TERRAIN - VEHICLE SYSTEMS

DR. ED. WRONSKI

1987 GOTTSTEIN FELLOWSHIP REPORT

JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organisation (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust has three major forms of activity,

(1) Fellowships - each year applications are invited from eligible candidates to submit a study programme in an area considered to be of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate.

(2) Study Tours - industry group study tours are arranged periodically and have been well supported.

(3) Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

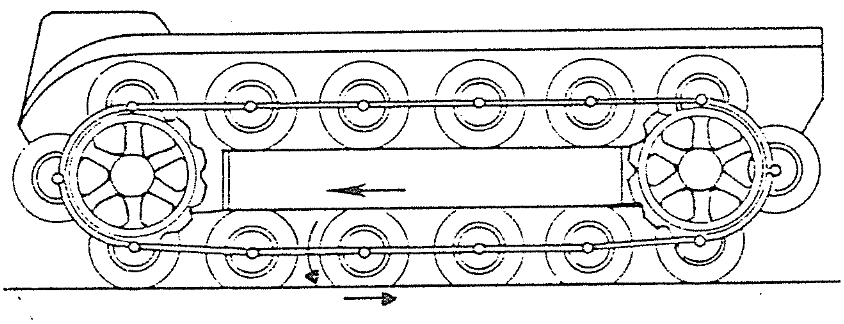
Further information may be obtained by writing to, The Secretary, J.W. Gottstein Memorial Trust Fund, P.O. Box 56, Highett, Victoria, 3190. Australia.

REPORT TO

JOSEPH WILLIAM GOTTSTEIN TRUST

ON STUDY TOUR OF

"TERRAIN-VEHICLE SYSTEMS"



Dr. Ed Wronski

February 1988

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Dr Ed Wronski - 1 March 1988

EXECUTIVE SUMMARY

Relative to military vehicles capable of carrying similar loads, the trafficability of forwarders is poor. Only when the widest recommended tyres and wide tracks are fitted to the more commonly used forwarders in Australia does their trafficability on flat ground approach that of a standard military truck. On steep ground their trafficability is significantly worse. Improvements can be brought about possibly through a reduction in chassis weight and the fitting of larger tyres, providing the axle strengths are increased. With tracks fitted, the load distribution applied to flat ground appears to be optimum but on steep ground significant improvements can be obtained by better design of the bogie wheel system. Other potential improvements involve reducing the shear stresses imposed on the soil by eliminating differential rates of slip between wheels and locating the position of the pivot axis between the front and rear wheels as close to the centre of gravity of the loaded machine as possible, while still ensuring the wheels track one another during a turn.

There are two systems available for simulating vehicle mobility relevant to the forestry industry: the empirical and the analytical approaches. The empirical approach used by the military and tested on soils in the Tumut region, definitely has application in the operational sense for managing logging

operations. Estimates of vehicle and soil trafficability are obtained from parameters which are relatively easy to measure which facilitates an objective assessment of the likely impact of forwarder operations on various terrains. However the system requires significant modifications if it is to be applied to forecasting the impact of skidder operations. The simplicity of the approach imposes limits on its usefulness for evaluating competing machine designs.

The analytical approach requires soil parameters which are difficult and expensive to measure and therefore this approach is not useful in the operational sense. However, it has greater potential for evaluating competing machine designs designed for operating on particular terrain and would be particularly useful in evaluating skidder trafficability.

The trend to higher axle loads in forest harvesting equipment is likely to lead to a decline in forest growth on nutrient poor soils due to a general tendency for large machines to develop deep ruts and cause greater subsoil compaction. Reductions in growth due to compaction and soil disturbance are likely to be greatest on shallow, coarse, alkaline or strongly acid soils with limited nutrient availability, located in areas of high rainfall. The impact is reduced the deeper the soil profile, the finer the soil, the more the soils ph tends to neutrality and the drier the climate. In certain restricted situations (eg. high frost potential) compaction and soil disturbance may actually be beneficial to forest establishment.

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ACKNOWLEDGEMENTS

I am grateful to the Joesph William Gottstein Trust for providing me with the opportunity to undertake this study tour and trust the information contained herein will be useful to the forestry industry. Thanks are due to CSIRO, in particular Mr Bill Kerruish and Mr Allen Brown, the Chief of the Division of Forestry and Forest Products Research, who assisted in the development of my itinerary and supported my request for access to the US Army Mobility models. Thanks are also due to John Paul Senyk of the Canadian Forestry Service who arranged my visit to British Columbia and Victoria Island, Dr Iwan Wasterlund from the Garpenberg campus of the Swedish University of Agricultural Sciences, who arranged my itinerary in Sweden, and Mr Newell Murphy from the US Army Engineer Corps, who arranged my visit to Vicksburg, Mississippi.

I am also indebted to Mr. Neil Humphreys of Australian Newsprint Mills Limited, who has attempted to educate me on the practical problems encountered by a forest harvesting manager, and who arranged additional finance to assist me in the preparation of this report.

INTRODUCTION

Purpose of Study Tour

The primary objective of this trip was to evaluate the applicability of the US Army's Mobility Model to predicting the relative mobility and trafficability of logging machines on Australian soils. Secondary objectives were to visit other laboratories to obtain the latest information relating to the assessment of machine mobility and trafficability and to report to the Gottstein Trust any policy or other recommendations which are believed to be for the future of the forest products industry in Australia.

Itinerary

My study tour commenced on August 24th 1987 and was completed late in October. It began with my attendance at the International Society of Terrain Vehicle Systems conference in Barcelona (see paper listing in Appendix 1). The countries and institutions visited thereafter are summarised below.

Barcelona - ISTVS Conference

Britain - Institute of Hydrology

Sweden - Skogsarbeten, Swedish University of Agricultural Sciences and Osa factory

Canada - In Ottawa visited Carleton University. In Vancouver visited University of British Columbia. In Victoria visited Canadian Forestry Service and Macmillan Bloudel.

USA - In Vicksburg visited US Army Corp of Engineers

At the ISTVS conference I met scientists and engineers (some of whom I had intended to visit), working in the field of off-road vehicle design and evaluation and made detailed arrangements with some of them concerning my itinerary (this method of developing a detailed itinerary is to be highly recommended for the time it saves and the convenience).

Visit to Britain

The purpose of this visit was to examine instrumentation the Institute of Hydrology had developed in measuring soil moisture and to examine the models that they had developed for predicting soil moisture variations. This group was hard pressed for funds indeed under Mrs Thatcher's iron fist. It has become an overseas consulting organization and in order to survive was very reluctant to part with anything but the most general of information.

Visit to Sweden

The objective of this visit was to see how forestry research is structured in Sweden and to examine the research that is being undertaken in forest harvesting technology. While in Sweden my itinerary was modified to include a visit to Uppsala to assess the research that has been undertaken on the effects of soil physical conditions on plant growth and the implications this may have on future tractor and forwarder design.

Visit to Canada

My visit to Canada was primarily to review the research that has been undertaken over the last two decades by Dr Wong in the Department of Transport Engineering, University of Carleton and assess the applicability of his computer mobility models to evaluating logging machine trafficability. Secondary objectives were to visit the Canadian applied forestry research group FERIC and researchers on the west coast working at evaluating the environmental impact of changing from cable yarding and skidding systems on moderately steep and flat country to wheeled skidder operations.

Visit to USA

My visit to the USA centred on obtaining as much information as I could on the US Army's research on vehicle mobility relevant to predicting logging machine performance and evaluating the computer models that the military have developed for this purpose. It also involved a visit to John Deere.

SUMMARY OF ISTVS CONFERENCE

The proceedings of this conference are over 1000 pages long and therefore it is not my intention to summarise all the papers, a listing of which is given in Appendix 1. The sessions of most interest to the logging industry were:

session 1:	terrain evaluation
session 2:	the soil/vehicle interaction
sessions 3 and 4:	vehicle design and steering
session 5:	non-conventional land transport systems

Copies of papers to interested parties can be supplied on request.

A review paper on terrain evaluation by Dr George Balardi was most illuminating and extracts from that paper, which summarise the main techniques for trafficability prediction, are reproduced in Appendix 2.

Professor Wong presented a paper on the simulation and evaluation of tracked vehicle designs. He described a computer model which predicts the performance of tracked vehicles from their basic design features and on the basis of this model he made the following conclusions:

1. The higher the number of road wheels the better the tractive performance and the less the sinkage (this is a well known result).

2. An increase in the initial track tension result in less sinkage and better performance. This result is also well known and suggests adjustable track tensions from the cabin of a vehicle could be beneficial. However, higher tension means greater wear.

3. Locating the drive sprocket at the rear of a vehicle results in better performance through lower internal friction losses.

The model developed by Wong has been used to predict changes in mobility of heavy combat vehicles resulting from additional or shifted weights on the vehicle. It has applicability in evaluating the change in weight distribution for FMC skidders when they pull logs of various sizes. It can be shown that when an FMC skids logs substantial changes is ground pressure occur along the tracks, especially on slopes compared to wheeled skidders. The main reason for the rapid increase in ground pressure with ground slope and log load for the FMC skidder is the height of the retracted choker above the machine relative to other machines.

There were 3 papers in the sessions on terrain evaluation and soil/vehicle interaction relating to minimising the impact of forwarders on forest soils. Iwan Wasterlund and Bjorn Marklund presented reviews of their work aimed at designing "smoother terrain machines" and Jari Ala-Ilomaki presented a paper on the weight distribution of a forwarder and its effect on rut formation on peat land (Appendix 3). From Jari's tests on peat land one may conclude that damage to the surface layer of peat is smaller for forwarders of the same total weight but with a light front axle relative to the rear ones and is also less as the moment of inertia around the horizontal pivot axle between the front and the rear frame declines.

The reason for a light front axle causing reduced sinkage resides mainly in the strength properties of peat. Peat has a strong surface layer and it also has a threshold strength. As stress is gradually applied to peat it gradually yields but then a threshold is reached at which further shear displacement results in greater sinkage (Fig 1). If a heavy front axle crosses peat and the surface layer is broken then the rear wheels travel in softer material and so cause greater sinkage. On the other hand,

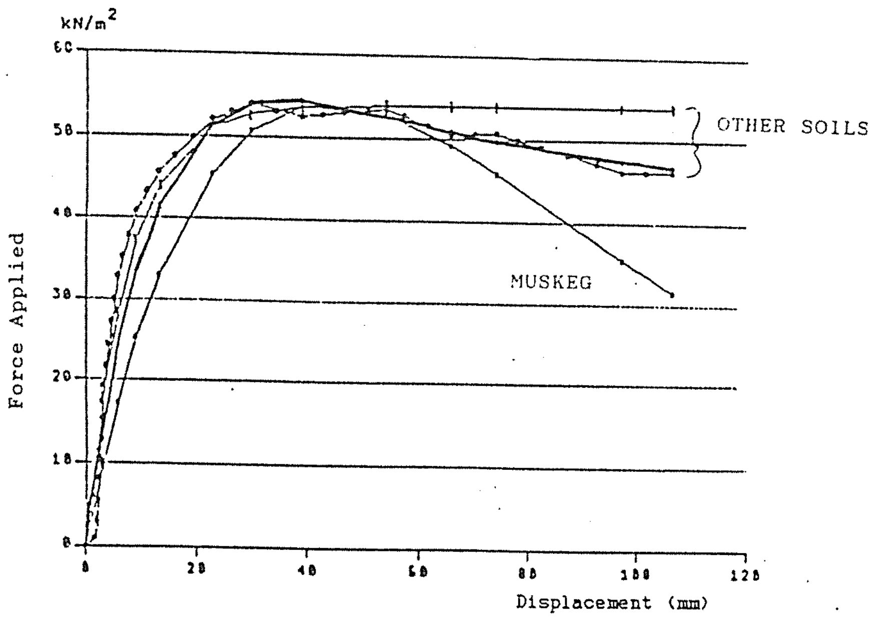

Fig 1. Sinkage of a flat plate versus applied pressure for muskeg and three normal soils.

if the light front wheel travels over the peat first, the threshold strength will not have been exceeded in at least some parts of the soil profile and thus, relatively speaking, the rear heavy axle will travel over a stronger surface. This result is pertinent to some Australian soil conditions. While peat is not very prevalent, perched water tables are overlain by a strong root mat do occur, eg Tumut region and Western Australia, and with such soils obtaining much of their strength from the root mat, a similar behaviour can be expected.

The reason the moment of inertia about the central pivot axis is important is that unprepared terrain is rarely flat and the ease with which the frames of a forwarder move relative to one another as a vehicle moves over rough ground determines to some extent the pressures that are applied to the ground.

In the section on vehicle design Dragan Kornicer outlined the history of development of logging machines in Yugoslavia. These machines were designed according to the following requirements:

1. Achievement of the greatest transport output possible measured in m3/hour .

2. The highest degree of utilisation in hours per year at the lowest possible cost.

The design of skidders and forwarders in Yugoslavia was heavily influenced by the need to develop vehicles around existing parts for agricultural tractors in order to cut the costs of the necessarily small production runs. What was most interesting was the application of morphological and statistical techniques to the specifications of currently available tractors on the world market to determine design parameters such as the length to breadth to height ratio and the weight to power ratio of the vehicles it was proposed to build and export.

A contrasting approach to vehicle design was given by Michael Dwyer from the Institute of Engineering Research in the United Kingdom. An analysis of the time farm tractors are used for various purposes show that they spent most of their time on transport tasks rather than the heavy draft work for which they were originally designed. In response to this result the Institute developed a hybrid vehicle which had a maximum speed of 65km/hour and had the ability to load and unload different bodies onto its chassis much in the same way as a forwarder (a manufacturer of small forwarders could possibly extend his market into this area if he included some suspension system on the vehicle).

These papers highlight two approaches to machine design. The first is to simply copy what has already been developed through trial and error elsewhere and incorporate all those features (including some design faults) into a new machine (the Yugoslav approach). The second is to analyse the proposed mission of a vehicle and design a machine around that mission rather than force the mission to match the machine.

In relation to this issue, consider the introduction of Swedish forwarders into Australia. Current forwarder design for servicing large forestry companies in Sweden is based on a mission that requires a vehicle to carry a large load over a rough, generally hard (frozen or dry) ground surface to trucks on roads. The terrain is generally not steep.

In Australia the ground is not frozen during winter and thus is often relatively weak and of low bearing capacity for a longer period than in Sweden. In plantations, the terrain is generally not rough, though it may be steep. This is not the mission for which the machine was originally designed. Thus in some situations, the introduction into Australia of Swedish forwarders designed for a different mission has introduced inefficiencies into the local logging system. For example, the road density required is higher than would be necessary if a logging machine of better trafficability characteristics were used.

Compromise is always required when designing or purchasing a machine. However, with the manufacture of a forwarder here in Australia becoming economically attractive, it would be of interest to determine objectively just what is optimum mission for such a machine in this country (an optimum mission would minimise the overall costs associated with harvesting timber - it may be that the mission for thinning regrowth forests is different to harvesting plantations). In forestry developments where the cost of roading is borne by the logging company, a hybrid forwarder/truck capable of covering significant distances at speed on unballasted roads might significantly reduce overall costs and also increase the efficiency within the forest. A prerequisite for such a concept is to include a decent suspension system into the machine.

Several papers were written on the physics of tyres mainly relating to their deflection, contact area and rolling resistances. Awatif Hassan presented a paper on a comparison between forestry and agricultural tyres. She found the performance of similarly sized tyres was almost identical on clay soils but on loam soils agricultural tyres performed better (efficiency 10% better) despite the fact that the forestry tyre had lugs twice the size of the agricultural tyre. The cause of the lower traction performance of the forestry tyre (and hence greater compaction and rut formation caused by it) could be attributed to the wide steel belting incorporated into the tyre which is required to minimise punctures. This resulted in greater carcass stiffness and less traction. The general conclusions on tyre performance from several papers was the softer the carcass the better the economy of operation.

One of the more enlightening papers was on the resistance forces in manual timber transportation - this is a system used in Tanzania. As a rule of thumb, a man can generate a pulling force over extensive distances equal to one fifth of his weight. After calculating the rolling resistance of the tyres on the small buggies pulled by coolies and undertaking an analysis of the local terrain and the size of logs brought to the mill, the author concluded the coolies were not pulling enough logs and that the load on each buggy could be increased without affecting their health.

VISITS TO MACHINE MANUFACTURERS

Three factories were visited: the Osa factory in Sweden, the John Deere factory in the USA and the Pegasus truck factory in Spain.

Visit to Osa Factory (host Hans Elofson and Kjell Michelsson)

Apart from viewing the production facilities at the Osa factory and the operator training centre there I attended a lecture given by Hans Elofson and Kjell Michelsson on the development of a Raumna Repola Group and their concern about the Australian market (they have observed closely the development of the Waltana machine).

Sales to Australia currently represent about 10% of their production of forwarders. The small size of the Australian market hardly justifies modifying their machines to handle the low bearing capacity of some of our soils.

Research facilities at the plant were very limited and were orientated mainly to mechanical engineering aspects of machine design. No research is undertaken on the geomechanical aspects of running gear design.

Visit to John Deere (host Bernard Poore)

John Deere established a soil bin research facility for obtaining traction prediction equations for off-road vehicles about 15 is portrayed in the institutions literature as applied research). New ideas must come from the universities and be proven goers before Skogsarbeten will support them.

The Forest Engineering Research Institute of Canada (FERIC) - host Ray Krag.

FERIC does similar work to Skogsarbeten and like that organisation is industry controlled. Like Skogsarbeten it concentrates on forest engineering projects, or putting into practice ideas which come from industry or sometimes, universities. One of FERIC's more notable projects was the development of an experimental forwarder which was demonstrated in 1986.

An extension and training service to industry was a major component of the operations of both institution's work. As the industry pays for these services there is a greater tendency for its managers to take notice of the advice it receives. Since industry pays it also ensures the persons providing that advice are qualified to do so too.

A significant contrast between the institutions is their attitude to the development of commercial products. Skogsarbeten neither develops machines nor applies for patents, feeling that this locks in research, whereas FERIC does develop machines and then asks industry to purchase the manufacturing rights, much in the same way as does CSIRO and British research institutions.

The Swedes argue that there is an inherent clash of egos between research and industry managers. Researchers believe what is important for human advancement is the generation of new ideas. Having chosen to work at the forefront of humanities struggle to advance, they feel they deserve recognition and prestige, and then often become paternalistic.

On the other hand industry managers feel that without them the world wouldn't go round, despite what scientists say, and generally they are not in the mood to beg or buy manufacturing rights from a patronising research organisation. This would be seen as reinforcing the research organisation's prestige at the expense of their own. The result, as the Swedes see it, is that for reasons of prestige, research becomes locked into the research institution and therefore they have set up Skogsarbeten to support in house company research rather than to conduct research in its own right.

A problem with this approach is that innovations in forest harvesting have generally originated not from Skogsarbeten and the large companies but from smaller, often back yard, operators who if they capture a slice of the market, are then bought out by large companies. Consequently, Skogsarbeten takes more of an evaluatory role rather than a development role which seems to be a waste of a valuable research resource.

In general, large companies which have captured a market have little need of research which is expensive and risky (eg John Deere/Rauma Repola Group). The main way small new companies can break into a market dominated by a large company is to produce a new product. From the point of view of the user, government funds would be better spent if bodies like Skogsarbeten were required to provide design information and new concepts which smaller operators/companies could use prior to production.

FORWARDER DESIGN TRENDS

At Garpenberg campus of the Faculty of Forestry, Swedish University of Agricultural Sciences, my host was Iwan Wasterlund and we concentrated on examining the work initiated by Bjorn Marklund (since left Garpenberg) relating to new forwarder transmission design. Marklund's hypothesis is that the surface layer of forest soils makes a major contribution to the total strength of the soil and that damage to this surface layer must be minimised if it is hoped to reduce compaction of the soil and the development of ruts.

When a vehicle's transmission is linked directly to all the wheels, tensions are built up within the transmission system especially when wheels are designed to rotate at different speeds. If a forwarder runs on a hard surface these internal tensions result in increased tyre wear but when machine runs on softer ground these tensions manifest themselves as wear and tear on the soil surface and breaking up of the organic layer. By providing each wheel with its own independent power system and limiting the amount of slip on each wheel Marklund believes there will be less damage to the surface layer and the bearing capacity of the soil will be much improved. They have in mind the use of micro-processors to control the drive on each wheel.

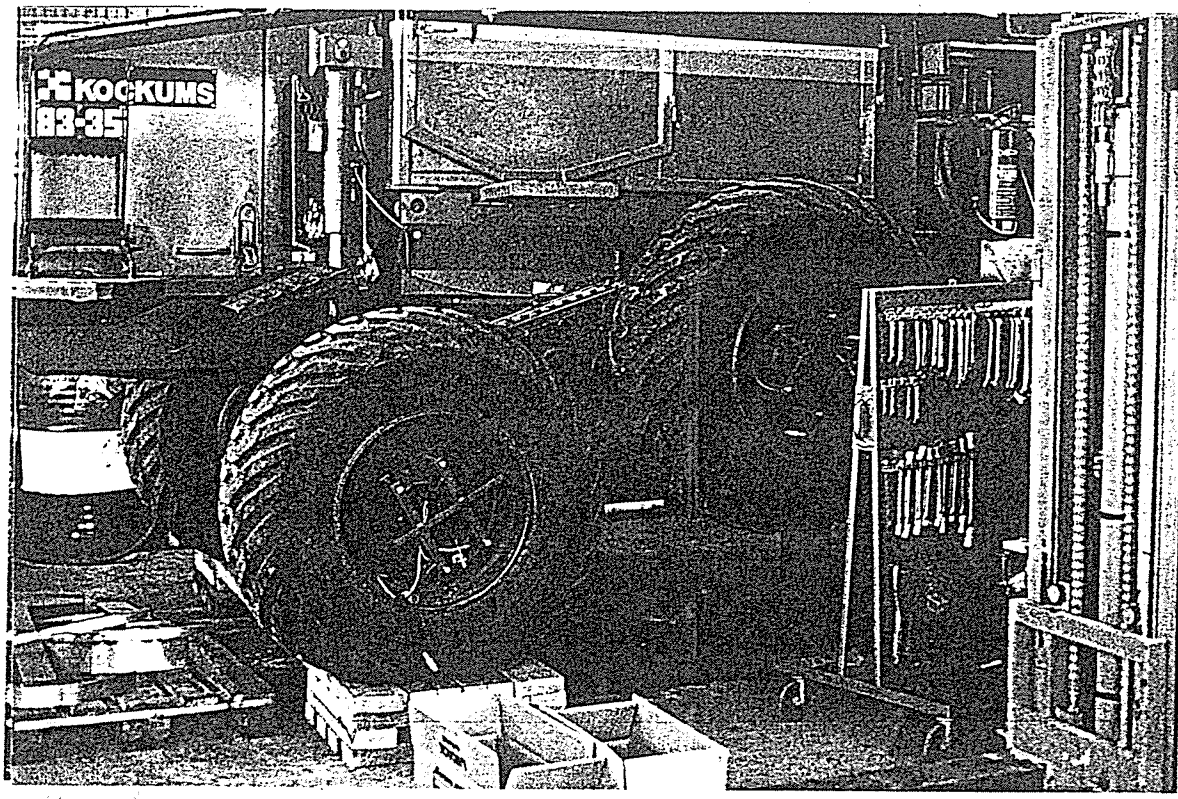

Fig 2. Mounting arrangement of recording instruments within wheel hubs. Note the hydraulic ram above the front bogie used to restrict the bogie movement.

The Forestry School at Garpenberg has been given a Kockums 83-35 forwarder. They have extracted all the axles from the machines, modified them to include strain transducers linked to micro-processor recording systems housed in the hub of each of the wheels. The system records all the vertical, lateral and horizontal stresses imposed on the wheels by the soil during normal operations (Fig 2).

The experiment has shown as expected, there are marked shear forces are induced on the ground due to the linkage in transmission between wheels of conventional forwarders. These forces arise mainly from changes in the effective diameter of the wheels as they undergo various degrees of deflection and from differential rates of wheel slip actually built into the machines to improve forwarder stability on steep ground. Once the force required on the wheels and its effect on the ground is understood it will then be possible to program the processor controlling the drive to each wheel to distribute the drive between wheels for any given situation, eg turning to minimise the overall impact on the ground.

In relation to forwarder design it has been the general experience at Skogsarbeten that the larger the forwarder the greater is its cost efficiency. However, at least on peatland there is also a general trend for large machines to cause deeper ruts for a given amount of wood transported (Fig 3a & b). This may not be the general case for all soils.

Research initiated to explain this result indicates that the design of the bogie wheel system is very important. When torque is applied to the bogie extra force can appear on the rear bogie wheel arising from moment forces about the bogie axles (Fig 4). When some machines travel upslope the extra torque augments to normal shift in weight to the rear of the machine and may result in 80 % of the total axle weight appearing on the rear bogie. This extra loading on the rear bogie may be countered by reversing the moments developed around the bogie drive shaft and changing gear ratios in the bogie. Good design practice should seek to balance all the opposing forces to ensure a balanced wheel loading (Fig 4a).

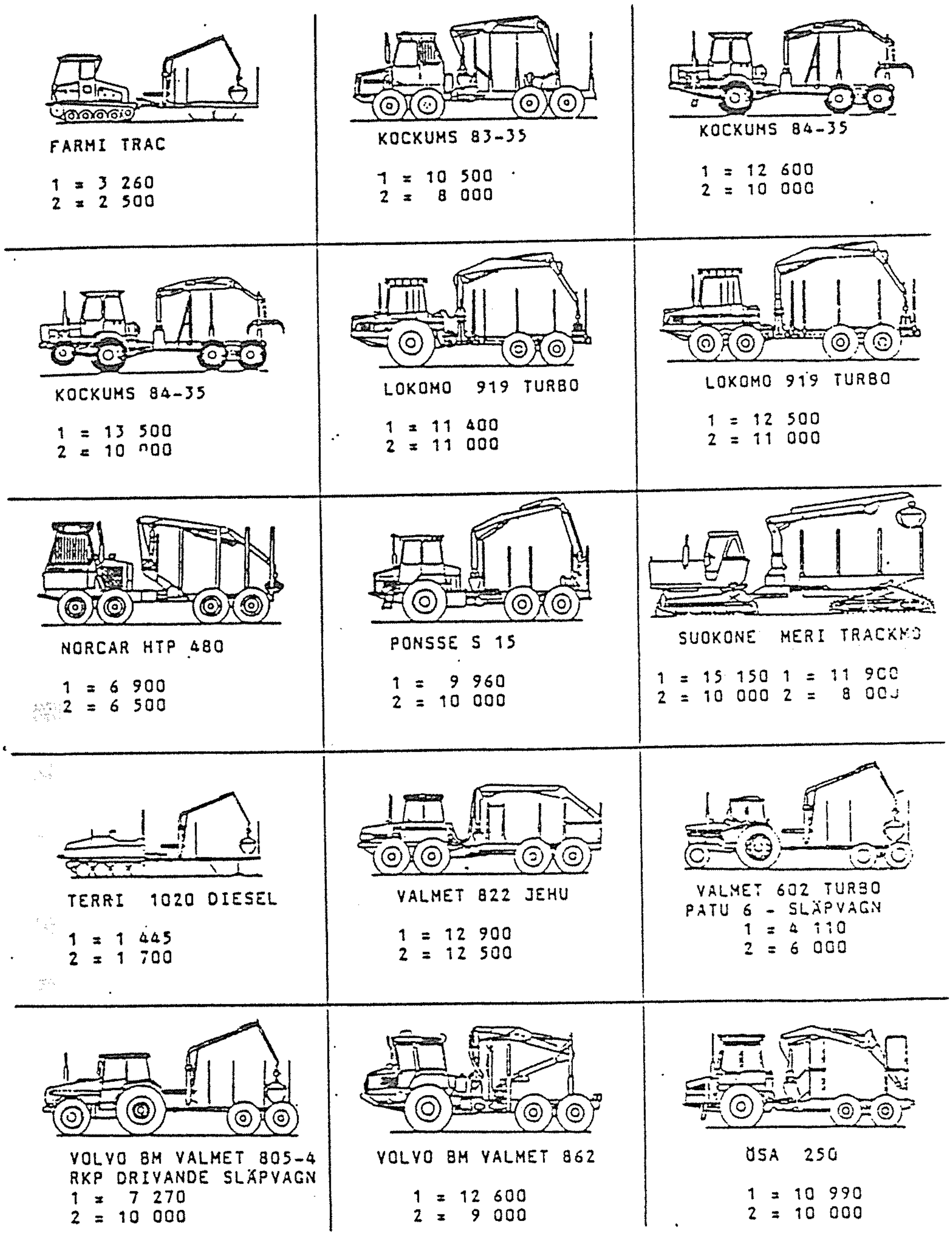

Fig 3a. Unloaded weights (1) maximum load(2)and configuration of forwarders used to obtain test results in Fig 3b.

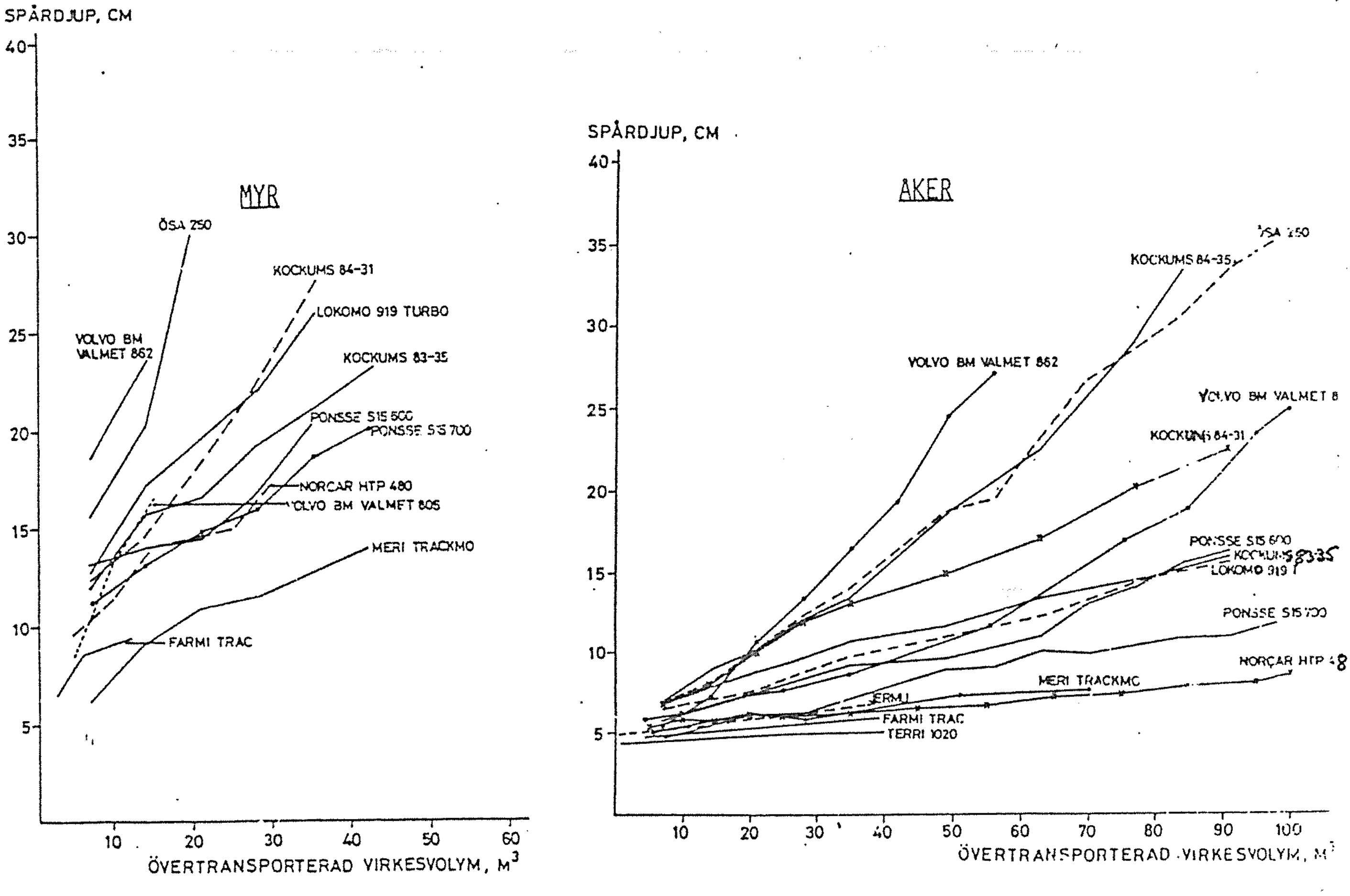

Fig 3b. Depth of rut caused by various machines versus total volume of wood transported across peatland (MYR) and agricultural load (AKER).

Loading of the bogie front axle as a proportion of the total loading x can readily be calculated from certain design parameters. As a proportion of the total load it is given by (Fig 4a):

$$x = 0.5 - u\left(\frac{p + r}{c} - \frac{r}{ic}\right)$$

where $u = F/N$

F = drawbar pull of bogies

N = bogie load

i = gear ratio within the bogie

p = vertical distance between bogie hitch point and wheel axle

c = axle spacing of bogie

r = wheel radius

The term $k = [(p + r)/c - r/ci)$ is a design parameter which should be minimised in order to minimise rut formation and maximise slope climbing ability on soft soils which is when the term u becomes large. Values of k for various machines and the resultant proportion of loading on the front bogie as u increases as shown in Fig 4b.

That such design problems are inherent in most forwarders is a consequence of the way in which the machines have evolved. Most vehicles have been built by small back yard operators. As they

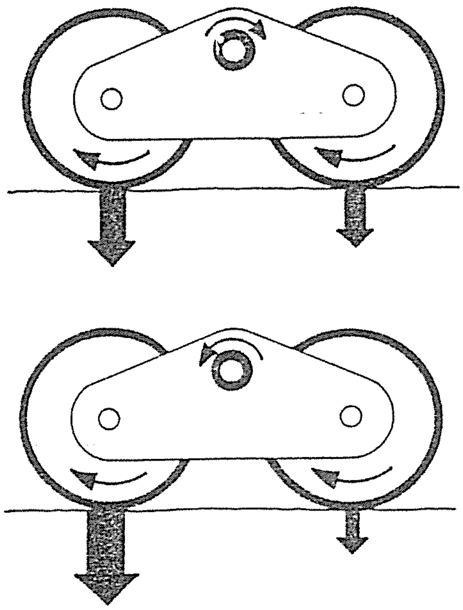

Fig 4a. Gearing of bogies can affect the relative weight transferred to the rear bogie.

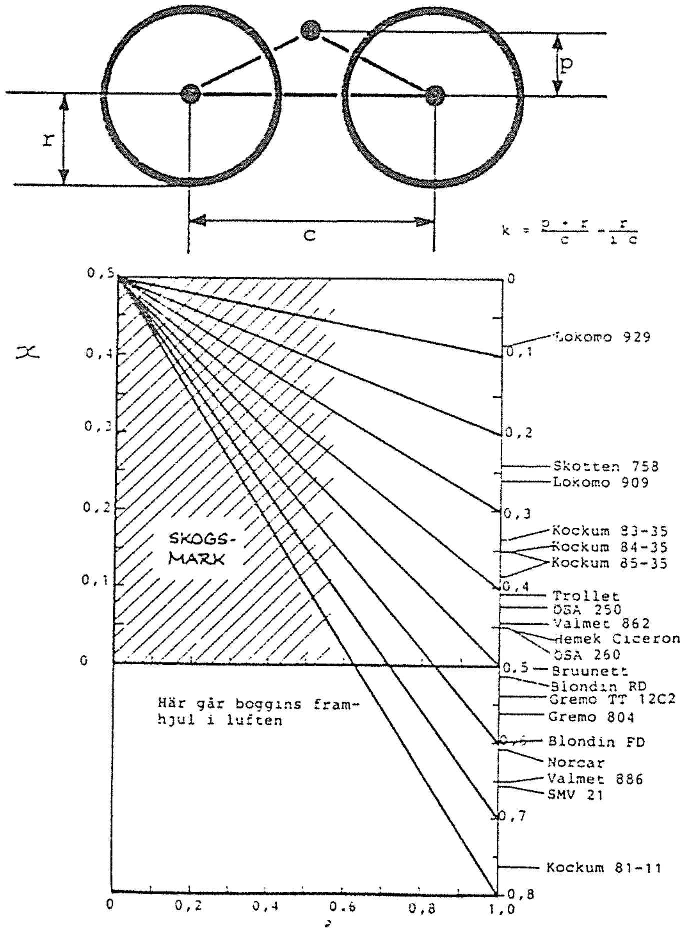

Fig 4b. The dependence of the fraction of weight on the front bogie on the ratio u = (drawbar pull)/(weight). When a vehicle is immobilised travelling upslope, u $\simeq$ 0.5.

expand and their market increases, larger companies come in and buy these operators out but generally produce the same equipment and undertake little further development. Consequently there are numerous machines available in Sweden, most of which have had design effort concentrated on the transmission, hydraulics and outward appearance of a vehicle (and more recently on their ergonomics) - (these would appear to be the main factors determining sales) but very little effort has been expended on the soil/wheel interaction. Current research in Sweden and Finland is aimed at rectifying this situation.

IMPACT OF MACHINES ON SOILS

Swedish till soils are highly compactable because of their wide particle distribution (glacial origins). Shear introduced into the soil as excessive wheel slip occurs, orientates the pores horizontally causing reductions in infiltration rates and regeneration problems. Prior to the 1980's, 30 % of strip roads in Sweden had ruts in them deeper than 100 mm but through better planning of operations and the introduction of smaller machines with wider tyres the degree of rut formation has been reduced by one third.

The concern with such ruts is that the area between the ruts does not seem to be utilised by the remaining trees. Experiments have shown that the fruit bodies of mycorrhizal fungi do not appear between the wheel ruts and that when phospate applied to the area is not taken up by the trees despite the fact that herbs and shrubs flourish between the wheel ruts giving an overall satisfactory visual appearance to the forest. Growth reductions of up to the 30% have been observed near the ruts. However the effect on growth is determined largely by sight quality and whether nutrient availability is a factor limiting tree growth. It is because of concern over the likely impact of harvesting operations on tree growth that the experimental program at Garpenberg aimed at evaluating the forces applied to the soil by machines and the effect these forces have on the bearing capacity of the soil was started.

Iwan Wasterlund's experiments involve the application of shear forces to the ground and examination of how these forces affect the penetration of a wheel. Iwan's methodology is to press a curved plate into the ground which is coated with rubber on the underside to measure the sinkage as a function of the vertical stress and horizontal slip applied to the curved plate (Fig 5). Some initial results from these experiments (Fig 6) indicate there is ground pressure threshold above which any slip (displacement) contributes to increased sinkage.

In Victoria, Canada, I visited Dr Bob Smith and Dr John Paul Senyk of the Pacific Forestry Centre who are investigating the environmental effects of logging operations. This group is currently working with industry in an attempt to assess the impact of the reintroduction of skidders to replace cable logging systems in some of the moderately steep country in western Canada. Ground skidding used to be the major logging system in east British Columbia and was used on slopes with gradients in excess of 40 %. On such slopes skids roads were excavated into

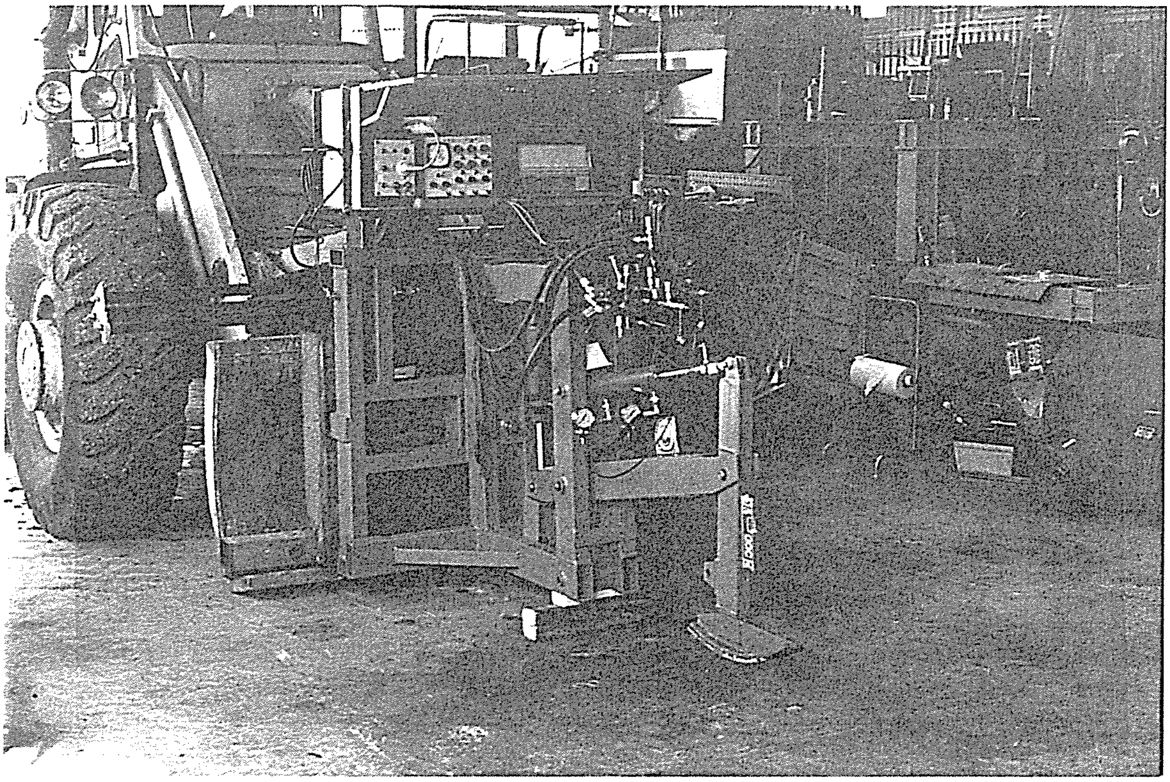

Fig 5. Recording equipment and shoe arrangement designed to simulate the forces applied to the ground by a wheel.

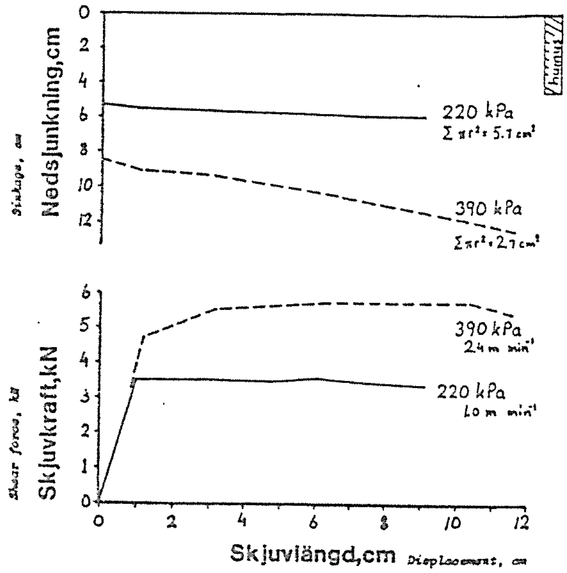

Fig 6. The dependence of the sinkage and horizontal displacement of a curved plate (simulating a wheel) and the applied load and shear force.

the contour to provide a safe running surface for the skidders. Construction of these contour skid roads on steep slopes entailed deep gouging of the soil profile and its displacement outwards as fill and side cast. It resulted in about 30 to 35 percent of a clearcut being covered by bare ground consisting of skid roads. Studies indicated that height growth was reduced by the order of 10 to 15 percent. Soil exposed on the inside skid roads often had different characteristics than the upper undisturbed layers. Even when this soil was mixed with top soil an influence on subsequent tree establishment and growth was observed. Growths were generally lower for trees on the inner half than on the outer half of skid roads. Tree growth was reduced most on calcareous, shallow or coarse textured soils in a wet bioclimatic region. Least sensitive sites were those with slightly acid non-calcareous medium to moderately coarse textured soils in dry climates. From observations of the reduced growth, Dick Smith developed the rating system for estimating the growth reduction following soil disturbance shown in Table 1.

Problem sites are those with ratings of 7 or more and can be expected to experience a loss in height of 5 to 15 percent based on 32 % coverage of skidder trails. This growth reduction should be increased or decreased proportionally with increasing or decreasing skidrow density. Those sites with a rating less than 7 may suffer small growth losses or in special cases an enhancement in growth of up to 20 %. In eastern British Columbia the latter are an extreme minority.

Table 1 Rating scheme for assessing sites for growth response of trees growing on skidroad surfaces.

Factor		Degree	Points	Characteristics[1]
1. SOIL ACIDITY	a)	Calcareous: free carbonates within 1 m of surface; pH 7.0 - 8.5; usually Eutric Brunisols, Regosols and Gray Luvisols.	6	Very low availability of elements such as P, Fe, Zn, B and Mn (Thorne 1955; Lutz and Chandler 1946).
	b)	Acid: pH of C horizon less than 5.6 (measured in $CaCl_2$); usually Podzols and Dystric Brunisols.	3	Low rate of microbiological tranformations (Thorne 1955); low N availability, low cation availability (Pritchett 1979).
	c)	Neutral: non-calcareous in upper 1 m and pH of C horizon 5.6 or greater; usually Eutric Brunisols, Dystric Brunisols and Gray Luvisols.	1	Relatively favorable nutrient status and availability throughout profile.
2. SOIL TEXTURE and DEPTH	a)	Coarse: sands and loamy sands; and/or shallow: less than 1 m to bedrock.	3	Low cation exchange capacity in mineral soil; low soil volume; low moisture holding capacity in mineral soil; rapid leaching of nutrients.
	b)	Moderately fine to fine: sandy clay, clay, silty clay, clay loam, silty clay loam.	2	Restricted root growth through compaction by machinery and naturally compact horizons (Forristall and Gessel 1955; Pearce 1958; Dyrness 1965).
	c)	Medium to moderately coarse; sandy loam, loam, silt loam, silt, very fine sandy loam.	1	Relatively high cation exchange capacity in mineral soil; moderate to low compactibility.
3. CLIMATE	a)	Wet: Engelmann Spruce - Subalpine Fir Zone in Moist and Wet Biogeoclimatic Regions (Utzig *et al.* 1978) and all Western Hemlock Zone.	3	Rapid leaching of exposed mineral soils which are generally podzolized and of relatively low base status.
	b)	Moist: Engelmann Spruce - Subalpine Fir Zone in Dry Biogeoclimatic Regions and all Sub-boreal Spruce.	2	Moderately rapid leaching of exposed mineral soils which are weakly podzolized, Luvisols or Brunisols of moderate base status.
	c)	Dry: Interior Douglas-fir and Ponderosa Pine zones.	1	Slow leaching of exposed mineral soils which are Brunisolic to Chernozemic and provided with relatively high base status and more uniform organic carbon distribution.

[1] General notes on nutrient status of the various soils comes from Smith (1965) and Valentine, *et al.* (1978).

Widespread concern over the amount of soil disturbance associated with clear cut logging on steep slopes led to the British Columbia Forest Service prohibiting all skidding on slopes over 70 % and restricting its use on slopes between 50 and 70 percent and the gradual replacement of skidder operations by cable logging systems.

On the west coast, because of the steep terrain and very strong environmental pressures, cable yarding systems have become the norm. The trouble with cable yarding here is that timber is smaller on the slopes yet the cost of logging increases on the steeper slopes. Therefore the industry is trying to develop a cheap logging system in the valley floors to balance the costs.

I visited one experiment at Worthless Creek aimed at evaluating the impact of skidding using wide tyres on moderately steep terrain and examining the factors which have caused failures in regeneration in the region. The Worthless Creek experiment (Fig 7) has involved the detailed monitoring of skidder routes during the logging operation after the logging operation measurements have been made of the changes in soil physical conditions on tracks of various intensities of trafficking. A weather station has been installed on the site and temperatures in the tracks and in undisturbed soil are being monitored to determine the best forest establishment practice.

In general the temperatures in the tracks are higher by 2 to 3 degrees centigrade. In some cases, where compaction is not too intense, this could be beneficial to tree growth in reducing the

Fig 7. Terrain and soil disturbance following skidder logging at Worthless Creek.

potential frost damage. The area logged is about to be planted and it is intended to compare the success of regeneration in a series of plots with the amount of soil disturbance in these plots. During the planting of this area considerable care will be taken to account for the micro-climate positions. To assess the effects of microclimate plants will be placed in low spots and in shaded areas because water in summer is limiting and their growth will be monitored. Others will be planted in exposed mineral soil because the site is cold and their growth monitored too.

John Deere provided me with results of a study on the relative compaction caused by a crawler tractor (Caterpillar D6D) a rubber tyred skidder (John Deere model 640 with 23.1 x 26 tyres inflated to 20 psi) and an FMC 210CA tracked skider. The results (Figs 8a & 8b) suggest at first, that the John Deere machine and the FMC caused less compaction than the crawler tractor, but when it is taken into account that the John Deere machine requires twice as many passes to extract the same volume of timber, its performance tends to match that of the crawler tractor. Overall, the FMC produced the least impact on the soil for the soil moisture conditions encountered.

This study also showed 54 % of the variation in compaction between sites and machines could be explained in terms of the number of trips and the original soil strength (cone index). Only a further 14 % of the variation was explained by considering the applied ground pressure, the soil organic matter, its intial density, moisture content and the depth of the water layer.

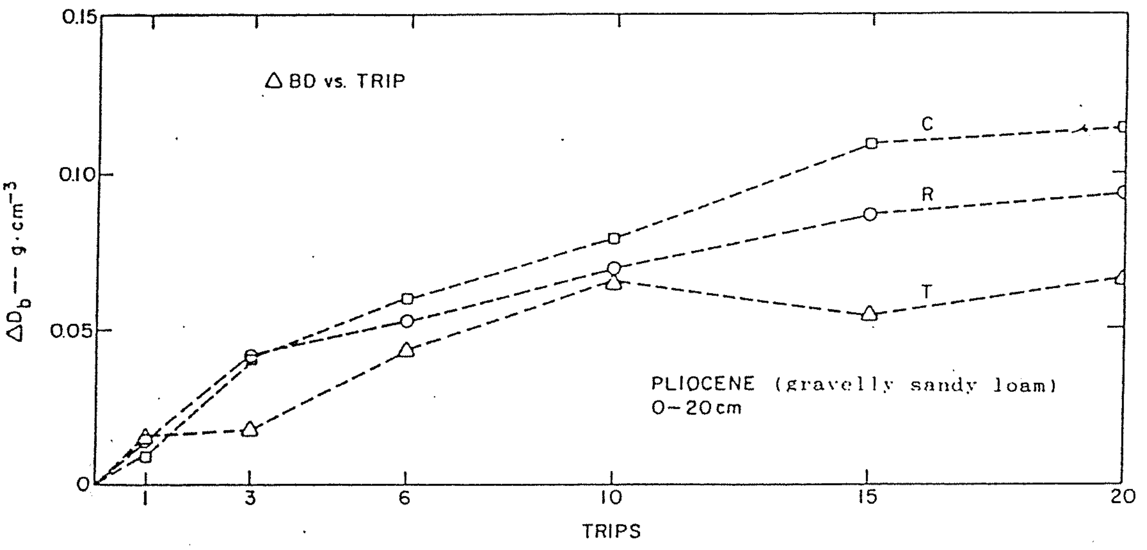

Figure 8a Cumulative change in soil density in the surface 20 cm with successive trips with three different logging vehicles. Vehicle code: C = crawler tractor; R = rubber-tired skidder; T = torsion suspension vehicle.

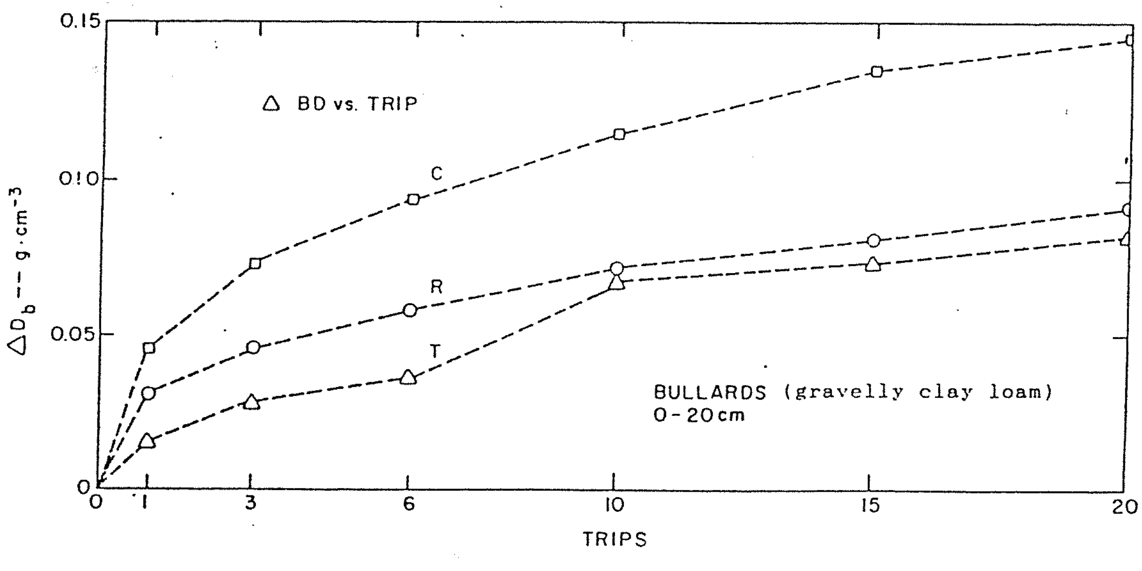

Figure 8b Cumulative change in soil density in the surface 20 cm with successive trips with three different logging vehicles. Vehicle code: C = crawler tractor; R = rubber-tired skidder; T = torsion suspension vehicle.

Macmillan Bloudel Project

Since 1974 Macmillan Bloudel Limited has had its own group of scientists and environmental specialists to assist its divisional engineers and foresters. The men and women who formed the Land Use Planning Advisory Team specialise in forest sciences, soils, wildlife, fish, water resources and growth and yield projection. The group reviews harvesting plans and advises of methods of mi.imising or eliminating the impact of harvesting on non-timber resources. The company is very conscious of public relations and produces a number of pamphlets and booklets explaining exactly what its forestry operations involve and the reasons behind certain activities.

The objectives of the study initiated by the company, that I visited were:

1. To compare the compactive effects of ground based yarding on several coastal soils over a range of soil moisture conditions.

2. To establish baseline sites suitable for evaluating the growth of conifer seedlings on compacted soils.

3. To provide data which will assist in the development of guidelines for the use of mechanised harvesting equipment on coastal sites.

This project was unique in that it is the first I have seen initiated by industry on this topic. Having established the program the company has asked government research workers to become involved in the study and this indicates a move away from the adversary situation of industry being policed by government, to a situation where industry initiates and undertakes research aimed at maintaining the productivity of its resource base. This is consistent with the company's policy to know about potential problems before they happen and to seek external inputs into the decision making process. While the company is generally happy with the internal advice it received based on the enormous experience of its logging managers, it recognises the need to obtain other inputs to counter possible claims that the company has undertaken a subjective analysis of a situation for its short term advantage.

Relevant trends in agriculture

The foresters at Garpenberg have kept a close eye on compaction research in the context of Swedish agriculture. While they are undertaking some research on the effects of compaction in forest soils it is difficult to quantify the effects of such soil disturbance on tree growth because of the long term nature of such experiments. In the case of annual crops the impact of compaction can be readily measured on an annual basis.

Inge Hakansson in the Department of Agriculture has been undertaking research in relation to the effects of compaction on the growth of annual crops for the last 15 to 20 years. It is found that the crop response (decrease in growth) to traffic persists for more than 5 years and increases with a clay content of a soil and traffic intensity. On sandy soils it is concluded compaction below 500mm is permanent even though Swedish soils undergo freezing and thawing (very relevant to logging around Mount Gambier). He observed at all sites that he has studied axle load of 10 tonnes cause subsoil compaction to depths of at least 500 mm. With observed compaction effects persisting for at least a decade, the economic consequences of reduced growth are so great cable systems of tillage are being promoted. An international working group on soil compaction by vehicles with high axle loads has also been formed with the objective of making recommendations to tractor manufacturers to limit the size of all agricultural tractors working in Europe to <u>axle loads less than 6 tonnes</u> when working on clay soils and less than 10 tonnes when working on any other soil type. In Australia, we do not have freezing and thawing conditions and so compaction effects are likely to persist much longer.

The relevance of such compaction effects on the design of the logging systems is difficult to estimate. As the value of the crop produced increases the economics justify trading off a decrease in machine productivity against the higher yields that result. However, if the cost of logging is very high relative to the value of the trees in the forest then it may be better to accept the lower yield associated with compaction in order to reduce logging costs and improve the efficiency of the total harvesting operation.

DEVELOPMENTS IN FOREST ESTABLISHMENT

One project that was being undertaken at Garpenberg involved the quantifying of forces necessary to scarify different soil types. The aim was to control the forces on the scarifying element in the same way as it is proposed to control the forces applied by a forwarder's wheel on the soil. The objective is to minimise blade damage when striking stones and allow the scarifying blades to follow the ground contour more closely. The system represents a more sophisticated version of Australia's stump jump plough and the use of forwarders as the base machine for this operation seemed to be an overkill.

At the University of British Columbia I spoke to Dr Andrew Black who is currently undertaking a program of research on site preparation and planting procedures aimed at minimising seedling water and temperature stress and maximising seedling survival rates. Andy is well known for his work in evapotranspiration but his interest has shifted to applying basic principles of environmental physics to establish the optimum environment for seedling regeneration. Their findings to date is that large scalps (at least 1.2 metres wide) improve survival and growth of planted seedlings in central Idaho. There are good reasons for this.

Central Idaho has a high frost potential and the effect of scalping is to increase soil temperatures and air temperatures just above ground level. They also have the benefit of reproducing competition for soil moisture early in the summer period. However, scalps have the disadvantage of removing a potential supply of nutrients. The application of herbicides reduces this problem and also overcomes the problem of competition for soil water in the summer period. Unfortunately, herbicides still maintains the presence of organic matter which increases the risk of frost damage during cold winters. It is evident that there is no universal optimum method of site preparation and that several factors including the climate, soil fertility and soil physical properties have to be considered when determining an appropriate rehabilitation procedure.

SIMULATIONS OF VEHICLE MOBILITY

Visit to Dr Wong, Canada-Department of Transport Engineering, University of Carleton, Ottawa.

Dr Wong has been working in the field of locomotion for over a decade. He has recently established a consulting company, Vehicle Systems Development Corporation, which has available for hire two computer simulation models for evaluating and predicting the tractive performance of tracked and wheel vehicles over unprepared terrain. These simulation models are tools that can be used by vehicle procurement managers in the selection of vehicle candidates for a given mission and environment (descriptions appear in Appendix 6).

Soil parameters used in the models are based on the Becker approach (the analytical approach - see Appendix 1) to characterising soil trafficability. The instruments required for these parameters are expensive to construct and operate and logistically difficult to employ and therefore Wong's models and approach are pertinent mainly to evaluating machine design. They do not have any ready application to predicting the performance of vehicles on a routine basis mainly because of the difficulties associated with obtaining the temporal variation in soil parameters required as input for his models.

Access to the models can be obtained through his own private company at a price we did not discuss. Dr Wong says he has a library of soil parameters and is prepared to undertake logging machine evaluations given the appropriate vehicle parameters and description of the soil. His models have the greatest applicability to understanding and evaluating the relative performance of track skidders and wheeled skidders on various soil types. Numerous papers were obtained from Dr Wong, summarising his work over the last 2 decades. Relevant titles are given in Appendix 7.

At Vicksburg, Mississippi, I was successful in obtaining access to the US Army-Nato mobility computer model for predicting the off road performance of military vehicles and have brought back to Australia, for use by the CSIRO and the forestry industry two sub-models referred to as the Vehicle Cone Index model (the VCI model) and the soil moisture-strength prediction model (SMSP model) and other information that can be used to predict the mobility and trafficability of logging machines on various terrains.

Description of the VCI and SMSP models

The VCI model computes from certain vehicle characteristics (eg axle weight, tyre dimensions, transmission type etc.) the soil strengths required to obtain one and fifty passes over the soil. These soil strength values computed for a given vehicle, are known as the vehicle cone indices (eg VCI(1), VCI(50)), some of which are listed in Table 2. Relations have been obtained from

TABLE 2: VCI(50) VALUES FOR VARIOUS VEHICLES

Vehicle Description (military specs.)	Vehicle Weight	VCI(50)
CARGO TRUCK 10 ton M125 (6 x 6)	22 tons	84
TRUCK, wrecker 10 ton M 553 (4 x 4)	18 tons	94
FUEL TRUCK 9.5 ton	19.3 tons	111
CATERPILLAR D4	8.6 tons	49
TRUCK TRACTOR 5 ton M818 towing 12 ton semi-trailer	-	111
Logging Vehicles		
OSA 280 (carrying 11.5 tons)	32.5 tons	107 (82)
KOCKUMS 85 - 35 (carrying 11.5 tons)	32.5 tons	112 (98)

(Bracketed values are for wide tracks fitted to 22 x 25/16 tyres) the Mobility Division which allow the VCI(50) value to be converted into a predicted rut depth after a given number of passes. Relations have also been obtained which give the extra soil strength required for a vehicle to pull a given load up a given slope fifty times before being immobilised (the capability to obtain 50 passes translates approximately to the development of ruts 100 mm and 200 mm deep after 3 and 12 vehicle passes respectively).

The VCI model has been developed for standard vehicle configuration and requires modifications to assess appropriate VCI values for skidders and forwarders. Specifically, modifications are required to account for:-

1. change and increase in weight distribution with load;

2. change in weight distribution with slope (especially FMC tracked skidders);

3. increase in drag with log load;

4. in the case of forwarders, the bogie weight distribution.

The VCI model does not incorporate some other design features known to influence forwarder mobility such as vehicle articulation and the steering system.

The Soil Moisture - Strength Prediction Program (SMSP) computes from relations obtained in the laboratory and from a data base of seasonal soil moisture changes, average soil strengths for eleven soil types (classified according to the Unified Soil

Classification System) under five drainage conditions subject to given rainfall conditions. The soil strength this model predicts is measured in terms of the Rating Cone Index (RCI) which can be measured directly using a cone penetrometer and remold kit.

An assessment of a vehicles mobility is obtained by comparing the VCI value for that vehicle computed from the first program (see Table 2) with the measured or predicted RCI value for the soil. If the VCI(50) value is less than the soil RCI value than the soil is too weak to support fifty passes of the vehicle.

For a given geographical area SMSP predicts soil strengths in terms of rating cone index (RCI) from a statistical representation of the long term rainfall of that area. The model also makes predictions from an actual daily rainfall record lasting over a period of one year. Predictions are made for four classes of ground surface seasonal scenario (dry, average, wet, wet wet seasons). These four seasonal classes are defined as follows:-

a) SUMMER (dry) - maximum average RCI for thirty (30) consecutive days.

b) TRANSITION (average) - maximum average RCI for 180 consecutive days.

c) WINTER (wet) - minimum average RCI for 30 consecutive days.

d) WET WINTER (wet wet) - the daily rainfall is multiplied by 1.5 and the average resulting minimum RCI for 10 consecutive days is the wet wet condition.

The wet wet condition approximates the occurrence of an especially wet season. SMSP also requires as input the approximate dates of the change of one season of the year to the other. Summer, winter and transition (spring/autumn) drying curves are generally used in SMSP and transition dates are needed to determine when to shift from one set of depletion curves to another. Since the changes in soil moisture depletion rates are caused by seasonal variation in weather and vegetation the season transition dates vary both with latitude and elevation and may change at the same location from year to year.

For the SMSP model to be of benefit to the planning of logging operations the following modifications are required:

1. change soil classifications to match Australian forest soils;

2. change in output format according to industry needs.

The main limitation and concern regarding this model is that it does not directly take into account evapotranspiration as a factor determining soil moisture (however it is implicit in the soil moisture depletion relations contained in the model). This is unlikely to be a significant problem in winter in the temperate regions of Australia (while precipitation exceeds evaporation), but may be a problem in tropical regions or during the transition seasons in temperate climates.

Test of VCI and SMSP models

Descriptions of the soils near Tumut obtained from soil scientists in the NSW Forestry Commission were provided to US Army Engineering Corps personell who reclassified them according to the Unified Soil Classification System used in the SMSP model. An average years rainfall record was fed into the SMSP model and the results obtained are consistent with observations obtained over the past year. For example for soils derived from basalts which are known to be slippery but loggable in wet conditions, the model predicts there would be no 10 day period during a wet winter (rainfall 50% above average) over which at least fifty passes could be obtained by a fully loaded OSA 280 forwarder (without tracks) whereas on clay loam soils derived from granites, the model predicts there would be a period of at least ten days when the same machine would not be able to achieve a single pass. This is consistent with the known logging characteristics of the area.

INNOVATIVE DESIGNS OF RUNNING GEAR

As a general rule, trafficability is improved, the lower the ground pressure and the internal tyre pressure. Off road vehicles capable of carrying similar loads to large forwarders on muskeg that do not cause ruts have been designed (Fig 9). Their main feature is the use of soft Rolligan tyres placed well under the vehicle chassis to minimise the width of the vehicle. The main disadvantage of such vehicles is the possible puncturing of the tyres in a rough forest terrain but with the advent of high

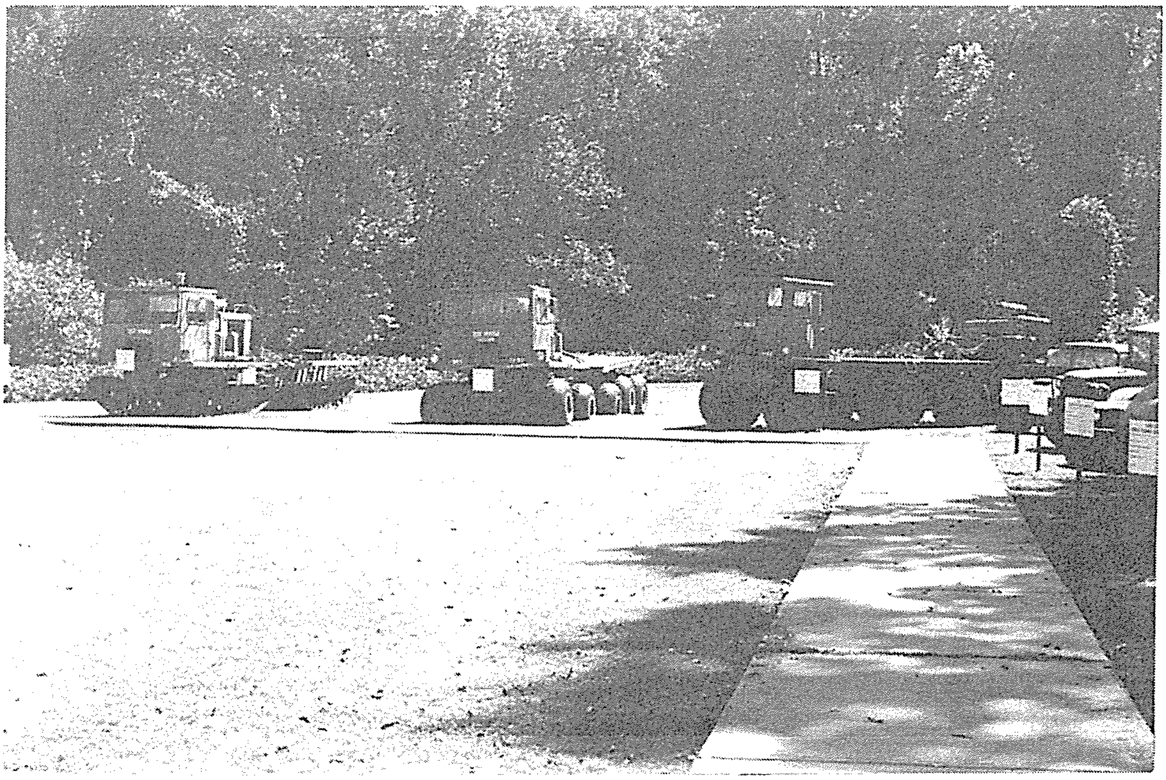

Fig 9. Example of trucks developed by the the oil industry for operations on muskeg.

strength fibres capable of replacing the steel webbing generally used in forestry tyres, there is no technical reason to why soft tyres suitable for forestry operations cannot now be manufactured.

In the longer term, the loop wheel (Fig 10) may eventually replace tracks. Developed by Lockheed, it consists of a circle of elastic material spread into an ellipse by two or more inner rollers. When installed in a vehicle it combines the functions of load carrying and spring suspension and distributes the load over a very large footprint. A farm tractor trailer based on the loop wheel suspension system is currently being developed in Germany.

LOOPWHEELED FARM TRAILER

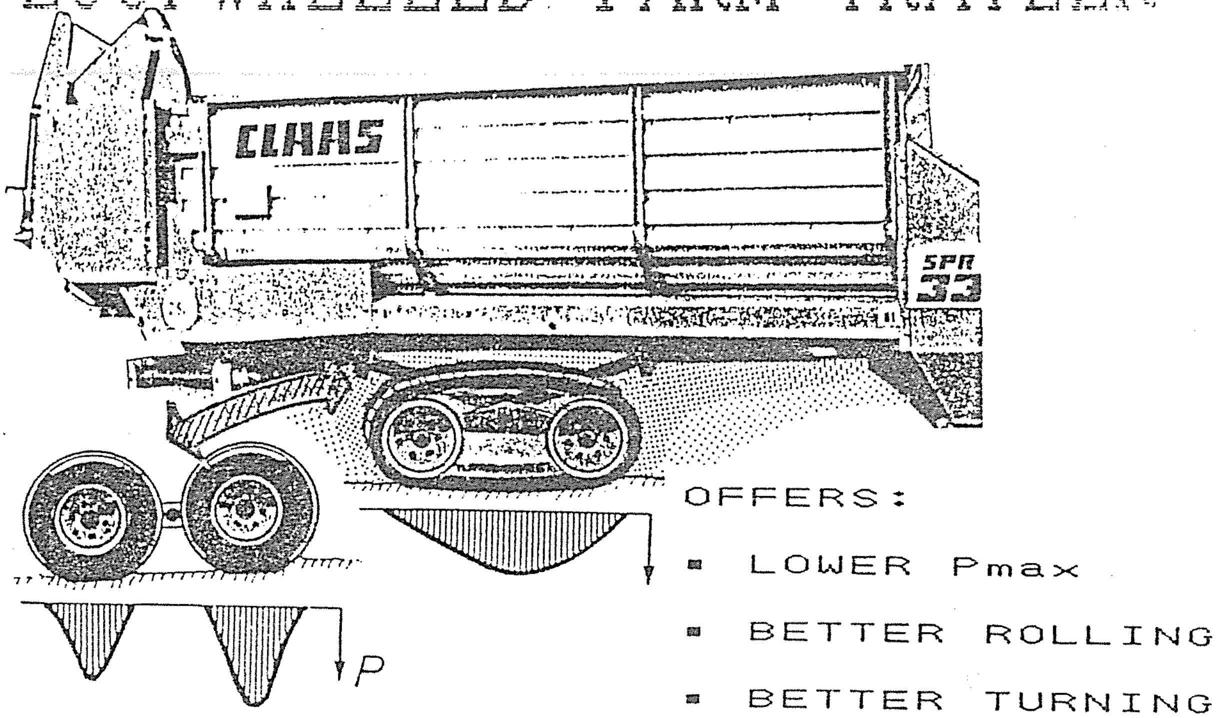

Fig 10. The LOOPWHEEL shows equal promise in farm and forestry mobility. In a pilot project just getting started in West Germany the bogie wheel suspension of a heavy farm trailer (11 ton axle load) will be replaced by LOOPWHEELS which - contrary to the high mobility applications discussed before - will be suspended in a very simple and low-cost manner by two steel wheels mounted on standard trailer hubs and bogie suspension. The LOOPWHEELS' very benign pressure distribution as shown is expected to lower peak ground pressures by roughly 40 % with respect to tandem wheels and also reduce rolling resistance substantially. Improvements are likewise expected during turning maneuvers where the near-elliptical pressure distribution should reduce soil damage noticeably.

MISCELLANEOUS PROJECTS

Other research programs that were reviewed at Garpenberg was the development of a bunch delimber. This machine arises from the Swedish policy of maximising the energy production from a forest. The basic idea is to forward whole trees to a central station where the waste can be collected and fed into a chunker machine for producing wood chips. The prototype machine that was seen had much development still to be undertaken.

In Nanaimo, Victoria, I visited the company Digital Resource Systems limited who produce a geographic information system called "Terrasoft" which has application to mapping trafficability.

Equipment

The Institute of Hydrology in Britain was working on an instrument for measuring soil moisture based on measuring the day to day variation in di-electric constant of soil mass. This is not new. Like the neutron probe, which is the most precise way of directly measuring soil moisture the instrument is also slightly effected by the chemical constituents of the soil. However, it has the advantage of being much cheaper and more stable in the long term and can be left in the field over a full season. Once fully developed these probes could be used at base stations in an area and to be used on a routine basis to measure soil moisture for trafficability and fire hazard predictions.

At the Waterways Experimental Station (WES) in Vicksburg I obtained the drawings for the WES penetrometer and remold kit. Soils often become weaker after trafficking (rootlets broken, structure broken down) and in order to predict the strength for multiple vehicle passes this decline in strength must be measured. This is done by inserting a cored sample into a container and measuring its strength with a penetrometer before and after remolding the sample in the container.

GENERAL CONCLUSIONS

Forwarder design features

In order to minimise soil disturbance by logging vehicles and maximise their operating efficiency, the following features should be assessed when purchasing a machine:

1. The design of the bogie wheel transmission should be examined. The ideal machine is one where moment forces about the bogie axle arising from the drive torque counter the tendency for the weight on the bogie to be shifted to the rear wheel when travelling upslope.

2. The weight distribution between the front and rear wheels should be as even as possible, as sinkage increases exponentially with load.

3. The moment of inertia about the pivot axis between the front and rear wheels should be minimal. This is achieved by having the pivot axis as close to the centre of gravity of the loaded machine as possible.

4. Undue shear stresses on the soil should be minimised. With current design trends this latter requirement is impossible. In general, machines are designed with the front wheels travelling slower than the rear. The main reason for this is that the rear half of the machine generally has a high centre of gravity when loaded and if the front half is pulling the rear, there is a tendency for machines to topple over on steep ground when it turns uphill.

5. The main advantage of an articulated vehicle is that its turning radius is generally reduced and the wheels of a vehicle can be maintained in a single rut during turning which improves trafficability by reducing the resistance to forward motion. An indication of a vehicles capability in this area is the ratio of its road width on full turn to that when travelling straight. The closer this ratio is to unity the better the machine. Few machines on the market are capable of creating a single rut during a turn.

Relative to military cargo trucks, the trafficability of typical forwarders with standard wheel configurations is poor, largely because of the weight incorporated into the chassis of these machines. Only when wide tracks are fitted to the widest tyres available does their VCI(50) value approach that of military trucks. However it should be noted the VCI(50) values for forwarders given in Table 2 are pertinent to operations on flat ground. On slopes they could increase by the order of 20 -30 % depending on the bogie wheel design. In certain situations where forest roading costs are high, and the topography is steep, it might prove worthwhile to replace a forwarder with a 6 x 6 or 4 x 4 wheel articulated 10 tonne military truck.

Soil Disturbance and Forest Establishment

It is clear that in Canada significant reductions in site productivity occur on some steeply sloping ecosystems when ground skidding is employed. On other ecosystems, effects appear minimal or even favourable to tree growth. By using a rating system based on soil and climatic factors the direction and general degree of response to disturbance has been estimated. Basically tree growth is inhibited on shallow soils with poor nutrient availability in areas of high rainfall. There is little reason to suspect the situation is much different in Australia.

Reductions of any adverse effects from soil disturbance can result from shifting to cable systems, modifying ground skidding techniques (eg changing extraction track pattern) or timing and management, that is, skidding on sensitive soils when they are relatively dry or by ameliorating effects after skidding by site rehabilitation. Choosing an appropriate action requires knowledge of those soil factors most responsible for the tree growth problems. Differences in foliage colour, for instance, would suggest nutrient deficiencies on portions of the skidrow arising from loss of the organic layer. However, soil compaction is a probably the main factor effecting growth particularly in medium to fine textured soils and soils that are compacted to depth.

To gain confidence in selecting an effective ameliorative procedure detailed studies of soils underlying skidrow surfaces must be conducted to corollate specific physical and chemical soil characteristics with varying tree growth responses. Once sufficient information is available for the planning of an effective ameliorative action, the costs of such action can be estimated and included in projections of total costs when comparing alternative harvesting systems and techniques.

Site preparation is best determined by evaluating the micro-climate rainfall distribution and nutrient availability in the area and using models of the system to predict the optimum procedure which would then be tested by trials. Modelling is required to develop some understanding of the system, for this helps to reduce the cost of undertaking trials. Another benefit of modelling the seedling environment is that it allows one to understand the effects of various establishment procedures and thereby ascertain the geographical limits for applying any particular procedure.

Mobility Models

Dr Wong's simulation models based on the "analytical" approach to trafficability assessment has application to predicting the relative performance of tracked and wheeled skidders and assessing the relative merits of other machines in relation to their mobility. The models are tools for design evaluation. They do not have application in an operational sense because of logistical problems associated with obtaining the appropriate soil parameters.

The VCI and SMSP models used by the US military have applicability to the logging industry in an operational sense. They are of limited usefulness for evaluating competing vehicle designs.

Comparison of the VCI(50) values for various logging machines available for purchase on the market with rating cone indexes for various soils obtained from the SMSP model on a regional basis would allow a Wood Production Manager or Logging Manager to objectively evaluate the likely performance of various logging machines in the region. He would then be in a position to incorporate the mobility aspects of a machine into a cost benefit analysis of various machines.

Aid to potential harvesting equipment manufacturers in Australia

Current forest harvesting systems are based on technology that is generally purchased overseas. With the decline in the value of the Australian dollar there is possibly opportunity to develop systems here in Australia. Potential manufacturers should get support now - not after they have already manufactured equipment.

It would be helpful if the industry could identify the system for which there is greatest potential for local replacement and assist in the formation or consolidation of a unit in government to define the optimum mission for such equipment, so as to ensure its relevance in the longer term. Once markets and missions have been defined, then the technical information available on specific design features of the more promising items should be compiled and be available to prospective manufacturers. The Forest Harvesting Group in CSIRO seems to me the most appropriate body to conduct this work.

Communication of Land Management Practices to Industry

Many forest management practices are based on learning from problems experienced in the past and trials planned on the basis of experience. With the concern by the public on the effects of forest operations on the environment, fewer mistakes can be tolerated. Such mistakes are seized upon and often highlighted as part of the environmental movement's campaign to contain the exploitation of forested lands. To avoid such mistakes, good planning based on the wealth of information already available in the literature and simulations of the natural environment (computer models) is required. A significant problem is how the manager in the field can obtain such information. The use of videos, films and other media used by Skogsarbeten and FERIC is one way. An alternative is the use of an "expert system" similar to those developed for medical diagnosis. At the very least such a system accessed in some way as VIDEOTEXT would provide a manager with a list of all the issues to be addressed and provide an early warning of possible problems.

The Use of Trials in Forestry Research

The trial I saw conducted by MacMillan Bloudel personnel was instructive in that they had forecast the likely results from reviewing the literature and laboratory experiments. It was being conducted simply to prove a point in the field.

There has been a tendency in much forestry research especially in the Australian State Agencies to use trials as the basis for an R & D effort. Research and development is expensive and therefore should not be duplicated. Duplication is inevitable when trials form the basis of an R & D effort for conditions at one location or in one state are rarely the same as in another and one rarely knows how extensively the results of a particular trial can be applied, eg a trial comparing the rut formation by two machines on a particular soil under particular weather conditions. The main advantages of trials are that they provide a means of identifying a problem. Lesser advantages are they allow a person to obtain an answer to a local problem without having to read a journal, provide a good basis for gossip between managers and researchers (therapeutic benefits here) and a never-ending activity for the applied research worker (increased employment). This is not meant to belittle trials for they provide the final evidence upon which expenditure or policies should be based. However the cost of obtaining such evidence by reducing the number of trials conducted through the better planning and conduct of the occasional definitive trial. This can best be brought about by an understanding of the system.

Natural systems are often too complex for individuals to understand then without the aid of analytical or computer simulations to combine and incorporate the bits and pieces of the system which individuals can understand. The Canadian Forestry Service has recognised this problem and is currently trying to rectify it by incorporating the results of its past trials into computer models of various systems so that fewer trials need to be conducted in the future. The same approach would be useful in Australia.

10.15: Coffee break

10.45: Following Session IV

13.00: Lunch

14.30: Following Session IV

15.00: Poster Session IV

16.30: Closing Session

PAPERS

The papers translated into English will be distributed to the participants before the Conference.

Session I: Terrain-Evaluation

ELECTRONIC CONE PENETROMETER FOR FIELD TEST. H.J. Olsen, Swedish University of Agricultural Sciences, Sweden.

THE INFLUENCE OF SHAPE AND SIZE OF A PENETRATION BODY ON THE PRESSURE-SINKAGE RELATIONSHIP. C. Holm, G.J. Hefer and D. Hintze, University of the Federal Armed Forces Hamburg, West Germany.

INVESTIGATION OF THE INFLUENCE OF PENETRATION VELOCITY ON THE PRESSURE/SINKAGE RELATIONSHIP. M. Grahn, University of the Federal Armed Forces Hamburg, West Germany.

SOIL DYNAMICS PROPERTIES EVALUATION. D. Jorajuría, R. Balbuena and L. Draghi, Faculty of Agronomy, La Plata National University, Argentina.

CONTRIBUTION TO THE STUDIES ON THE DYNAMIC SHEARING STRENGTH OF SOILS. P.A. Dudzinski, Technical University of Wroclaw, Poland.

PREDICTION OF UNSATURATED SOIL STRENGTH FOR TRACTION DEVELOPMENT IN VEHICLE MOBILITY. R.N. Yong, Geotechnical Research Centre, McGill University, Canada.

EFFECT OF MIXING CONDITION ON STRENGTH AND DEFORMATION OF CEMENT TREATED SOIL. T. Muro, R. Fukagawa and K. Mukaihata, Ehime University, Japan.

STRENGTH COMPONENTS IN THE FOREST FLOOR RESTRICTING MAXIMUM TOLERABLE MACHINE FORCES. I. Wästerlund, Swedish University of Agricultural Sciences, Faculty of Forestry, Sweden.

ANALYSIS OF STRESS STATE IN SOIL MECHANICS. J. García de Diego, The School of Agricultural Engineering of the Polytechnical University of Madrid, Spain.

A COMPARATIVE STUDY OF THE PHYSICAL PROPERTIES OF AN IMPREVIOUS SOIL AND POROUS SOIL. J.M.ª Gasco Montes, Advanced Technical School of Agrarian Engineers, Polytechnical University of Madrid, Spain.

RHEOLOGICAL PHENOMENON OF THE SINKAGE AND HORIZONTAL DISPLACEMENT OF PADDY FIELD SOIL AND ITS APPLICATION. Luo Dahai, Zhuge Qian and Jiang Chongxian, Wuhan Institute of Technology, People's Republic of China.

A NON LINEAR VISCO-ELASTIC RHEOLOGICAL MODEL AND THE MECHANICAL BEHAVIOUR OF AGRICULTURAL SOILS. K. Konstankiewicz, Polish Academy of Sciences, Poland.

STRESS-DENSITY RELATIONSHIP UNDER VARIOUS COMPACTIVE LOADS. S. Gameda, G.S.V. Raghavan and E. McKyes, Agricultural Engineering Department, MacDonal College of McGill University, Canada.

APPLICATION OF GAMMA RAYS TO DETERMINATION OF THE MEDIUM DENSITY DURING THE TRIALS IN SOIL BINS. J. Jaworski, Warsaw University of Technology, Poland.

PRECONDITIONING OF SNOW TO IMPROVE TRAFFICABILITY. G.J. Irwin, Defence Research Establishment Suffield, Canada; P. Boonsinsuk, F. Caporuscio and R.N. Yong, Geotechnical Research Centre, McGill University, Canada.

STATISTICAL PROCEDURES FOR EVALUATION OF TERRAIN MEASURING DATA. G.W. Heiming, University of the Federal Armed Forces Hamburg, West Germany.

MEASUREMENT OF SOIL SURFACES PROFILES WITH AN OPTICAL DISPLACEMENT TRANSDUCER. M.F. Destain and J.C. Verbrugge, Faculté des Sciences Agronomiques, Belgium.

TERRAIN DESCRIPTION FOR MOBILITY PREDICTION. W. Koeppel and W. Grabau, Battelle Motor- und Fahrzeugtechnik GmbH, West Germany.

Session II: Soil-Vehicle Interaction

PERFORMANCE STUDY OF HIGH FLOTATION TIRES USING THE NIAE TESTERS. A.E. Hassan, North Carolina State University, USA; D. Culshaw, C. Plackett and J.R. Dawson, National Institute of Agricultural Engineering, United Kingdom.

CHARACTERIZATION OF TIRES IN STUDIES OF TIRE-SOIL INTERACTION. P. Boonsinsuk, R.N. Yong, F. Ishikawa, Geotechnical Research Centre, McGill University, Canada; and G.J. Irwin, Defence Research Establishment Suffield, Canada.

MEASURING TRAFFIC-INDUCED STRESSES AT THE INTERFACE OF SOIL LAYERS OF CONTRASTING STIFFNESS. A.J.J.M. Schoenmakers and A.J. Koolen, Wageingen Agricultural University, Tillage Laboratory, The Netherlands.

ELEMENTARY INVESTIGATIONS ON THE CROSSING OF INLAND WATERS. B. Hug, Bunderministerium der Verteidigung, West Germany.

A CALCULATION METHOD OF THE SLIP SINKAGE OF A RIGID DRIVEN WHEEL ON SAND. Fang Chuanliu, Zhuang Jide, Wang Qingnian, Department of Automobile Engineering, Jilin University of Technology, People's Republic of China.

STUDIES ON EFFECT OF LUG SURFACE COATING ON SOIL ADHESION OF CAGE WHEEL LUGS. V.M. Salokhe and D. Gee-Clough, Asian Institute of Technology, Thailand.

TRACTION PERFORMANCE. J. García de Diego, The School of Agricultural Engineering of the Polytechnical University of Madrid, Spain.

RESISTING FORCES IN MANUAL TIMBER TRANSPORTATION. M. Saarilahti and G.E. Fue, Faculty of Forestry, Sokoine University of Agriculture, Tanzania.

CRITICAL DESCENT SLOPES FOR AGRICULTURAL TRACTORS ON GRASS: A COMPARISON OF SEVERAL TYRE, WHEEL AND DRIVE CONFIGURATIONS. P. Zwaenepoel, Cemagref, France; A.G.M. Hunter and G.M. Owen, Scottish Institute of Agricultural Engineering, United Kingdom.

THE DYNAMIC BEHAVIOUR OF SOIL-ENGAGING IMPLEMENTS. D.A. Crolla and J.S. Tang, Department of Mechanical Engineering, University of Leeds, United Kingdom.

A MODEL TO PREDICT THE COMBINED LATERAL AND LONGITUDINAL FORCES ON AN OFF ROAD TYRE. D.A. Crolla, A.S.A. El-Razaz, C.J. Alstead and C. Hockley, Department of Mechanical Engineering, The University of Leeds, United Kingdom.

THE STUDY OF PARAMETERS WHICH AFFECT TRACKED VEHICLE GROUND PRESSURES ON DRY SAND. I. Littleton and J.G. Hetherington, Royal Military College of Science, United Kingdom.

A RESEARCH OF THE DYNAMIC PERFORMANCE OF THE PADDLE DRIVING WHEEL WORKING ON SOFT TERRAIN. Xu Da, Wuhan Institute of Technology, People's Republic of China.

PHOTOELASTIC METHOD OF PREDICTION OF GROUND PRESSURE DISTRIBUTION BENEATH THE TRACK LAYING MODEL. Marek M. Poncyliusz, Warsaw Technical University, Poland.

THE INFLUENCE OF THE FORM OF SURCHARGE ON THE SHAPE OF FAILURE LINE DURING THE PASSIVE THRUST. G. Tyro, Warsaw University of Technology, Poland.

OPTIMIZATION OF CYCLIC PROCESSES OF SOIL WORKING MACHINERY. M. Spektor, Oregon Institute of Technology, USA.

A METHOD TO DETERMINE COEFFICIENT OF TRACTION-SLIP RELATIONSHIP OF TYRES IN «IN-SITU»-TESTS. Günter H. Hohl, Austrian Federal Army, Austria.

TORQUE DISTRIBUTION ON WHEELED VEHICLES AFFECTS DAMAGE ON THE FOREST GROUND. Björn Marklund, Swedish University of Agricultural Sciences, Sweden.

FURTHER DEVELOPMENTS AND APPLICATIONS OF A COMPUTER SIMULATION MODEL FOR PARAMETRIC EVALUATION OF TRACKED VEHICLE DESIGN. J.Y. Wong, Carleton University, Canada; and J. Preston-Thomas, Vehicle Systems Development Corporation, Canada.

WEIGHT DISTRIBUTION OF A FORWARDER AND ITS EFFECT ON RUT FORMATION ON PEATLAND. J. Ala-Ilomäki, The Finnish Forest Research Institute, Finland.

ON THE MODELLING AND SIMULATION OF TIRE-SOIL SYSTEMS. Yu Qun, Gong Sunrong and Yu Guyuan, Beijing Agricultural Engineering University, People's Republic of China.

GENERAL SOIL MODEL FOR CALCULATING TRACTIVE FORCES BETWEEN THE TERRAIN AND A GIVEN VEHICLE. G.Y. Baladi and R.W. Meier, US Army Engineer Waterways Experiment Station, USA.

TRAILING-TIRE MOTION RESISTANCE IN SHALLOW SNOW. George L. Blaisdell, US Army Cold Regions Research and Engineering Laboratory, USA.

CONTACT AREA TESTS OF A NEW WIDE SECTION AGRICULTURAL TYRE. P. Febo and D. Pessina, Institute of Agricultural Engineering, University of Milan, Italy.

OFF THE ROAD TIRES, CONCEPTS AND APPLICATIONS. P.F.J. Abeels, Université Catholique de Louvain, Belgium.

EXPERIMENTAL RESEARCH ON THE SOIL FLOW AND SOIL REACTION BENEATH LUGS OF POWERED WHEEL. Hua Zhong Lu and Yao Jian Shao, South China Agricultural University, People's Republic of China.

DETERMINATION OF LIFT HEIGHT IN SOIL COMPACTION. S. Hata and K. Tateyama, School of Civil Engineering, Kyoto University, Japan.

THE IMPORTANCE OF STANDARDIZATION IN THE DETERMINATION OF LAND-VEHICLE PARAMETERS. P. Linares, The School of Agricultural Engineering of the Polytechnical University of Madrid, Spain.

AN ANALYSIS OF ROLLING RESISTENCE IN DRIVEN WHEELS. J. Mery, National Institute for Agricultural Livestock Investigations, Chile; P. Linares and J. Jevenois, The School of Agricultural Engineering of the Polytechnical University of Madrid, Spain.

Session III: Vehicle Dynamics, Steering

Vehicles Dynamics:

MODELLING OF TYRE ENVELOPING AGAINST TERRAIN ROUGHNESS. W. Berés, The Technical University of Wroclaw, Poland.

THE DYNAMIC BEHAVIOUR OF A TRACTOR-VIBRATING SUBSOILER SYSTEM AND THE EFFECT OF THE VIRTUAL HITCH POINT. K. Sakai, H. Terao and S. Nanbu, Department of Agricultural Engineering of the Hokkaido University, Japan.

DYNAMIC BEHAVIOUR OF ROLLING TRACTOR TIRES. H.D. Kutzbach and H. Schrogl, University of Hohenheim, West Germany.

USING A COMPUTER MODEL TO DETERMINE PREFERRED CHARACTERISTICS FOR THE SUSPENSIONS OF TRACKED VEHICLES. E.B. Maclaurin, R. Gray and R.E. Warwick, Royal Armaments Research and Development Establisment (RARDE), United Kingdom.

INVESTIGATION OF THE ON-ROAD DRIVING BEHAVIOUR OF FAST UNSPRUNG WHEEL VEHICLES. J. Betzler and B. Breuer, Fachgebiet Fahrzeugtechnik der Technischen Hochschule Darmstad, West Germany.

SENSIVITY METHOD FOR OPTIMIZING THE DYNAMIC RESPONSE OF OFF-ROAD VEHICLES. Paul W. Claar II and Liansuo Xie, Iowa State University, USA.

DYNAMIC SIMULATION OF TERRAIN VEHICLES. H. Hahn, IABG, West Germany; and R. Wehage, Tacom, USA.

AGRICULTURAL TRACTOR SUSPENSION AND ITS EFFECT ON IMPLEMENT PERFORMANCE. J.S. Tang and D.A. Crolla, University of Leeds, United Kingdom.

OPTIMIZATION OF VEHICLE SUSPENSION COMPONENTS TO MAXIMIZE THE MOBILITY OF A VEHICLE IN OFF-ROAD TRAVEL. B.C. Lesage, Space Research Corporation, Belgium: and R.N. Yong, Geotechnical Research Centre of McGill University, Canada.

EFFECTS OF VIBRATION OF ROLLING RESISTANCE. A. Orlandi and M. Matassa, Transport Institute, Faculty of Engineering, University of Bologna, Italy.

DYNAMIC LOADING OF SKIDDER AXLES AT WOOD SKIDDING. S. Sever, Faculty of Forestry of the University of Zagreb, Yugoslavia.

SKIDDER WHEEL TORQUES MEASURING. D. Horvat, Faculty of Forestry of Zagreb University, Yugoslavia.

THE EFFICIENT USE OF VEHICLES WITH PNEUMATIC SUSPENSIONS IN BAD ROAD CONDITIONS. G.D. Jokhadze, Georgian Polytechnical Institute, Tbilisi, USSR.

Steering:

INFLUENCE OF TYRE TREAD ON STEERING FORCES WITH NON DRIVEN TYRES ON HARD SURFACE. H. Schwanghart, Institut fur Landmaschinen, Technical Universitat München, West Germany.

PREDICTION OF STEERING CHARACTERISTICS FOR WHEELED VEHICLES IN SAND - A MATHEMATICAL TREATMENT. Col. Tej Paul and P.S. Deshpande, Vehicle Research and Development Establisment Ahmednagar, India.

LANE-CHANGE MANOEUVER OF HIGH SPEED TRACKED VEHICLES. M. Kitano, K. Watanabe and Y. Takaba, The National Defense Academy, Japan.

STEERING FORCES ON CAGE-WHEELS AND TYRES IN PUDDLED CLAY SOIL. J.K. Agarwalla and D. gee-Clough, Asian Institute of Technology, Thailand.

ON CERTAIN PROBLEMS AND SOLUTIONS IN THE DESIGN OF SUSPENSION AND STEERING SYSTEMS OF OFF-ROAD VEHICLES WITH FOUR-WHEEL DRIVE. V. Dedović, D. Kecman, University of Belgrade, Yugoslavia; J. Vlahović and D. Veselinović, Industrija motora Rakovica, Yugoslavia.

STEERING OF TRACKED VEHICLES - A PARAMETER STUDY. C. Strauss, Battelle Motor und Fahrzeugtechnik GmbH, West Germany; and G.Y. Baladi, US Army Engineer Waterways Experiment Station, USA.

INVESTIGATION ON THE TRAJECTORIES OF WHEELS IN A VEHICLE-TRAILER COMBINATION IN THE TURNING PROCESS. Li Zhen-An, Beijing Agricultural Engineering University, People's Republic of China.

ANTISYMMETRICAL BITRAPEZOID FOR SELF-STEERING OF AXIAL ASYMMETRIC ARTICULATED VEHICLES. J. Pinto Silva, Eurotren Monoviga, S.A., Spain.

THE EFFECT OF UNDER-LOAD OPERATION OF THE STEERING ON THE CONTROLLABILITY OF AN ALL-WHEEL DRIVE VEHICLE. R. M. Partskhaladze and D.D. Dzotsenidze, Georgian Polytechnical Institute, Tbilisi, USSR.

Session IV: Vehicle and Machinery Design

EXPERIMENTAL AND ANALYTICAL DETERMINATION OF STRUCTURAL AND THERMAL BEHAVIOUR OF TANK TRACKS. N.R. Murphy, A.S. Lessem and B.E, Reed, US Army Engineer Waterways Experiment Station, USA.

SOME ASPECTS ON HIGH MOBILITY DEVELOPMENT OF TRACKED VEHICLES. I.C. Scmid, University of the Federal Armed Forces Hamburg, West Germany.

OPTIMISATION SELECTION OF A SYSTEM SOLUTION OF HYDROMECHANICAL TRANSMISSION WITH A HYDROSTATIC TRANSFORMER FOR OPERATING AGRICULTURAL TRACKED TRACTORS. S. Milidrag, M. Gavrić, Mechanical Faculty of Sarajevo, Yugoslavia; M. Dautović and R. Herbez, SOUR «BNT», Yugoslavia.

TRACTOR ENGINE OPERATION UNDER FULL-LOAD CONDITIONS. A. Fekete, Hungarian Institute of Agricultural Engineering, Hungary.

LAND MECHANICS AND ITS INFLUENCE ON AGRICULTURAL VEHICLES. P. Linares, The School of Agricultural Engineers of the Polytechnical University of Madrid, Spain.

ANALYSIS OF THE ROTATIONAL VIBRATIONS OF A SMALL TRACTOR. K. Ohmiya, Faculty of Agriculture, Hokkaido University, Japan.

A SAFE SLOPE MONITOR FOR AGRICULTURAL TRACTORS: SURVEY OF USE ON FARMS. G.M. Owen, A.G.M. Hunter, Scottish Institute of Agricultural Engineering, United Kingdom.

APPLICATION OF MORPHOLOGICAL ANALYSIS FOR RECONSTRUCTION AND DESIGN OF LOGGING TRACTORS. D. Kornicer, Industrija Masina i Traktora, Yugoslavia.

FUEL CONSUMPTION PREDICTION FOR DIESEL-POWERED VEHICLES IN DIFFERENT OPERATION CONDITIONS. O.G. Gelashvili, Georgian Polytechnical Institute, Tbilisi, USSR.

EXCAVATING PERFORMANCE OF BULLDOZER FOR A LAYERED ROCK MASS. T. Muro, Faculty of Engineering, Ehime University, Japan.

EXPERIMENTAL RESEARCH OF GEOMETRIC SHAPE AND ITS WORKING RESISTANCE OF LOADER BUCKET. L. Shuxue, J. Wanjun, G. Lingfen and N. Jixin, Jilin University of Technology, Popular's Republic of China.

Session V: Non Conventional Land Transport Systems

EVALUATION OF SEDIMENT PROFILE IN TERRAMECHANICS. M. Fukue, S. Okusa, Marine Science and Technology, Tokai University, Japan; P. Boonsinsuk and R.N. Yong, Geotechnical Research Centre, McGill University, Canada.

A STUDY ON AN UNCONVENTIONAL WALKING MECHANISM IN PADDY FIELD -WALKING BOAT- TYPE TRACTOR». Chen Bingcong and Lu Huaimin, Jilin University of Technology People's Republic of China.

A STUDY OF WALKING WHEEL FOR PADDY FIELD. Chen De-Xing and Gao Feng, Jilin University of Technology, People's Republic of China.

THE DEVELOPMENT, PERFOMANCE TEST AND STRUCTURE ANALYSIS OF BOAT-TRACTOR. Zhuge Zhen and Jiang Chong-xian, Wuhan Institute of Technology, Popular's Republic of China.

THE TEST STUDY ON MORPHOLOGY AND PARAMETERS OF DRIVING WHEEL OF BOAT-TRACTOR. Jiang Chongxian, Wuhan Institute of Technology, People's Republic of China.

AIR CUSHION TRANSPORT TECHNOLOGY IN BRAZIL - THE «PROJECTO VCA» EXPERIENCE. M.H. de Souza Oliveira, M.A. de Rezende Veiga, P.J. Bandeira de Mello and R.R. de Araújo, University of Brasilia, Brazil.

INNOVATIVE MOBILITY DESIGNS UTILIZED ON FOREIGN WHEELED AND TRACKED VEHICLES. R.W. Kaczmarek, US Army Tank-Automotive Command, USA.

NOVEL ALTERNATIVE PRIME MOVERS FOR AGRICULTURAL TRACTORS. B.T. Fijalkowski, Cracow Polytechnical University, Poland.

AN EXPERIMENTAL SPECIALISED VEHICLE FOR AGRICULTURE. M.J. Dwyer and J.A. Wheeler, Agricultural and Food Research Council Institute of Engineering Research (NIAE), United Kingdom.

LOOPWHEEL SUSPENSION SYSTEM DEVELOPMENT STATUS. W. Trautwein, West Germany.

ARTICULATE TRAIN VEHICLE OF MULTI-USAGE ON ROUGH TERRAIN AND STEEP SLOPES. H. Horio and H. Yamamoto, Faculty of Agricultural, Kobe University, Japan.

DEVELOPMENT STATUS OF HIGH-MOBILITY COMMERCIAL VEHICLES FOR HIGH SPEEDS. G. Paprocki. MAN Nutzfahrzeuge GmbH, West Germany.

DEVELOPMENT-RESULTS OF THE HIGH SPEED MAGLEV TRANSPORTATION SYSTEM TRANSRAPID. J. Meins and L. Miller, Thyssen Industrie AG Henschel Advanced Transportation Technologies, West Germany.

THE EUROTREN MONOVIGA SYSTEM FOR SPEEDS OF 200 KM/H AND 300 KM/H. J. Pinto Silva, Eurotren Monoviga, S.A., Spain.

OUTPUT IMPROVEMENT OF MACHINE WITH VIBRATING BLADE FOR PIPE OR CABLING LAYING. A. Quibel, Centre d'Expérimentations Routières, France; and E. Poncerry, Centre National d'Etudes des Télécommunications, France.

VISUALIZATION OF THE CUTTING MECHANISM OF SOILS BY THE X-RAY RADIOGRAPHY. S. Ichiba, K. Hyodo and Y. Ooishi, Mitsubishi Heavy Industries, Ltd., Japan.

DESIGN PARAMETERS OF MULTI-POWERED SOIL TILLAGE TOOLS IN RELATION TO ENERGY DEMAND. U.D. Perdok and G.D. Vermeulen, Institute of Agricultural Engineering, The Netherlands.

THE PHYSICAL INTERPRETATION OF RELATIONSHIP BETWEEN THE RATE OF WEAR OF DIGGING ELEMENTS AND PARAMETERS OF FRICTION PROCESS. A. Selenta, Warsaw University of Technology, Poland.

APPENDIX 2: SUMMARY OF TECHNIQUES FOR PREDICTING TRAFFICABILITY

PREDICTION TECHNIQUES

A number of techniques have been developed over the past 100 years for predicting the performance of a vehicle in relation to terrain conditions and for predicting the changes of soil conditions caused by the passage of vehicles. These "prediction techniques can be divided generally into three categories: (a) empirical approach, (b) analytical approach, and (c) numerical approach. The empirical approach contains several empirical parameters that are not defined explicitly in terms of the constitutive properties of the near surface materials (Reference 1). Some of these parameters are indicative of soil strength (such as cone index) while others are only descriptive (such as soil type, slope of the terrain, vegetation, etc.). The numerical values of these parameters must be determined directly from field experiments. The reliability of such an approach is, therefore, limited to the range of test conditions for which the empirical parameters have been evaluated (i.e., the empirical approach must be used only in the range of its data base).

In the analytical approach, a simple constitutive law which contains only the basic features of the material that are relevant to the analytical formulation of the problem at hand is first postulated. Once a useful constitutive law has been established, it is possible to construct a model of a given mobility problem (such as soil-wheel interaction model, terrain-vehicle interaction model, etc.) under ideal conditions (References 2, 3, and 4). Unlike the empirical approach, the analytical approach does not contain empirical parameters that must be evaluated from field tests. The parameters appearing in the analytical equation are defined explicitly in terms of the physical properties of near surface material (which can be determined independently rather than from a mobility test). Accordingly, the analytical approach can be used for cause-and-effect studies for any near surface material that can be characterized within the framework of the constitutive law adopted for the theoretical analysis. The accuracy and range of application must be determined from actual test events and obviously depend upon the degree of relevance of the analytical approach as an approximation to the real event. It should be noted that the set of equations resulting from the analytical approach is often relatively simple mathematical expressions which can be solved quickly and inexpensively.

The most comprehensive approach to mobility problems is the numerical approach using two- or three-dimensional finite element and/or finite difference computer codes (Reference 5). In this approach, a complex constitutive law (such as an elastic-plastic work-hardening model) is used to describe the near surface terrain material (Reference 6). Such a constitutive law requires a comprehensive evaluation of the terrain material and a complete determination of its mechanical response. This can be done , for example, through the use of triaxial test devices.

The above three techniques and the type of tests required by each of them are summarized in Figure 11. The various testing techniques for measuring and characterizing the terrain behavior are presented in the next section.

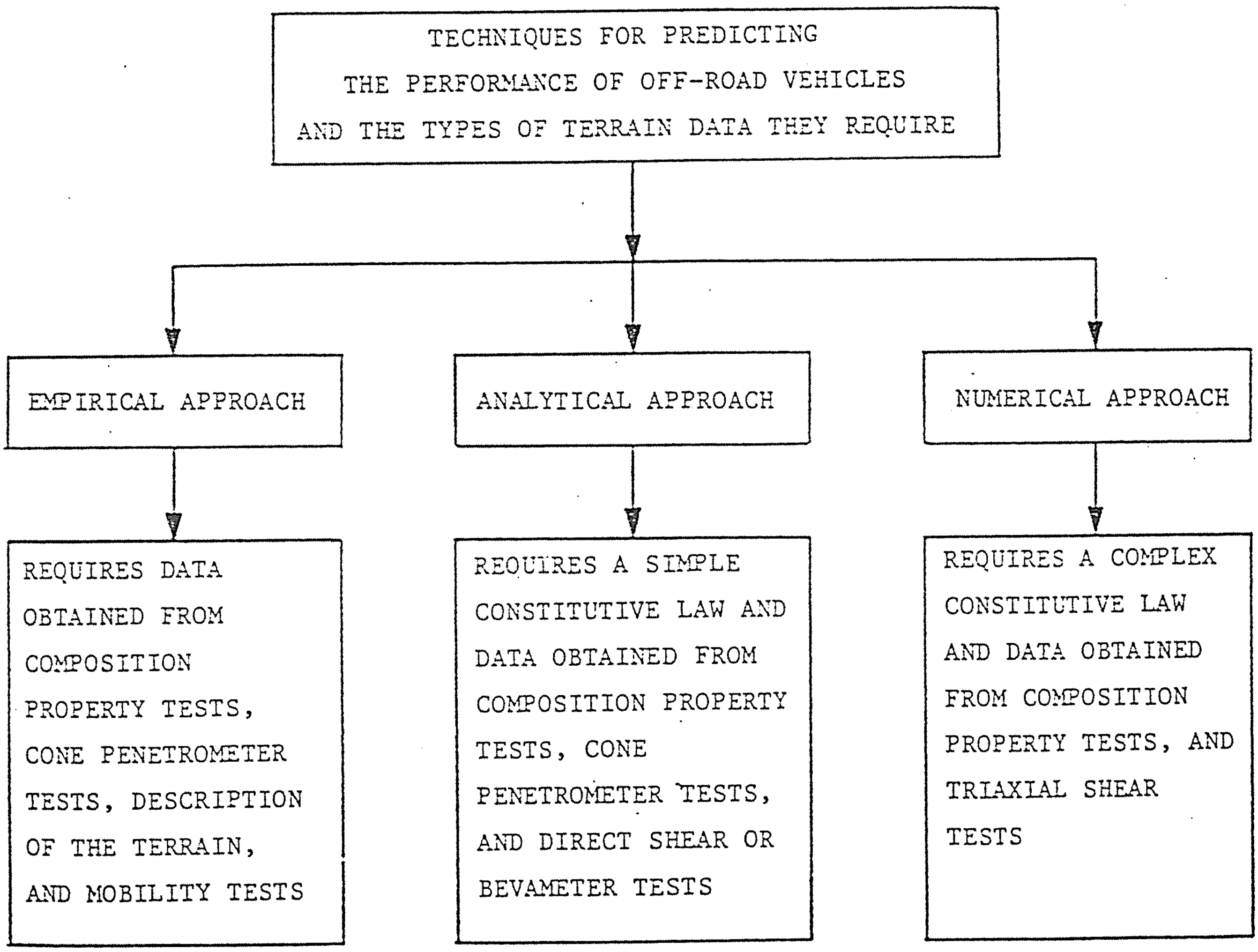

FIG. 11.--Comparison of Techniques for Predicting the Performance of Off-Road Vehicles and Types of Terrain Data They Require

APPENDIX 3: SUMMARY OF ISTVS PAPERS ON FORWARDERS

STRENGTH COMPONENTS IN THE FOREST FLOOR RESTRICTING MAXIMUM TOLERABLE MACHINE FORCES

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Summary

In forestry operations machines used should have a high practicability, yet damage the stand as little as possible. The machine forces are undoubtedly too high in many cases, causing deep ruts, soil compaction and cutting off the tree roots. The knowledge of what forces a forest stand can withstand is still quite limited.

One of the aims of our project, "Smoother Terrain Machine", is to supply information about the strength of the forest floor. Since the forest floor of podzol-type is a complex layered structure, we have started by studying the components in the system.

A sand sediment can bear high pressures, whereas a moist fine sandy till soil should not be loaded to more than 30 kPa if severe soil compaction is to be avoided. However, the effect of shear forces and slippage is poorly studied. The humus layer above the mineral soil is armoured by tree roots, shrub roots, grass roots, etc. Intact bark is the best guarantee for healthy trees. During the sap period the shear strength of tree root bark is at least 40 N cm^{-2}. The armouring effect of roots and rhizomes on the humus layer is considerable, as the total length of roots may be 200-500 m m^{-2}. The strength of the humus layer is being measured.

TORQUE DISTRIBUTION ON WHEELED VEHICLES AFFECTS DAMAGE ON THE FOREST GROUND

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The tractive effort of heavier terrain vehicles is by tradition developed through an aggressive contact with the ground. This causes damages to the ground as soil compaction and damage to roots and vegetation.

In the research project 'Smoother Terrain Machine' we have studied how torque distribution between wheels on a forest terrain vehicle varies under different conditions. The results so far show that with conventional four wheel drive high peak forces occur on individual wheels and that single vehicle parameters affect the torque distribution in varying degrees. Uneven torque distribution means a greater risk for slip and damage to the ground.

By varying machine parameters as weight distribution, steering geometry, steering angle and number of wheels driven under different ground and topografy conditions, we are able to show the negative effects of uneven torque distribution and how vehicle characteristics can be improved by controlling different machine parameters. E.g. the torque variations on a single wheel can be lowered with 50 per cent if we could control the torque distribution over the wheels fully.

WEIGHT DISTRIBUTION OF A FORWARDER AND ITS EFFECT ON RUT FORMATION ON PEATLAND

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ABSTRACT

The purpose of the research project was to study the effect of a forwarder's weight distribution on rut formation on a swampy field. The field was marked with straight strip roads 60 m in length, the bearing capacity of which was measured using a vane shear. The amount of subshrub, grass, moss, and free surface water on the strips was estimated. The weight distribution of the tractor was altered by placing 1 200 kg of additional weight on the front axle, in the middle of the tractor, on the rear bogie, or distributed on the front bumper and the bogie. Simulated forest haulage runs were made empty and with a 6 200 kg load of 3 m pulpwood. Increases in the front axle weight, front frame weight, and moment of inertia resulted in greater rut formation. The static drawbar pull test was made to determine the changes in axle weight as a function of tractive force. As tractive force increased, the front axle loading of the bogie decreased and rear axle loading increased. The proportion of the bogie front axle of the total loading of the bogie was greater than calculated.

APPENDIX 4: THE USE OF HIGH FLOTATION TYRES FOR SKIDDING IN WET OR STEEP TERRAIN (MELLGREN P AND HEIDERSDORF E)

SUMMARY

Adequate flotation of off-road vehicles (i.e. the avoidance of excessive sinkage) has long been a problem, particularly on the low strength soils which underlie large portions of the forest area throughout Canada. Attempts to harvest these wet areas in summer with "conventional" logging tires have proved environmentally unacceptable and costly because of bogged down machines, reduced loads and excessive ground disturbance. Efforts to solve this problem with tracked vehicles have had only limited success, mainly because of high track and undercarriage maintenance costs.

To help resolve these problems, FERIC initiated a search for a dependable high-flotation tire that could be used to improve the performance of existing machines in soft-ground conditions. Testing commenced in 1980 with FERIC's introduction of 68 in.-wide tires to skidding operations in the black spruce swamps of Northern Ontario (Clay Belt). Ground conditions in this area consist of a thin root mat overlying deep organic soils of negligible shear and compression strength. It was hoped that the large footprint of the wide tires would keep the machines from breaking through the root mat.

The spectacular initial results led to a four-year testing and development program by FERIC, the forest industry and several tire manufacturers culminating in a new breed of wide, flexible, low-pressure, high-flotation tires capable of significantly improving skidder performance both in soft-ground and steep-slope applications. Such tires are presently manufactured by Rolligon Corp. (68-in. wide), United Tire (50-in. width), Firestone (50 in.) and Goodyear (43 in. available, 50 in. pending) with approximately 100 already (1983) in service in Canada.

The success of the new wide, high-flotation tires stems from a number of advantages they have demonstrated over conventional, narrow skidder tires, notably:

+ Productivity increases of up to 60% in wet ground. There are also indications of lesser, but significant, improvements in performance on rough or steep terrain.

+ Fuel savings per unit volume of up to 40% depending on the ground.

+ Drastic reductions in ground disturbance (rutting) on sensitive soils even after repeated passes.

+ Less soil compaction providing improved regeneration and high future growth rates.

+ The possibility to go to smaller machines to do an equivalent job.

+ A softer ride for man and machine.

+ Improved stability and thus safety on sidehills owing to the tire width.

+ Increase access to conventionally inaccessible timber because of the improved flotation and stability. This increased access can also mean less idle time for the skidder fleet and a reduced need for expensive specialized equipment.

Naturally, along with the benefits come a number of tradeoffs, notably:

- The high initial cost of the tires (double or more than that of conventional tires).

- The wide tires' performance in deep snow is questionable. Moreover, the tires are more susceptible to puncture in cold weather. Therefore, a change of tires with season may be required.

- The tire width places increased stress on the axles and final drives thus possibly necessitating the reinforcing of such especially on smaller-size class skidders.

- The increased vehicle width may affect manoeuverability, garage size and ease of freighting.

- The use of wide tires may require specialized equipment and facilities for tire maintenance.

- Their life, though appearing promising, remains as yet unproved.

Prospective users must weigh these advantages and disadvantages before choosing what is right for their particular conditions, needs and applications. However, there is no doubt that in the right application, the use of the new breed of wide, high-flotation tires can improve the range and capabilities of conventional skidders drastically.

APPENDIX 5: SKOGSARBETEN - ANNUAL REPORT

No. 2 1987

Translation from the Swedish issue No. 6, 1986:
Raymond W. Lipton

Forskningsstiftelsen
Skogsarbeten
news

Annual Report for 1985–86

Research

Germination frames for container seedlings?

A number of transport studies at nurseries during the year found it doubtful whether the use of germination frames with returnable containers is a profitable option for handling and transport. It would probably be more profitable to improve and rationalize handling systems that do not involve the use of germination frames.

We have also made an analysis of the scope for investment in transplanting container seedlings. Our calculations suggest that what is really important is that the germination period is more than a year, with final germination taking place in disposable containers without the use of germination frames.

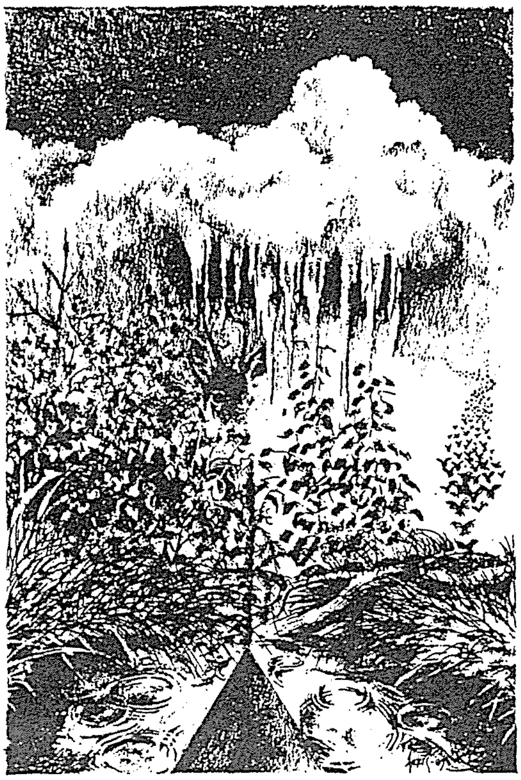
(Project leader: Staffan Berg)

Scarification needs on different sites

During the year a working group, with specialists from Skogsarbeten and the Swedish University of Agricultural Sciences (SLU), completed a theoretical analysis of the need for scarification on sites of different classes. One of the findings was that scarification in the form of mound-making is desirable on about 50% of the area of productive, firm soils. Another working group examined the use of line planting and estimated that the terrain conditions on over half of the forest land area in Sweden are such that line planting is economically attractive.

We have also examined the conditions, problems and potential in artificial regeneration in southern Sweden. Where the problems of competing vegetation and insect infestation are most pronounced, there is considerable financial scope for introducing measures to enhance the regeneration conditions. The project also coined a slogan: 'Don't leave it to chance - do it right, right from the start'.

(Project leader: Staffan Berg)



Drawing: Anders Brunberg

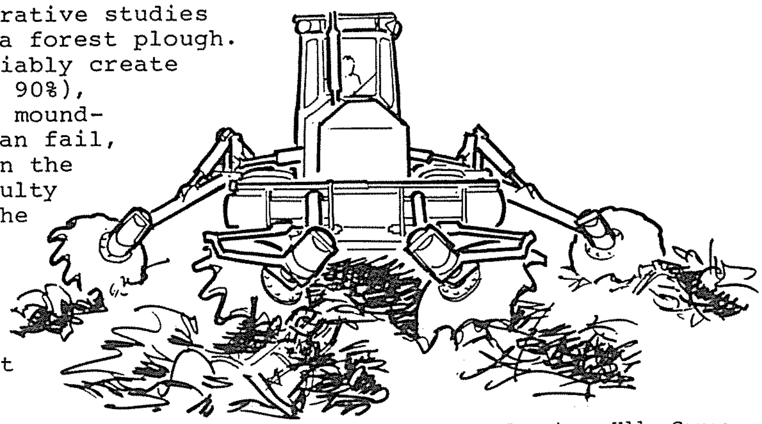
Mechanized planting technically viable

During the year our project team on mechanized planting studied the various aspects of organization and production-planning relating to the Silva Nova machine. Experience gained with the machine operating on a semi-practical scale in recent years has confirmed that mechanized planting should now be included among the options for artificial regeneration. During the 1985 planting season, four machines, which together clocked up some 1900 operating hours, successfully planted 1.8 million seedlings on a total area of 800 ha. Technical utilization was approx. 65%.

(Project leader: Ulf Hallonborg)

Disc trencher, mound-maker or plough?

During the year we carried out comparative studies on disc trenchers, mound-makers and a forest plough. All three types of machine could reliably create planting spots in mineral soil (over 90%), even in fairly difficult terrain. In mound-making, up to half of the attempts can fail, which means that the distance between the runs has to be adapted to the difficulty of the terrain. In disc trenching, the proportion of planting spots above ground level is small, although it varies with the terrain and make of machine. The highest proportion of raised planting spots was achieved in the ploughing (more than 90%), but ploughing also produced the largest proportion of treated soil (70-80%).



Drawing: Ulla Carne

In a special study of the Bräcke and Donhög mound-makers (the latter with scarifier heads 2 m in diameter), we found that terrain difficulty, particularly the prevalence of large stones in the soil, greatly influenced the results. In stone-free terrain, 80-90% of mound-making attempts were successful, as against less than 50% in stony terrain. We also found that driving speeds of up to 60 m/min can be used without any adverse effect on the results.

We have also studied the newly developed FIAB Quattro quadruple-row disc trencher. The results proved that the performance of this machine in all four rows is completely on a par with that of an equivalent two-row machine.

(Project leader: Ulf Hallonborg)

Variable-function scarifiers

In our work on developing versatile machines, we have concentrated on variable-function scarifiers, which, by variation of the operating mode of the scarifier head, can perform different types of scarification.

Four concepts have been produced to date, making it possible for patch scarification to be performed, e.g. by either cutter-type scarifiers or disc trenchers. From our studies we have found that the results achieved are influenced by the speed of rotation of the cutter or disc.

(Project leader: Ulf Hallonborg)

Bright prospects for mechanized cleaning

At present there are five machines being used on a practical scale for mechanized cleaning, which together cover an area of about 1000 ha a year. There are two types of machine for cleaning: the most widely used is the Bruunett Mini forwarder, which has been converted and fitted with a boom- mounted cleaning unit. Skogsarbeten, together with the manufacturer and host company, has been involved in the development of the loader and cleaning unit for this type of machine. We have also worked on the development of a cleaning machine, which is a specialized four-wheeler, weighing about six tonnes and having a ground clearance of about one metre. This machine is manufactured by Häglinge Industri AB.

About 80% of the weight on the converted forwarders is over the front axle, with the result that maximum ground pressure is high. On the Haglinge machine, however, the weight is distributed more evenly and the maximum ground pressure is therefore lower. We have also outlined the technical solutions for reducing ground pressure on machines in operation.

The level of productivity achieved in mechanized cleaning is largely dependent upon visibility in the stand and the number of residual stems. Because the number of stems removed is of minor importance, the method is suitable for use in stands requiring heavy removals. We have also found that the smaller and lighter cleaning units and also the improved loader controls developed on two Bruunett machines have increased productivity substantially.

From an analysis of the data compiled in the National Forest Survey, we estimate that the total cleaning requirement for the next five years is of the order of 385,000 ha a year. During the 1990s, the cleaning requirement will decline, falling to a level of about 300,000 ha a year. About 20% of the cleaning that needs to be done is in stands that are suited to cleaning using the type of machines existing today. The main limitations on the use of these machines are stands with a poor bearing capacity and stands in which the average height of the main stems is so great that existing machines will do unacceptable damage to the stand. However, if machines with high ground clearance are developed, cleaning is carried out earlier and line planting is implemented wherever possible, by the turn of the century it should be possible to complete 40% of the cleaning by machine.

From our follow-up studies we know that between 5 and 10% of the main crop is damaged by mechanized cleaning, with half of the damage being classified as serious. In cooperation with the department of silviculture at SLU, we have therefore tried to assess the future significance of this damage. We have estimated that the loss in volume increment will be 3-6 m3 (gross volume) a hectare during the rotation period. The adverse effects of damage to roots or of compaction of the soil are likely to be very slight and there is no evidence to suggest that hardwood growth will be more vigorous than after motor-manual cleaning.

We have also assessed the economic consequences of introducing mechanized cleaning. In conjunction with the introduction, the number of jobs in cleaning will fall, helping to offset the imbalance between the size of the labour force needed during the silvicultural season and that needed during the logging season, and making it possible to increase the level of mechanization in logging. Depending on the conditions prevailing in a given area, it should be possible to reduce the logging costs by between 1 and 3% a year, which corresponds to a reduction of between 800 and 1800 kronor per hectare of area cleaned by machine.

(Project leader: Johan Lindman)

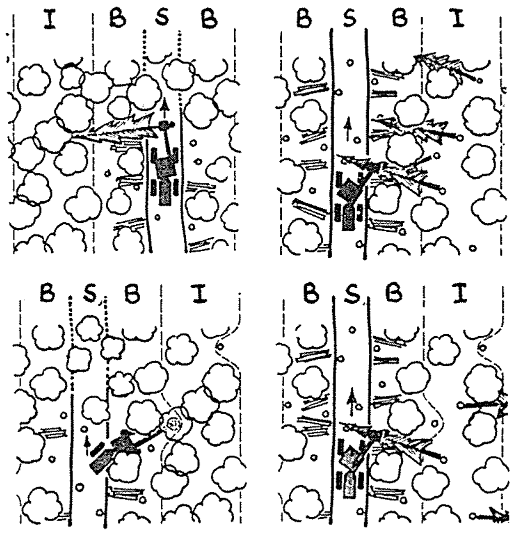
Single-grip harvesters on strip roads and in the stand

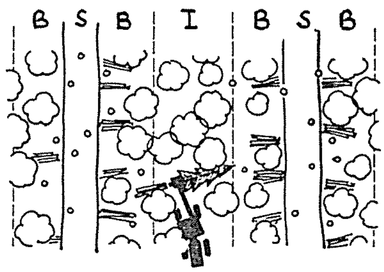
Single-grip harvesters used in thinnings are usually strip road operating, which means that their use is confined to strip roads. Consequently, if the entire area between the roads is to be thinned, some 20 or 30% of the trees must be felled motor-manually, for subsequent processing by the harvester serving as a processor. The proportion of trees needing to be felled motor-manually could be reduced if the machines were able to operate in the area of stand between the roads as well as from the roads themselves. To find out whether this was possible, we conducted a study of the Valmet 901/935, a machine designed to operate from the strip road. We found that it was indeed possible to reduce the proportion of motor-manual felling in this way, although a machine the size of the Valmet 901/935, because of the damage it would do to the soil and residual trees, cannot operate between the strip roads in stands with more than 900 residual stems per hectare or with trees having roots on the surface of the ground.

However, several single-grip harvesters have been designed specially to operate between the strip roads in dense stands. Such a machine is the Bruun Twoo 202, which we studied during the year. Our findings from this and previous studies showed that the biological results are roughly the same as those following the use of strip road-operating machines. However, in stands with surface roots, it is not advisable to use stand-operating machines for thinning during the sap-flow period, because of the risk of damaging the roots. The studies also revealed that there are apparently no notable differences in productivity between strip-road-operating and stand-operating single-grip harvesters.

A large proportion of the work of single-grip harvesters is attributable to loader-boom operation. The most common types of loader used on single-grip harvesters are the telescopic boom and the knuckle boom, and we conducted a comparative study of the two types in thinnings during the year. We found that the telescopic boom is easier to manipulate than the knuckle boom, although it is more awkward to use in close-up work. Greater productivity was achieved on average by the telescopic boom, although the difference was only slight. Both types of loader are well-suited to achieve high levels of productivity and good biological results.

I = Intermediate zone
B = Boom-operating zone
S = Strip road

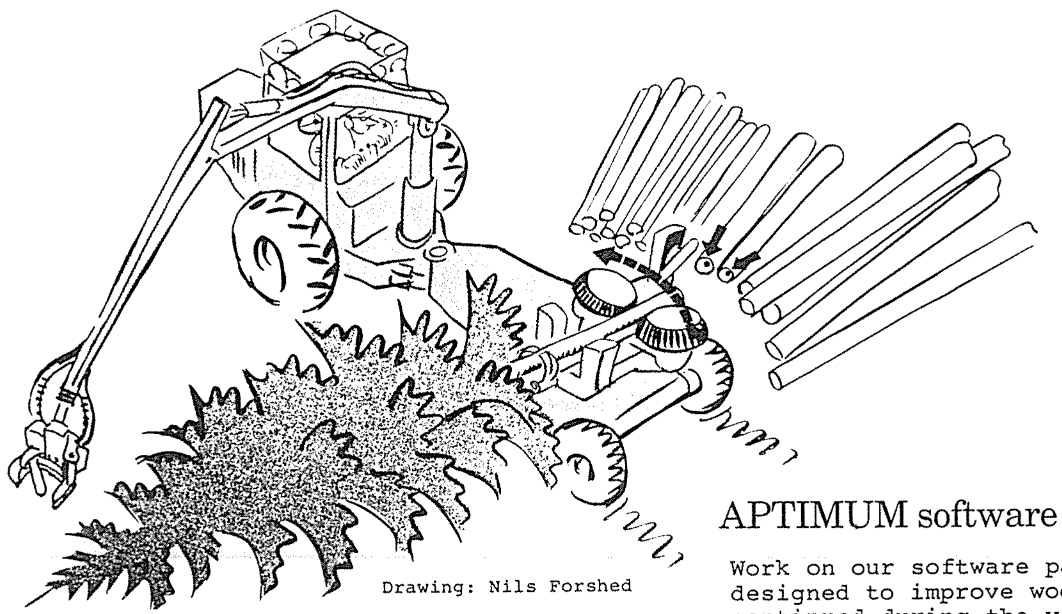




Different thinning methods. Source: 'Resultat' No. 2, 1986.

Strip-road-operating single-grip harvesters are mounted either on converted forwarders or on special base machines designed to carry boom-mounted harvester units. In a comparative study we found that visibility from the cab was better on the specialized machine. Also, because the distance between the operator and the boom post was short, it was also easier to monitor the boom work. Thus, the specialized machine was better equipped to achieve high productivity and good biological results in thinning.

(Project leader: Svante Scherman)



Drawing: Nils Forshed

Computerized bucking in sight

Trials have been made of bucking to taper using HMA-15 (Söderhamns Mobila Elsystem) and Aptor 11 (ÖSA) equipment and bucking to value using DAPT 500 (ÖSA) equipment. Our own follow-up studies have found that the equipment exploits the yield value of the wood quite satisfactorily. The signs are therefore very promising as the equipment performs very much in keeping with the specified requirements.

As bucking aids become increasingly sophisticated, the need grows for improved methods of follow-up. We have worked on this during the year and have produced a computerized routine for follow-up, which works well.

Once computerized bucking has been implemented on a practical scale, we will need to be able to transfer bucking criteria and data readily between office and logging machine. We have therefore drawn up a draft standard for communication via a data logger or modem between the bucking computer and the office computer.

In consultation with the machine technology advisory group, we have produced a standard for controls on single-grip harvesters, the machines likely to be among the first using computerized bucking, and sent copies of the standard to the manufacturers. We have also been involved in testing miniature controls for two-grip harvesters, and these are now being fitted as standard to ÖSA 707/280 harvesters.

(Project leader: Jan Sondell)

Marking improves sorting

During the year we completed a survey of paint-marker equipment available for logging machines. We produced technical descriptions of the equipment and made observations on the use and profitability of such equipment. Our calculations suggest that the improved sorting resulting from the use of paint-marker equipment produces increased revenue of 2-7 Skr/m3 (solid).

(Project leader: Jan Orke)

APTIMUM software package adopted

Work on our software package APTIMUM, designed to improve wood utilization, continued during the year. The program for bucking follow-up was demonstrated and trial runs took place at ten or more companies. Several of these companies have now purchased equipment and are implementing the system on a practical scale.

The other programs, for price-list analysis, log-tally evaluation and log-price listings, have been run in a number of practical cases. In collaboration with the sawmills and suppliers, we have designed price lists that steer the wood yield towards what the sawmills actually require. These price lists were used during the year and the results were favourable. The programs are being run on an experimental basis at a number of enterprises.

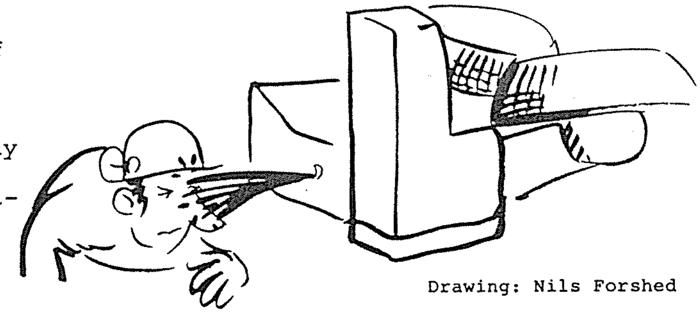
Feedback of the responses of the users to the various programs has already resulted in further development of the software, directed particularly at making the programs easier for inexperienced users.

(Project leader: Jan Orke)

Narrower strip-road spacing reduces costs

In a study of different thinning patterns, we found that reducing the strip road spacing to below 25 m can result in a reduction of logging costs of up to 25%. Consequent increases in productivity enable more-extensive thinning to be carried out using the same resources.

(Project leader: Tomas Jonsson)



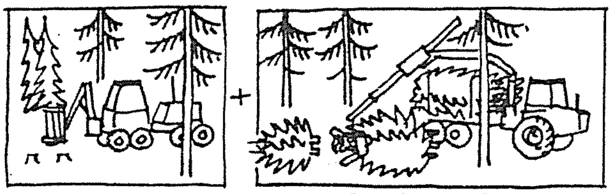
Drawing: Nils Forshed

Deferred first-thinnings profitable

Studies have shown that the thinning juncture has a bearing on the economy of a stand. By deferring first thinnings to five or ten years after the recommended thinning time, greater profitability can be achieved, because the trees removed are larger. On the other hand, increasing the thinning weight will not increase overall profitability.

Our studies also included an assessment of different forest-management programmes. Because the logging costs in first thinnings are greatly influenced by the tree dimensions in the stand, cleaning in densely populated young stands is necessary. The number of thinnings carried out is less significant to the overall economic result.

(Project leader: Tomas Jonsson)



Drawing: Nils Forshed

Further advances in tree-section logging

Advances in tree-section logging have resulted in some interesting method variations in motor-manual work. For instance, in one of the methods the cutter also bucks and prelimbs roughly the trees after felling, thereby achieving better lengths, greater payload density, and a larger proportion of the slash left in the stand - an ecological benefit. This method is particularly attractive when haulage distances are great.

New and improved equipment is available for mechanized felling in tree-section logging. Mechanization of felling is particularly necessary in difficult snow conditions and we have found that feller-buckers or feller-bucker-forwarders perform well in northern Sweden. One study revealed that, in winter conditions, logging costs can be reduced by more than Skr 1000/ha if the felling work is mechanized. A number of prototypes of other types of machine were also studied during the year.

A variety of equipment is now available for bunch-limbing of tree sections. In a study of the KMW drum-delimber for tree sections we found that the limbing quality was good and that good fuelwood could also be obtained. Productivity was roughly 50 m3 (solid) of biomass per G15-hour* and that the cost of limbing amounted to approximately Skr 25/m3 of biomass. In a study of a mobile flail delimber, manufactured by Bruks Mekaniska AB, we found the processing cost to be somewhat higher, although the machine was more versatile and the haulage costs can probably also be reduced.

(Project leader: Tomas Jonsson)

* Basic G x hour = Hour of productive time including downtime not exceeding ´x´ minutes per occasion.

Forest truck roads

We have studied two methods for improving forest truck roads and have found that the cost of gravel can be reduced by two-thirds by excavating and screening natural gravel from the side of the road and then mixing various aggregates with it, either on the road itself or in conjunction with loading the gravel onto trucks. The other method, which we are still studying, involves the construction and maintenance of roads using coarse pavements (stones up to 70-80 mm in diameter).

We are now finishing our work on the subproject dealing with transport in areas with substandard roads. We have already completed a major study into the transfer of loads from one form of transport to another. We found that the average additional distance travelled to transfer the load was 2 km and the cost for transferring the load was about Skr 8/tonne. Another study completed during the year examined the road standards required by modern timber-haulage vehicles. We found that the geometrical standard required by today´s vehicles is not as high as for the vehicles included in our 1970 study.

We also took part in a project run by the Transport Research Commission (TFK) on behalf of the National Road Administration, in which we examined the economical implications for road haulage of changes in payload regulations. We found that a transition to 10/16/60 or 10/18/60 configurations (axle load/bogie load/GVW) was greatly advantageous.

(Project leader: Lennart Rådström)

Photo: Erik Petré

Evaluation of logging and transport systems

During the year we started work on a program for calculating the efficiency, in terms of costs and revenue, of different logging and transport systems. An important precondition for the work is that logging and transport can be monitored with equal precision, and that the same starting and finishing points can be taken for the calculation, regardless of the assortment being handled. At present, the program can calculate the impact of diameter, extraction distance, distance to or from the terminal, etc.

(Project leader: Lennart Rådström)

Vehicle-mounted or separate loader?

During the year we carried out a study to find the consequences of a transition from the use of trucks equipped with loaders to small fleets of trucks served by a separate loader. In the case studied, a saving of about Skr 2 per tonne was made in the transport cost.

(Project leader: Lennart Rådström)

Role of staff changing

When an organization decentralizes its activities, the work content and the pattern of work done by staff change, both at head office and at area level. In collaboration with one region of the Swedish Forest Service during the year, we worked on redesigning the role of regional staff in conjunction with the district being made more directly responsible for the results it achieves. In their new role, the staff have a more-limited operational responsibility and much more of an advisory capacity. The formulation of overriding objectives and strategies was identified as a principal responsibility of staff.

(Project leader: Klas Norin)

Devolution of responsibility

Stresses acting on cab seats

During the year, in cooperation with a college of technology, we have been testing cab seats. The testing involves the monitoring of signals that provide information about the forces and movements taking place in the cab seat of a forwarder operating off-road in varying terrain conditions. So far we have found that it is only in exceptional cases that the forces acting on the seat mountings are of sufficient magnitude to explain the typical wear and tear evident in the seat subframe member. Although fatigue cannot be ruled out, we have been unable to determine whether in fact it has occurred. It is possible that play in the springing mechanism could give rise to forces momentarily of sufficient magnitude to be destructive.

(Project leader: Assar Johansson)

Important for management to set targets supported by all

Supervisor aids

In our work in a number of forest districts we have found considerable scope for developing the way in which work is organized. Many supervisors are snowed under and need help to put the work in order of priority. Furthermore, supervisors can seldom find time in practice to discuss objectives and results with the forest workers and thereby make full use of the knowledge and skills to be found among them. This approach is one which needs to be built in as a matter of routine. A number of districts also expressed a wish for greater employee involvement to help meet the targets for the individual area.

We have therefore produced a number of trial aids aimed at supporting the area managers and supervisors in their work. The idea is that the managers and supervisors - with only a minimum of help from us - together shall use the aids to help streamline their work. So far the aids we have produced are directed at three areas: putting work in order of priority; setting targets and discussing the results for individual sites; and setting objectives that have the general support of all concerned. The aids are now being used on an experimental basis and it is hoped that finished versions will be available to all by the spring of 1987.

(Project leader: Klas Norin)

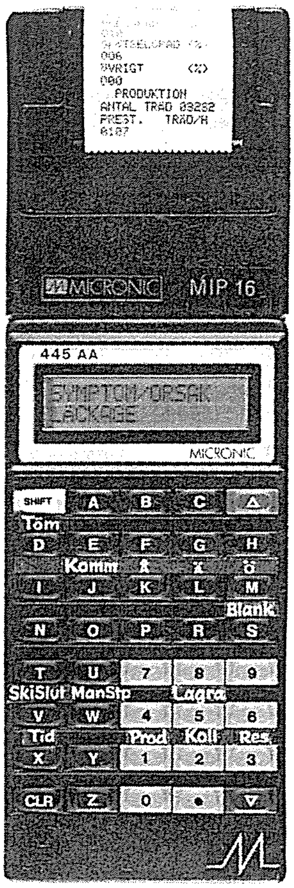
System for controlling the end of the boom

To reduce the training time and increase precision in knuckle-boom operation, we have developed a special control system for knuckle-boom loaders. The system consists of a computer linked between the operator's controls and the hydraulic valves. All the operator needs to do is to move the control enough to select the direction in which he wants the boom tip to move and the speed of movement, and the computer then takes care of distributing the oil to the various hydraulic functions. The first complete system, incorporating sensors, a computer and the necessary software for the revolutionary approach to controlling knuckle-boom loaders, has been developed on an ÖSA 260 forwarder.

(Project leader: Assar Johansson)

Practical hand-held computer

In computerized follow-up of operations, the operator can enter details of the reason for a stoppage and the remedial action taken, using a hand-held computer in the cab. A system designed to analyse the data collected in this way has been tested at three concerns by more than 50 operators. The components developed specially for this application have achieved a very high level of reliability. One of these is the Micronic 445AA-40 hand-held computer, in spite of being used in an environment totally foreign to that for which it was originally designed. The same hand-held computer can also be used to record signals automatically from a standard harvester, provided data on the tree species, assortments and log lengths. It is also fairly easy to supplement the system with a sensor for continuous diameter measurement, enabling log tallies to be compiled while the machine is operating. There is no doubt that this technology will be adopted rapidly by the forestry sector.



The Micronic 445AA-40 hand-held computer with the MIP 16 microprinter

(Project leader: Assar Johansson)

Refined gathering of forest data

A great deal of our development work focuses on improving the routines for gathering forest data. Of topical interest are electronic data loggers, hypsometers and hand-held computers. Such instruments provide tremendous scope for developing efficient methods. The benefits include data gathering with much less work and fewer sources of error, more reliable and precise data and faster processing. Applications for the equipment include various types of survey with the ability to record tree diameter and height automatically, stand cruises, and production and operations follow-up. Software programs for these and other applications have been produced and others are under development.

(Project leader: Olle Ericson)

Productivity targets for cleaning

We have now completed our compilation of the basic information required for setting productivity targets in cleaning and have made the results available to forestry concerns. Several enterprises are now planning to revise their standards in line with the new study material. Although the result of the new information is the same as that compiled earlier for the average site, greater consideration is given in the new information to non-typical sites. For instance, our studies were aimed specifically at providing more reliable information for sites requiring a large number of stems to be removed.

(Project leader: Karl-Georg Bergstrand)

Rapid updating of forest maps

During the year we presented our report of a study dealing with a simple method for keeping forestry maps up to date. The method is based on aerial photographs being taken every year of areas in which major changes have occurred (for instance, new clear-felled areas or new roads), and then, by means of simple projectors, superimposing the images on maps. Our findings so far show that acceptable accuracy can be achieved at a cost of Skr 7-8 per hectare of effective area. We also conducted preliminary studies during the year of two mapping systems designed for microcomputers, with a view to integrating the systems with our own FOREST PLAN 84 planning system.

(Project leader: Olle Ericson)

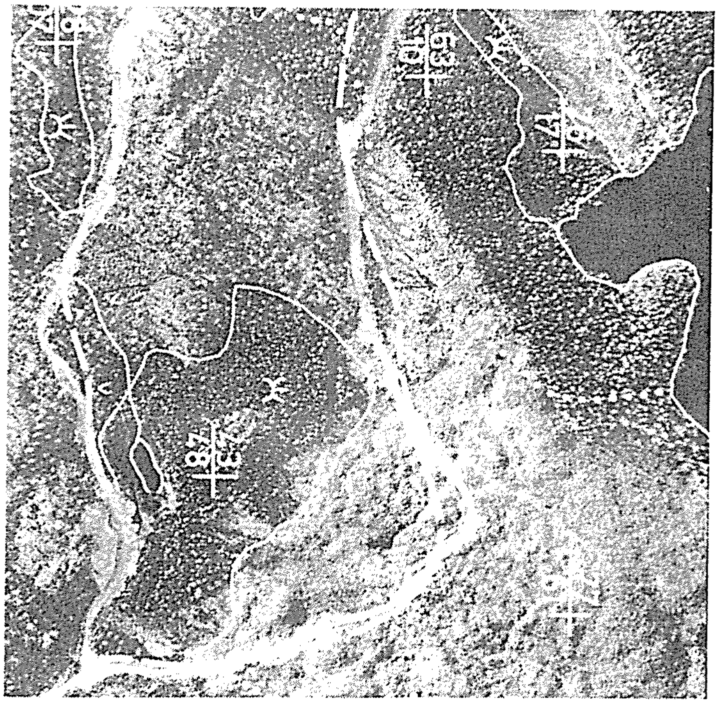


Photo superimposed on forest map

Information and extension services

Courses growing in number

During the year we arranged 41 courses and conferences, attracting 1,528 participants and covering a total of 2,543 participant-days.

The courses and conferences included the following:

Methods course for single-grip harvesters
Economical maintenance
More-economical transportation
Cleaning
The use of PCs in planning
Rationalization conference ´86
More-reliable regeneration
District manager meeting ´86

In addition to the courses, a number of management seminars were held and we also arranged a conference for foresters to provide information specially geared to the conditions prevailing in southern Sweden.

As in the previous year, we also arranged a number of courses on behalf of other educational establishments.

(Head of training: Svante Hössjer)

Stream of visitors from overseas

As usual, Skogsarbeten provided an information service not only for its members but also for numerous authorities, organizations and individuals at home and abroad.

During the year we were pleased to receive more than 80 visitors from 14 countries outside Scandinavia.

(Head of extension services: Ingemar Nordansjö)

100 new subscriptions to 'Results'

During the year ten issues of ´Redogörelse´ (Report) and a total of 33 issues of ´Nytt´ (News) and ´Resultat´ (Results) were published. Supplementary pages to the ´Safety Folder´ were also published. New for the year was a production of a methods folder for ´Maintenance of Chainsaws and Brush Saws´. New editions of a number of earlier manuals were also published.

The number of subscriptions to the various publications was largely unchanged, apart from ´Resultat´, which attracted 100 new subscribers.

(Editor: Gunilla Sundquist)

Four new films

In cooperation with a Swedish file manufacturer, during the year we produced the training film, ´Chainsaw Sharpening´, which shows the best methods and equipment for sharpening chains in the field.

Another film, ´The Silva Nova Planting Machine´, shows the machine at work and the organization of peripheral work such as seedling care, loading of seedlings, choosing the site, etc.

´Management by Objectives for Work Gangs´ shows a supervisor using the management by objectives method to head a cleaning gang. The film is designed to be used in discussions about different forms of management in a forest district and is therefore accompanied by study material relating to questions of management.

´Caring for our Forests´ has been produced to form part of the permanent forestry exhibition at the Museum of Technology in Stockholm. The aim of the film is to provide the general public with a brief insight into modern forestry.

(Head of filming and photography: Björn Söderlund)

At the 'Grüne Woche' festival in Berlin, the Skogsarbeten film, 'Working Technique in Limbing' won third prize in the training-film category.

The prize was presented to Rune Gårdh (at left), who wrote the narrative, and Bengt Dahlfors, who was responsible for the photography and editing.

Photo: Björn Söderlund

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APPENDIX 6: DESCRIPTION OF WONG'S MODELS

1. THE NEPEAN TRACKED VEHICLE PERFORMANCE MODEL NTVPM-86

NTVPM-86 is a comprehensive computer simulation model for evaluating and predicting the tractive performance of tracked vehicles over unprepared terrain.

The model takes into account all major design parameters of the vehicle, including vehicle weight, location of the centre of gravity, track system configuration, number of roadwheels, roadwheel radius, roadwheel spacing, sprocket pitch radius, location of the sprocket, tensioning wheel radius, location of the tensioning wheel, track supporting roller arrangements, suspension characteristics, initial track tension, track dimensions, track link geometry, track longitudinal elasticity, weight per unit length of the track, and vehicle hull (belly) shape. A complete list of vehicle parameters required as inputs to the simulation model NTVPM-86 is given in Table 1.1.

The model also takes into account the responses of the terrain to normal and shear loadings, including the pressure-sinkage characteristics, the response to repetitive normal load, internal shearing characteristics of the terrain, rubber-terrain shearing characteristics (for tracks with rubber pads or for rubber belt tracks), and vehicle belly-terrain shearing characteristics (when vehicle belly is in contact with the terrain). A complete list of terrain parameters required as inputs to the simulation model NTVPM-86 is given in Table 1.2.

The model is capable of predicting the normal and shear stress distributions on the track-terrain interface, track motion resistance, thrust, drawbar pull, tractive efficiency, load supported by the belly and associated belly drag (when the belly is in contact with the ground) as functions of track slip. Sample outputs of the computer simulation model NTVPM-86 are shown in Table 1.3. The basic features of the model have been substantiated with full-scale tests of instrumented vehicles over a variety of terrains, including sandy terrain, muskeg and snow (1,2).

NTVPM-86 can be used to examine the effects of vehicle design parameters, including vehicle weight, location of the centre of gravity, track system configuration, track design, initial track tension, and suspension design, on the tractive performance (2,3,4). It can also be used to evaluate the effects of terrain conditions on vehicle performance. Thus, NTVPM-86 is an extremely useful tool for the evaluation of competing designs and in the examination of the effects on performance of design modifications and changing operational environment, prior to the expensive hardware construction or full-scale testing.

2. THE NEPEAN WHEELED VEHICLE PERFORMANCE MODEL (NWVPM)

NWVPM is a computer simulation model for evaluating and predicting the tractive performance of wheeled vehicles over unprepared terrain.

The model takes into account all major design parameters of the vehicle, including vehicle weight, location of the centre of gravity, number of axles, axle suspension stiffness, tire diameter, tread width, section height, lug height, lug width, spacing between lugs, inflation pressure, tire construction, and location of the drawbar (5). A complete list of vehicle parameters required as inputs to the simulation model NWVPM is given in Table 2.1.

The model also takes into account the responses of the terrain to normal and shear loadings, including the pressure-sinkage characteristics, the response to repetitive normal load, internal shearing characteristics of the terrain, and rubber-terrain shearing characteristics (5). A complete list of terrain parameters required as inputs to the simulation model NWVPM is given in Table 2.2.

The model is capable of predicting tire deflection, contact length, rut depth, normal and shear stress distributions on the tire-terrain interface, compaction resistance, tire flexing resistance, thrust, drawbar pull and tractive efficiency as functions of tire slip. Sample outputs of the computer simulation model are shown in Table 2.3. The predictions made using the simulation model NWVPM have been compared with available experimental data. It has been found that there is a reasonably close agreement between them (5).

NWVPM can be used to examine the effects of tire and vehicle design parameters on the tractive performance of wheeled vehicles over unprepared terrain. It can also be used to evaluate the effects of terrain conditions on wheeled vehicle performance.

APPENDIX 7

Publications obtained from Professor Wong

Optimisation of the Tractive Performance of Four-Wheel Drive Off-road Vehicles

An Improved Method for Predicting Tractive Vehicle Performance on the Characterisation of the Sheer Stress Displacement Relationship of Terrain

Some Further Studies on the Mechanical Properties of Muskegg in Relation to Vehicle Mobility on the Study of the Wheel/Soil Interaction

Steering Response of Articulated Vehicles in Steady State Turns

Effect of Vibration on the Performance of Off-road Vehicles

Computer-aided analysis of the Effects of Design Parameters on the Performance of Tracked Vehicles

Parametric Analysis of Tractive Vehicle Performance using Advanced Computer Simulation Model

Theoretical Prediction and Experimental Substantiation of the Ground Pressure Distribution and Tractive Performance of tracked vehicles

APPENDIX 8: OUTPUT FROM SMSP MODEL

EXAMPLE OF OUYPUT FROM THE SOIL MOISTURE-
SOIL STRENGTH PREDICTION MODEL (SMSP).
(1980 RAINFALL FOR BATLOW USED AS INPUT)

		DRY		AVG		WET		WET-WET	
	WI	0-6	6-12	0-6	6-12	0-6	6-12	0-6	6-12
SAND	1	295.	265.	270.	226.	70.	67.	48.	63
		1	2	2	2	5	5	6	5
SM	1	300.	300.	280.	297.	209.	279.	126.	247
		1	1	2	1	3	2	4	2
SM	2	300.	300.	268.	287.	168.	230.	87.	147.
		1	1	2	1	3	2	5	4
SM	3	300.	300.	253.	278.	130.	197.	63.	93.
		1	1	2	2	4	3	5	5
SM	4	300.	300.	238.	273.	98.	193.	47.	62.
		1	1	2	2	5	3	6	5
SM	5	10.	10.	10.	10.	10.	10.	10.	10.
		11	11	11	11	11	11	11	11
SC	1	300.	300.	271.	292.	182.	254.	104.	195.
		1	1	2	1	3	2	4	3
SC	2	300.	300.	256.	280.	140.	208.	74.	120.
		1	1	2	2	4	3	5	4
SC	3	300.	300.	240.	270.	106.	176.	55.	79.
		1	1	2	2	4	3	6	5
SC	4	300.	300.	224.	261.	81.	152.	42.	55.
		1	1	2	2	5	4	6	6
SC	5	10.	10.	10.	10.	10.	10.	10.	10.
		11	11	11	11	11	11	11	11
SMSC	1	300.	300.	281.	296.	210.	272.	127.	228.
		1	1	1	1	3	2	4	2
SMSC	2	300.	300.	270.	287.	175.	229.	90.	140.
		1	1	2	1	3	2	5	4
SMSC	3	300.	300.	257.	280.	139.	204.	66.	92.
		1	1	2	2	4	3	5	5
SMSC	4	300.	300.	251.	276.	108.	195.	50.	63.
		1	1	2	2	4	3	6	5
SMSC	5	11.	11.	11.	11.	11.	11.	11.	11.
		10	10	10	10	10	10	10	10
CL	1	300.	300.	272.	283.	172.	214.	88.	128.
		1	1	2	1	3	3	5	4
CL	2	300.	300.	266.	273.	136.	184.	65.	85.
		1	1	2	2	4	3	5	5
CL	3	300.	300.	258.	277.	103.	175.	48.	58.
		1	1	2	2	4	3	6	6
CL	4	300.	300.	246.	280.	79.	153.	37.	41.
		1	1	2	2	5	4	7	6
CL	5	7.	7.	7.	7.	7.	7.	7.	7.
		11	11	11	11	11	11	11	11
ML	1	300.	300.	289.	270.	196.	173.	63.	86.
		1	1	1	2	3	3	5	5
ML	2	300.	300.	284.	272.	177.	139.	45.	56.
		1	1	1	2	3	4	6	6
ML	3	300.	300.	278.	278.	159.	136.	34.	38.
		1	1	2	2	4	4	7	7
ML	4	300.	300.	273.	274.	145.	111.	25.	27.
		1	1	2	2	4	4	9	8
ML	5	4.	4.	4.	4.	4.	4.	4.	4.
		11	11	11	11	11	11	11	11

Annotations beside the table:

- WI — WETNESS INDEX (SEE FOLLOWING PAGE)
- First line of each row — RATING CONE INDEX
- Second line of each row — SOIL CLASS CODE USED MOBILITY MODEL
- CL 2 — CLAY LOAM ON BASALT (TUMUT)
- CL 3, CL 4 — CLAY LOAM ON GRANITE (TUMUT)

Wetness Index

Wetness Index	Potential Wetness	Depth to Water Table*	Depth of Wetting	General Characteristics of Sites**
0	Arid	Indeterminable	Less than 1 ft (0.3 m)	Located in desert regions
1	Dry	Indeterminable	1-4 ft (0.3 to 1.2 m)	Steeply sloping, denuded, or severely eroded and gullied. Mostly semi-arid to arid regions
2	Average	More than 4 ft (1.2 m)	More than 4 ft (1.2 m)	Well-drained soil with no restricting layers or pans; fair to good internal and external drainage. Slope may be flat to steep
3	Wet	1-4 ft (0.3-1.2 m)	To water table	Soil not well drained. Restricting layers or deep pans may be present. May occur at base of slopes, on terraces, upland flats, or bottomlands
4	Saturated	Less than 1 ft (0.3 m)	To water table	Sites waterlogged or flooded at least part of year. Bottomlands subject to frequent overflow. Upland flats with poor internal drainage or shallow pans. Slopes with very poor internal drainage
5	Saturated	0 (surface)	Complete	Areas perennially waterlogged. No change in water content or strength

* Water table depth with reference to the surface had to be maintained for at least one day during the year or during the period of record used in the predictions.

** For use in classification when water table and wetting depths are not measured.