaction effects in both loading and unloading. The remaining effects of the interaction between operator and machine were not significant.

The method seems to offer more possibilities to generalize and statistically validate differences, even when the number of operators is limited.

Keywords: *work science, grapple loading, forwarder, farm tractor, logging, short-wood.*

The author is a Professor in the Department of Operational Efficiency, Faculty of Forestry.

INTRODUCTION

The comparison of productivity between different machines or different methods is a common and important task for researchers in forest engineering. Although many such studies have been carried out, very few can demonstrate differences in a scientifically acceptable way [7]. The real differences are often hidden behind a large amount of unexplained variation. It is well known that the operator has a large influence on productivity for most types of forest work [3, 6, 17, 20].

Knowledge about the great variation in forest conditions and among forest workers was the basis for the early development of "comparative studies" in the Nordic countries [2, 14, 15]. The general strategy was to keep conditions as uniform as possible in order to isolate the examined entity (machine or method). The main focus of such studies was comparisons between equipment, methods or forest conditions, rather than a general absolute productivity level.

Harstela [11, 12] has shown that by using the same operators for different methods being compared, the variation in relative time consumption between methods was smaller than the absolute variation in time consumption within each method. In Harstela [12] a small-scale model of a forwarder was used in a laboratory to compare loading at final felling with loading at thinning. He stressed that when comparing the methods, the operators should have similar abilities, motivation, and training.

Possibilities for keeping the conditions constant are sometimes limited. It is, for example, difficult to find trees and plots that closely resemble each other when comparing harvesting methods. These differences (e.g., tree size) can be handled by using functional relations between the tree size and time consumption and normalize to a certain level. The most difficult factor to keep constant is the operator.

Ahlgren et al. [1] compared different types of crane levers that were all handled by the same five operators. They found a strong interaction between operator and lever type. It was, therefore, impossible to establish a general order of precedence among the lever types. Gullberg [10], who compared three forwarding equipages, all driven by the same two operators, also found strong interactions between these factors.

In both studies the operators were given time for training on the different types of equipment. Nevertheless, in both studies interaction effects were judged to be mainly due to differences in experience between operators. If only one operator is used there is no possibility to detect interaction effects. Therefore, results of such studies must be interpreted with great caution.

To ensure that the results of comparative studies have general applicability, several operators with similar amounts of experience with all of the equipment types being tested would be needed. This is, however, seldom possible, for both practical and economic reasons. If it were possible to analyse and correct for differences in each operator's interaction with the equipment, not as many operators would be needed to make generalizations regarding relative differences.

Another "problem" in experimentally designed studies of man-machine systems is the difficulty in obtaining valid replicates. Even if the same work is being done, there is often some effect of learning resulting in decreasing time consumption.

The objective of this study was to develop and test a method for analysing and correcting for interaction effects between operator and machine in comparative time studies with few operators.

MODEL

Briefly, the factors influencing time consumption can be divided into five categories:

* *Machine* (basic technical characteristics).
* *Method* (the way the work is done).
* *Work* (level of difficulty, terrain conditions, etc.).
* *Operator* - physical and mental abilities and characteristics
  - training and experience
  - motivation
  - "daily form", etc.
* *Framework* (culture, wage system, etc.).

In an experimentally designed comparative study of various machine types driven by several operators with the same motivation and amount of experience etc., on all machines, variation in time consumption can be expressed as follows:

$$T_{ij} = \mu + M_i + O_j + r$$

where

T_{ij} = time consumption for machine *i* and operator *j*
μ = mean value
M_i = effect of machine *i*
O_j = effect of operator *j*
r = residual variation

It is easy to draw conclusions about relations between both machines and operators when the model is estimated by statistical methods.

If one or more of the operators can drive some of the machines better than others, the model has to be expanded:

$$T_{ij} = \mu + M_i + O_j + (MO)_{ij} + r$$

where

$(MO)_{ij}$ = interaction effect between machine *i* and operator *j*

This case, which can be considered as normal, results in a situation where neither the machine nor the operators can be ranked. One machine could get low ratings because one or several operators drive it poorly. In the same way, the performance of a particular operator could be poor owing to the operator's lack of practice in driving several machines.

It is reasonable to assume that a significant interaction effect is caused by differences in certain factors connected with the combination of operator and machine. The word "adaptation" may be used to comprehensively describe differences in a given operator's ability to drive specific machines.

If it were possible to measure how well adapted each operator is to various machines, the chances of establishing a general ranking of machines would increase.

We have therefore included the variable "Adaptation" with the aim of describing a person's differences in degree of adaptation to various machines. "Adaptation" is a figure relative to each operator's own reference level. The reference level may be defined as "total adaptation" and gives the absolute maximum productivity level for a given operator.

An alternative definition is "best adaptation" (among compared machines). This definition is much easier to use and gives the same results regarding the ranking of machines; however, it limits possibilities to rank operators.

The model can now be written as:

$$T_{ij} = \mu + M_i + O_j + c \cdot A_{ij} + r$$

where

c = coefficient
A_{ij} = "adaptation" for operator *i* on machine *j* (at the reference level $c \cdot A_{ij} = O$)

This model involves a resetting to the simple additive model formula simultaneously as interaction effects can be handled.

In this study the reference level "best adaptation" was used. The experimental comparative study design simplified the analysis of the differences in adaptation since several of the influencing factors could be kept constant. Other influencing factors, like motivation, could also be judged to be constant.

Estimation of the model requires that the value of the variable "Adaptation" is found. In this study the variable "Adaptation" was defined as a categorical variable (used as a covariate) with figures proportional to deviation from the reference level. There may be several alternative ways/sources for estimating the level:

* The operator's background, education, and train ing.
* The operator's own subjective feeling of "adapta tion."
* Comparison with theoretical models.
* Comparison with empirical models.
* Physiological measures of operators.
* Body-posture studies.
* Method studies.
* Technical measures on the machine.

It is probable that the reliability of a measure of "adaptation" increases as the number of types of relevant sources being used is increased. It is difficult, however, to combine all information, in order to obtain an overall estimate of "adaptation," since weighting it is difficult.

ANALYSED TIME STUDY

The approach was tested on an experimentally designed comparative time study of loading in connection with thinning and unloading at roadside [10]. Three forwarding equipages, a forwarder, a farm tractor with a large grapple-load trailer, and a farm tractor with a small grapple-load trailer, were driven by two operators on two plots (strip-road sections). For each combination of machine, operator and plot, one training drive and three time studies were made in random order. Replicates were obtained by replacing the logs in the original position after each time study. In total, 36 observations (163 m^3 solid wood) were time-studied at loading. In the case of unloading, two time studies were made for each combination of machine, operator and logs from each plot. In total, 24 observations (99 m^3 solid wood) were time-studied at unloading.

The first three sources mentioned above were used in the analysed study to estimate the level of adaptation.

A test was also carried out with an empirical model [9] where the variable crane power x weight was used to explain differences in time consumption at unloading. The very large deviation between estimated and measured time consumption for the smallest forwarding combination (despite the operator) made it impossible to use the model here.

Estimation of the Operators' "Adaptation"

1. *Previous experience*

Although both operators had extensive experience in forwarding, they had not used any of the analysed machines before the study. The operators were given the opportunity to practice for four weeks under normal practical operating conditions. They changed machines after one working day and were allowed to practice on the area that later was to be used for the time studies.

Operator No. 1 (Op. 1), 40 years of age, had 10 years of experience as a forwarding contractor with a Hemek forwarder. This machine has a three-lever control (two functions in each lever). He also had some experience with five- or six-lever controls in farm tractors, but had no earlier experience with two-lever controls like those in the studied forwarder.

Operator No. 2 (Op. 2), 60 years of age, used to drive an ÖSA 250 forwarder with two-lever controls. He has been driving different types of forwarding machines since forestry became mechanized in the 1950s. He had earlier experience with five- or six-lever controls from early types of forwarders (1960s-1970s), and farm-tractor mounted grapple-loader cranes in the 1950s. Op. 2 also had experience in farm-tractor driving, being a former farmer.

2. *Subjective feeling of "adaptation" by operators*

Op. 1 considered himself capable of driving all base machines without any problem. He also considered himself capable of mastering the five- or six-lever controls in the farm tractors, since they worked in a way similar to that of the levers in his own forwarder. He thought he could achieve a small, but negligible, increase in productivity on the farm-tractor equipage. He thought himself to be far from skilled to manoeuvre the two-lever controls in the forwarder, but he felt himself capable of increasing productivity significantly through practice.

Op. 2 considered himself capable of driving all base machines without any problem. He had some difficulties in simultaneously using all functions (trailer-power and brakes, trailer steering, etc.) on the large farm-tractor combination. "Normal" driving was, however, no problem. He considered himself most capable of mastering the two-lever controls, close to his own maximum capacity. Op. 2 also handled the crane manoeuvring rather well on the farm-tractor combinations. He nevertheless felt that it would be possible to increase productivity somewhat through further practice. It was easier for him to operate the smaller crane of the farm tractor than the larger crane.

3. *Comparison with predictions of a theoretical model*

The amounts of time consumption per volume for loading and unloading are affected by the relation between time and volume per loading cycle. When unloading, it is the operator's ambition to take full grapples, assuming that the technical capacity is sufficient. The grapple area should, therefore, be a very important factor at unloading. This relation between grapple area and productivity for unloading has been shown in several studies [13, 16, 17, and 19].

According to Gullberg [10], the technical possibilities regarding lifting force and hydraulic power to utilize the available grapple area are almost the same for the three machines that were compared.

An experimental control study of loading from a pile was made. The measured productivity was then compared with values predicted by a model assuming that productivity is proportional to the grapple area (Fig. 1).

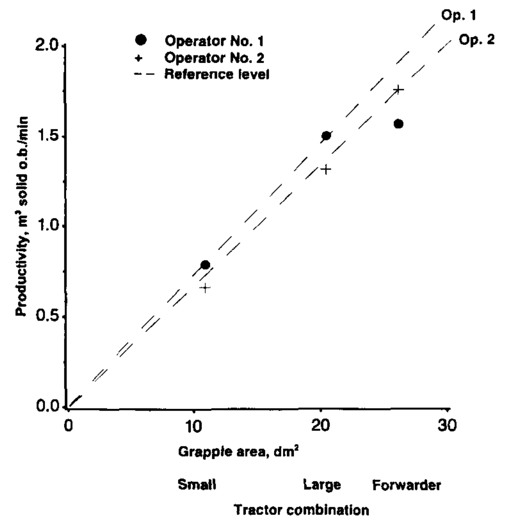

Figure 1. Productivity associated with standardized loading from a pile. The reference level "best adaptation," based on the hypothesis that productivity is proportional to grapple area, is marked for each operator.

Conclusion

Results of the control time study and analyses of the interview findings (i.e., the operators' previous experience and their feeling of "adaptation") were in relatively good agreement regarding "adaptation."

In this study the variable "Adaptation" was defined as a categorical variable with four possible values (0, 1, 2, 3), with figures proportional to the deviation from the reference level. The reference level was given the value 0 and the largest deviation from the reference level the value 3.

Based on the reference level, that is each operator's "best adaptation," the conclusion is that Op. 1 on both tractor combinations and Op. 2 on the forwarder can be set to the reference level (value 0). The largest deviation was found for Op. 1 on the forwarder (value 3). There was also a small deviation for Op. 2 on both tractor combinations (value 1).

It is likely that the degree to which "adaptation" affects a work-element will vary depending on its type. Loading in the stand requires more skill than unloading at roadside; thus practice should enhance loading efficiency more than it improves unloading efficiency. Nevertheless, it is assumed there is little difference in the relative impact of adaptation among the various work elements.

Variation in adaptation in this study is assumed to have been due mainly to the fact that the operators had practiced more with some control-lever types than with others.

RESULTS

Loading

Analysis of variance using SAS statistical package [5] showed that the introduction of the variable "Adaptation" almost totally explained the interaction effect (Table 1). The variable "Operator x Machine" was no longer significant in the model. However, in the case where the variable "Operator x Machine" had already been included, the variable "Adaptation" did not improve the degree of explanation. Thus, analysis of variance indicated that "Adaptation" did only have effect if entering the model before the variable "Operator x Machine" (type I), not if entered last (type III). The variable can be regarded as a part of the overall effect of the interaction between operator and machine. The remaining interaction effects are not significant.

Table 1. Analysis of variance (GLM, type III) in time consumption for loading (min/m^3 solid o.b.). Within brackets is also shown the type I test for "Adaptation." Type III: variables added last to the model. Type I: variables added to the model in the order listed.

Source	**df**			**Sum of squares**			**F-value and signific.**		
	without Adapt.		with Adapt.	without Adpat.		with Adapt.	without Adapt.		with Adapt.
Operator	---	1	---	0.86		1.50	30.9 ***		54.0 ***
Machine	---	2	---	4.48		7.22	80.9 ***		130.3 ***
Plot (strip-road section)	---	1	---	---	0.02	---	---	0.9 ns	---
Order (repetition)	---	2	---	---	1.00	---	---	18.1 ***	---
Operator × Plot	---	1	---	---	0.07	---	---	2.4 ns	---
Operator × Order	---	2	---	---	0.27	---	---	4.8 *	---
Machine × Plot	---	2	---	---	0.02	---	---	0.4 ns	---
Machine × Order	---	4	---	---	0.11	---	---	1.0 ns	---
Plot × Order	---	2	---	---	0.03	---	---	0.6 ns	---
(Adaptation [type I]			1			3.20			115.7 ***)
Rest of Operator × Machine when using Adaptation			1			0.03			0.9 ns
Operator × Machine when not using Adaptation	2			3.23			58.3 ***		
Residual variation	---	16	---	---	0.44	---			
Corrected total	---	35	---	---	10.54	---			

The effect of "Order" is judged to be caused mainly by the fact that operators learned how to load the actual piles efficiently. The more general effect of learning how to drive the machines is judged to be very limited during the relatively short study period.

For the model that only included the variables "Operator," "Machine," "Order," and "Operator x Machine," $R^2 = 0.9086$. When "Operator x Machine" was replaced by "Adaptation" the R^2 was reduced to 0.9063.

In an analysis of variance for single work-elements, the same type of result was obtained. Thus, in all cases where the variable "Operator x Machine" was significant, the variable "Adaptation" explained almost all of the interaction, if included.

Mean time consumption for the three types of equipage and the results of Student's T-tests comparing them are presented in Table 2. Comparisons were made of measured values as well as on estimates based on a model with the variables "Machine," "Operator," "Order," and "Adaptation."

Analyses were made using LSMEANS with the GLM procedure in the SAS statistical package [5].

The relations between machines obtained utilizing the model differed from those indicated by the observations. Furthermore, with the model, differences between machines did not have to be as large to be statistically significant owing to the lower amount of residual variation in the model.

Table 2. Comparison of time consumption for loading and pairwise test of differences between machines.

	Time consumption, min/m³ solid o.b.		
		Estimated expected value	
	Observed mean value	**Mean Operator Mean Order Mean Adaptation**	**Mean Operator Mean Order Adaptation = 0**
Forwarder	3.17	2.96	2.70
Large tractor combination	3.79	3.90	3.64
Small tractor combination	4.00	4.11	3.85
Relative time consumption compared with the forwarder (100%)			
Large tractor combination	119.6	131.8	134.8
Small tractor combination	126.2	138.9	142.6
Difference between machines (Student's T) P-value and level of significance			
Forwarder - large tractor	0.001 **	< 0.001 ***	< 0.001 ***
Forwarder - small tractor	< 0.001 ***	< 0.001 ***	< 0.001 ***
Large tractor - small tractor	0.242 ns	0.009 **	0.009 **

Unloading

The results of analysis of variance are presented in Table 3. The approach seemed to work in the same way as for loading.

A model with only the variables "Operator," "Machine," "Order," and "Operator x Machine" explained 99.379% of the variation. When "Operator x Machine" was replaced by "Adaptation," 99.377% of the variation was explained. The very low amount of unexplained variation indicates that unloading and loading from a pile are suitable types of work for use in control studies.

Table 3. Analysis of variance (GLM, type III) in time consumption for unloading (min/m^3 solid o.b.). Within brackets is also shown the type I test for "Adaptation". Type III: variables added last to the model. Type I: variables added to the model in the order listed.

Source	**df**			**Sum of squares**			**F-value and signific.**		
	without Adapt.		with Adapt.	without Adpat.		with Adapt.	without Adapt.		with Adapt.
Operator	---	1	---	0.01		0.03	9.9 ***		25.4 ***
Machine	---	2	---	2.61		2.56	1095.9 ***		1074.6 ***
Plot (logs from strip-road section)	---	1	---	---	0.00	---	---	1.8 ns	---
Order (repetition)	---	1	---	---	0.07	---	---	57.4 ***	---
Operator × Plot	---	1	---	---	0.00	---	---	0.2 ns	---
Operator × Order	---	1	---	---	0.00	---	---	0.4 ns	---
Machine × Plot	---	2	---	---	0.01	---	---	2.1 ns	---
Machine × Order	---	2	---	---	0.00	---	---	0.5 ns	---
Plot × Order	---	1	---	---	0.00	---	---	0.9 ns	---
(Adaptation [type I]			1			0.175			147.1***)
Rest of Operator × Machine when using Adaptation			1			0.00			0.0 ns
Operator × Machine when not using Adaptation	2			0.175			73.6 ***		
Residual variation	---	7	---	---	0.01	---			
Corrected total	---	21	---	---	3.14	---			

Comparison of machines (Table 4) also indicated that the approach worked in the same way as for loading. The larger difference between the machines, however, made it possible to statistically demonstrate all differences even without using the model.

Table 4. Comparison of time consumption for unloading and pairwise test of differences between machines.

	Time consumption, min/m³ solid o.b.		
		Estimated expected value	
	Observed mean value	**Mean Operator Mean Order Mean Adaptation**	**Mean Operator Mean Order Adaptation = 0**
Forwarder	0.89	0.83	0.75
Large tractor combination	1.12	1.13	1.05
Small tractor combination	1.75	1.78	1.70
Relative time consumption compared with the forwarder (100 %)			
Large tractor combination	126.0	136.0	141.0
Small tractor combination	197.0	214.0	228.0
Difference between machines (Student's T) P-value and level of significance			
Forwarder - large tractor	0.002 **	< 0.001 ***	< 0.001 ***
Forwarder - small tractor	< 0.001 ***	< 0.001 ***	< 0.001 ***
Large tractor - small tractor	< 0.001 ***	< 0.001 ***	< 0.001 ***

DISCUSSION

The approach used to analyse and correct for interaction effects between operator and machine seemed to work in the present study. Thus, it was possible to "sharpen" comparisons so that even small differences were statistically significant in some cases. Correction for the interaction effects (varying adaptation) offers new possibilities for making generalizations regarding relative differences between machines under actual loading conditions. The absolute productivity level is, on the other hand, only valid for the operators in the study.

The model has been validated to some extent for the conditions in the analysed study since the method was tested for both loading and unloading, as well as for the work-element level.

On a more general level, for various operators, machines, and conditions, the method is still hypothetic. More tests of the method are, therefore, desirable.

The fact that "Adaptation" explained the interaction effect cannot be automatically taken as a proof of having found the correct adaptation level. It is, however, a strong indication that the estimation of the variable "Adaptation" is reliable.

The objective of using a control study, previous experience, etc., was to provide as reliable and objective a basis as possible for making corrections. This most difficult part of the method can be further refined, and its design probably has to be tailored to the conditions in each study.

All three sources used to estimate the degree of adaptation in this study involve uncertainty. The good concordance, however, enhances the reliablility of the estimate.

The hypothesis that productivity is proportional to grapple area is very rough and incomplete. There are lots of other factors affecting productivity that vary between machines. In this case, however, the large differences in grapple area made the simple model meaningful. In other cases where differences in grapple area are smaller, differences in design between machines may have too much influence and thereby preclude this kind of control study. Other types of control studies or more detailed models would be necessary in such cases. For example, one could record variations in pressure in the hydraulic system [8] which may give information about a given operator's degrees of adaptation to various machines.

Control tests should be simple, as well as fast to make and evaluate. There is a risk for "self-generating evidence" in this type of control test. The theory or functions used can be said to be automatically proved. As a result, more sources should be utilized, to estimate the degree of adaptation, if there is any uncertainty concerning the theory.

It is hard to combine different measures of "adaptation" to obtain an overall estimate. In the examined study, with only a few operators and a manageable amount of material, it was decided to make it subjective.

In larger studies more formal measures and methods may be used. For example, one could use categorical classes for scoring previous experience and the subjective feeling of adaptation, and results from the control studies could be transformed to a continuous variable defined as the quotient between measured and hypothetical productivity. The weighting of "adaptation" variables can be done with the help of a statistical package.

What are the differences between this approach and traditional performance ratings (PR) [18]? PR aims at giving the absolute productivity level, whereas this method only aims at giving the relative productivity level in accordance with the principle of comparative time studies. The described method can only be used in comparative experimental time studies, whereas PR can be used in all kinds of time studies. Another difference is that corrections may differ between work elements in the present method but not in PR.

Despite the differences, one could say that the method described is a modified form of performance rating for use in comparative time studies.

In spite of the possibilities the approach seems to have to handle the interaction effects, the choice of operators is still important.

At a certain point a limit will be reached where the advantages of using the same operators on all machines are counterbalanced by too large differences in adaptation.

According to Harstela [12], the objective should be to minimize the effects of interaction by choosing operators with as equal degrees of adaptation to the studied machines or methods as possible. If this is not possible, an attempt should be made to ensure that there is at least one well-adapted operator per machine.

The approach presented in this article is the first example of trying to handle the interaction effects within the field of forest engineering. Similar types of methods have, however, been used in other areas of research, for example, in medicine and research on military pilots [4].

All kinds of normalization or corrections are connected with an introduction of new error sources and uncontrolled variation in the data material. Therefore, the total effect on the unexplained variation must be significant to justify the action.

ACKNOWLEDGEMENTS

I wish to thank Prof. O. Sallnäs, Dr. B. Persson, Ass. Prof. S. Holm, and two anonymous referees for valuable comments to the manuscript.

The work was financially supported by the Swedish research program "Non-industrial private forestry" (Ramprogram Privatskogsbruk).

REFERENCES

[1] Ahlgren, T., Brundin, L., Jonsson, B., Löfroth, C., Morenius, B. and Myhrman, D. 1982. Manöversystem för hydraulkranar. (Summary: Control systems for hydraulic loaders.) Logging Research Foundation, Stockholm, Sweden. Redogörelse nr 6/1982.

[2] Almqvist, G. 1945. Några synpunkter på tidsstudierna och deras användning inom skogsbruket. SDA, Stockholm, Sweden. Meddelande nr 18.

[3] Andersson, S. and Sprängare, B. 1967. Sortimentshuggning i Norrland. (Summary: Short-wood cutting in the north of Sweden.) Logging Research Foundation, Stockholm, Sweden. Report No. 14 .

[4] Angelborg-Thanderz, M. 1990. Prisvärd militär flygning med rimliga risker. (Englishsummary.) Handelshögskolan, Stockholm, Sweden.

[5] Anonymous. 1987. SAS/STAT Guide for Personal Computers. Version 6 Edition. SAS Institute Inc., Cary, N.C., USA.

[6] Appelroth, S.-E. 1983. Tidsbehovet vid manuell plantering av täckrotsplantor efter maskinell markberedning. (Summary: Time Required for Manual Planting of Containerized Nursery Stock after Mechanical Site Preparation.) Dissertation. University of Helsinki, Helsinki, Finland.

[7] Bergstrand, K.-G. 1985. Planering och analys av skogstekniska tidsstudier. (Summary: Planning and Analysis of Time Studies on Forest Technology.) Forest Operations Institute of Sweden, Stockholm, Sweden. Bulletin No. 17.

[8] Carlsson, M. and Frisk, T. 1992. Test av krandämpare på en liten vikarmskran. (Summary: Test of shock absorber in the hydraulic system on a small knuckle boom crane.) Swedish University of Agricultural Sciences, Dept. of Operational Efficiency, Garpenberg, Sweden. Research Notes No. 238.

[9] Gjedtjernet, A.M. Furuberg. 1989. Tømmertransport med traktor i norsk skogterreng. (Summary: Timber transport with Tractor in Norwegian Forest Terrain.) Agricultural University of Norway, Dept. of Forest Operations, Ås, Norway. Doctor Scientarium Theses 1989:11.

[10] Gullberg, T. Jämförande experimentella studier av lantbrukstraktor med griplastarvagn och liten skotare. (Summary: Comparative experimental studies of farm tractors with grapple-load trailers and a small forwarder.) Swedish University of Agricultural Sciences, Dept. of Operational Efficiency, Garpenberg, Sweden.

[11] Harstela, P. 1975. Työajan menekkiin ja työntekijän kourmittumiseen raikuttavat tekijät eräissä metsätyîmenetelmissä. (Summary: Factors affecting the consumption of working time and the strain on the worker in some forest work methods.) Metsätieteellisen tutkimuslaitoksen julkaisuja 87(2), pp. 1-30.

[12] Harstela, P. 1988. Principle of Comparative Time Studies in Mechanized Forest Work. Scand. J. For Res. 3:253-257.

[13] Lindén, P. 1962. Studier över barmarkskörning i terräng med traktor utrustad med Bimbo griplastare. SDA, Stockholm, Sweden. Redogörelse nr 2.

[14] Makkonen, O. 1954 . Metsätöiden vertailevan aikatutkimuksen periaate. (Summary: The principle of comparative time studies in forest work.) Acta For. Fenn. 61, 14.

[15] Mattsson Morn, L. 1953. The fundamental background of the Swedish job study technique in forestry according to the SDA. Proceedings of the 11th Congress of IUFRO, Rome, pp. 996-1002.

[16] Nordström, S. 1985. Griplastarvagnar -84. Studie av kranarbete m m. (Summary: Grapple boom log trailers -84. A study of loading boom equipped log trailers.) Swedish University of Agricultural Sciences, Dept. of Operational Efficiency, Garpenberg, Sweden. Research Notes No. 14.

[17] Pettersson, B. 1968. Terrängtransport av massaved med griplastarutrustad traktor. (Summary: Extraction of pulpwood by grapple equipped forwarder.) Logging Research Foundation, Stockholm, Sweden.

[18] Scott, A.H. 1973. Work measurement: Observed time to standard time. In: Wittering, W.O. 1973. Work Study in Forestry. Forestry Commission Bulletin No. 47, pp. 26-39.

[19] Sköldberg, B. 1963. Huggarbrossling och maskinell lastning av virke vid terrängkörning med traktor. SDA, Stockholm, Sweden. Redogörelse nr 2.

[20] Steinlin, H. 1955. Zur Methodik von Feldversuchen im Hauungsbetrieb. Mitt. Schw. Anst. forst. Versuchswesen. 31 Band, 2 Heft. Zürich.