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The Effect of Terrain on the Output in Forest Transportation of Timber

Maaston vaikutus puutavaran metsäkuljetustuotokseen

Rihko Haarlaa

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THE EFFECT OF TERRAIN ON THE OUTPUT IN FOREST TRANSPORTATION OF TIMBER

RIHKO HAARLAA

SELOSTE

MAASTON VAIKUTUS PUUTAVARAN METSÄKULJETUSTUOTOKSEEN

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PREFACE

The present study of relationships between the difficulty of forest terrain and timber transportation is a result of the Inter-Nordic activity in the field of forest engineering within the Forest Terrain Classification Project.

This series of studies at the Department of Logging and Utilization of Forest Products, University of Helsinki, was guided by Professor KALLE PUTKISTO. I wish to express my deep gratitude to him for advice and criticism during the many years which I have been studying this topic. I also want to thank the other personnel of the department, especially Professor BROR-ANTON GRANVIK and Mr. MATTI KÄRKKÄINEN (Lic. For.), for a beneficial cooperative effort. Dr. ERKKI H. OKSANEN, Associate Professor of Agricultural Engineering, also read the manuscript and made several valuable comments.

The gathering of data for this type of a study would not have been possible without the help of many persons and organizations from the field and other research institutes. Without repeating the names included in each preliminary publication, I will here express my thanks to Mr. MIKKO KAHALA (M. For.) from METSÄTEHO (Forest Work Studies Section of the Central Association of Finnish Forest Industries), who volunteered to gather, together with his own work, a part of the data required for this study. Mr. UNTO SILVENNOINEN (M. For.) from the State Board of Forestry arranged the tests on the mobility of forest tractors in deep snow and was the co-author of one of the earlier preliminary publications.

During the last phase of this study I received special help from Mrs. RIITTA MÄÄTTÄ, who translated my ideas to SIMULA-language for the computer simulation procedure. Miss HELME LINTANEN drew the graphs. Dr. KIM VON WEISSENBERG and his wife JOANN VON WEISSENBERG (M.A.) revised the English manuscript.

This series of studies has been supported (in addition to direct government financing) by grants received from the National Research Council for Agriculture and Forestry, the University of Helsinki, the Foundation of Technology, and the Niemi Foundation. The Society of Forestry has kindly accepted the study for publication in Acta Forestalia Fennica.

I wish to express my sincere thanks to the persons and institutions mentioned above.

Helsinki 1973

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1 INTRODUCTION

11 Outline of the Present Study

The first part of this publication is based largely on the following preliminary reports dealing with the separate factors affecting the output in forest transportation of timber:

A. HAARLAA, R. 1970. Puutavaran maastokuljetus traktorilla. Kustannuslaskentatekninen tarkastelu. Summary: Timber skidding by tractor. A study on calculation of costs. Department of Logging and Utilization of Forest Products. University of Helsinki. Research notes 7. 64 pp.

B. HAARLAA, R. 1971. Maaston ja kuorman vaikutus metsätraktoreiden ajonopeuteen. Summary: Effect of terrain and load on the driving speed of logging tractors. Department of Logging and Utilization of Forest Products. University of Helsinki. Research notes 9. 88 pp.

C. SILVENNOINEN, U. and HAARLAA, R. 1971. Metsätraktoreiden liikkuvuus lumessa. Summary: The mobility of logging tractors on snow. Silva Fenn. 5(2): 145–167.

D. HAARLAA, R. 1972 a. Lisättyjen konekomponenttien vaikutus metsätraktoreiden maastokelpoisuuteen. Summary: Effect of additional machine components on the mobility of forest tractors. Department of Logging and Utilization of Forest Products. University of Helsinki. Research notes 15. 35 pp.

E. HAARLAA, R. 1972 b. Kuormatraktorin ajomatka puutavaran metsäkuljetuksessa. Summary: Driving distance of forwarders in forest transportation of timber. Department of Logging and Utilization of Forest Products. University of Helsinki. Research notes 16. 36 pp.

These publications are referred to by capital letters in the text.

In the second part of the present publication the results from the analysis of the joint effect of these separate output components are presented. Finally, as a synthesis of the whole research project, the concluding remarks are made.

12 Factors Affecting Costs in Forest Transportation of Timber

The harvesting of wood raw material in the forest and transporting it to the place of use forms a multi-phased series of operations. The objective of increasing the efficiency in logging is, first of all, to prevent a rise in harvesting costs, which have a central influence in determining the price of forest industry products and in securing their position on international markets. Since during the last years, the costs for mechanized work have gone up more slowly than those of manual labour, the level of mechanization in transportation of timber has risen, a situation which will be discussed in this study.

The structure, the methods of calculation and the factors affecting costs in mechanized timber transportation have been discussed first in publication A. In this connection only some of that background information is repeated by especially stressing the central position of the output as a factor regulating the costs in forest transportation of timber.

In the literature review of publication A (p. 1–3) it may be observed that several different units of measure have been and are still used. In some countries the transport output is measured using metric units and in others by inch-based measurements. It is thus a very laborious and uncertain task to compare these cost figures which have been presented in the literature. The objective is to identify the transportation costs as a function of distance in the currency of each country calculated per cubic unit, from stump to the roadside of the hauling route, e.g. in terms of Fmk/cu.m.

The calculation of timber transportation costs is always a task in two steps (A, p. 3). First, one has to determine the time-unit cost in the use of the vehicle (Fmk/h), and after that, the work result i.e. the transport output during the same time unit (cu.m/h). Subsequently, the timber transportation cost is the ratio of these two figures, having in this case the unit Fmk/cu.m. By using the input-output terms, it follows:

$$\frac{\boxed{\text{Manpower input}}}{\boxed{\text{Machine input}}} \quad \boxed{\text{Transport output}}$$

from which, after fixing the price, follows:

$$\frac{\boxed{\text{The price of manpower input}}}{\boxed{\text{The price of machine input}}} \quad \boxed{\text{Transportation cost}}$$

The time-unit cost for a transportation vehicle can be determined using the common machine cost calculation technique (i.e. STAAF et al. 1966). According to their nature, the cost elements are divided into fixed and variable ones (A, p. 3). The capital costs are derived both from the tractor and its additional machine components (anti-skid devices, etc.), tax, insurance and other costs, which are not dependent on the amount of use of the vehicle but are fixed costs. For example, fuel, maintenance (lubrication, spare parts, repairs, service), salary and other costs dependent on the amount of use of the machine are variable costs. Also, the moving cost from one working place to another is usually regarded as a variable cost. The price of manpower input is included in the costs of salary, reparation and service. Because of the ever-rising social costs, these have a steeper trend than the other machine costs.

In general, there are more factors regulating the time-unit costs than those dependent on the working environment factors. It is a rather complicated task to determine whether there are significantly higher repair or service costs, e.g. on working areas with a terrain difficulty worse than the average. Due to the lack of sufficient and detailed statistics on this matter, one must consider first the variation observed in transport output when investigating the effect of terrain factors on timber transportation.

It is possible to analyze the variation in transport output within the entire lifetime of a machine or only within a limited time period, while performing a single operation. In respect to the length of the work period VÄISÄNEN (1967) has considered that the output is not equal during the first, last and intermediate days in a logging area. The planning of the work, organizing the service, the preparations, and finishing of the job in the middle of the day cause some loss in transport output. According to VÄISÄNEN, the loss in 1967 was 0.80 . . . 1.08 Fmk/cu.m. in an operation of 50 cu.m and 0.06. . .0.08 Fmk/cu.m in that of 700 cu.m depending on the type of tractor. Otherwise, the size of the logging area has only a minor effect on the output, e.g. because of the proportion of unfilled loads.

In principle the determination of the output in forest transportation of timber is based on measuring the time which is required to bring a typical tractor-load from the forest to a landing on the roadside (A, p. 31). This so-called cycle time includes the times for driving empty, driving during loading and driving loaded, as well as the times for terminal work such as loading and unloading. In some cases there also may be some driving during unloading due to the necessity for sorting. Its proportion of the cycle time is, however, always small due to the very short distances involved. Because the difficulty of terrain has no direct influence on it, the separate driving during unloading has been excluded from these studies.

The time consumption during driving depends on the speed and the distance. With slower speeds, longer distances, and smaller load size the transport output is admittedly lower. If the proportion of driving during the cycle becomes small, the proportion of loading and unloading times is increased and the factors regulating the terminal works have, in such a case, a decisive effect on the output in forest transportation of timber.

On the basis of the foregoing, it is possible to divide the factors regulating the output in timber transportation into four groups:

1. Factors connected with the driving speed of the tractors
2. Factors regulating the size of a tractor load
3. Factors determining the driving distance
4. Factors connected with terminal activities.

13 Literature Review

One of the most central tasks within logging engineering research is to correctly define the output in timber transportation. That is why research results and articles on this topic have been published in such an abundance in many different publications. Especially because of the continuous importance of this question, it is not possible to present here a complete list of publications.

In the five preliminary reports (p. 5) some literature dealing with each output component has been cited. These reviews are not repeated here, but the references are included in the reference list of this publication with a note referring to the preliminary report in question.

Publications on mechanized forest transportation published before the year 1956 have been summarized by PUTKISTO (1956 b). The present literature review is limited to publications from the latter part of the 1960's to the present time since the machinery used earlier is no longer in use. In addition, the review is limited mainly to the Nordic and North American publications, although the topic has also been dealt with in other countries, e.g. the Federal Republic of Germany by KNELL (1967) and by LOYCKE (1970), in Switzerland by PFEIFFER (1970), in England by PETROV (1964) and by BARRACLOUGH (1967), in Peru by CHRISTIANSEN (1967), in India by ASTHANA and THAPLIYAL (1971), in Yugoslavia by AKIMOVSKI and TADOROVSKI (1968), in Bulgaria by VASILEV and MARINOV (1969), in Czechoslovakia by KERN (1967), in the Democratic Republic of Germany by MATTHES (1970), in Holland by SCHAAFSMA (1970), in the USSR by GARUZOV (1965) and by MURAŠKIN and GORYŠIN (1971). Some Japanese publications will be cited later. The reason for this limitation of the literature review is that the construction of the machines and the operating conditions in many countries differ so entirely from those of this study that no comparison between the results is possible.

Most North American studies on the output in forest transportation of timber deal with skidding (e.g. BARTHOLOMEW et al. 1965, JOHNSON 1965, LUCAS 1965, SILVERSIDES 1966). In Norway the skidding of tree-lengths has been studied both as farm-tractor (STRØMNES 1965) and forest-tractor transportation (ARVENSEN 1970). From the earlier Swedish terraintransportation studies the output table presented by JACOBSON (1965) and later, the method study on forwarding by ELD (1970) may be mentioned. In addition to the previously mentioned study by PUTKISTO (1956 b), the most detailed reports from the Finnish forest-transport output studies are those on skidding of tree-lengths and trees by KAHALA and RANTAPUU (1968), the study on forwarding by KAHALA and RANTAPUU (1970), and the study providing basic information for fixing the contract rates in forwarding by KAHALA (1972).

The effect of transportation planning on the output has been treated by, i.a. PUTKISTO (1963), GARDNER (1966) and NEWNHAM (1972). In particular, the effect of the transportation method on the output has been studied by, i.a. BYGREN and PETTERSON (1967), GARDNER (1968), BYGREN and LINDBERG (1969), TENHOLA (1969, 1971), HAAJA (1971) and HAAJA and KOSKINEN (1971). Data on the use of a certain tractor or results from a comparison of several tractors have been published, in addition to those mentioned in the preliminary reports, i.a. by HAKKARAINEN and KAHALA (1965), SILVENNOINEN (1966 c), SILANDER (1966 a, 1966 b), MELVASALO (1967), KOJIMA et al. (1967), HAAPAMÄKI and HAATAJA (1969), SALMINEN (1969), ANON. (1970) and BJAANES (1970).

The measuring of factors affecting output in forest transportation of timber by using a regression analysis has been described earlier, i.a. by the Japanese Kojima (1961, 1963), the Canadians Bennett et al. (1965), and by Harvey and Corcoran (1967) in the USA. Control of the output and transport costs and the interaction between them have been studied, i.a. by Donelly (1962), Berlyn and Keen (1964), Sievert (1966), Bennett and Winer (1967), Nikunen (1968), Samset (1969), Väisänen (1970), Rysä (1971) and Partanen (1971). Output and cost statistics from Finnish logging areas have been published by Silander (1965) and Säteri (1971, 1972 a, 1972 b, 1972 c).

Comments on the interaction between terrain and output in forest transportation of timber can be found in some articles included in the proceedings of a Iufro[1]) meeting (Anon. 1964). The results from the Inter-Nordic Forest Terrain Classification Project and the last investigations on this topic are presented in the final report of that project (Haarlaa and Asserståhl 1972) and in the references of its publications. Relations between terrain classification and terrain transportation from the military point of view have been discussed by Parry et al. (1968). A method for predicting the transportation output of a terrain vehicle on the basis of terrain classes was presented by Söderlund (1971).

From the long list of publications it is evident that to be able to find an answer to some special, detailed question on transport output on the basis of a literature survey, one must define the question very accurately in advance. Only after that, can the question finally be formulated using the necessary key-words and an answer (e.g. from data in the computer memory bank or from a reference) be obtained.

On the basis of the earlier studies it was not possible to solve sufficiently the question of the effect of terrain on the output in forest transportation of timber.

[1]) International Union of Forestry Research Organizations.

14 The Objective of the Study and its Limitations

The objective of this study was to analyze factors affecting the output in forest transportation of timber both theoretically and using empirical data.

From the many regulating output factors only those were chosen for closer investigation which were dependent, or at least seemed to be dependent, on the difficulty factors of forest terrain. These were 1. the driving speed of the tractors, 2. the size of one load and 3. the driving distance needed.[2]) The terminal activities, like loading and unloading, have not been analyzed more closely because the difficulty of terrain does not have an obvious effect on them. On the other hand, much data is available on these work phases on the basis of the earlier studies (e.g. Eld 1970, Kahala and Rantapuu 1970, and Kahala 1972).

Mathematical models for main factors affecting transport output were developed first. In this respect the results from the earlier preliminary reports dealing with separate output components are summarized. The joint effect of those factors was then combined and models for the output in forest transportation of timber were developed.

The study program was designed to gather the information necessary for a terrain classification. Since the objective of a terrain classification is to indicate the differences in working conditions, there are reasons to use the transport output as a basis for a forest terrain classification.

[2]) The internationally adopted method for measuring speed is to use the distance being traveled during a specific time unit, e.g. m/s, km/h. Because the calculations for transport output specifically assume the determination of the cycle time, the calculations in this project are based on time consumption per unit distance (min/100 m) to avoid mistakes and keep the calculations simple. The time consumption figure can be converted to the standard unit (m/s) by dividing the constant $100/60 = 5/3$ by the presented figure.

2 MATERIALS AND METHODS

21 Collecting of Data

211 Driving-Speed Tests for Predicting the Variation in Transport Output

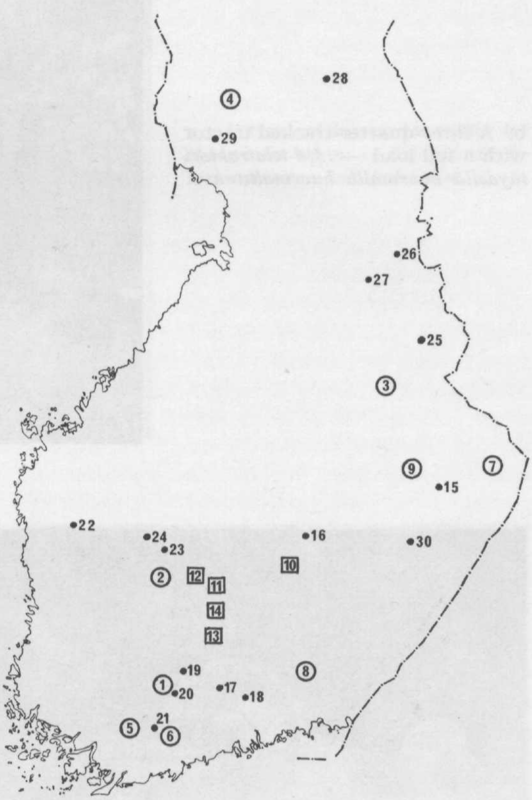
In performing a forestry job, it is characteristic that the work very seldom is carried out using the same work methods, equal skill and the same kind of tools in corresponding conditions. The difference between a forestry and a regular industrial job is thus very great. There are many factors affecting a forestry job; variation within each factor is large, non-homogenous and, in addition, many factors are changing with time (e.g. PUTKISTO 1956 b). Consequently, the scope of this study is very heterogenous. These special features have to be taken into account already when choosing the research methods.

The artificial standardization of as many factors as possible is a common method in research where independent variables are affecting the dependent variable. In principle this was the method followed in the tests designed for measuring the driving speed of tractors in terrain. These tests formed the first main phase of this investigation. To identify the factors affecting driving speed and the size of load, comparable routes marked in varying terrain were driven using tractors and loads of different size and form. The times measured at homogenous intervals of the driving route formed the observations used in the comparative calculations.

The details in organizing the test drives have been explained in the preliminary reports (B, p. 10–18; C, p. 147–155; D, p. 3–8) and are not repeated here. The locations of the test areas are indicated on Map 1. The basic tests on the driving speed were carried out at locations 1 to 3. Their control tests were at locations 5 and 6. Location 4 was used for mobility tests on snow. Locations 7 to 9 were for studying the effect of additional machine components. Location 10 includes seven logging areas where data on the driving distance were collected. Correspondingly, the locations from 11 to 14 are logging areas for the same purpose, but they deal with another tractor. In locations 15 to 30 data on the driving speeds during the work were collected from real logging conditions.

At these locations the choice of test areas and tractors with respect to factors affecting that choice have been discussed in the corresponding preliminary reports (B, p. 12–15;

Map. 1. Location of test areas. — *Koealueiden sijainti.*



Expl. — *Selitys*

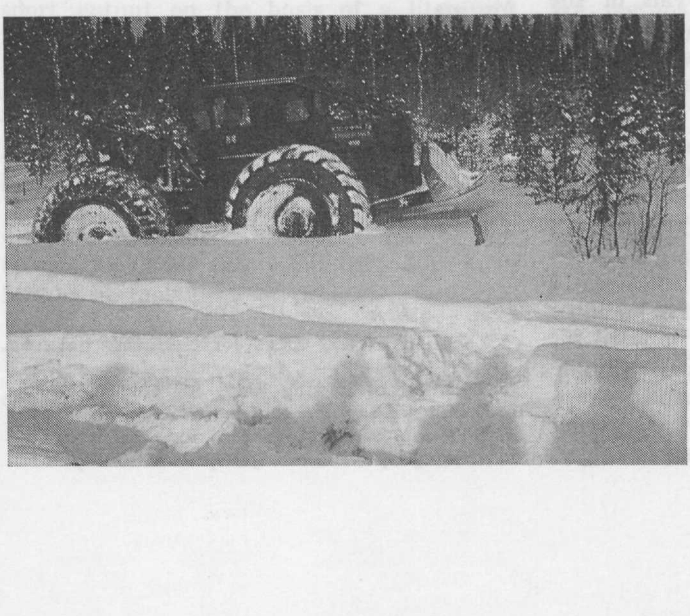
○ Location of test areas for collecting data on driving speeds. — *Ajonopeuskoealueet.*

□ Location of logging areas for collecting data on driving distances. — *Ajomatkatutkimustyömaat.*

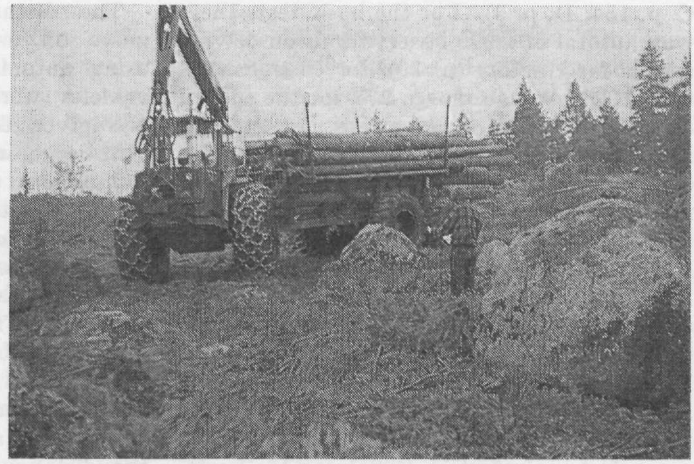
• Location of logging areas for collecting data on driving speeds. — *Ajonopeustutkimustyömaat.*

a. A half-tracked tractor with a half load in a winter test. — *Puolitelatraktori puolella kuormalla kuormattuna talvikokeissa.*

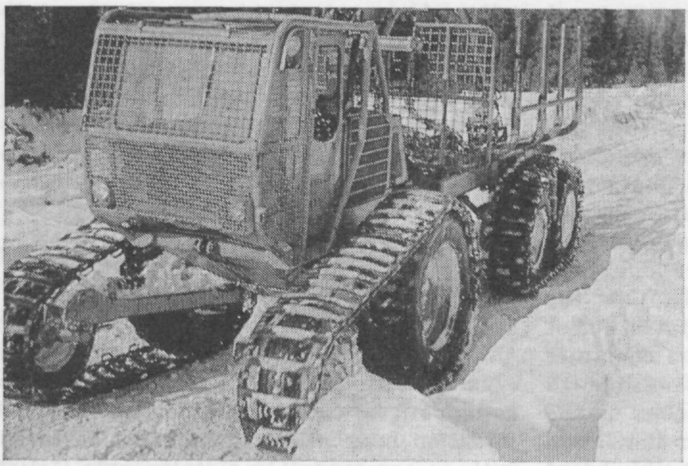
b. A three-quarter-tracked tractor with a full load — *3/4-telatraktori täydellä kuormalla kuormattuna.*



c. A skidder driving empty on untouched snow. — *Laahuspyörätraktori tyhjänäajossa umpilumessa.*



d. A half-loaded forwarder in a spring test. — *Kuormapyörätraktori puolella kuormalla kuormattuna kevätkokeissa.*



e. A tracked forwarder ready for the winter tests. — *Telapyörätraktori valmiina talvikokeisiin.*

f. Another tracked forwarder with a sled in the winter tests. — *Toinen telapyörätraktori rekineen talvikokeissa.*

All photographs were taken by the author. — *Kuvat kirjoittajan ottamia.*

C, p. 154; D, p. 3). For the basic tests there was a total of 1 975 observations on driving speeds for tractors (p. 20), for their control tests 192 observations (p. 27), for the special snow tests 1 218 observations (p. 21), for measuring the effect of additional machine components 463 observations (D); and the number of speed observations from logging areas was 721 (p. 42).

The purpose of the test drives was to find out how the driving speed of forest tractors varied on passable terrain routes when using loads of different size. The hypothesis in the study was that the driving speed indicates the difficulty level of the terrain. By analyzing the significance of the separate terrain factors explaining the variation in driving speed, information was found which is useful in designing a terrain classification in a case where the output in forest transportation of timber is used as a final criterion.

It was uncertain whether the results from the test conditions were enough for drawing generally acceptable conclusions about the problem. Therefore, data was also collected on the variation in driving speeds of tractors under real logging conditions. Not until these observations were combined together with the data on the other factors affecting the output in forest transportation timber by using a computer simulation technique, was it possible to analyze the effect of separate factors on the transport output. The computer simulation formed the s e c o n d m a i n p h a s e of this investigation.

212 Empirical Observations on the Driving Speeds and Distances

The objective of the empirical data collected from logging areas was, in addition, to check the validity of the results from test conditions and to provide the necessary data for the computer simulation phase (Appendix 2, p. 43). The driving routes on the logging areas were divided into homogenous parts like the test lines. Many terrain and other environmental factors were thus simultaneously affecting the speed observations. The quantity of data per tractor is presented in Appendix 1 (p. 42).

The distances which tractors have to move on a logging area were measured using automatic recorders. Since the test vehicles were tracked ones, no attention was given to the slippage. The rotations of the tractors braking axle were transformed to distance units, which were tallied both into a digital recorder and onto a wax-covered disc. (The relationship between the rotations of the braking axle and the tractor's rear axle is always practically constant). The distance driven could be divided into driving empty, driving during loading and driving loaded, based on the working time of the engine and the driving speed. By analyzing the factors affecting the distance driven on a logging area the significance of the terrain factors on its length was evaluated. The details in collecting and processing this part of the data were presented in the corresponding preliminary report (E, p. 9—11). The observations on the driving distance were made during 217 days of harvesting timber on 17 logging areas.

22 Data Processing

221 Determination of the Driving Speed, the Size of Load, and the Length of Driving Distance

In the tests the time it took for a tractor to move from the starting point of the observation interval to its end was measured with an accuracy of one centiminute (1/100 min). In order to simplify the calculations and to avoid the harmonic means, the driving speed is given in this study report as the time consumption per 100 meters (min/100 m, cf. p. 8). The unit times always were used in this form when the mean values were given according to the season, tractor type, terrain factor etc. (cf. B, p. 22—41). The same speed unit was used as a dependent variable when developing the regression models for the driving speed of tractors.

The size of the load was measured in the tests for timber assortments as technical wood measures, which were converted to solid cubic meters on the basis of coefficients published in handbooks. Whole trees were measured directly in solid volume according to the tables for standing trees. The loads of different tree species were given the same dimension after the solid cubic volumes were converted to weights by using average density coefficients. The level of loading the tractor was indicated as a percentage of the normal full load. A normal full tractor load included, in this case, fresh softwood timber of design length in such an amount that the whole load space reserved for timber was utilized. The changes in the driving properties of the tractors due to the form of the load or the differences in the load space were not taken into account during the study, except in special cases (D, p. 21–24).

The most detailed observations dealt with the parts of a cycle distance. On the basis of the total daily distances (so-called day-distances) it was possible to calculate the total distance for a logging area (so-called logging area-distance). This was the only parameter of driving distances which provided data for studying the variation of the driving distance in relation to the terrain difficulty data.

222 Design of the Prediction Models

One of the objectives in this project was to develop mathematical prediction models for the driving speed, the size of load, the driving distance of tractors, and finally, to design a prediction model for their joint effect, that is a model for the output in forest transportation of timber.

Regression analysis (i.a. Draper and Smith 1968) was chosen as a basic data processing method. There is a feasible computer application of it in the program library (Hylps) at the Computing Centre of the University of Helsinki. In programming one has to identify, in addition to the dependent variable, at least one compulsory independent variable and a desired number of other independent variables. The program always adds to the regression equation that variable which most increases the multiple correlation coefficient (R^2). In addition to the regression coefficients, the program prints some test values, e.g. on the value of each variable explaining the variation.

223 Computer Simulation of the Output Data in Forest Transportation

Some basic computer simulation techniques and their present applications to timber harvesting were recently reviewed by Rogers (1972). It is necessary to rely on computer simulation, e.g. in those cases where the formulation of a mathematical function has proven to be difficult because of the indefinite nature of the phenomenon or, in general, because of a large random variation. Also, the lack of empirical data may force one to use computer simulation, if collection of a large and homogenous set of empirical data becomes too expensive.

In the Finnish forest technological literature the computer simulation technique has been described earlier by Väisänen (1966) and Seppälä (1971). The leading idea in the simulation is to operate with probability numbers instead of real figures. The data on each factor are based on field observations, however. The forest transportation of timber can be illustrated with the following flow chart, which is well-suited to a basic simulation model.

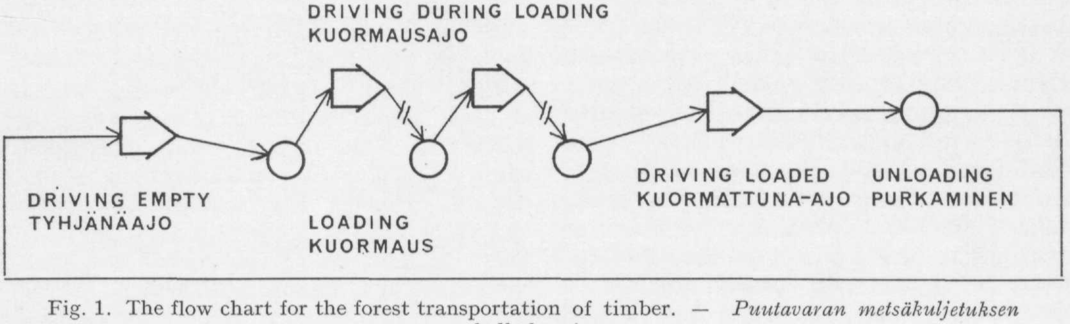


Fig. 1. The flow chart for the forest transportation of timber. — *Puutavaran metsäkuljetuksen kulkukaavio.*

The activity consists of cycles (cf. p. 6), where the first phase is driving empty from the landing to the starting point of loading. The time measured for this phase is the result of multiplying the driving distance (100 m) by the speed for driving empty (min/100 m). The time for the loading operation is the size of load (cu. m) multiplied by the speed in loading (min/cu. m). The time for driving between the loading points is, correspondingly, the distance multiplied by the speed of driving during loading; likewise, the time measured for driving loaded is the distance multiplied by the speed in driving loaded. The unloading time is the size of load multiplied by the unloading speed. The cycle time is the sum of all these subtimes.

The output in forest transportation of timber can be determined from the following equation:

$$\text{Transport output (cu. m/h)} = \frac{\text{Effective time (min/h)}}{\text{Cycle time (min)}} \times \text{Size of load (cu. m)}$$

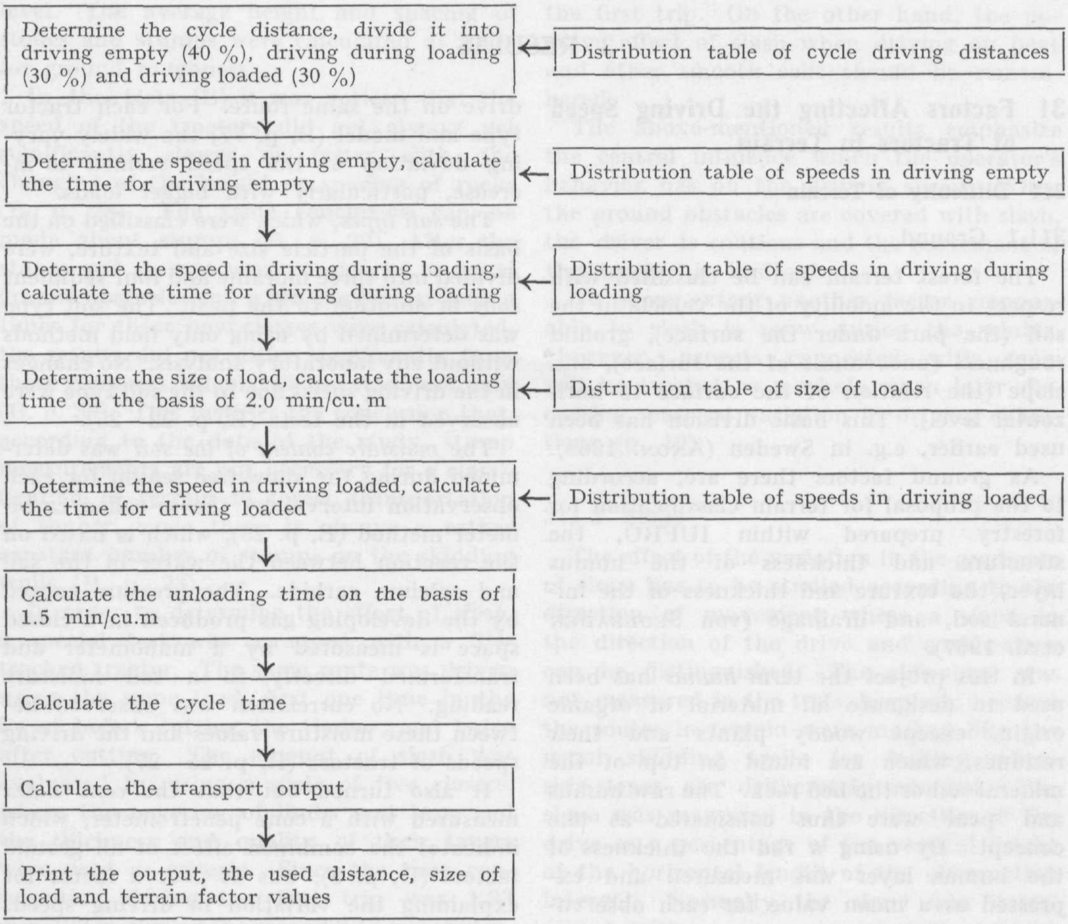
In order to simplify the calculations, the proportion of the effective time can be held constant at 45 min/h; and for loading and unloading the fixed rounded speeds of 2.0 min/cu.m and 1.5 min/cu.m can be used (Kahala 1972). This simplification excludes most of the effect of the timber assortment on the output in timber transportation. Only the effect due to the quality of timber remains, and this is tied to the size of the load. Also, the internal ratio of the driving distances during the cycle can be kept as 4: 3: 3 (E, p. 17). The distance in driving empty is longer than in the other two phases, because the operator more likely wants to drive the longer distances with an empty than with a loaded tractor. Thus, he wants, at least at the end of the driving during loading, to drive towards the landing.

A simulation flow chart designed on the basis of the foregoing principles is presented in Figure 2 (p. 15). According to the chart, there are as basic values for the process three tables on frequencies of driving speeds, one table for the distribution of the size of loads and one table for the distribution of the cycle driving distances. All of these frequencies are based on data from real operating conditions. Thus, the results and a new set of data calculated on the basis of this are comparable to direct observations in the field. These calculated figures can also be processed further, e.g. by using a regression analysis.

The simulation procedure was carried out using the UNIVAC 1108 computer. The SIMULA-language was applied especially because of the form of the output, which should be readily readable by the computer for further processing.[1] A data set of 3 000 loads was considered to be adequate for studying the output in forest transportation of timber.

[1] The essentials of the program can be seen at the Department of Logging and Utilization of Forest Products, University of Helsinki.

Fig. 2. Flow chart for simulating the output in forest transportation of timber. — *Puutavaran metsäkuljetustuotoksen simulointikaavio.*



3 RESULTS

31 Factors Affecting the Driving Speed of Tractors in Terrain

311 Difficulty of Terrain

311.1 Ground

The forest terrain can be classified with respect to the mobility of the vehicle in the soil (the part under the surface), ground roughness (unevenness of the surface), and slope (the relation of the surface to horizontal level). This basic division has been used earlier, e.g. in Sweden (ANON. 1969).

As ground factors there are, according to the proposal for terrain classification for forestry prepared within IUFRO, the structure and thickness of the humus layer, the texture and thickness of the mineral soil, and drainage (von SEGEBADEN et al. 1967).

In this project the term *humus* has been used to designate all material of organic origin, except woody plants and their residues, which are found on top of the mineral soil or the bed rock. The raw humus and peat were thus considered as one concept. By using a rod the thickness of the humus layer was measured and expressed as a mean value for each observation interval.

No significant correlation between the driving speed of any tractor type (p. 19) and the thickness of the humus layer was observed, even when observations were made while driving on one meter thick humus layers (B, p. 21—23). The result is to some extent surprising, because one would expect a slower speed after the wheel or the track sinks deeper into the ground. The deeper sinking of wheeled vehicles due to the higher ground pressure was noticed in the tests especially when the size of the load was increasing. The increase in driving speed due to the use of the same driving route a second time was greater than the slowing due to the deeper sinking into the ground. In this respect the maximum speeds were usually reached during the second drive on the same route. For each tractor type and model (B, p. 77) the widely varying deviation of the speed seemed to increase, particularly with bigger loads.

The *soil types*, which were classified on the basis of the particle size and texture, were divided into three moraine and four sediment soils in addition to the peat. The soil type was determined by using only field methods without any laboratory analysis. No changes in the driving speed due to the soil type were observed in the tests (B, p. 23—25).

The *moisture content of the soil* was determined during the snow-free season for each observation interval by the so-called carbimeter method (B, p. 25), which is based on the reaction between the water in the soil and calcium carbide. The pressure caused by the developing gas produced in a closed space is measured by a manometer and transformed directly to a soil moisture reading. No correlation was observed between these moisture values and the driving speeds of tractors (B, p. 25—27).

It also turned out that the *cone index* measured with a cone penetrometer, which indicates the combined effect of all ground factors (D, p. 8), was as poor a factor for explaining the variation in driving speeds as were the separate ground factors (D, p. 21). Briefly, it may be concluded that the ground factors do not have any significant effect on the driving speed of tractors on *passable* terrain routes.

311.2 Ground Roughness

In forests ground roughness during the snow-free season usually is caused by stones, stumps, slash, pits or hummocks which, in fact, often contain a stone, stump or fallen tree. Due to their nature, the stones cause a permanent unevenness of the ground surface, whereas the stumps and other factors of organic origin are changing with time. In determining the ground roughness the height and number of *stones* and *stumps* were measured on each observation interval in height classes of 5 cm. The lowest obstacle tallied was 6 cm and the highest was 70 cm above the surrounding average ground level. The average height and spacing of stones and stumps were calculated as units for ground roughness.

In the tests (B) it was noticed that the speed of the tractors did not always get significantly slower or faster with the changing of the height or spacing of rocks (B, p. 28). The same conclusion can be made about stumps (B, p. 29). After the stones and stumps were considered as equal ground obstacles and when the corresponding times for those new classes were calculated, the results did not differ significantly from those numbers calculated for stoniness only (B, p. 30). This justifies the conclusion that, according to the data of the study, stump measurements are not necessary for a classification of terrain in forest transportation of timber, since there is always a rather constant number of stumps on the skidding trails (B, p. 23).

In order to determine the effect of *slash*, a special test was arranged with a 3/4-tracked tractor. The same route was driven using the same load, first one time in the forest before cutting the timber, and twice after cutting. The amount of slash was evaluated by using a scale of five classes, where the covering of limbs and tops and the thickness and quality of their layers were used as criteria. Since the time consumption during the first trip was 1.93 min/100 m, during the second 2.13 min/100 m, and during the third 2.01 min/100 m, with a t-test it was possible to verify that an increase in the amount of logging slash between the first and the second trip made the drive very significantly ($t = 4.71^{***}$)[1]) slower during the second drive (B, p. 30—32). On the contrary, between the second and third or the first and third trips there were no significant differences ($t = 0.94$ and $t = -0.55$). The reasons for this result, according to which the effect of slash exists only during the first trip, is the fact that the tractor presses the slash down during the first trip. On the other hand, the positive effect of slash when driving on peat and other smooth soils should be remembered.

The above-mentioned results emphasize the central influence which the operator's behavior has on the driving speed. When the ground obstacles are covered with slash, the driver is cautious and the movement of the tractor is hesitant.

To some extent another factor comparable to slash is snow during the winter. However, aspects connected with snow will be treated as a whole when later discussing seasonal variation in driving conditions (p. 19).

311.3 Slope

The effect of the variation in the gradients of slope has to be studied according to the direction of movement where a slope in the direction of the drive and a side-slope can be distinguished. The side-slope was not measured in the tests, however, because the routes in terrain were marked like the usual skidding trails for logging where side-slopes are deliberately avoided. The slope was measured in the direction of the drive as a percentage of the vertical height of the horizontal length of the observation interval. Normally the slope was determined with an accuracy of 1 % using a SUUNTO clinometer. Only some determinations were checked with an engineer's level and rod.

As a result of the test drives, a steady increase was noticed in the driving speed when moving from a too steep up-hill slope to a gentle down-hill slope (B, p. 35—37 and p. 84—85). With an ever steeper down-hill slope the drive became slower again. The changes were relatively small, however, which also is indicated by the rather small correlation coefficient ($r = 0.16$) between the slope and the time consumption figures. This can be explained mainly by the fact that the amount of horsepower is no longer a limiting factor in the present-day tractors even when driving loaded. Now there are a large

[1]) * = Hypotheses H_0 discarded with a risk level of 5 %

** = Hypotheses H_0 discarded with a risk level of 1 %

*** = Hypotheses H_0 discarded with a risk level of 0.1 %

number of gears or speed areas available in the transmission of the tractor. After making a suitable choice of gear, the driving speed of a tractor is mostly regulated (in addition to a dependence on the tractor type and model) through the limitations set by the comfort of the operator, keeping the logs in the load space, or the risk of breaking the machine.

312 Season

Slope is the only terrain factor on which the season does not have any appreciable effect. The season alters one ground factor especially, namely the moisture of the soil. During the winter the surface of the ground is covered by snow. Consequently, the disadvantages of ground roughness vary according to the depth and quality of the snow layer.

The amount of free water in the ground is highest in spring when the snow is melting. If frost still remains in the deeper ground layers, water cannot sink into the ground; and the top layers stay saturated with water. A case like this can also exist during the summer after abundant rainfall on impermeable soil. The amount of free water in the ground is lowest during the winter when the ground is frozen. Frozen soil bears a heavy load very well. Even wet and frozen peat bears the loads occurring in timber transportation. Therefore, in the winter the thickness of the humus layer has no real importance. Consequently, during the winter it is more important to know the moisture content of the soil than the soil type. If the moisture content of the soil at the moment of freezing is low, a cohesion soil may stay fragile and crumble under loading.

The average time consumption for driving in the homogenous conditions of the tests (B) was 2.38 min/100 m during the winter, 1.61 min/100 m during the spring, and 1.75 min/100 m during the summer (B, p. 38—40). From the winter there were 601, from the spring 447, and from the summer 927 observations (cf. Fig. 3). The time consumption for driving during the winter was very significantly greater than during the spring (t = 11.72***) or

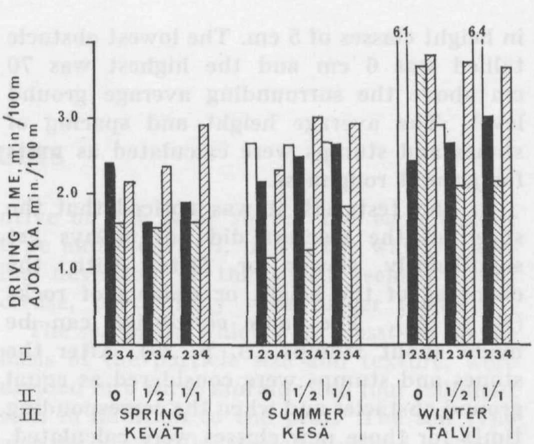


Fig. 3. The average time consumption for driving during different seasons. — *Keskimääräiset ajoajanmenekit vuodenajoittain*

Explanation: — *Selitys*

I Tractor type: 1 = 1/2-tracked tractors, 2 = 3/4-tracked tractors 3 = Skidders, 4 = Forwarders II Level of loading: 0 = Empty, 1/2 = Half a load, 1/1 = Fully loaded, III Season. — *I Traktorityyppi: 1 = Puolitelatraktorit, 2 = 3/4-telatraktorit, 3 = Laahuspyörätraktorit, 4 = Kuormapyörätraktorit, II Kuormausaste: 0 = Tyhjä, 1/2 = Puoli kuorma, 1/1 = Täysi kuorma, III Vuodenaika*

summer (t = 9.59***). Also, the difference between the times of the spring and the summer is significant (t = 3.29**). The reason for the higher speed in spring than in summer is obviously related to the condition of the test route. During the spring the route was already familiar to the operator, and there were no deep and troublesome spurs on the route as there were sometimes during the summer. It may also be noticed that the deviations (standard errors) in the time figures indicate that the driving was essentially more irregular in the winter (s = 1.16) than during the spring (s = 0.90) or summer (s = 0.91). This again may be a result of the properties of the ground contact conditions which, because of snow, are during the winter more slippery than during the snow-free season. Consequently, there existed more temporary short breaks in the movement than in conditions without snow.

In the tests (B) it was observed that all the other terrain factors, except the slope, lose their central influence when driving on snow. Therefore, the examination of environmental factors in winter deals mainly with slope, thickness and quality of the snow. A 60 cm deep snow layer made the drive of the tracked vehicles about 10 % slower and that of the wheeled tractors 30 to 40 % slower compared to the values during the snow-free season. Even a snow layer of 40 cm caused a slowing of about 15 % of the driving speed of forwarders (B, p. 32–35).

The effect of a very thick snow layer on the mobility of the vehicles was different according to the tractor type (C, p. 155). The tracked vehicles acquired a better mobility on untouched snow than the wheeled tractors. Among the tracked vehicles, the oversnow models were best on the deep snow (about 1 m). The drive during the second trip was, without exception, always faster than during the first (C, p. 158). The time consumption in general was reduced to three-fourths of that during the first trip. The time consumption during the third trip was correspondingly only two-thirds of the starting value. If the snow became firm because of frost before the next drive, the time consumption of the second drive was only 44 % of that of the first one. If the tractor did not mix the snow thoroughly, the packed snow layer did not stand the driving during the second trip, especially on up-hill slopes; but the tractor had to grind the snow again, consuming a great amount of time. In order to achieve a properly packed snow layer, according to the tests, only one drive is necessary if the winter is not exceptional. Only the layer formed by the oversnow vehicles during the first trip was too weak (C, p. 158–159).

The quality of untouched snow had a positive effect on the driving speed only in those cases where the snow was thoroughly wet and heavy, or if it was quite soft and light. If the top layer of snow gets wet it will promote the packing phenonenon and increase the speeds during the next trips. The time for tracked tractors on wet snow was 60 to 70 % of the time on dry snow. The increase in the density of snow had a positive effect, especially on the mobility of broad-tired, wheeled tractors (C, p. 160–161).

313 Other Factors Affecting the Driving Speed

The objective was to eliminate the effect of all other factors by means of test arrangements described previously. This objective was not reached fully because

— it was necessary to include several tractor types, makes and models in the tests for increasing the useability of the results,

— each tractor was always operated by its own driver. Consequently, the differences between the operators affected the results, and because

— there was sometimes a little variation in the daily weather conditions.

For the data processing the tractors were grouped into 1/2-tracked and 3/4-tracked tractors, skidders and forwarders. In this case there was a hypothesis that there were significant differences in the driving speeds of these tractor types. In fact, the speed of the half-tracked tractors was significantly slower in the tests than that of 3/4-tracked tractors, especially during the winter (cf. Fig. 4). Also, between skidders and forwarders a significant difference in speed was observed, except in driving empty during the winter. For these reasons the driving speeds of tractors always should be examined at least with respect to the tractor type or, better still, with respect to the tractor model.

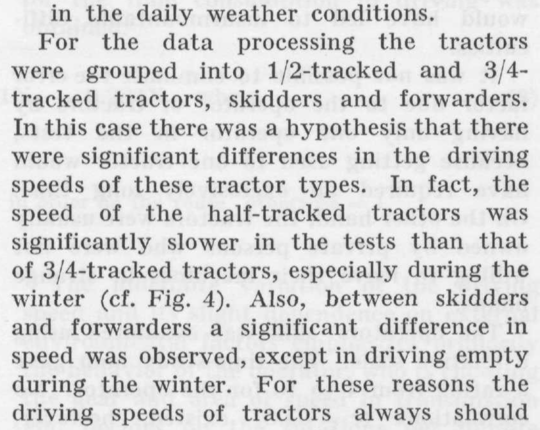


Fig. 4. The driving speeds according to the tractor type — *Keskimääräiset ajoajanmenekit traktorityypeittäin.*

I Level of loading, II Season, III Tractor type Cf. fig. 3, p. 18. — *I Kuormausaste, II Vuodenaika III Traktorityyppi Vrt. kuva 3, s. 18*

One possibility for eliminating the error due to the test tractor would have been to use only one »Standard Tractor». The successful or unsuccessful choice of this tractor would have determined entirely the useability of the results, however. Because the tractors are developing very rapidly, this would have meant taking a rather high risk. Consequently, the idea was discarded. It was also considered unfeasible to carry out a comparison of the observed and the technically possible highest driving speed, because defining the technically highest feasible speed in field conditions would have led to insurmountable difficulties.

It was not possible to eliminate the error factor due to the operator of tractors by having only one operator in the tests, because getting used to one tractor would have required an excessively long time. On the other hand, the tractors were usually owned by private persons who were not willing to leave their machines in strange hands.

The operators' skill was evaluated using a relative scale. The time-study man gave a rating from 4 to 10 for the operator. No correlations ($r = 0.08$) existed, however, between this rating and the time consumption (B, p. 82). The operator can, in any case, by quick evaluation of the situation and applying the right driving methods, avoid a big part of the handicap caused by bad terrain.

One factor, which probably also has an effect on the driving speed of tractors is the visibility. In dusk or in virtual darkness, moving with artificial lights probably becomes more hesitant and slower than in good light conditions. On the other hand, in the USA many people in practice claim[1]) that the output for terminal activities becomes higher compared to daylight conditions, when operating in proper artificial light. The lights limit the field of vision and thus promote the operator's ability to concentrate. These points of view have to be taken into consideration in planning work in shifts. The visibility in the tests was not reduced because of dusk, darkness, rain, snow or fog (B, p. 42–43). The only factor causing hesitancy in driving was the use of a route for the first time, as stated before in connection with studying the effect of slash (p. 17).

The variation in the daily driving conditions were caused, e.g. by a rainfall during the night, which changed the moisture contents of upper layers of soil. Although wet moss is more slippery than dry, this and related minor aspects were considered to have an insignificant effect on the driving speed of tractors in the test.

314 The Joint Effect of the Factors — Prediction Models for the Driving Speed

According to the results presented earlier, it was not possible to determine, with in the limits of the data, those dominating terrain factors which would strongly regulate the driving speed of tractors in forest transportation of timber. The correlation coefficients between the values of environmental factors and the time consumption in driving were always small ($r = 0.10 \ldots 0.30$) (B, p. 82–83). From this fact it follows that it is not possible to form a simple and reliable prediction model for the driving speed of the tractors; but the model always becomes complicated in form if a high level of determination is desired.

On the basis of the data consisting of 1 672 observations gathered in the tests (B) under snow-free conditions it was possible to design a common regression model (1) for the variations in the time consumption for driving by forest tractors:

[1]) Personal communication by Professor Kalle Putkisto

$$\hat{Y}_1 = 1.92 - 0.989X_1 + 0.769X_2 + 0.005X_3 + 0.351X_4 + 0.016X_5, \text{ where} \quad (1)$$

$\hat{Y}_1$ = driving time, min/100 m
X_1 = tractor type = 1, if a skidder, otherwise = 0
X_2 = spacing of rocks = 1, if the spacing of at least 50 cm high rocks is less than 3.0 m, otherwise = 0
X_3 = level of loading, % of the full load
X_4 = spacing of rocks on slopes = 1, if spacing of rocks is less than 3.0 m on gradients over 10 %, otherwise = 0
X_5 = slope, %

The level of determination in the model (1) was 15.1 %; and the contribution of all variables, according to the t-value ($t \geqq 4.34^{***}$) was highly significant. When examining the residuals no bias was found.

Three effective independent variables in the model (1) are artificial, so-called dummy variables. The models formed on the basis of the separate environmental factors only acquired a still smaller (< 10 %) multiple correlation coefficient. Two of the dummy variables are a result of combining two terrain factors. In the first case, the existence of high rocks and in the other, the narrow spacing of rocks on slopes have been separated from the other cases. The skidders differ the most in construction and in operating principle from the other tractor types, so they have also been separated.

Model (1) has, without any doubt, an artificial nature. Even its low multiple correlation coefficient indicates that it is not possible to predict reliably and generally the driving speed of forest tractors in snow-free conditions. Therefore, the examination should be directed separately to each vehicle (B, p. 46—48).

A somewhat simpler model was obtained when studying the driving in winter in deep snow. In northern Finland in 1969 data consisting of 1 218 observations was collected (C, p. 154), and a regression model (2) for the time consumption in driving was obtained.

$$\hat{Y}_2 = 1.20 + 0.264X_1 - 3.491X_2 - 0.284X_3, \text{ where} \qquad (2)$$

$\hat{Y}_2$ = driving time, min/100 m
X_1 = slope, % (real + 50 %)
X_2 = trip number = 0, if the first in order on the route, otherwise = 1
X_3 = weight of snow, 10 g/dm³

The thickness of the snow layer varied in the tests from 57 cm to about one meter. Also, driving empty, half- and fullyloaded were tested by tractors. However, no other variables than those in model (2) were included in the equation, using the same limitations as in forming model (1). The level of determination of model (2) was 34.9 %.

The higher multiple correlation coefficient of model (2) is due mainly to the fact that the tractors used in the tests during the winter were more homogenous than those used during the spring and summer. In winter only data from tractors which as a rule were able to move on deep snow were accepted. Because no similar strict requirements were set for the tractors used in the tests during the snow-free seasons, the machinery was technically more heterogenous during the summer than during the winter. Also, the driving conditions during the winter varied more one-sidedly; but, with respect to the mobility, the variation was wider than during the other seasons. Consequently, a greater numeric variation in driving times was observed during the winter than in snow-free conditions (cf. p. 18).

The indefinite variation of the driving speed and its slight dependence on external environmental factors emphasizes primarily the behavior of the operator, who is choosing the gear and area of speed in transmission and decides on the rotations per minute of the engine, always on the basis of a subjective choice independent of the factors measured in the tests. Therefore, it does not seem to be possible to design for the variation in the driving speed of tractors a general model which could be used to predict the driving speed under certain conditions. In the subsequent analysis it is thus necessary to design a separate speed equation for each tractor model or utilize speed numbers determined on a pure probability basis.

32 Factors Affecting the Size of a Tractor Load

Previously when examining the driving speeds, it was concluded that the size of the load did not have a very decisive influence on the driving speed of present-day tractors (cf. Fig. 5, p. 22). A second drive on the same route during the snow-free season

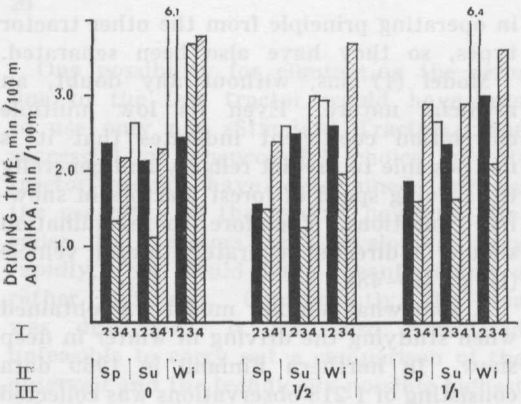


Fig. 5. Average driving speeds according to the level of loading. — *Keskimääräiset ajoajanmenekit kuormausasteittain.*

I Tractor type, II Season, III Level of loading Cf. fig. 3, p. 18. — *I Traktorityyppi, II Vuodenaika, III Kuormausaste Vrt. kuva 3, s. 18.*

with a half-load might be even faster than with an empty tractor (B, p. 29). Not even the effect of a full load could be observed in the means of the test driving times. On untouched snow the time consumption with a half-load increased from 20 to 55 %, depending on the tractor, and with a full load from 60 to 90 % when compared to driving empty (C, p. 160). The most evident effect of increasing the load was the greater deviation in the time consumption figures (e.g. B, p. 84). Under these circumstances, it was not possible to determine adequately the factors affecting the load size of tractors using the tests on the driving speed.

Theoretically, the size of load depends primarily on the construction of the tractor. If there is a roomy load space with correct measures, the transport capacity of the vehicle is high. It is, however, possible to utilize the whole load space only in a case where the axles and other constructional parts allow a maximum loading of the tractor and when a suitable timber assortment is transported. Consequently, the calculated maximum loading capacity is decisive in forest transportation of timber. Full loads are not brought, or it may not be possible to bring loads of the full loading capacity to the landing due to the following reasons:

— the length of timber differs from the length for which the load space of the vehicle was designed,

— because of dryness, the timber being transported is lighter than fresh timber,

— because of poor planning, the driving route on one cycle is not enough for a full load,

— a certain timber assortment from a cycle does not fill the space reserved for it in the load, or

— when bringing the last load from the logging area, the load still is not full.

In practice, the load size of forwarders on logging areas varies rather widely (e.g. from 3.25 to 11.75 cu. m, Kahala 1972). In the data of Kahala, gathered from logging areas with a somewhat easier terrain than the average, the changing of the terrain class from I to II (a classification for contract rates) lowered the average size of loads from 0.2 to 0.4 cu. m. Also, a change in the transport distance from the class less than 500 m to the class 500 to 1 000 m increased the average load size for some tractors from 0.2 to 0.5 cu. m.

The figures presented above indicate that the large variation observed in the size of load on logging areas in practice is only partly due to the external environmental factors, such as the difficulty of terrain and the transportation distance. Even when skidding the same timber assortment by the same tractor, there is a large variation (in the data of Kahala 3.25 to 8.0 cu. m), which cannot be proven to be due to some external factor. Especially, the decision by the driver as to the size of the load he will take is of central importance.

At the present time there are no data available which could form the basis for designing a mathematical model for the variation in the load size during one cycle. In the subsequent analysis it is, therefore, necessary to choose the size of a tractor load as the proportion of a maximum load or to simulate it by using random numbers from a probability distribution (Appendix 2, p. 43).

33 Factors Affecting the Driving Distance

In publication E, especially, the determination of the driving distance of forwarders in forest transportation of timber was discussed. A theoretical prediction model for the driving distance in a logging area was developed. This model was based on knowledge of the amount of timber cut on the area, the size of an average load, the length of the main haul road, the length of the sides of the logging area, and the distance between the driving routes. The last of these parameters proved to be unnecessary in the data collected from actual logging areas. A satisfactory result (E, p. 27) for the length of driving distance on a logging area can be determined, therefore, by multiplying the number of loads and the average distance driven during the cycle, according to the formula (3),

$$M = n\,(2C + L_1 + L_2), \text{ where} \tag{3}$$

M = distance driven in a logging area, m
n = number of loads
C = length of the main haul road, m
L_1 = length of the longer side of the logging area, m
L_2 = length of the shorter side of the logging area, m.

The number of loads is a result of the amount of timber cut on the logging area divided by the average load size of the tractor in question. The average distance driven during the cycle is, on the basis of empirical data, a sum of the two-way distance on the main haul road and half of the sum of the sides. The main haul road is here taken to be the distance from the landing to the edge of the logging area.

In general, the distance driven in a logging area remains shorter with a larger sized single load, which means less frequent traffic on the main haul road. On the other hand, if the loads regularly remain unfilled the number of necessary cycles is increased and the distance driven in a logging area becomes longer. The location of the logging area with respect to the roads, beside which the landings are situated, naturally determines the length of the main haul road. In those cases where there is no driving on a main haul road, the distance driven for collecting the load exclusively determines the cycle distance.

The location of the one or several landing places on the logging area and the planning of the driving routes determine the internal relations between the distances for driving empty, driving during loading and fully-loaded. The shape of the logging area, the average distance between the driving routes, distribution of the timber to the different parts of the area and also the ground obstacles (rocks and stumps) may be significant factors regulating the distance driven on a logging area. Among the terrain factors, the ground roughness and the slope especially proved to be statistically significant factors affecting the driving distance. However, these factors were not included in the corresponding regression model as very significant variables because the terrain factors seem not to cause an excessive curvature of the driving route when using the present forest tractors (E, p. 28).

The influence of the decisions made by the operator in choosing the driving routes should not, even here, be underestimated because, in the final analysis, he makes the decisions on the order of loading the piles and on the systematic performance of the job, which finally determine the distance to be driven.

34 Factors Affecting the Output in Forest Transportation

The problem of factors affecting the output in forest transportation of timber was analyzed earlier under point 12 (p. 6) and 223 (p. 14). In order to find out the joint effect of those factors, the only feasible solution was the use of a computer simulation technique. The following results are, therefore, based on the data from 3 000 tractor loads described earlier (p. 14).

341 Size of Load

The factor with the strongest influence on the output of forest transportation of timber is the size of load. The correlation coefficient between the load size and the output was $r = 0.59$. The size of the load alone explains 35.5 % of the variation in the logging output.

The size of load varied in the data from 1.6 to 12.0 cu. m (with an average of 5.9 cu. m) when the average distance fully-loaded was 279 m (cf. Appendix 2, p. 43).

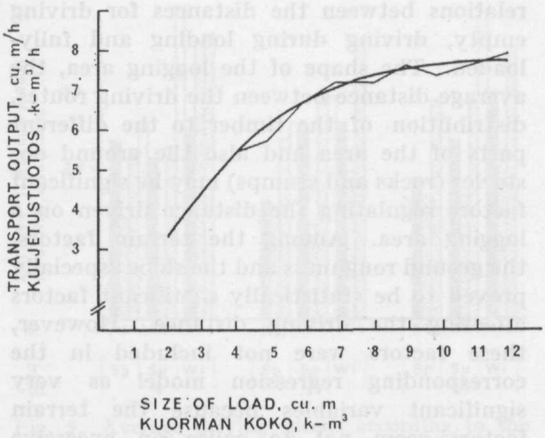


Fig. 6. Correlation between the size of load and the transport output. — *Kuorman koon ja kuljetustuotoksen välinen riippuvuus.*

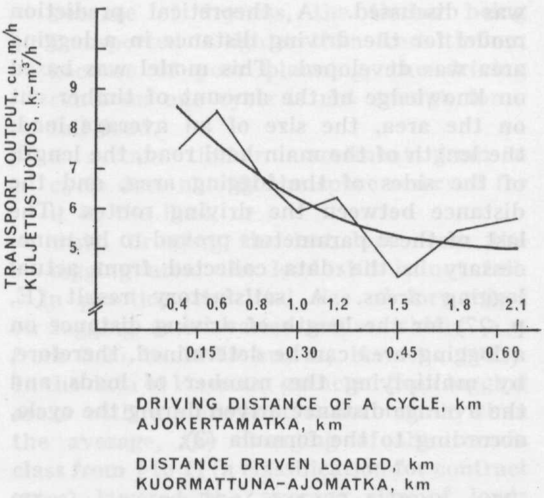


Fig. 7. Correlation between the driving distance and the transport output. — *Ajomatkan pituuden ja kuljetustuotoksen välinen riippuvuus.*

The variation interval covers the most common cases in present forest transportation of timber (e.g. Säteri 1971, 1972a, 1972b, 1972c; Kahala 1972).

The corresponding output in forest transportation of timber varied now from 1.7 to 9.8 cu. m/h (with an average of 6.3 cu. m/h), a result which can be generalized also for the tractors included in this study. The correlation between the size of load and the output is shown in Fig. 6. The effect of the size of the load becomes larger when the loads being transported become smaller.

342 Driving Distance of a Cycle

The distance driven during the cycle is almost as good a variable as the size of the load for explaining the variation in the output in forest transportation of timber. The correlation coefficient between the driving distance of a cycle and the output was r = −0.53. The distance alone explains 28.1 % of the variation in the output. Together with the size of load they explain 78.9 % of the variation in transport output. Their joint effect explains so 15.3 % of the variation. These two are thus the most important factors regulating the output in forest transportation of timber.

In practice, there is a big variation in the driving distance of a cycle within the logging areas and even within one area (cf. point 33, p. 23). The distribution of the distances presented in Appendix 2 (p. 43), on which the results under review are based, is only slightly skewed. The main part of the observations correspond to the actual short-distance transportation of timber (less than 500 m) in the contract wage tables, which is a goal in planning the logging so that it does not become necessary to pay any additional sum for the so-called continued shortdistance transportation (Anon. 1972). On this basis the driving distances of the cycles, which varied from 0.3 to 2.1 km (with an average of 929 m), can be regarded as representative data from actual conditions.

The correlation between the driving distance of a cycle and the output in forest transportation of timber is shown in Fig. 7. It may be seen that within those limits and on the same scale the effect of the driving distance is slightly smaller than that of load size. According to Fig. 8, the output decreases faster with increasing driving distance and with the transportation of smaller loads.

343 Driving Speed in Terrain

In the simulated data the variable on driving speed of tractors in driving empty proved to be a more significant variable in the regression model than the variable

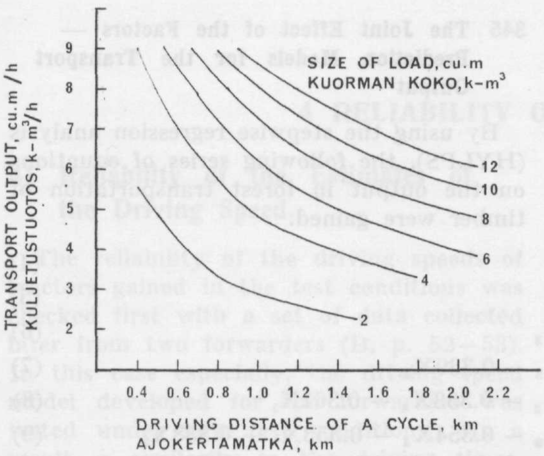


Fig. 8. The combined effect of the size of load and the driving distance on the output in forest transportation of timber. — *Kuorman koon ja ajomatkan pituuden yhteisvaikutus puutavaran metsäkuljetustuotokseen.*

for driving during loading and fully-loaded. Compared to the size of the load and the driving distance, the correlation coefficient was, in this case, much lower ($r = -0.39$). The corresponding coefficients for driving during loading and driving loaded were $r = -0.24$ and $r = -0.14$. After including the variable on driving empty, in addition to the size of load and the driving distance, the multiple correlation coefficient rose from 0.789 to 0.850. When the variable on driving loaded also was included, the coefficient rose to 0.891. After all the variables on time consumption in driving were included, the level of determination was 92.9 %.

The main reason why the time consumption in driving empty explained more variation than the others is due to the length of the corresponding driving distance. In the simulation process 40 % of the driving distance of a cycle was always regarded as belonging to driving empty, and 30 % to driving during loading and loaded, respectively (cf. p. 15). Since the driving speeds during the separate driving phases varied very little (cf. Appendix 2, p. 43), the absolute time consumption in driving empty was always greater than the other driving times due only to the distance. In any case, the contribution of all time consumption variables for driving were, according to the t-value ($t \geqq 39.9^{***}$), highly significant in the model for the output in forest transportation of timber.

344 Terrain Factors Regulating the Driving Speed

According to the results presented in sections 311, 32 and 33, it was evident that it probably would not be possible to find any significant correlation between the separate terrain factors and the output in forest transportation of timber. Most of the terrain factors tabulated during the course of the study acquired only a correlation coefficient less than $r = 0.10$ with the output figure. The highest correlation coefficients were found between the thickness of the snow layer when driving empty ($r = 0.29$) and the thickness of the humus layer when driving empty ($r = -0.24$) or loaded ($r = -0.12$). Nor did the artificial variables combined from several terrain factors correlate significantly with the output figure (e.g. the stoniness on slopes when driving empty, $r = 0.11$).

When considering also the terrain factors during driving (in addition to the variables on load size, distance driven, and time consumption in driving), it was possible to raise the multiple correlation coefficient from 0.929 to 0.933. In this case the variables of the thickness of the snow when driving empty and the thickness of humus when driving loaded were included. In the alternative case where the time consumption figures were entirely excluded, a model based on the size of load, the distance driven and some terrain factors explained, at the most, 81.2 % of the variation in the output. The increase in the level of determination was thus, because of the terrain factors only 2.3 %. In that case a total of nine artificial dummy variables were included from the different phases of the transportation. *The minor increase in the multiple correlation coefficient indicates that the terrain factors have a rather small direct effect on the output in forest transportation of timber.*

As was discussed earlier (p. 22 and 23), the terrain factors have only a minor influence on the size of load and on the distance driven during a cycle. Therefore, it was not regarded as appropriate to analyze the effect of those terrain factors which are connected with size of load and driving distance on the output, especially since no suitable data was readily available.

345 The Joint Effect of the Factors — Prediction Models for the Transport Output

By using the stepwise regression analysis (HYLPS), the following series of equations on the output in forest transportation of timber were gained:

$$\hat{Y}_3 = 3.489 + 0.476X_1 \quad (4)$$

$$\hat{Y}_4 = 6.381 + 0.581X_1 - 0.378X_2 \quad (5)$$

$$\hat{Y}_5 = 7.283 + 0.559X_1 - 0.356X_2 - 0.454X_3 \quad (6)$$

$$\hat{Y}_6 = 8.034 + 0.556X_1 - 0.351X_2 - 0.448X_3 - 0.339X_4 \quad (7)$$

$$\hat{Y}_7 = 8.950 + 0.567X_1 - 0.348X_2 - 0.466X_3 - 0.353X_4 - 0.361X_5 \quad (8)$$

$$\hat{Y}_8 = 8.747 + 0.566X_1 - 0.336X_2 - 0.447X_3 - 0.354X_4 - 0.353X_5 + 0.838X_6 \quad (9)$$

$$\hat{Y}_9 = 8.766 + 0.567X_1 - 0.334X_2 - 0.443X_3 - 0.337X_4 - 0.353X_5 + 0.898X_6 - 0.741X_7 \quad (10)$$

where

$\hat{Y}_{3...9}$ = the transport output, cu.m/h
X_1 = size of load, cu.m
X_2 = driving distance, 100 m
X_3 = time consumption in driving empty, min/100 m
X_4 = time consumption in driving loaded, min/100 m
X_5 = time consumption in driving during loading, min/100 m
X_6 = thickness of snow layer when driving empty, m
X_7 = thickness of humus layer when driving loaded, m

The significance of each variable explaining the variation and the increase in the level of determination after adding each factor to the model was as follows:

Variable	X_1	X_2	X_3	X_4	X_5	X_6	X_7
t-value	146.1	−115.1	−50.9	−41.2	−40.3	12.9	−8.4
R^2	0.355	0.789	0.850	0.891	0.929	0.932	0.933

Only two terrain factors were included in the model (10) although, according to the t-value even, e.g. the thickness of the snow layer when driving loaded and the thickness of the humus layer when driving empty, would have belonged to the model. The level of determination would have risen, because of all these excluded factors, at the most, 0.2 %.

In the case where, in addition to the load size and the driving distance, only variables on terrain factors were taken into account, a very complicated equation for the output in forest transportation of timber resulted. By including all nine terrain factor variables, the multiple correlation coefficient was raised from 0.789 to 0.812. All the nine variables were, according to the t-value, very significant factors to be included in the model for the variation in the output in forest transportation of timber. Because the value of this complicated model is not in practice better than that of model (5), it has not been presented here.

4 RELIABILITY OF THE RESULTS

41 Reliability of the Estimates of the Driving Speed

The reliability of the driving speeds of tractors gained in the test conditions was checked first with a set of data collected later from two forwarders (B, p. 52–53). In this case especially, the driving speed model developed for the forwarders was tested under new test conditions. As a result, a similarity in the driving times, which could not be due to pure chance, was observed.

During the continued analysis, the validity of the model (1) (p. 20) also was checked with the same data on two forwarders. Likewise, the validity of the model (1) was checked with the data on two skidders gathered in the study on the effect of additional machine components on the mobility of tractors (D, p. 3–8). These results have been presented in Table 1.

The correlation coefficient between the predicted and observed driving times was, for forwarders, r = 0.42** and for skidders, r = 0.25**. On the other hand, there were no significant differences between the means (t = 1.50 or t = 1.71). On the basis of the figures presented previously, it is possible to reach the conclusion that the models formed from the test data give, at least for forwarders and skidders, results which can be applied to other snow-free test conditions.

It was not possible to test in this connection the model (2) (p. 21) designed for tracked vehicles and especially, for tractors moving in deep snow. On the other hand, no reasons appeared in the course of the study which would justify questioning the validity of the model (2).

42 Validity of the Estimates of the Driving Speed

The conclusions made previously on factors affecting the driving speed of forest tractors in terrain were based on data from tests where the tractors were removed from their regular jobs. However, the driving routes in the tests corresponded to those trails which are customarily planned in logging areas. For checking the validity of the

Table 1. Comparison of the predicted and observed driving times in test conditions.
Taulukko 1. Ennustettujen ja testiolosuhteissa havaittujen ajoaikojen vertailu.

Explanation - *Selitys*	Time consumption — *Ajanmenekki,* min/100 m: 0–1.5	1.6–2.0	2.1–2.5	2.6–3.0	3.1–3.5	3.6–5.0	Overall average (Sum) *Keskim. (Yht.)*
	Average driving time — *Keskim. ajoajanmenekki,* min/100m						
Forwarders — *Kuormapyörätraktorit:*							
— predicted — *ennustettu* .	2.07	2.08	2.08	2.19	2.25	2.31	2.03
— observed — *havaittu*	1.25	1.72	2.28	2.83	3.21	3.89	2.11
— number of observations — *havaintoja, kpl*	(46)	(67)	(39)	(17)	(14)	(9)	(192)
Skidders — *Laahuspyörätraktorit*:							
— predicted — *ennustettu*	1.17	1.32	1.41	1.21	1.41	1.42	1.20
— observed — *havaittu*	1.03	1.70	2.12	2.69	3.04	4.05	1.16
— number of observations — *havaintoja, kpl*	(301)	(43)	(6)	(2)	(1)	(2)	(355)

Table 2. Comparison of the predicted and observed driving times in logging areas.
Taulukko 2. Ennustettujen ja työmailla havaittujen ajoaikojen vertailu.

Explanation — *Selitys*	Time consumption — *Ajanmenekki*, min/100 m						Overall average (Sum) *Keskim.* (*Yht.*)
	0—1.5	1.6—2.0	2.1—2.5	2.6—3.0	3.1—3.5	3.6—5.0	
	Average driving time — *Keskim. ajoajanmenekki*, min/100 m						
Predicted — *Ennustettu*	2.14	2.16	2.19	2.22	2.23	2.24	2.19
Observed — *Havaittu*	1.18	1.77	2.25	2.73	3.23	4.10	2.29
Number of observations — *Havaintoja, kpl*	(146)	(165)	(183)	(120)	(50)	(42)	(724)

test figures the model (1) was tested by using empirical data from real working conditions (Appendix 1, p. 42). The correlation between the predicted and observed driving times (Table 2) was, in this case, r = 0.12**. On the other hand, in this case there probably was a significant (t = 2.42*) difference between the means. The figures previously justify the conclusion that the speed models formed on the basis of data collected from test conditions provide results which are valid also in real logging conditions. The possibly significant difference in the latter means may be caused by the method of collecting these data. The observations from operating logging areas might also contain some short breaks within the drive, all of which were excluded from the data collected under test conditions. The steady rising trend of the predicted values within the whole variation interval indicates a similarity of the figures, in a way which cannot be due to pure chance.

43 Validity of the Transport Output Model

The validity of the output models in forest transportation of timber (equations (4) . . . (10)) was not tested in such detail as those models on driving speed. The main reason for this was the lack of suitable data. To be able to get at least a rough idea of the validity of those models, a part of the data collected for publication E was utilized, although it is a brief study including only 10 logging areas.

In Fig. 9 the correlation between the predicted (equation (5), p. 26) and observed output numbers are presented. The pairs of figures are, without any doubt, very consistent with each other. The correlation coefficient between them is r = 0.95**.

The equation (5) was chosen, not only because of the fact that a set of data was available for it, but also because both of the two central variables regulating the transport output — the size of load and the driving distance — belong to it already. During the calculation the minor effect of the variables $X_3 \ldots X_7$ in the model (10) on the transport output figure was noticed. Since the output varies regularly between 4 and 13 cu. m/h, the total effect of the excluded variables can usually be counted in one-tenths or one-hundredths of a cubic meter per hour.

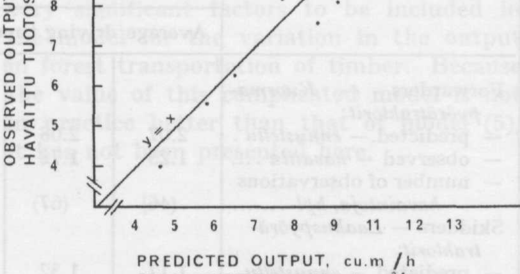


Fig. 9. Comparison of the predicted and observed output figures. — *Ennustettujen ja havaittujen tuotoslukujen vertailu.*

44 Effect of the Technical Progress on the Results

A common feature in the development of the timber harvesting is to increase the capacity of the machinery in forest transportation. The construction of the tractors, which plays the main role in this question, is changing continuously, both in domestic and foreign models. To be able to clarify what kind of an effect the changes in the technical construction of the tractors have on the mobility of the vehicles, a series of tests were arranged with tractors after mounting some additional machine components on them. In this study there were skidders, onto which a grapple, a delimbing-bucking device or a felling device was mounted. In addition, aspects on the mobility of a forwarder were studied with a delimbing machine mounted onto it (D).

As a result of these tests it was noted that it is not possible to predict reliably the changes in the driving speed of such a machine on the basis of data on the basic machine only. The machine must always be regarded as a new vehicle. The changes in the mobility may come out either with a positive or a negative effect (D, p. 10). In general, decreasing the driving properties of a new forest tractor in terrain should be prevented, especially since the timber must be transported in the future by machines from all forests.

As the effect of the technical development on the results of this study is analyzed, one can consider that the tractors studied here acted in terrain, to a certain extent, rather homogenously. In some special conditions, like driving on deep snow, the heterogenous properties of the equipment also became evident. The homogenous performance, with respect to the driving properties, appeared in such a way that there was not always a significant difference in the mobility within the same tractor type, although there were even large differences in the technical construction of the tractor models used. Knowing this, one can assume that there will probably not, in the near future, arise such a great general change in the driving speed of forest tractors due to the technical progress that the output in forest transportation of timber would rise significantly from the present level. This kind of slow development is also indicated by the great interest which nowadays is centered on the ergonomic development of the tractors. The risk of increasing the rocking and swinging of the vehicle already prevents a noticable raising of the driving speed, if the ergonomic properties are not improved at the same time.

The technical improvements in the transport vehicles seem not to have a significant effect on the distance driven during a cycle. During the course of the study, it was not noticed that the distance driven would have become longer because of the curvature of the driving route caused by terrain obstacles. The present tractors already seem to be able to pass the obstacles left on the passable driving routes in Finnish forest terrain. This can also be interpreted by saying that in general there are available in the logging areas a sufficient number of alternatives for planning the driving routes, so that the harm due to obstacles can be avoided.

The most important change in the transport output is probably due to improvements which increase the size of the load. Up to a certain limit, it is possible to raise the transport output by increasing the size of the load. The problem in machine design is, on the other hand, to make the load space and the size of wheels and tracks larger; and, at the same time, keep the vehicle's weight distribution within such limits that the machine can move in terrain without sinking into the ground and without causing an unstable drive. There are only limited possibilities for increasing the width of the vehicle because most of the timber must be transported along narrow trails from thinnings and also because the vehicle must be moved frequently from one working place to another along public roads. Also, the risk of causing damage to the standing trees will limit the size of the tractors.

In principle, the technical development of the tools used for the terminal activities can also promote the transport output. The most decisive limitation in this respect is due to the fact that the timber always has to be collected in a logging area from rather small piles, and thus an increase in the capacity of the loader does not help very much.

In any case, the evaluation of the effect of the technical progress in always a difficult task. The driving properties in terrain of the new tractor models should be tested uniformly in advance so that the planner can be correct in his decision when choosing the transport equipment or the way it is to be used. The best way to do this would probably be the use of a standard test track. At the same time, it would be possible to gain information on the limit values for the use of the machine, which is useful data even for machine design and education of the operators.

5 ADAPTATION OF THE RESULTS FOR PRACTICAL USE

51 Basis for the Contract Rates

The contract rates for forest transportation of timber used in Finland today (ANON. 1972) include a separate unit rate for the transportation of pulpwood, softwood logs, plywood birchlogs and stems. Factors affecting the rate are the basic rate, unloading to a measureable pile, deduction for degree of debarking, compensation for thinning, compensation for sorting, compensation for snow, compensation for bundling, distance in the continued transportation, compensation or deduction for size of logs, compensation because of density in marked stand, sorting of the stems and the compensation for moving. The basic rate is dependent, in the case of timber, on the terrain class, density of the marked stand, transport distance, and the timber assortment and its dryness. The size of stem, the terrain class, and the distance determine the transport rate for stems. The number of factors to be taken into consideration proves already that fixing a rate today is a many-phased and laborious job.

All rationalized planning and activities performed on the basis of this planning have as an objective to attain the simplest possible procedures. Therefore, the results of this study have to be analyzed by asking whether there are any possibilities to simplify the basis for the contract rates in the forest transportation of timber.

The skidding of stems differs the most from the other transportation methods because the basic principle for using the equipment is entirely different. A variable describing just a skidder was included in the model developed for the driving speed of forest tractors (equation (1), p. 20). For this reason it might be a good idea to keep the skidding of stems separate from the forwarding, even in the future, when fixing the contract rates. On the other hand, in the present study no closer examination was directed to skidding than the tests for the driving speed. Consequently it is not possible to draw the same conclusions on it as will be done in the following discussion of forwarding.

Earlier, it was considered that the output in forwarding depends mostly on the size of the load and the distance driven (equation (5), p. 26). Because in practice these two entities determine that part of the transport output which can be predicted reliably, the basis for the contract rates should be chosen considering how they regulate the average size of the load and the distance driven during the cycle. The construction of the tractor, the timber assortment, and partly also the difficulty of terrain are decisive in determining what size of loads can be transported. In load-size determination the examination should thus be more connected with the vehicle than it has been previously. The dimensions of the logging area and the density of the marked stand especially affect the distance driven. The driving distance during the cycle would thus include the real distance a tractor has to move during the cycle because the driving time is actually dependent on it. The present distance figure corresponds to about a half of the real distance and is considered as double in the calculation of the rate values in the tables. It is measured from the gravity point (determined by weighting with the amount of timber) of the area along the driving route to the midpoint of the landing (ANON. 1972). — Although the present system, which is based on a rather subjective procedure, as such fulfills the requirements of practical work, a measurable entity should always be kept as a goal.

A feasible solution for reforming the basis for the contract rates is provided by a method called the work-phased system. The time consumption figures for each work phase would be used as a basis for a contract rate. Particularly for defining the time consumption figures for driving, the earlier results of this study are providing useful information. A benefit from this new system of paying would be in the case of special unloading, sorting, bundling, etc., that the time consumption of a cycle would be a sum of all subsums. The relation between the cycle time and the contract rate could be presented in only one table, which would be a result of the negotiations between the unions. This would thus mean a very much simpler system than that used today. However, adoption of this system would mean a large educational problem in the field and might not be readily feasible.

52 Terrain Classification

In the present study the work environmental factors connected with the terrain difficulty in passable forest areas have been studied. The limit of passability was not determined because of lack of resources. In spite of the fact that the investigations were carried out in many phases it was not possible to identify such dominating terrain factors which generally and unequivocally would regulate the driving speed, size of the load or the length of the driving distance of forest tractors. The effect of terrain as a factor affecting the output of timber transportation seems to be mainly interwoven with the variation caused by the other affecting factors, or it will be eliminated through the flexible *human factor* which is connected with the operator.

Information for classifying the terrain as a work environmental factor has been presented in this project, e.g. in the publication B (cf. Table 16, p. 60), in publication C and in the present paper, cf. equations (1) (p. 20) and (2) (p. 21). Without going into an analysis dealing with an individual tractor, it has proved to be a very difficult task to present a terrain classification which would sufficiently, accurately and reliably indicate the effect of terrain on the mobility of a vehicle.

Therefore, it is evident that the classification of terrain should be divided into two phases: 1) a primary classification of the basic factors and 2) a secondary classification which will indicate the behavior of the particular machinery. Because the vehicles are developing continuously and their abilities to move in terrain are changing, the secondary classification should be checked intermittently as guided by the test results. The most essential task is to establish a uniform method for classifying and measuring the primary terrain factors (soil type, spacing of obstacles, etc.) so that the classification will be as unchanging with time as possible (cf. Haarlaa and Asserståhl 1972).

53 Conversion of the Output to Cost Figures

As it was pointed out in the second section of the introduction, the transport output figures can be converted easily to cost figures by dividing the hourly operating cost by the output figure in question (cf. p. 6).

The unit-cost figures in forest transportation of timber can be used in many kinds of decision-making, as presented, e.g. in the publication A (p. 50) in the case of choosing a tractor. Also, the influence of different cost factors on the cost figures can be studied with a sensitivity analysis (i.a. Nikunen 1969). When making rentability calculations on investments in tractors, the output figures have a central position (i.a. Väisänen 1969b). However, one has to remember when calculating the cost figures in transportation of timber, that there always remain many definition problems in these calculation procedures. They may deal with the unknown properties of the transport vehicle, with the operator of the tractor or they may even depend on natural phenomena. For these reasons the result of a cost calculation in forest transportation of timber always rests on a weak foundation, and the result of a pre-calculation may differ, even significantly, from that of the subsequent observation.

6 SUMMARY

The basic data for this study were provided by the observations made in several field tests on the mobility of forest tractors in terrain. Also, some data on the driving speed and the curvature of the route of forwarders were gathered from logging operations.

Multiple regression analysis as a computer application was used as the basic data processing method. The joint effect of several factors regulating the forwarding output was determined by computer simulation of 3 000 loads.

The first part of the present investigation includes the summarized conclusions from the five earlier reports, which are mentioned on page 5. In the first of these the structure of terrain transportation costs has been discussed and the importance of terrain as a factor regulating the transport output has been stressed. In the next three papers the effect of terrain on the mobility of forest tractors has been dealt with using their driving speed as a basic variable. In the fifth report the driving distance of forwarders in forest transportation of timber has been studied.

In the second part of this investigation the effect of terrain on forwarding output has been analyzed. The computer simulation method was chosen here because no sufficient data from the field were available. The data on each factor were based on field observations, however.

On the basis of the results it can be concluded that no one of the separate terrain factors has proved to have a dominating effect on any component of the forwarding output, but their effect exists always as a joint one. It has been possible, however, to identify many terrain factor combinations with a nonsignificant effect on the mobility and also on the forwarding output of forest tractors.

The form of the regression model (1) (p. 20) developed for the driving speed of forest tractors in snow-free conditions was rather complicated. Even the corresponding model (2) (p. 21) for driving on a thick snow explained only about 35 % of the variance. Also, the terrain factors had only a joint and a minor effect on the size of the load and on the distance driven. A more significant role in this problem seems to be played by the individual and flexible behaviour of the tractor operator, which is affected by the ergonomic properties of the tractor in question.

The most significant factors affecting the forwarding output were the size of load and the distance driven during the forwarding cycle. They explained 78.9 % of the variation in output. If the variables on the driving speed were included in the model, the level explained rose to 92.6 %. In an alternative case where variables on driving speed were replaced by several regulating terrain variables, it was possible to raise the level of determination from 78.9 % to 81.2 %.

The validity of the regression models on driving speed of tractors was tested and found valid both in other tests and in working conditions. The model on variation in forwarding output was tested and found valid, too.

The influence of the general indefinite effect of different terrain factors in output has to be taken into consideration when choosing entities for contract rates and when classifying the terrain environment in timber transportation. A new approach related more to the tractor in question should be adapted. Only those terrain factors shall be included in the classification which in that individual case do regulate the size of a possible load and the distance to be driven. However, before one is able to move to such an individual system, each new transportation vehicle has to be tested in uniform test track conditions, where interaction with each terrain factor and the machine in question can be measured. The tests should be carried out as early as possible because it has been proven that the behaviour of a new machine in terrain cannot

be predicted reliably on the basis of the earlier models.

In the classification of terrain the following basic rules should be adopted: 1. Each terrain should be measured first using primary terrain factors, which should be kept constant with time. 2. On the basis of the primary terrain classes a secondary terrain classification should be formed, which would indicate the interaction between the machinery and the particular terrain. This classification should also be adjusted according to the technical development of machinery.

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ABBREVIATIONS:

MA = Metsätaloudellinen Aikakauslehti. Helsinki.
SFM = Samarbetsorganisation för fordon-markforskning. Swedish Society for Collaboration on Terrain-Vehicle Research. Meddelande — Report. Stockholm.

Seloste

MAASTON VAIKUTUS PUUTAVARAN METSÄKULJETUSTUOTOKSEEN

Esillä oleva maastovaikeuden ja puutavaran metsäkuljetustuotoksen välisiä suhteita käsittelevä tutkimus on syntynyt yhteispohjoismaisen metsämaaston luokitusprojektin tuloksena. Perusaineiston ovat tarjonneet maastotekijöiden vaikutusta metsätraktoreiden liikkumiseen selvittäneiden ajonopeuskokeiden havainnot. Lisäksi on kerätty aineistoa traktoreiden ajonopeuden, ajomatkan pituuden ja kuorman koon vaihtelusta työmaaolosuhteissa.

Tutkimusaineiston käsittelyn perusmenetelmänä on käytetty valikoivaa regressioanalyysiä tietokonesovellutuksena. Useiden tuotostekijöiden yhteisvaikutuksen selvittämiseksi simuloitiin 3 000 kuorman aineisto todellisista työskentelyolosuhteista peräisin oleviin havaintoihin nojautuvien todennäköisyysjakautumien avulla.

Tutkimustulosten alkuosa koostuu tiivistetyistä päätelmistä, jotka on tehty kohdassa 11 lueteltujen viiden aiemmin ilmestyneen tutkimusselostuksen perusteella. Ensimmäisessä näistä julkaisuista on valotettu puutavaran kuljetuskustannusten muodostumista yleensä ja painotettu erityisesti maastovaikeuden merkitystä puutavaran metsäkuljetustuotosta säätelevänä tekijänä. Kolmessa seuraavassa tutkimusselostuksessa on käsitelty metsätraktoreiden maastoliikkuvuuteen vaikuttavia tekijöitä lähinnä maastoajonopeutta indikaattorina käyttäen. Viidennessä ennakkoselostuksessa on analysoitu metsätraktorin puutavaran metsäkuljetuksessa liikkuman matkan pituuteen vaikuttavia tekijöitä. Tutkimustulosten loppuosassa on analysoitu maaston vaikeuden vaikutusta puutavaran metsäkuljetustuotokseen.

Tutkimusten tuloksista selviää, ettei millään maastovaikeustekijällä voitu osoittaa olevan erillistä dominoivaa vaikutusta johonkin puutavaran metsäkuljetustuotoksen komponenttiin, vaan maaston vaikeuden vaikutus ilmenee aina usean tekijän yhteisvaikutuksena. Koetulosten perusteella on tosin voitu rajoittaa joukko sellaisia maastotunnusten kombinaatioita, joilla ei ole yleensä merkitsevää vaikutusta ajoneuvon maastoliikkuvuuteen eikä siten myöskään puutavaran metsäkuljetustuotokseen.

Lumettoman maan kuljetusolosuhteita koskevan traktoreiden maastoajoajanmenekin ennustemallin (1) (s. 20) rakenne muotoutui varsin keinotekoiseksi. Traktoreiden paksussa lumessa liikkumisnopeutta indikoiva regressiomalli (2) (s. 21) selitti samoin vain n. 35 % ajoajanmenekin vaihtelusta. Ajokerralla kuljetetun kuorman kokoon ja ajokertamatkan pituuteen maastovaikeustekijöillä oli niin ikään vain välillinen ja vähäinen vaikutus. Maastotekijää ratkaisevampaa osaa ongelmakentässä näyttelevätkin ilmeisesti traktorinkuljettajan yksilöllinen ja joustava käyttäytyminen sekä kuljetusvälineen ergonomiset ominaisuudet.

Puutavaran metsäkuljetustuotokseen vaikuttavista tekijöistä voitiin todeta, että kuorman koko ja ajokertamatkan pituus selittivät yhdessä jo 78.9 % tuotoksen vaihtelusta. Jos ajon ajanmenekkiä koskevat muuttujat otettiin malliin mukaan, yhtälön selitysaste nousi lukuun 92.9 %. Vaihtoehtoisessa tapauksessa, missä ajoajanmenekkimuuttujia ei otettu huomioon, maastovaikeusmuuttujat nostivat mallin selitysasteen 78.9 %:sta 81.2 %:iin.

Traktoreiden ajoajanmenekin perusmalli voitiin todeta testauksin sekä toisiin koe- että käytännön työmaaolosuhteisiin soveltamiskelpoiseksi. Myös puutavaran metsäkuljetustuotosmalli antoi yleistämiskelpoisia tuloksia (s. 28).

Maastovaikeustekijöiden epämääräinen vaikutus merkitsee maksuperusteiden ja maaston luokittamisen kannalta sitä, että vastaisuudessa kuljetusmaksun määrityksessä olisi siirryttävä entistä ajoneuvokohtaisempaan tarkasteluun. Vain kulloinkin kuorman kokoon ja ajokertamatkan pituuteen vaikuttavien maastotekijöiden ottaminen huomioon luokitusperusteina näyttää olevan perusteltua. Jotta ajoneuvokohtaiseen tarkasteluun voitaisiin mennä, uusien koneiden ja primääristen maastotekijöiden välinen riippuvuus olisi selvitettävä yhdenmukaisissa koerataolosuhteissa jo mieluummin ennen ajoneuvon tuloa markkinoille, sillä uuden mallin maastoliikkuvuutta ei voida ennakoida luotettavasti aiempien traktorimallien perusteella. Maaston luokittamisessa olisi omaksuttava vain maastotunnusten primäärinen luokitus- ja mittaustapa yhdenmukaiseksi. Primääristen luokkien nojalla muodostettavia sekundäärisiä maastoluokkia sitä vastoin tulee voida tarkistaa soveltamisalueittain aika ajoin koneiden kehittymisen mukaisesti.

Amount of Data on Driving Speeds, according to the Tractor Model, Gathered from Logging Areas (cf. KAHALA 1972)

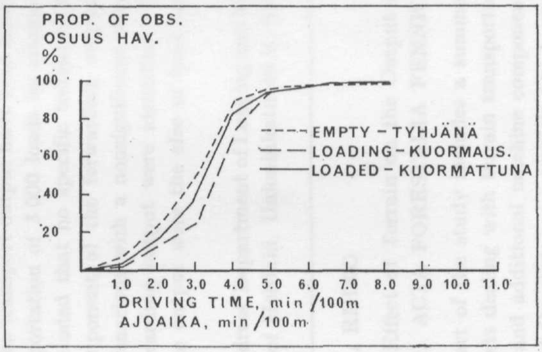
Työmaaolosuhteista kerättyjen ajonopeushavaintojen määrä traktoreittain (*vrt.* KAHALA *1972*)

Tractor make and model *Traktorin merkki ja malli*	Phase of driving — *Ajovaihe* Empty *Tyhjänä ajo*	 During loading *Kuormausajo*	 Loaded *Kuormattuna ajo*	Total *Yhteensä*
	Number of observations — *Havaintoja, kpl*			
BM-Volvo SM 460	107	14	75	196
BM-Volvo SM 660 & 661	62	6	51	119
BM-Volvo SM 668	74	30	44	148
Valmet 865 LM	65	3	52	120
Teli-Lokkeri	. . .	. .	10	10
Ford County 6	57	25	30	112
VMV Stalo	8	. .	8	16
Total — *Yhteensä*	373	78	270	721

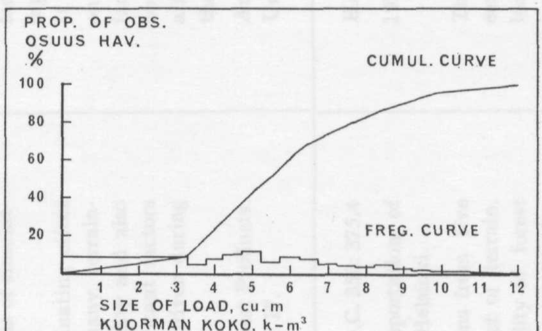
APPENDIX 2 — *LIITE 2*

The Empirical Data Used for the Simulation Procedure
Simuloinnissa käytetty empiirinen aineisto

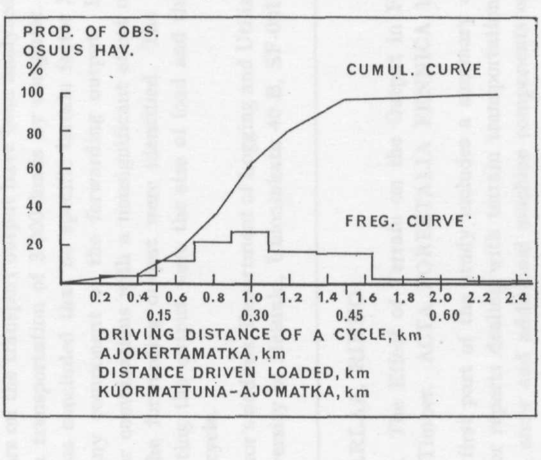
Data on the driving speed
Ajonopeusaineisto



Data on the size of load
Kuormankokoaineisto



Data on the driving distance
Ajomatka-aineisto



HAARLAA, RIHKO O.D.C. 356: 375.4

1973. The Effect of Terrain on the Output in Forest Transportation of Timber. ACTA FORESTALIA FENNICA 128. 43 p. Helsinki.

The first part of the study includes a summary of conclusions from five earlier reports dealing with terrain transportation costs, effect of terrain, load, snow and additional machine components on the mobility of forest tractors, and the distance a vehicle has to move in forest transportation of timber. In the second part of the study the effect of these separate factors on the transport output have been analysed on the basis of simulating a transportation of 3 000 loads by computer.
It was concluded that no specific terrain factor had a dominating effect on any component of the forwarding output. However, many terrain-factor combinations with a nonsignificant effect on the mobility and also on the forwarding output were identified. The most significant factors affecting the output were the size of load and the distance driven during the cycle.

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KANNATTAJAJÄSENET — UNDERSTÖDANDE MEDLEMMAR

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