FOURTH ANNUAL
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PROCEEDINGS

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Welcome Address
to
Fourth Annual Workshop
COUNCIL ON FOREST ENGINEERING
Tartan Room, Alumni Memorial Building
University of New Brunswick
Wednesday, August 12, 1981 - 9 a.m.

It is a distinct pleasure for me to extend to you, on behalf of the University of New Brunswick, a warm welcome to Canada, to the Province of New Brunswick, and to this one of the older universities in Canada. With a charter issued in 1785, patterned on that of King's College, New York, <u>this</u> King's College is now laying plans for its bicentennial celebrations.

But forestry and forest engineering were not among the subjects taught until early in this century. In the four years from 1907 to 1910, with the catalytic effect of lectures by Dr. Bernard E. Fernow, forestry schools were established at Toronto in 1907, at U.N.B. in 1908 and at Université Laval in 1910.

While the program at Laval was known as "genie forestier" (forest engineering), it was closer to a classical forestry program than to forest engineering. It was not until the B.A.Sc. (Forest Engineering) degree program was started in the post World War I years at U.B.C. that a truly forest engineering curriculum was offered in Canada. This was basically one year of Arts and Sciences, three years of Civil Engineering with one mandatory Forestry "elective" each year culminating in a fifth year of Forestry. It was such a degree that I received 40 years ago this spring.

Meanwhile at U.N.B., more so than at either of the other two eastern Canadian universities, the need was realized for a curriculum more appropriate to the professional forest harvester, or logger as he was then known.

Post World War II saw the evolution of the forestry curricula at U.N.B., Forest Entomology and Logging. The latter, under the initiatives of Professor L. R. Seheult, now Professor Emeritus, evolved into an Industrial Production option, and to service this curriculum the Forest Engineering Group was developed.

With the excellent and continuing co-operation of the Faculty of Engineering, from the late J. O. Dineen to Prof. A. M. Stevens, now past Acting Dean of Engineering, who is with us this morning, the forest engineering curriculum at U.N.B. has evolved into a fully accredited engineering program, approved by the Accreditation Board of the Canadian Council of Professional Engineers. While administered on a day-to-day basis by the Faculty of Forestry, this unique program could not be mounted and maintained without the strong and effective support of the Faculty of Engineering.

While welcoming you to New Brunswick and to U.N.B. this morning, I thought that the evolution of our forest engineering program might be of interest to you. I look forward to the opportunity of meeting many of you personally during the course of this workshop.

May your deliberations during this four-day conference be profitable and your stay in New Brunswick enjoyable.

Dr. J. W. Ker
Dean
Faculty of Forestry

SESSION NO. 1

ENERGY USE AND PRODUCTION

CHAIR: PROF. TONY SHORT

REDUCTION OF FUEL CONSUMPTION IN FOREST OPERATIONS

Forest Engineering Council Workshop
August 1981

University of New Brunswick
Fredericton

Keith C. Jones
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Ottawa, Ontario

ABSTRACT

The scale and basic distribution of forest harvesting energy requirements are presented. The average energy requirements of mechanized and semi-mechanized forest harvesting operations are compared. The importance of examining the distribution of energy use within, and not by, individual machines is pointed out. This leads to a brief listing of possible fuel saving programs, concluding with an economic examination of these measures that indicates permanently installing fuel monitoring systems on board large machines may be economically justifiable.

INTRODUCTION

Energy use in forest operations has undergone intensive examination from almost every angle possible. Therefore, in preparing a presentation which is intended to spark discussion on a broad basis, the sources for reference are varied and numerous. However, the wide variety of current publications emphasize not only the immediacy of the issue but unfortunately the specific nature of any given application's energy requirements. This wide variation in energy requirements to perform a given task makes the discussion of energy uses a rather wandering subject. However it also suggests that there is considerable room for improvement (reduction) in energy requirements in those applications whose consumption is high by average standards.

ENERGY OVERVIEW

The objective of the remainder of this presentation is to summarize in very general terms the scale of energy costs in current mechanized forest operations, and then to discuss in somewhat more specific terms, the potential reductions possible through the implementation of programs intended to reduce fuel consumption. It concludes with a very rough cost estimate of the point at which it becomes feasible to install fuel monitoring instrumentation on board individual machines.

In current mechanized forest operations energy is consumed as gasoline, diesel fuel and lubricating oils, with lesser fractions being consumed as natural gas, stove oil and electric energy in camp operations. The cost of each type of energy varies considerably both by form and location within forest operations. Table I compares the current Canadian prices for diesel fuel and Bunker "C" oil. It also compares the prices of each type on a Barrel of Oil Equivalent (BOE) basis.

TABLE I

PRICE COMPARISON OF ENERGY SOURCES

TYPE	SPECIFIC ENERGY	UNIT COST ($)	BOE* COST ($)
Bunker "C"	5.9 MBTU/bbl	21.75/bbl	21.75
Diesel Fuel	5.4 MBTU/bbl	25/litre	43

* Barrel of Oil Equivalent

With the above prices in mind, and using 1978 industry-wide figures compiled by the Canadian Pulp and Paper Association, we can visualize the magnitude of energy costs associated with forest operations. In Table II, the energy requirement by type associated with Canadian woodlands operations are presented.

TABLE II

ENERGY COSTS OF CANADIAN WOODLANDS OPERATIONS. (1978 CPPA figures)

Type	G.O.E*/cunit	Cost/cunit ($ CND)**
Gasoline	1.0	1.14
Diesel	4.2	4.79
Other: stove oil natural gas etc.	1.0	1.14
TOTAL	6.2	7.07

* Gallons of Diesel Oil Equivalent
** Assume $1.14/gallon for diesel

They are based on the delivery of 53% of the 29 million cunits of pulp and wood residue utilized in Canada during 1978. At the assumed price of $1.14/gallon the annual direct fuel cost is roughly 190 million dollars per year. For a company harvesting perhaps 180,000 cunits annually the fuel bill would be roughly $1.1 million. A smaller contractor, harvesting perhaps 25,000 cunits would be facing a fuel bill of roughly $160,000. Either cost is a substantial bill to contend with.

Determining what percentage this fuel bill is of total operating cost is rather difficult. With the miriad methods used to calculate wood costs, the percentages would presumably be as varied as the energy requirements. However, as a best estimate, I would assume $80/cunit unloaded at the mill. Fuel used in for harvesting operations therefore represents roughly 10% of the total operating costs.

ENERGY COST BY FOREST OPERATIONS

While the total fuel bill may be 10% of operating costs, the question remains which are the specific operations that contribute most and are consequently the most reasonable ones to examine in any effort to cut costs. In Table III, the energy requirements of various harvesting functions are compared on a per cunit basis.

TABLE III

FUEL REQUIREMENT TO RECOVER
8 in dbh softwood (GOE/cunit)

	SWEDEN		E. CANADA	
	MECH.	SEMI-M.	MECH.	SEMI-M.
Fell & Limb	-	.30	-	.07
Fell & Forward	.66	-	1.89 (KFF)	
Load & Forward	-	.34		
Skid to Roadside	.79	-	1.58 (limb)	.80
Load & Haul (50 Km one way)	1.15	1.15	3.48	3.48
TOTALS Energy Cost ($/cunit)**	2.60	1.79	7.95	4.35

* GOE = Gallons of Diesel Oil Equivalent
** $0.25/litre

The figures are taken from studies and calculations conducted in both North America and Sweden and are based on a 50 km one-way haul distance. Both the figures from Sweden and Eastern Canada indicate the higher energy costs associated with fully mechanized systems. Mechanized systems requiring twice as much energy as the semi-mechanized (chainsaw) felling operations.

The exampled Canadian figures for total fuel consumption in Table III bracket the industry average of 6.2 gallons/unit shown in Table I. The differences are accounted for primarily in camp and road construction operations and the effect of mechanized and semi-mechanized systems. With our assumed $1.14/gallon fuel price, our energy cost is roughly $9.00/cunit for mechanized and $5.00for semi-mechanized operations.

Having established a rough magnitude of the total energy cost of forest operations, and that it represents a significant proportion, roughly 10%, of production costs, the question that arises is how to reduce this fuel bill. However, before taking action to reduce energy costs it is essential to determine where, within each operation (or machine function) the fuel is being used, or wasted, dependent on your view point. Is the fuel consumed as an overhead cost without adding value to the product, or is it being consumed usefully. This means the distribution of fuel consumption must be determined either by calculation or measurement, and then presented in a manner that will relate to the fuel saving measures possible. One system defining this distribution recognizes 3 direct levels of energy required to accomplish a task, Machine, Work Cycle and Operational. It was first applied by the Department of Operational Efficiency of the Swedish Royal College of Forestry. Figure I illustrates the relationship between these levels. The Machine level is only that energy required to perform useful work. The Work Cycle level includes all fuel used in performing a standard operation; load a tree, one round trip etc. The Operational level includes all fuel used during a regular operating period, such as a shift. It includes the energy "wasted" during idle or waiting times.

By considering energy as a cost applied to a task, the Machine, Cycle and Operational levels can be modeled as fixed or variable overhead and operating costs. Machine energy is essentially a fixed operating cost. As long as the machine is operating properly, the Machine energy/unit of production is fixed. The difference betweed Machine and Cycle levels is a fixed overhead cost. It is the energy used during productive times, to simply operate the machine at governed speed. It is often a fixed, base load fuel consumption that can be measured under no-load conditions, at governed rpm. The difference between the Operational and Cycle levels is a variable overhead cost. It is the energy wasted while waiting for material, idling, warming up or moving to a new location.

In any operation minimizing overhead costs is a high priority and it is no different with energy accounting as the next example will indicate. Figure 2 illustrates the breakdown of Machine, Cycle and Operational energy requirements for mechanized and semi-mechanized harvesting systems. The figures are shown from a Swedish study however they are probably equally representative of the distribution of direct energy consumption in North America.

Figure 2 emphasizes that in both mechanized and semi-mechanized operations the largest fraction of fuel is consumed as an overhead energy cost in the Cycle and Operational level; in a mechanized system roughly 70%, and in semi-mechanized 52%.

Several approaches to reducing energy consumption associated with these different levels are possible, though none are simple to implement and seldom inexpensive. In Table IV the most common approaches are listed along with the energy level each affects.

TABLE IV

FUEL ECONOMIC MEASURES

APPROACH	ENERGY LEVEL AFFECTED		
	MACHINE	CYCLE	OPERATIONAL
1. **Mechanical Modifications**			
Repower			
- more efficient engine	X	X	X
- lower hp		X	X
Modify Existing Eng.			
- injector change			X
- precise tune-up	X	X	X
2. **Operational Mods (Training)**			
- smoother accelleration		X	X
- reduce idle time		X	
- improve operator techniques		X	X

The approaches to fuel savings have been classified primarily as mechanical or operational. Only the mechanical solutions of repowering with a more efficient engine or improved tuning offer any savings in Machine energy levels. These actions affect the basic energy conversion efficiency of an engine and while the actual energy requirement/cunit may decrease, the distribution will remain relatively unchanged.

The other two mechanical approaches listed lower the horse power available and thereby reduce the base load fuel consumption accumulated as an overhead load in the Cycle and Operational levels. Such measures seldom meet with operator approval and usually restrict the flexibility of the machine application.

Only the Operational solutions, which improve operator performance offer the potential to shift fuel consumption from the Cycle and Operational levels into usefully applied effort at the Machine energy level, without sacrificing machine flexibility or incurring high capital costs through repowering with more efficient engines.

Of course accomplishing changes to the operating or driving style of an individual requires considerable effort, training and demonstrated proof that the individuals efforts are worthwhile. To accomplish this an on-board fuel consumption totalizer, and preferrably a rate indicator, are required. Without these on operator cannot demonstrate to himself what fuel savings are immediately possible through modifications to operating techniques.

While the cost of re-power kits are high, from $10 - $20,000 for even a skidder, the cost of a reliable, rugged, fuel flow indicator is by no means low. However these instruments, which were once restricted to laboratory use, are, with escalating fuel prices, becoming more common and less expensive. At present several types of fuel flow meters and indicators are available for trucking applications for roughly $1,500 with ancillary equipment and installation costs being no more than $1,500 even on a first application basis.

With an estimated cost of $3,000 per machine and the potential to affect to some degree the fractions of fuel consumed as overheads; it is interesting to consider at what point an economical pay back on a fuel meter installation might be realized. To do this, in Table V typical hourly fuel consumption of several machine types are presented along with estimated capital costs and investment recovery periods if 5, 10 or 20% fuel savings are realized through operator training, much of which can be accomplished without instruction. All the operators need is a reliable indicator to observe immediately and continuously the results of their actions on a short and long-term basis.

TABLE V

INVESTMENT RECOVERY PERIOD FOR A $3,000 FUEL FLOW METER INSTALLATION*

MACHINE	HP.	FUEL RATE (gallons/hr.)	% FUEL SAVINGS 5	10	20	Capital Cost $ x 1000
			Recovery Period (hrs.)			
Rubber Tired Feller-Buncher	115	4.7	11200	5600	2800	160
Chipper	300	13	4600	2300	1153	180
Loader	115	3.2	16000	8000	4000	200
Tractor -Trailer	280	6	8770	4390	2190	130

* Assumed fuel price of $1.14/gallon (CND)

CONCLUSION

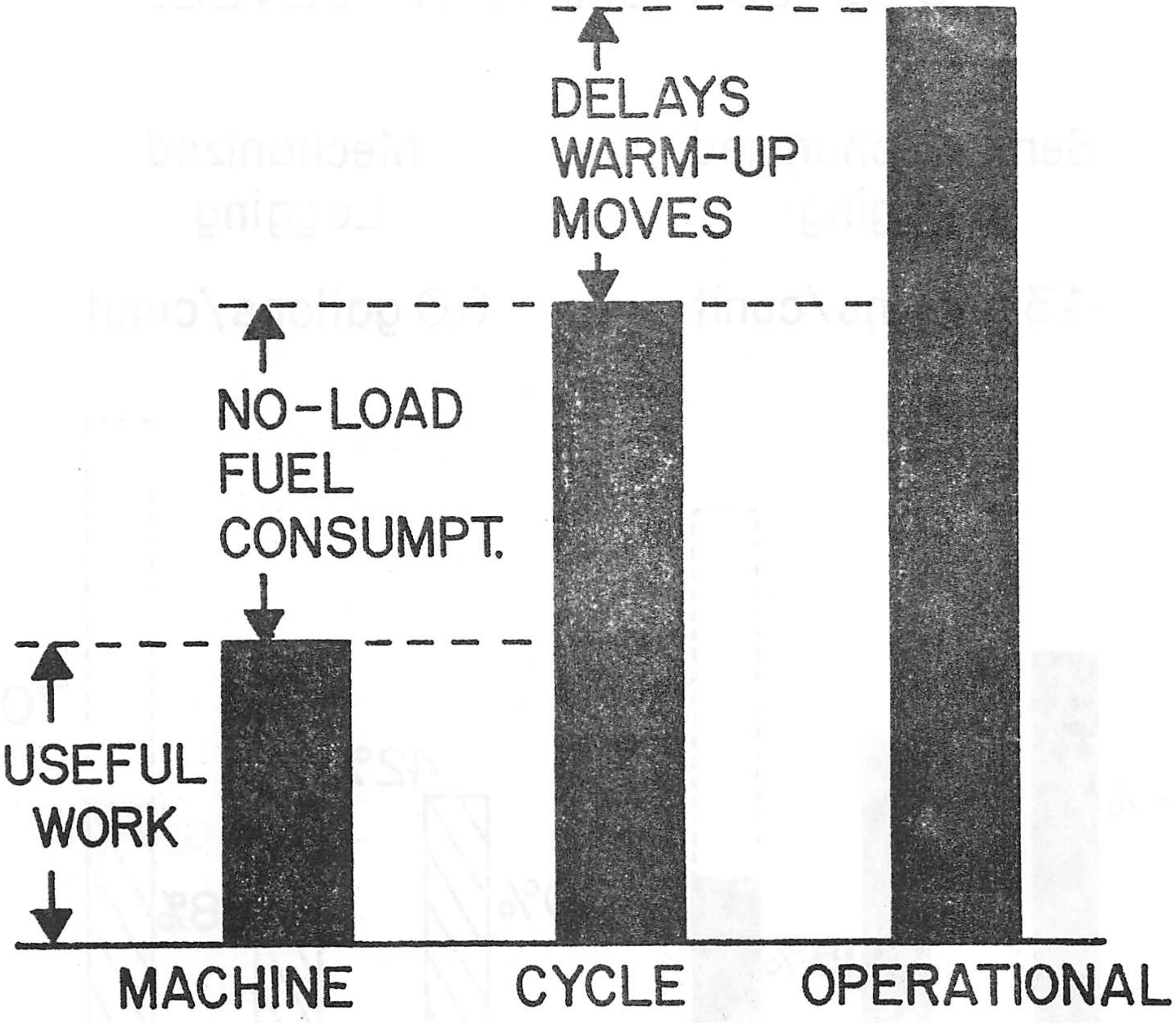
From Table V if we assume an average fuel saving of 10% is realized then the payback periods for the exampled machines would range from 2,300 - 8,000 operating hours (1 - 3 years). This ignores the possibility that fuel prices may continue to rise at a rate that has recently exceeded average inflation rates. By contrast if a repower approach was used even assuming a low cost of $10,000/unit the payback period would be roughly 3 times as long.

Now, obviously a decision to repower a machine would not be made simply on the basis of an energy saving project. This would only be one of several deciding factors and the repower itself would most likely be part of a rebuilding program. However, by contrast a flow meter system can be salvaged from any machine and installed on the next generation, or on another type once the learning process has been demonstrated and proven to operators.

Therefore on the basis of this very simple examination, installing an on board fuel monitoring system is, at least, economically, an attractive method for instituting a fuel economizing program within a fully mechanized harvesting operation.

The figures and opinions I have presented were originally intended to focus discussion on the topic of Energy use in Forest Operations. In my opinion, however, the topic of discussion should not be Energy Use, but Energy Saving in

Forest Harvesting Operations. In fact they are the same, for isn't energy saving the objective of any study into energy use. Therefore rather than take the approach of listing examples of energy requirements, all of which are site specific, I have attempted to gloss over them and finish by directing attention to the causes (inefficient utilization) fuel and cures rather than the symptoms.

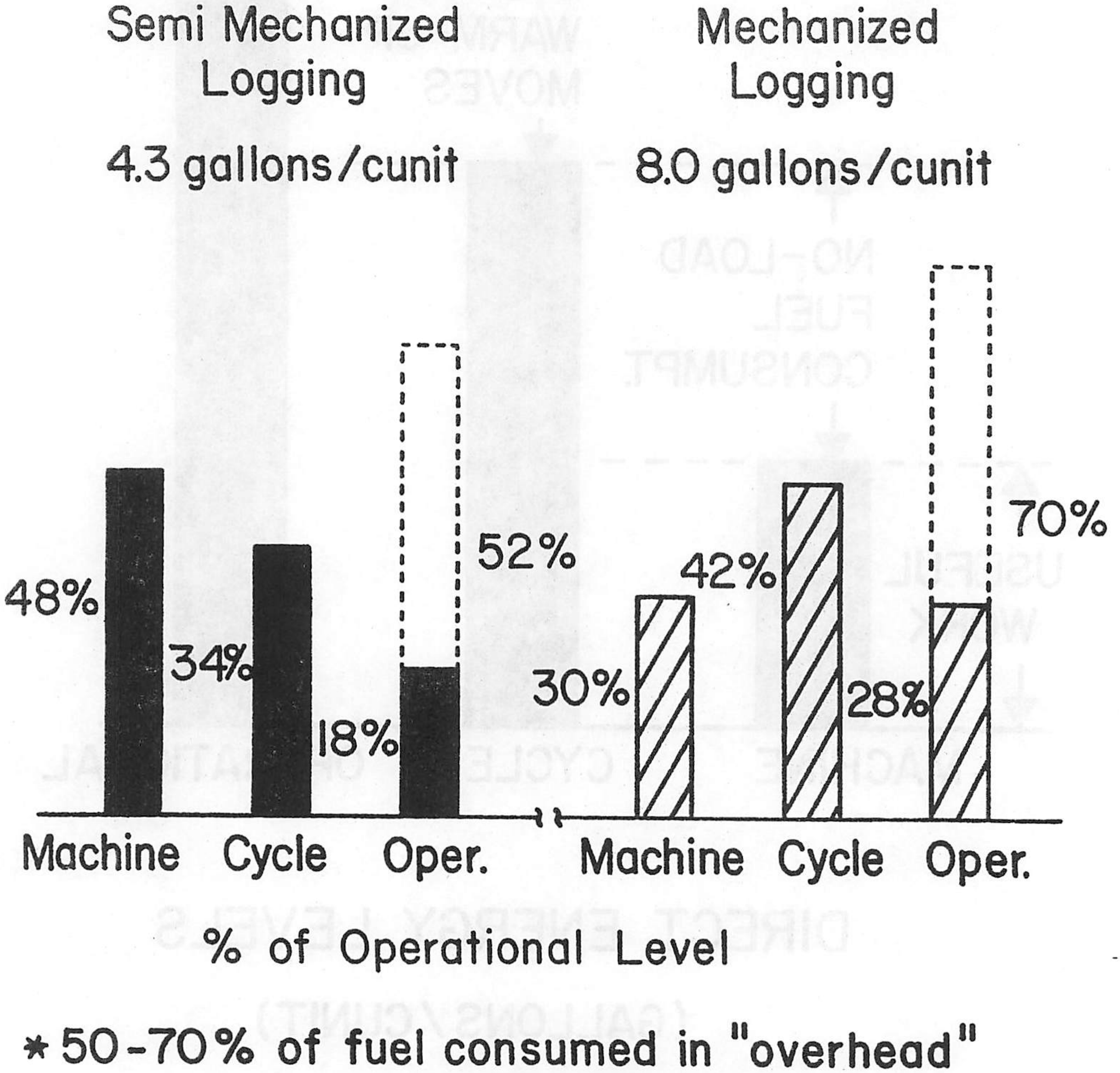


DIRECT ENERGY LEVELS

(GALLONS / CUNIT)

Figure 1

FUEL CONSUMPTION LEVELS



*50-70% of fuel consumed in "overhead" Cycle and Operational levels.

Figure 2.

MEASUREMENT OF PHYSICAL PARAMETERS DURING SKIDDER FUEL-USE STUDIES

by

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For presentation at the Fourth Annual Workshop
Council on Forest Engineering

University of New Brunswick
Fredericton, N. B., Canada
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ABSTRACT

Preliminary fuel-use studies were made during skidding operations using a cable skidder. Total fuel consumption, force in the mainline, angle of the mainline with the horizontal, skid speed, load volume, load weight and load orientation were measured or noted. Regression equations were developed for fuel-use versus horizontal force and fuel-use versus load volume.

MEASUREMENT OF PHYSICAL PARAMETERS DURING SKIDDER USE STUDIES [1]

by

R. Kenneth Matthes [2]
William F. Watson

Introduction

In the past, the low cost of fuel reduced the importance of fuel cost in harvesting and transporting wood products to the mill. However, during the past 10 years a five to six fold increase in diesel fuel and gasoline prices makes fuel usage an important cost consideration.

In the United States and Canada, most producers transport the felled tree from the stump to the loading deck by skidding. Skidding can be defined as the moving of whole trees or tree stems from one location to another by connecting a cable or chain or a grapple to one end of the tree which may or may not be lifted off the ground and dragging them over the ground with a four-wheel, articulated skidder, a track-driven machine such as a bulldozer, or a farm tractor.

The primary resistant force in moving trees in this manner is the friction between the stem and the ground. This force is reduced by lifting one end of the tree off the ground with a cable or grapple attached to the rear end of the skidder. If the stem end is lifted off the ground so that the vertical component of the force in the cable is increased and frictional resistance between the stem and the ground is reduced, the horizontal component of the resultant force in the cable resulting from skidding the log is reduced. The power output of a skidder engine is proportionally related to the fuel usage of the engine. The proportionality decreases somewhat on either side of the optimum power output of the engine. The power output required to propel a skidder across level ground is related to the rolling resistance of the tires on the ground and any horizontal forces opposing the movement of the skidder such as the

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[1] For presentation at the Fourth Annual Workshop Council on Forest Engineering, University of New Brunswick, Fredericton, N.B. Canada.

[2] The authors are Professor, Agricultural and Biological Engineering Department, Associate Professor, Forestry Department, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Mississippi State, MS.

horizontal component of force in the skidder cable. Rolling resistance is affected by the weight of the skidder and the vertical component of the force in the skidder cable.

The ultimate objective of this research is to relate various methods and procedures of skidding with fuel usage. Variables evaluated in this study are load size, load orientation, amount of load on the ground, skid speed, soil conditions, skidder size and type of skidder. The first step is to relate fuel usage to the resultant force in the skidder cable regardless of how the force is caused. Further work will attempt to relate resultant forces to load, soil conditions, stem orientation, speed and other variables encountered by various methods of skidding logs.

The objectives of this paper are to describe the procedures for measuring fuel usage and cable forces during skidding operations and to report preliminary evaluations of these methods.

Fuel Flow Measurements

The apparatus used for measuring fuel flow was a Systems Corporation Model ERD Diesel Engine Fuel Flow Monitor which is equipped with a digital readout for total flow to the nearest 0.01 of a gallon (0.038 liter). The apparatus does not compensate for temperature.

The fuel flow meter was calibrated at various temperatures of No. 2 diesel fuel to develop an equation to calibrate the meter for various operating temperatures of the fuel. The actual weight of fuel per 0.15 gallon (0.57 liter) measured by the flow meter was measured in 10°C increments from 22°C to 62°C.

The results of the flow calibration tests are given in the following conversion chart (Figure 1).

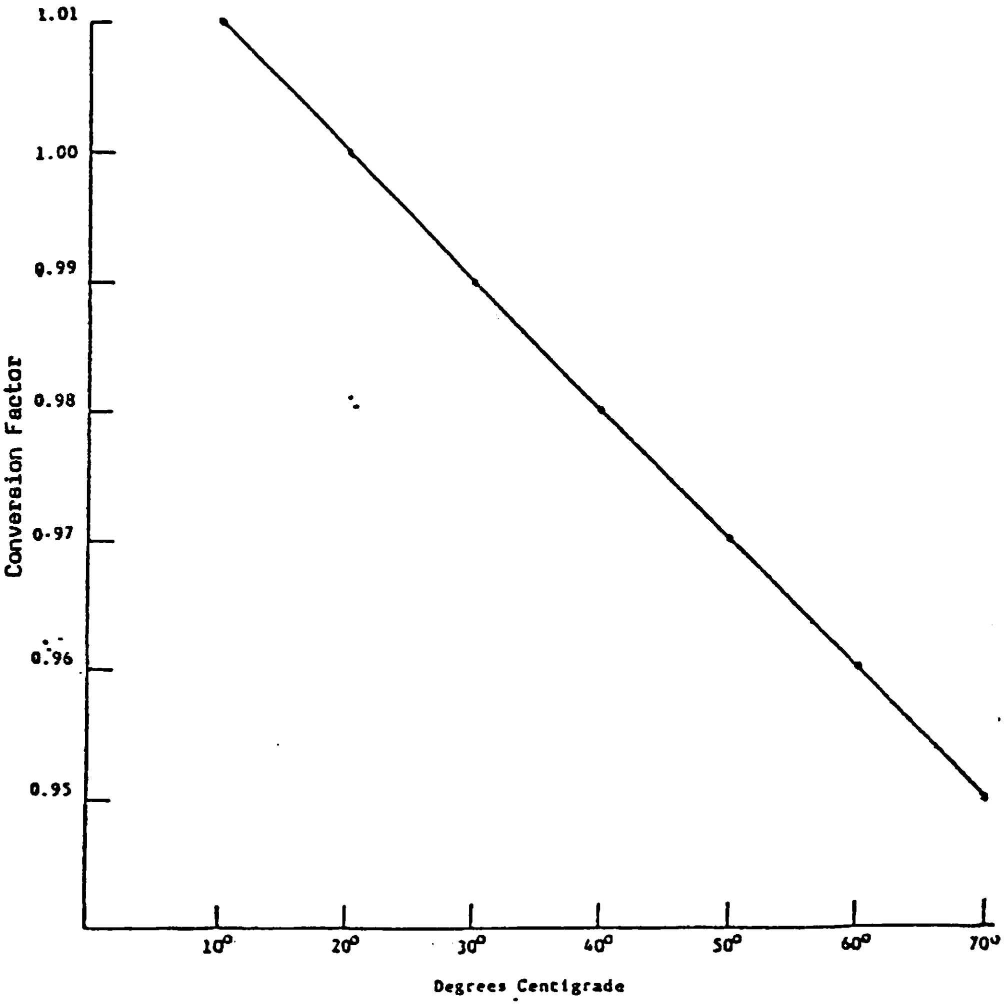

Figure 1. Converstion Factor for Compensating Fuel Flow Readings.

Force Measurements

The force measurement apparatus consisted of a 3-inch (7.62-cm) diameter hydraulic cylinder attached to the top of a winch housing and the mainline (Figure 2). A pressure gauge having a range of 0-5000 psi (0-3500 Kg/m^2) was attached to the cylinder with a high pressure hose and located in the skidder cab. The pressure in the hydraulic system was recorded by the driver during the skidding operation. The hydraulic cylinder was calibrated using a dynamometer, and it was determined that the piston in the cylinder has an effective area of 3.72 in^2 (24-cm^2).

As shown in Figure 2, the cylinder was attached forward of the fairlead roller. This introduced some error in the force determination; however, since the roller was free wheeling the error was considered to be unimportant for the preliminary evaluations.

Evaluation of Measurement Systems During Skidding Trials

The fuel flow system and force measurement system were installed on a 90 h.p. Taylor rubber-tired cable skidder. A 1400-ft. (427 m) skidder course was laid out on level ground composed mainly of clay-loam. Five hardwood trees were cut ranging in length from 34 to 74 ft. (10.4 to 22.6 m) and in volume from 14 to 60 ft^3 (0.4 to 1.7 m^3). Loads varying in volume from 20 ft^3 (0.56 m^3) to 100 ft^3 (2.8 m^3) were constructed using various combinations of the five stems. At least two tests each of skids of 1400-ft. (427 m) were made for loads of 20, 40, 60, 80 and 100 ft^3 (0.56, 1.12, 1.68, 2.24, 2.80 m^3) with the stems skidded flat on the ground and winched up with the butts clear of the ground. The stems were oriented butt-forward in all tests. It was attempted to maintain a constant speed for all skids. The average speed ranged from 6.00 to 7.22 ft/sec (1.80 to 2.17 m/sec).

The angle of the mainline with the horizontal was measured in a static condition, attempting to duplicate that occurring in the dynamic condition as closely as possible. Video tapes of the tests in dynamic conditions indicated that the angle of the cable varied periodically as the logs were skidded over the ground, particularly over the rougher surfaces. The angle variation was greater for the stems winched off the ground than those skidded flat on the ground. When more than one stem was being skidded and the main line was snubbed up to the fairlead, the angle was estimated by

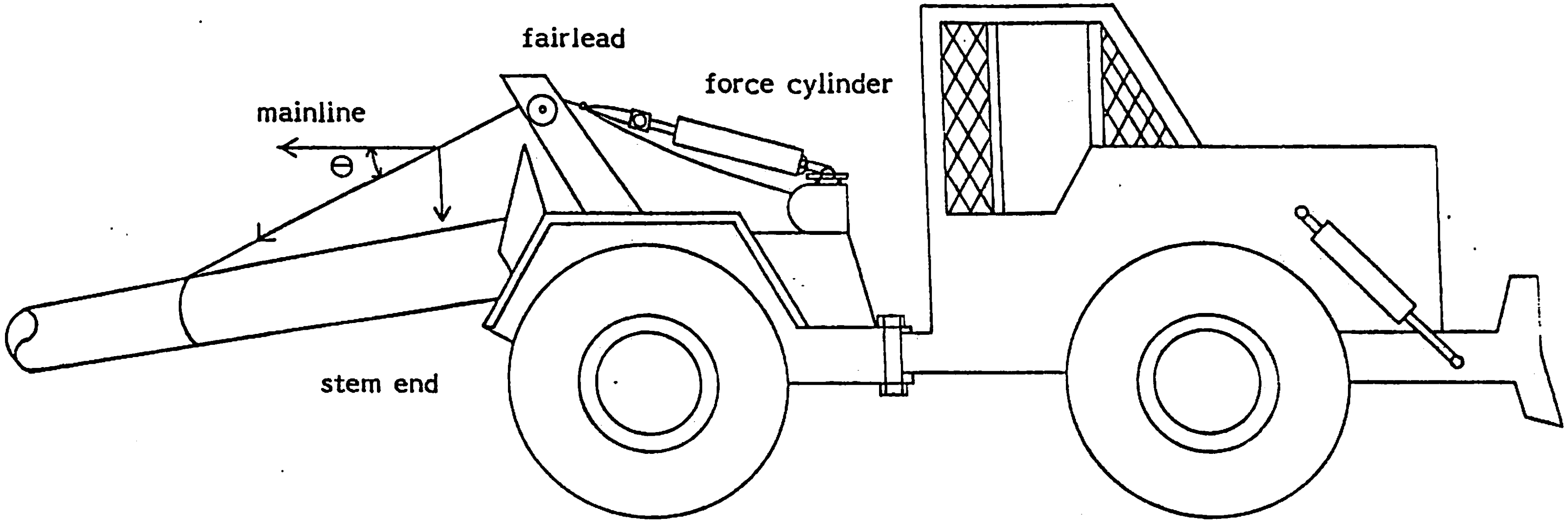

Figure 2. Force measurement apparatus attached to skidder.

averaging the angles of the two or more choker cables.

The fuel usage was determined for each 1400-ft (427-m) test run. The pressure in the force measurement cylinder was estimated during the run from the pressure gauge mounted in the skidder cab. Under dynamic conditions, there was variation in the pressure readings as force in the mainline fluctuated during the actual skid. It was necessary to estimate the average pressure reading visually using operator judgement. The total force was calculated by multiplying the average pressure by the effective cross-sectional area (3.72 in^2) (24 cm^2) of the cylinder, and the horizontal component of force was calculated by multiplying the total force in the mainline by the cosine of the angle of the mainline and the horizontal.

A regression analysis was used to determine the fuel use as related to the horizontal force in the mainline, and the results are:

$$\text{Fuel Use (gal)} = .217 + 2.64 \times 10^{-5} \times \text{Horizontal Force (lbs)}$$

$$\text{Fuel Use (liter)} = 0.82 + 5.81 \times 10^{-5} \times \text{Horizontal Force (kgs)}$$

Figure 3 is a graph of fuel use versus horizontal force including the linear regression line. The R square for this regression is 0.68.

The fuel consumed over the test course was also regressed on load volume. An indicator variable was introduced into the model to account for the difference in force required to overcome the additional friction incurred when the stems were skidded flat on the ground. The equation developed was:

$$\text{Fuel (gal.)} = .207 + [2.7 \times 10^{-4}\ I + 8.5 \times 10^{-4}]\ \text{Vol (ft}^3)$$

$$\text{Fuel (liter)} = .78 + (7.6 \times 10^{-6}\ I + 2.4 \times 10^{-5})\ \text{Vol (m}^3)$$

where

$I = 0$ if the load was winched up,

$I = 1$ if the load was flat on the ground.

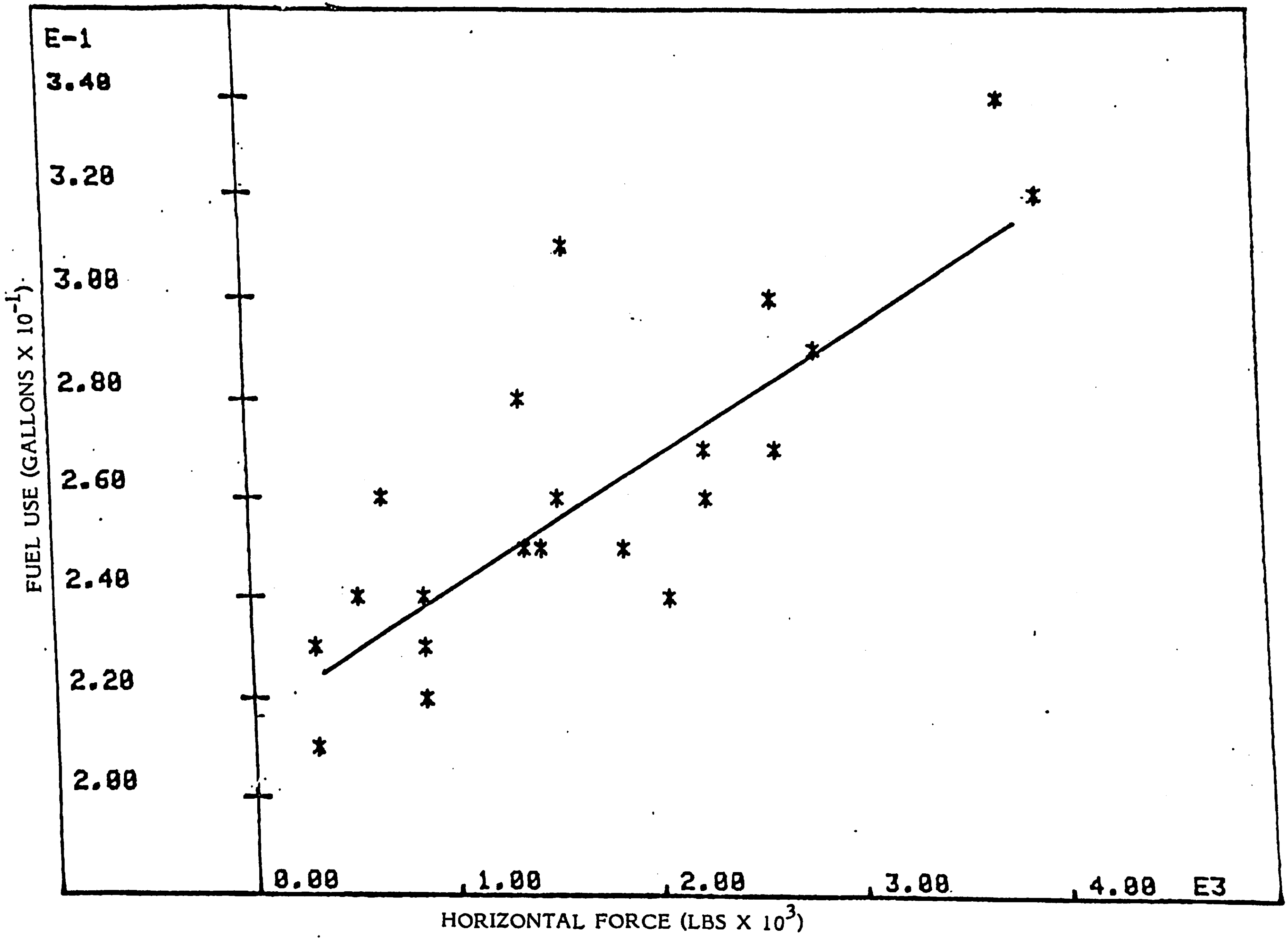

Figure 3. Fuel use versus horizontal force.

The R square for this regression is 0.80.

Figure 4 is a graph of fuel use versus volume of logs being skidded.

Figure 5 is a plot of horizontal force versus volume of logs being skidded. Note the spread between the force for the stems skidded with the butts winched off the ground and those skidded flat on the ground.

Discussion of Results and Recommendations

One hypothesis was that the fuel use versus the horizontal force would be influenced by whether the logs were winched up or skidded flat on the ground. In the up position, the vertical component of force, or the total weight on the wheels, would be increased and thus the rolling resistance would be increased. However, in the regression analysis the position of the stems in the up or down position proved to be a non-significant factor. One possible explanation for this was that the skidding surface was firm and in a dry condition.

The volume of the skid load was a better indicator of the fuel usage than the horizontal force when the position of the logs, up or down, was taken into consideration. This relationship can be very useful since an operator will have little trouble in estimating the volume (weight) of his loads during skidding operations. The relationship is further verified by dependency of the horizontal force on the skidder load and the position (up or down) of the load.

During this preliminary evaluation of the instrumentation, it was determined that 0.01 gallon (0.038 liter) (the measurement integer of the fuel flow meter) was too large of an increment. It is recommended that a flow meter be acquired that can measure to 0.001 gallon (0.0038 liter) for future fuel usage studies.

The video recordings of the skidding operations indicate that there is a rather periodic fluctuation in the angle of the mainline when the logs are being skidded in the raised position, depending on the ground conditions. This is further verified by the

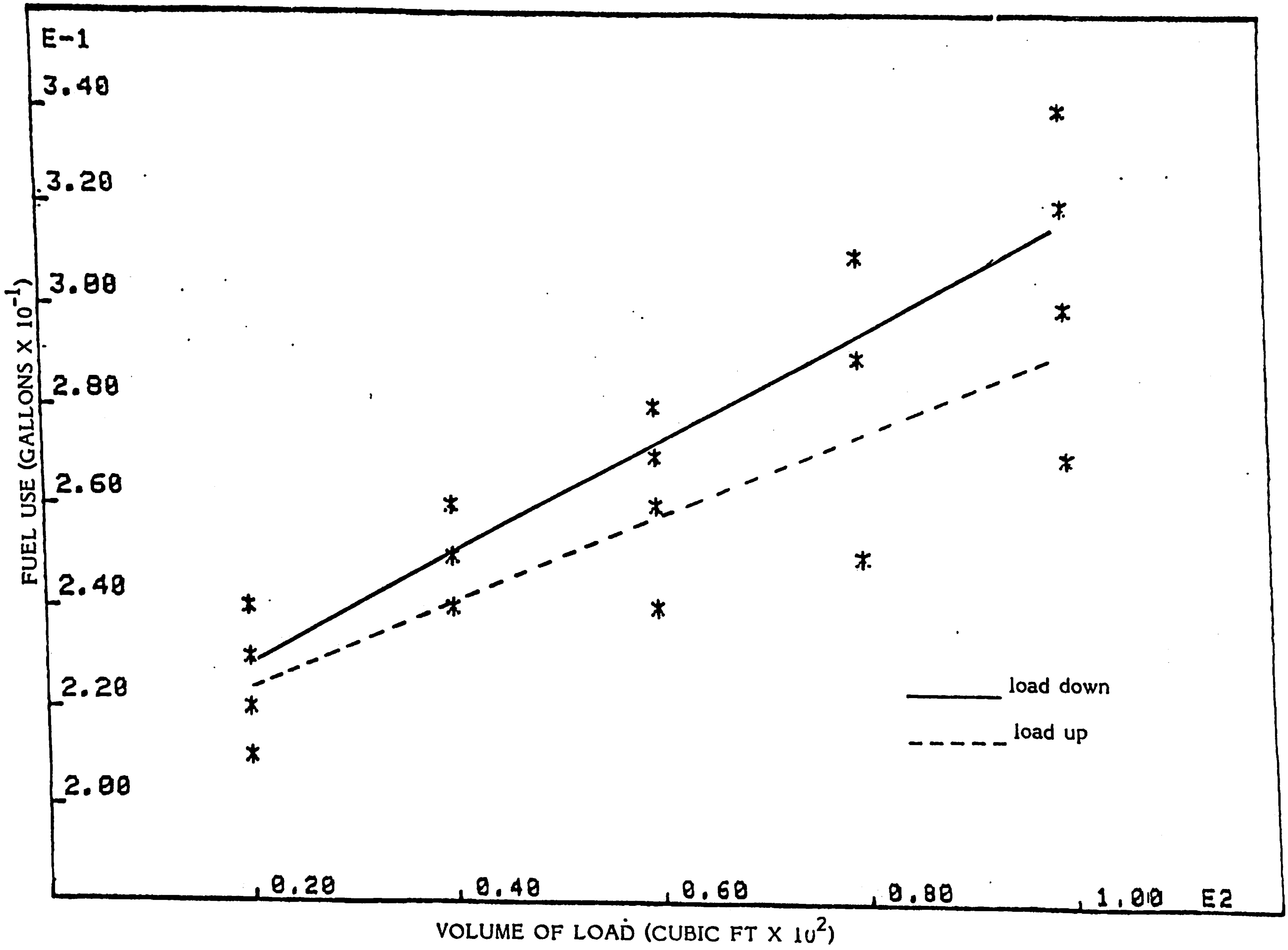

Figure 4. Fuel use versus volume of load.

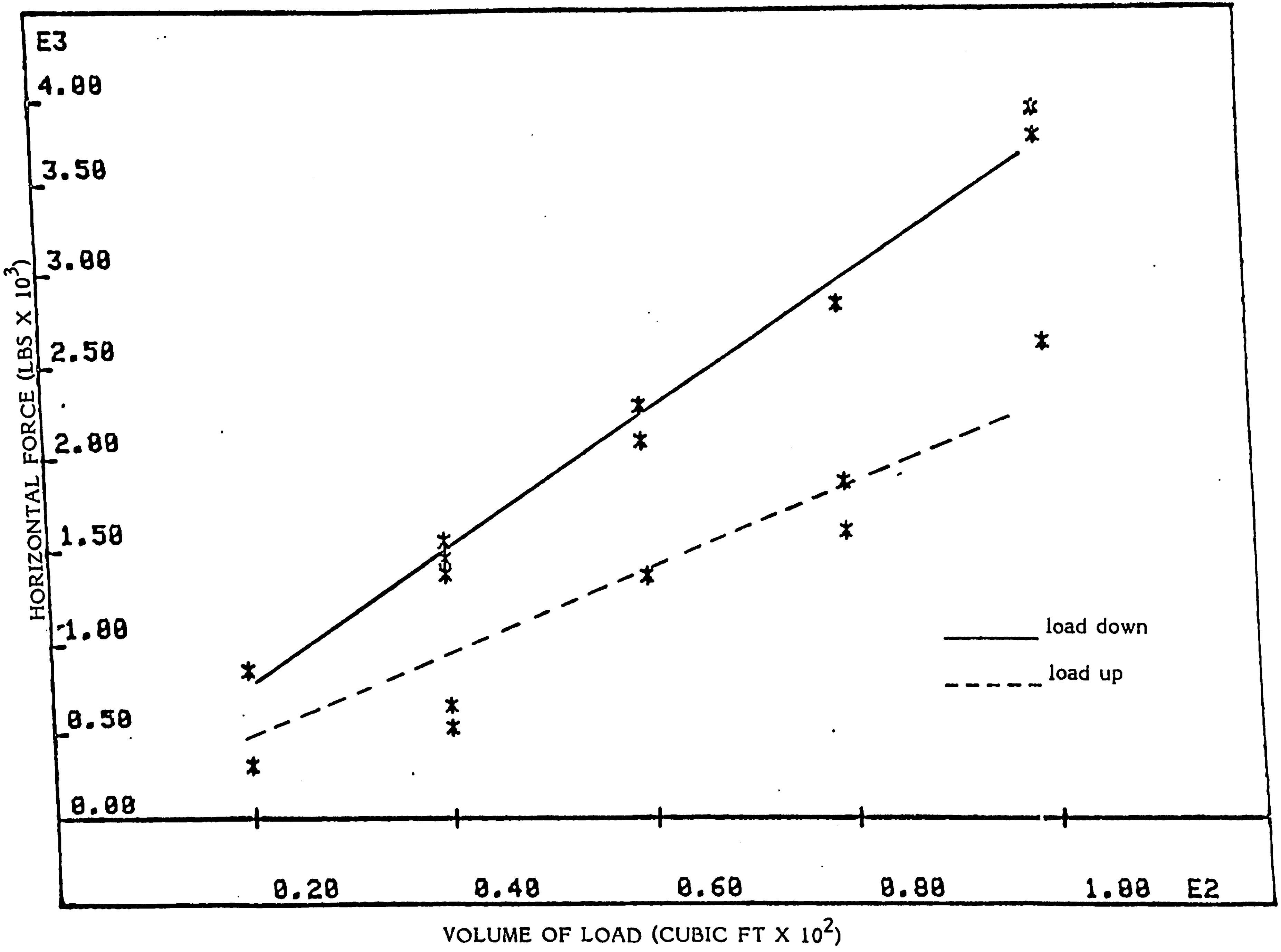

Figure 5. Horizontal force versus volume of load.

fluctuation of pressure reading in the force cylinder due to the change of the force in the mainline caused by the swing of the logs in the up position under dynamic conditions. A method for measuring force should be investigated which will record continuously, such as a force cell with a strip chart recorder.

The volume and density of stems also should be recorded in all skidding studies to establish a relationship between the weight of the load and the fuel usage. Realizing that the ground surface conditions are an important consideration in this relationship, the composition of the soil should be analyzed, the moisture content be determined, and the tire depression depth of the skidder tires should be measured in future studies. All of these parameters are of particular interest to the harvesting operator since they all can be easily measured and used to estimate fuel usage under various skidding conditions.

This presentation is based on the report:

INTEGRATED LOGGING FOR PRODUCTION OF PULPWOOD AND HOG FUEL

by

W.C. Wilton
Northland Associates Ltd.
St. John's, Nfld.

Presented by

Bill Evans

to the Council on Forest Engineering
August 10-13, 1981

INTRODUCTION

The utilization of forest biomass for hog fuel began in Newfoundland in 1978. In the first year approximately 6200 tonnes of material were harvested from a hardwood stand, and used as a supplementary fuel at the Abitibi-Price Pulp and Paper Mill in Grand Falls. The initial experiment was undertaken as a joint project by the Company and the Newfoundland Department of Forest Resources and Lands. The results of the experiment were sufficiently encouraging to warrant the continuation of the work in 1979 under an ENFOR project. The objective in extending these trials was to further develop operational techniques for harvesting under different stand conditions. During the second year of operation a total of 5700 tonnes of biomass from White Birch live stands and from fire-killed softwood stands, was harvested and converted into fuel. In this trial the total savings in energy obtained over production costs were approximately equivalent to the cost of 1000 barrels of oil.

These results proved conclusively that whole-tree harvesting for hog fuel was both economically and environmentally feasible.

The same basic harvesting system was used in both years' operations. This consisted of transporting whole trees from the cutting area to a central landing where they were chipped by a Morbark Model 22 Chiparvester. The chips were blown into modified dump trucks and transported to the mill yard for stockpiling and subsequent burning. The one difference was that Timberjack RW 30 Harvesters were used in 1978 for tree

INTRODUCTION (Cont'd.)

felling and transporting to the landing, whereas in 1979 this task was accomplished by manual felling and forwarding with wheeled skidders.

Harvesting in 1978 was conducted over a three-month period. It took place in an overstocked White Birch stand of low merchantability located about three kilometres from the mill. The 1979 operation also lasted approximately three months. It began in the same area as the 1978 trial and was then extended (two weeks) to a fire-killed Black Spruce stand, located six kilometres from the mill, which contained trees of minimum merchantability. The final phase of the operation took place in a fully-stocked White Birch stand, about 15 Km. from the mill, where the trees were in the medium merchantability class.

The 1978 trial resulted in a slight loss in terms of costs/benefits for the operation. This loss however, was more than offset by the advantages gained in providing employment and in reducing oil imports. The utilization in 1979 of fire-killed softwood stands also resulted in a loss but there were extentuating circumstances which left the results in doubt. The two 1979 trials in hardwood stands were both profitable with the greatest success being achieved in the stand with the larger-sized trees. Here the cost/benefit analysis showed a saving of $6.95 when compared with an equivalent barrel of Bunker "C" oil.

INTRODUCTION (Cont'd.)

A secondary objective of the 1979 trials was to assess the amount of disturbance to the site from whole-tree harvesting and the impact this disturbance could have on the future crop. In this respect it was concluded that these effects are no different than those to be expected from conventional harvesting methods. In fact, there are certain advantages in this type of harvesting as it clears the site of all debris which could be a hindrance to future silvicultural treatments.

All previous trials for the procurement of hog fuel were conducted in stands which had no value as a source of wood fibre for the Grand Falls mill. It is estimated that there are at least 16,000 hectares of productive forest land within 100 Km. of the mill which support such non-commercial wood fibre. In addition, there are considerable areas of mixed hardwood-softwood stands near the mill where only the softwood component is harvested for pulpwood. The hardwoods are left standing. If widespread use is to be made of these hardwoods as a fuel source, it can best be accomplished by integrated logging. Such operations could greatly increase the potential for utilization of the overall forest resource.

The Company was interested in extending the earlier trials into an integrated pulpwood-fuelwood operation. However, as before, there was a requirement to evaluate various harvesting techniques on a cost/benefit basis and to determine if any of these methods will result in site damage and consequent regeneration problems. The proposal for an integrated harvesting operation was therefore accepted as a cost-shared ENFOR project. Funding arrangements were similar to those in effect in 1979. ENFOR accepted expenses for project supervision, surveys, Chiparvester rental, minor extraction roads and the provision of a final report. The Company provided harvesting and transportation equipment, manpower and material. All phases of the work were undertaken by the Company (under contract) in accordance with a project plan prepared by the Newfoundland Forest Research Centre.

The project began in June 1980 and finished February 1981.

PROJECT OBJECTIVE AND SCOPE

The objective of this project was to conduct operational trials of integrated harvesting systems as follows:

1) Develop operational techniques for the combined harvesting of pulpwood and fuelwood in mixedwood and softwood stands;
2) Assess the technical and economic feasibility of integrated logging of stands in the vicinity of Grand Falls;
3) Assess the impact of integrated logging and complete tree removal on the site, and on the development of the future crop.

The project was essentially a continuation of whole-tree harvesting trials. It differs from last year's work only to the extent that it was an integrated operation where pulpwood was produced in addition to hog fuel. As in previous years, a two-phased study was carried out.

PROJECT OBJECTIVE AND SCOPE (Cont'd.)

The first part of the study was concerned with determining the best combination of harvesting techniques and utilization standards which would give the greatest economic return from mixedwood stands. The second phase was an extension of harvesting impact assessment into mixedwood forest conditions.

To evaluate all these factors the study was designed to consist of a number of harvesting trials under different undisturbed and cutover mixedwood stand conditions.

STUDY METHODS

The mensurational data required for the preparation of stand and volume tables were obtained from permanent sample plots. These plots, which are to be remeasured after cutting, will also provide information for the evaluation of harvesting impacts.

VOLUME AND BIOMASS DETERMINATION

Local, total volume tables, based upon measured height-diameter relationships, were derived for all commercial species, from the metric standard tree volume tables prepared by the Newfoundland Forest Research Centre. The volume per hectare was determined by applying the local volume tables to the individual area stand tables. Total biomass per hectare was obtained by using these area stand tables in conjunction with tree weight equations which had been developed in 1980 for the Grand Falls region.

HARVESTING

The current harvesting system is similar to that used in 1979. It consists of manual tree felling, hauling whole trees to a central landing using wheeled skidders, chipping with a Morbark Model 22 Chiparvester, and transporting chips to the mill yard in tractor-trailers (22-tonne capacity) and modified dump trucks (10.2 tonne capacity). In salvage operations (Test 3) the biomass material was stockpiled at the roadside for later chipping. In other operations (Tests 1 and 2) the material was delivered directly to the chipper (hot logging). In the integrated operation softwoods were initially sorted at the felling area; tree tops were lopped off at the chipper site and tree boles were bucked into pulpwood and sawlog sizes at a nearby landing.

Cost and production records were maintained for all phases of the operation on a weekly basis. Production was measured in green tonnes of delivered biomass. Time and production studies of the major components of the harvesting schedule were undertaken periodically. These studies will permit a later analysis of equipment productivity and availability as a basis for comparison with other harvesting systems.

BIOMASS CONVERSION

Two burning trials were undertaken to determine the fuel value of biomass harvested under different operating conditions. The methods and procedures for this evaluation were similar to those used in earlier burning trials.

The 1980-81 experiment was primarily an integrated logging operation in mixedwood stands. However, there are extensive pulpwood cutovers, in the vicinity of the mill, which contain sizeable quantities of standing hardwoods, together with the normal softwood cutting debris, which was suitable for wood chip production. It was therefore decided to extend the harvesting operations into such biomass conditions in the form of small-scale tests. The summer of 1980 was an exceptionally wet one and work progress was considerably delayed; consequently, the project did not proceed as planned. It was found to be impossible, under such adverse conditions, to construct a road to the designated integrated logging area and an alternate area had to be selected. This delav in startinǵ the princinal oneration resulted in more time being spent in salvage operations than was originally intended. Up to the end of February 1981, the following tests had been completed:

1) An integrated pulpwood-fuelwood full-tree operation undertaken in a stand containing 53 tonnes of biomass (oven-dry weight) per hectare.

2) A salvage operation which harvested hardwoods from a mixedwood cutover in combination with biomass from adjacent small undisturbed stands of pure hardwoods. Available biomass was estimated to average 40 tonnes (oven-dry weight) per hectare.

3) A salvage operation in mixedwood cutover which harvested the standing hardwood biomass plus some pulpwood cutting debris. Available material consisted of 23 tonnes (oven dry weight) per hectare.

Trial 1 took place in an undisturbed, 70-year-old, mixedwood stand, comprised of White Birch and Balsam Fir in about equal number and with small quantities of other species.

This area was selected for harvesting after it became obvious that the unusually wet summer prevented access to the pre-selected mixedwood stand.

Trial 2 took place in an area which originally supported a mixedwood forest type with inclusion of small, pure hardwood stands. It was cutover for pulpwood in 1977.

As well, this area was selected late in the season when, for reasons stated, it became obvious that operational plans required readjustment.

Trial 3 took place in an area which originally supported a 75 year old mixedwood stand which was cutover for softwoods in 1978.

RESULTS

The results of the tree trials in terms of benefits/costs are shown in an accompanying table. These results apply only to hog fuel. Pulpwood and sawtimber production costs were assumed as average for Company operations and were deducted from the

RESULTS (Cont'd.)

overall operational cost. A total of 207 M^3 of pulpwood and 28,000 FBM of sawtimber was produced.

TABLE 1

BENEFIT/COST COMPARISONS

	Test 1	Test 2	Test 3
Wood cost per* green tonne (dollars)	24.64	23.20	37.70
Chip moisture content when harvested (percent)	43.4	43.5	40.1
Chip moisture content at burning test (percent)	49.6	49.6	40.1
Oil equivalent per green tonne (barrels)	1.00	1.00	1.20
Oil cost per barrel (dollars)	21.27	21.27	21.27
Equivalent cost of wood per barrel (dollars)	24.64	23.20	30.31
Total production in green tonnes	5164	4712	1887
Profit or loss per green tonne (dollars)	-3.37	-1.93	-12.18

*Includes chip handling cost at mill - $1.32/gree tonne.

CONCLUSIONS

The overall trial to produce hog fuel from mixedwood stands was conducted at a loss. Adverse weather conditions during the trial period restricted the scope of the operation. The project as originally envisaged would have been profitable under normal operating conditions.

In the individual tests the attempt to salvage softwood cutting debris in addition to standing hardwoods (Test 3) was the least successful. Continuation of this type of operation using present methods is not recommended. The salvage of hardwood biomass only from mixedwood cutovers (Test 2) resulted in the least loss. This could be attributed to the inclusion of biomass from adjacent, undisturbed hardwood stands. The integrated operation (Test 1) which was intended to be the primary trial, also resulted in an apparent loss. However, in this instance a quantity of pulpwood and sawtimber was harvested.

In the first two trials the results as shown are deceptive. Pertinent data are based upon a burning test undertaken in mid-winter with chip moisture content as indicated, whereas actual mill utilization took place at time of chip production. This difference in moisture content altered the oil equivalent values sufficiently to indicate a loss. In actual fact, the integrated operation can be considered to have at least broken even, and Test 2 to have realized a slight profit. The continuation of both these operations is recommended.

SMALL-SCALE WOOD CHIP HEATING PROJECT

IN NEW BRUNSWICK

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ABSTRACT

There are three projects in Eastern North America demonstrating home heating systems firing particulate biomass fuels (wood chips, pellets). The New Brunswick project has one hot water installation and one hot air installation, both fuelled with 1 cm chips produced by a farm-tractor-mounted chipper. The hot water system provides all space heat and hot water; the hot air system all space heat and some hot water. The hot water system was imported from Sweden and the hot air stoker and furnace were made in Canada.

Fuel consumption in both units has been comparable to the oil used previously, requiring approximately 0.09 KWH $dd^{-1}m^{-2}$. There has been no flue creosote and little visible emissions. House temperature is maintained at constant set valves by a conventional thermostat.

INTRODUCTION

Most small- and medium-scale (3 kw to 1500 kw or 10,000 BTU/hr to 5,000,000 BTU/hr) wood burning units burn chunk wood using natural draft. Such units require periodic manual stoking with fuel, and, unless the fuel load is small, modulation is by means of limiting the combustion air since there is a large mass of fuel in the combustion zone. Complete combustion of volatile pyrolysis gasses some distance from the solid fuel apparently occurs only when such units are operated at high power (8, 9), which is normally only a small part of their operating time. Gasses which are not completely burned are either condensed on flue linings or lost to the atmosphere as smoke. Both of these are creating serious problems for wood burners.

The only small-scale chunk wood burning system which gives both very high combustion and heat transfer efficiencies is the Hill furnace (2), now commercially available. That furnace uses metered air, self-metering of the fuel (fall by gravity into a limited combustion zone), and sufficient heat, turbulence and time for very good combustion and heat transfer. The unit currently fires at one rate, with the heat put in water storage to be called on when needed.

Particulate biomass (pellets, wood chips, some mill residue) can be fed with automatic equipment into small burners. Feeding particulate fuels along with proper amounts of combustion air into an effective combustion zone can lead to complete combustion. Modulation to meet heat load can occur both by changing fuel and air speeds and by cycling fuel and air on and off. Also, particulate fuels can be made from material, such as harvesting and mill residues, for which limited markets now exist, and for which higher uses are not likely to be quickly developed.

SURVEY OF PARTICULATE BURNING PROJECTS IN NORTHEASTERN NORTH AMERICA

The work that researchers in New Brunswick and Prince Edward Island have been doing is to demonstrate, test, and improve small-scale particulate fuel burning systems using private residences for the installations. A group in Maine has also developed a small-scale chip burner which is being tested in several homes and in some commercial and institutional buildings. The objective of all of this work is to gain acceptance of wood burning systems which can use forest and mill residues, and which are safer, less polluting, more efficient, and more convenient than systems which burn chunk wood.

The Maine work is centred at the Agricultural Engineering Department at the University of Maine at Orono. The system designed there is auger fed over a grate in a refractory brick lined firebox. An oil gun is positioned to fire under and up through the grate, providing ignition for the chips. Underfire forced draft is provided. The firebox, whose outer casing is 16 ga mild steel, is connected to the furnace by a refractory tunnel. The tunnel enters the furnace through what was the oil gun port. The system is thus adaptable to existing conventional hot air or hot water oil systems.

When the thermostat calls for heat in the Maine system, the oil gun is fired and the auger begins to feed chips. After an interval, the oil burner shuts off. If a stack gas heat sensing device indicates that the fire is going, the oil gun remains off. If stack temperature is low, the oil gun refires for a second interval in order to ignite the chips. The auger stops feeding chips when the thermostat is satisfied, causing the fire to die out. At the next call for heat, the cycle restarts. This work is a refinement of concepts developed previously (3).

The Prince Edward Island workers installed some Swedish chip stokers and some North American pellet fed systems, as well as conventional chunk wood systems, in homes and monitored their performance. A Hampton Jetstream, (the commercial version of the Hill furnace), was also part of the study. The biomass pellet burner was of the underfed type with ring grate typical of coal-burning units once widely used in North America. The unit used was, in fact, a slightly modified coal stoker. The chip burners were a gravity-fed preheater gasifier, two underfed stokers with the grate inserted in the furnace proper, and one stoker firing a combustion chamber outside of the furnace. The combustion chamber in the latter, like that of the gravity-fed equipment and the Maine system, is connected to the main furnace by a refractory tube. The performance of these systems is reported in Institute of Man and Resources documents (6, 7).

RESULTS TO DATE OF THE NEW BRUNSWICK CHIP BURNING PROJECT

In New Brunswick, our work has consisted of installation and monitoring of two units in homes, and fuel preparation for them. We first purchased a Swedish boiler and chip stoker and installed these in a house previously heated with oil. Our second installation was a locally-designed and built stoker coupled to a conventional chunk wood burning hot air furnace. Both homes had other heating systems installed previously; these systems had been monitored for some time. In addition, hot water consumption and the energy used to heat the water had been monitored.

Both stokers are of the underfed type with the fuel building into a pile in the combustion bowl inserted through the side (or end) of the furnace. Combustion air is blown around the edge of the pile, promoting vigorous combustion.

FUEL

Chipping

The wood chip fuel being used is prepared by the Maritime Forest Ranger School using a BRUKS model 720 mobile chipper. This chipper is designed to mount behind a farm tractor of 40 hp or larger using a standard three point hitch. The manufacturer is BRUKS MEKANISKA AB, Box 46, S-820 10 ARBRA, Sweden and the importer is FORESTEC LTD. Cost of the chipper in late 1978 was in the order of $5,500.

Fuel Characteristics

The material being chipped is a "run-of-the-woods" mixture of hardwood and softwood, which had been seasoned in unprotected piles in 8 foot roundwood form for at least six months. When chipping, the chips were discharged directly into either a heated basement drying room or to an unheated basement storage bin. Moisture content (dry basis) of chips taken from heated storage ranged from 7.9% to 16.8% while that of chips from the unheated bin has ranged from 13.8% to

56.2% with considerable variation between samples taken from various randomly selected locations in the bin. Density varied from 197 kg m^{-3} (12.3 lb. ft^{-3}) to 271 kg m^{-3} (16.9 lb. ft^{-3}) when determined after settling the chips by vibrating the test container (a 55300 cm^{3} (2 ft^{3}) cube-shaped box). Chip size, ideally, is 0.3 cm (0.125 in.) thick by 0.6 to 1.3 cm (0.25 to 0.50 in.) square. While the bulk of chips are in this range, a few significantly oversize pieces do, somehow, get through the chipper. Particles 1 cm (0.4 in.) thick, 2 cm (0.75 in.) wide and 12.7 cm (5.0 in.) long have been found in the chips and also cards 0.3 cm (0.125 in.) thick, 7 cm (2.75 in.) wide and 21 cm (8.5 in.) long; such odd sized pieces are removed manually when seen, however some such pieces must inevitably escape detection and thus pass through the fuel feed system. Miscellaneous pieces of non-combustible metal (bailing wire, nails, a bed spring), and rock and glass have also been found in the ash bed within the grate; such items were probably discarded in the fuel chip bin after chipping since they bear no signs of knife marks and would probably have caused damage to the chipper had they passed through it.

HOT WATER SYSTEM INSTALLATION

House

The residence in which the wood chip stoker-boiler unit is installed is a 107 m^{2} (1152 ft.^{2}), split entry design built in 1971. The attic is insulated to R-20 over the living areas and to R-40 over the sleeping areas and is ventilated. All walls, including the basement walls, are insulated to R-12. All windows are double glazed. There are four occupants and living patterns are such that thermostats are set at 15.5°C (60°F) in all areas both night and day, but are adjusted to 20°C (68°F) during weekday evenings and during both day and evening periods on weekends.

The heating system uses hot water and is divided into four zones - living, bedroom, basement recreation room and garage - with baseboard units in all areas save the garage, where a unit heater is installed. The basement recreation and garage areas are unfinished, seldom used, and are not usually heated. The original boiler is an oil-fired New Yorker boiler, model NY-145 rated at 42.5 KW (145,000 btu hr^{-1}) with a 1.35 U.S. gal hr^{-1} nozzle. Average annual fuel oil consumption for 1974 to 1978 inclusive has been 4160 l (915 Imperial gal).

Boiler

The boiler used is a CTC, type 435B rated at 52.7 KW (180,000 btu hr^{-1}) when oil fired and so designed that it can be fired using either stick (or split) wood, wood chips or oil. The combustion chamber is surrounded on all sides and the top by water cooled surfaces. The gas flow is such that combustion gasses make four passes around water cooled baffles before leaving the unit. Boiler water volume is approximately 300 l (65 Imperial gal). The manufacturer is AB CTC, Box 135, S-341 00 Ljungby, Sweden.

The boiler is connected to the house plumbing so that it is in parallel with the original oil fired unit and either unit can be isolated and drained while the other provides heat.

Stoker

The stoker, manufactured by SKOGSMATERIEL AB, Box 12199, 102 25 Stockholm, is a SKOGMA 077 unit. It consists of a 15 cubic foot hopper, two augers turned by a 0.25 hp capacitor start electric motor through vee-belt and gear reducer drives, an anti-bridging mechanism (driven through a Scotch yoke from one auger) used to jostle the stored chips, an underfed fire bowl (or grate) and a forced draft fan.

Chips are moved by one auger from the hopper to a transfer box where they fall four inches to a second auger which conveys them into the underfed grate. The transfer box is intended to act as a fire break in the event fire burns back along the second auger. Draft conditions are such that burn back has not occurred thus far. The stoker stands on the floor, beside the boiler, so located that the fire bowl extends through a port cut low on one side of the boiler and is centered within the combustion chamber.

Two adjustable (from 5 to 300 seconds in 5 second increments) timing relays cause the stoker to run intermittently in order to ensure enough fuel in the grate to maintain a small flame or glowing coals, sufficient to act as a source of ignition; when heat is demanded by an aquastat on the boiler fresh fuel provided by the stoker is ignited by the small fire thus maintained.

Controls

Apart from the two timing relays provided with the stoker, which cycle on (for a 15 second period) and off (for a 300 second period), heating system control is virtually identical to that used on the original oil fired boiler. When any zone thermostat calls for heat, the appropriate zone control valve opens and, providing boiler water temperature is above the low limit set on the boiler aquastat (Honeywell L8124C), the circulating pump starts and delivers hot water to that zone. In the event that boiler temperature is low, then the stoker motor is started and the stoker runs as required to increase boiler water temperature in exactly the same way as would an oil burner. A second aquastat (Honeywell L4006A) is installed in series with the stoker motor and serves as a back-up high limit control, while leaving power available for circulating pump control and operation. Low and high limits are set at 71°C (160°F) and 82°C (180°F) respectively.

Fuelling

In order to obtain daily fuel consumption data, the stoker has been refilled at the same time each day with few exceptions. Refuelling is a simple matter with the present equipment, and involves emptying as many chip bags as may be required into the hopper. For the hopper size (0.42 m^3 or 15 ft^3) available, and if daily consumption information was not being collected, then in summer, refuelling could be performed as infrequently as once or twice a week. During the coldest month of winter, refuelling would remain a daily requirement.

Cleaning

Ash and soot removal are both readily accomplished. Ashes are scraped out of the combustion chamber through a clean-out door and into a metal pan; they are removed weekly in the winter months and twice a month during the summer, with the entire job taking no more than five minutes.

The flues within the heat exchange section of the boiler remain relatively clean during the heating season (October to March inclusive) as do the smoke pipes connecting the boiler to the masonry chimney. During the summer months when the stoker runs infrequently and a smoldering, fuel rich, ignition maintenance fire is the norm, a light, fluffy soot forms over the flue and smoke pipe surfaces and can reach a thickness of approximately one inch over a one month period. To ensure adequate heat transfer, the boiler flue surfaces have been cleaned monthly during the summer (April to September inclusive) while to obtain a good draft and to avoid any odour of smoke in the boiler room, the smoke pipes have been cleaned every two months. During the heating season, the boiler heat exchangers are cleaned every two months while the smoke pipes remain quite clean and need no attention at all. Flue and smoke pipe cleaning require ten minutes each. Chimney cleaning has not been required since there has been little or no soot or creosote formation in the chimney. Inspection following the first year of operation revealed a light creosote build-up in the top two or three feet of the chimney; this was removed using a readily available wire bristled chimney brush.

Ignition

Ignition is strictly a manual operation and is achieved by running the stoker until a pile of fresh chips accumulates in the grate. The stoker is turned off and the pile set on fire by playing a propane torch flame on it, or by pouring an ounce of cleaning fluid on it and then lighting the fluid with a match, or pushing paper into the pile and lighting it. Once lit, the fire is relatively insensitive to power failures; sufficient live coals have remained in the grate to permit continued operation following a three hour outage.

Fuel Consumption

Daily fuel consumption has varied over the first year of operation from a minimum of 5.9 Kg (13.1 lbs) to a maximum of 67.9 Kg (149.75 lbs). Average daily consumption in June 1979, was 15.4 Kg (34 lbs), while that for February 1980 was 58.0 Kg (128 lbs). For the one year period

1979 05 01 to 1980 04 30 total as-received fuel consumption was 10,206 Kg (22,500 lbs); of this amount, the dry weight of wood fibre was 8618 Kg (19,000 lbs). The difference between these two weights, 1588 Kg (3,500 lbs), represents water.

Firing Rates

Firing rates can not be related directly to stoker drive speed due to variability of the fuel, especially relative to its moisture content and density. However, the lowest possible feed auger speed is 2.9 rpm (limited by machine clearances relative to pulley sizes) while the highest speed is 16.8 rpm; however, at 16.8 rpm, the stoker is overfired with new fuel smothering the fire and spilling out of the grate unburned. At 2.9 rpm, the average fuel feed rate is 2.8 Kg hr^{-1} (6.2 lb hr^{-1}) (summer operation) while at 8.6 rpm, the rate is 8.1 Kg hr^{-1} (17.8 lb hr^{-1}) (winter operation). The corresponding firing rates based on chip fuel characteristics as used through 1979 (12.4% moisture content) are 13.9 Kw (47,400 btu hr^{-1}) and 40 Kw (136,200 btu hr^{-1}) respectively.

The maximum firing rate achieved thus far that the stoker can sustain without smothering the fire occurs at 13.6 rpm, with a fuel feed rate of 10.8 Kg hr^{-1} (23.75 lb hr^{-1}), equivalent to 53.3 Kw (182,000 btu hr^{-1}). The turn-down ratio, or ratio of maximum to minimum firing rate achievable with this equipment is, therefore, 3.8.

Comparison With Oil Fired System

The average annual fuel oil consumption for the house represents an energy requirement of 152 x 10^6 btu (44,500 kWh). The wood fibre consumed over a one year period has been 8618 Kg (19,000 lbs.); of this, some 4 x 10^6 btu (1170 Kwh) is required to drive off the water present

FUELWOOD PROCUREMENT FOR AN INDUSTRIAL POWER PLANT: A CASE STUDY OF DOW CORNING'S PROGRAM[1]

A. Gray Folger[2]

Phillip G. Sworden[3]

Charles T. Bond[4]

Abstract.--Dow Corning Corporation has developed effective procedures for meeting the fuelwood requirements of a 22.4-megawatt steam and electricity cogenerating power plant. The fuelwood procurement program of Dow Corning's Natural Resources Department involves special arrangements with private landowners, logging and hauling producers, and waste wood suppliers. The program's success is attributable to a favorable location, adequate allowance for advance planning, effective public relations, and flexible management. The program is significant because it demonstrates that industrial fuelwood requirements can be met and that improved production from nonindustrial private forests can be relied upon as a major source of fuelwood.

INTRODUCTION

Two major obstacles confront industrial plants considering using wood as a fuel: assurance of a reliable fuelwood supply and handling of the fuel at the plant site. Dow Corning Corporation is one of the first firms outside the forest products industry to produce energy from wood for large-scale industrial application. In a two-year cost-sharing agreement with SERI's former Industrial Applications and Analysis Branch, Dow Corning was to address problems of fuelwood procurement and handling by

1. Collecting data on test storage of local whole-tree-harvested chips and
2. Reporting on experience gained in planning and developing operational systems for fuelwood procurement, storage, and handling.

This paper reports only on Dow Corning's experience in planning and developing a fuelwood procurement program for the 22.4-megawatt steam and electricity cogenerating (SECO) plant at their facilities in Midland, Michigan.

FUELWOOD REQUIREMENTS

Dow Corning Corporation, an industrial manufacturer of silicone products, replaced two oil-fired boilers for process steam and heat with a wood-fired plant which was started up during the fourth quarter of 1982. The plant consists of a nominal 275,000 pounds per hour (pph) spreader-stoker boiler and a condensing turbine. The unit is designed to burn wood with gas or oil in a 9:1 ratio (by Btu) 11 months of the year. The admixture of natural gas or fuel oil promotes boiler operating stability (i.e., temperature and pressure) for efficient and smooth operation of the turbine. One month per year of down time is planned for inspection and maintenance as required by state law. The annual fuelwood requirements are approximately 165,000 dry tons, which amounts to about 15,000 dry tons of wood per month (±20% depending on the load and season).

The fuel handling and combustion systems of the plant are designed to operate with the variations in particle size and moisture content characteristic of wood fuels. The preferable particle size is a 1-inch chip having typical dimensions of about 1 by 1 by 3/8 inch. However, fuelwood ranging in size from that of sawdust and smaller fine material to a 2-inch cube can be accommodated. The plant is equipped with a wood hog to reduce oversized pieces. The boiler can handle a fuelwood mix containing as much as 20% fines (by dry weight). The boiler is designed for a wood moisture content of 40% (wet basis), but 50% moisture wood, such as is generally characteristic of fresh field-harvested chips, is acceptable.

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Requirements of industrial revenue bonds used to finance the plant dictate the types and sources of fuelwood. Seventy five percent (by dry weight) of the fuelwood must originate from noncommercial, or residue, sources. Forest-derived material from tops and limbs, standing dead trees, and noncommercial species are included, as well as mill residues and urban wood wastes.

Contaminants in the wood fuel are of concern for their effect on equipment and as occupational safety or environmental hazards. Major types of contamination to be avoided are (1) hazardous chemicals, such as the chlorinated hydrocarbons and heavy metals in preservatives and pesticides; (2) demolition rubble, such as glass, brick, stone, concrete, and metal; and (3) miscellaneous contaminants, such as asbestos and other types of insulating materials. With the exception of contaminated wood from forest areas recently treated with pesticides, including herbicides, the major potential wood sources with unacceptable contaminants are urban wood wastes. Limited quantities of mineral soil from field chipping operations are expected.

A limited area is available at the plant site for fuelwood handling and storage. The area designated for open storage of fuelwood can contain a pile of wood about 35 feet high extending over approximately 4 acres, as shown in figure 1. This amounts to a 30-day supply. It is imperative, therefore, that fuelwood be available and deliverable throughout the year without major disruptions.

RESOURCE EVALUATION

Construction of the SECO plant followed several years of investigation, evaluation, and planning. Critical questions involved the availability of wood resources. An internal study team was created early in 1977 to study the feasibility of using wood for fuel, addressing such questions as

- How much wood is there?
- Who owns the wood?
- How available is the wood?
- Who would produce the wood?
- How much competition is there for this resource?

The study team, initially comprised of a manager of engineering support, a utilities specialist, and an accountant, selected a forestry consulting firm to perform resource evaluation studies. A professional forester was hired to help direct and interpret the findings of the resource studies. Specifically, the forestry firm was to

1. Evaluate the economics of using Michigan's wood resources to meet Dow Corning's energy requirements,

2. Identify the wood procurement sources and procedures offering the most dependable long-term wood supplies at a reasonable cost, and

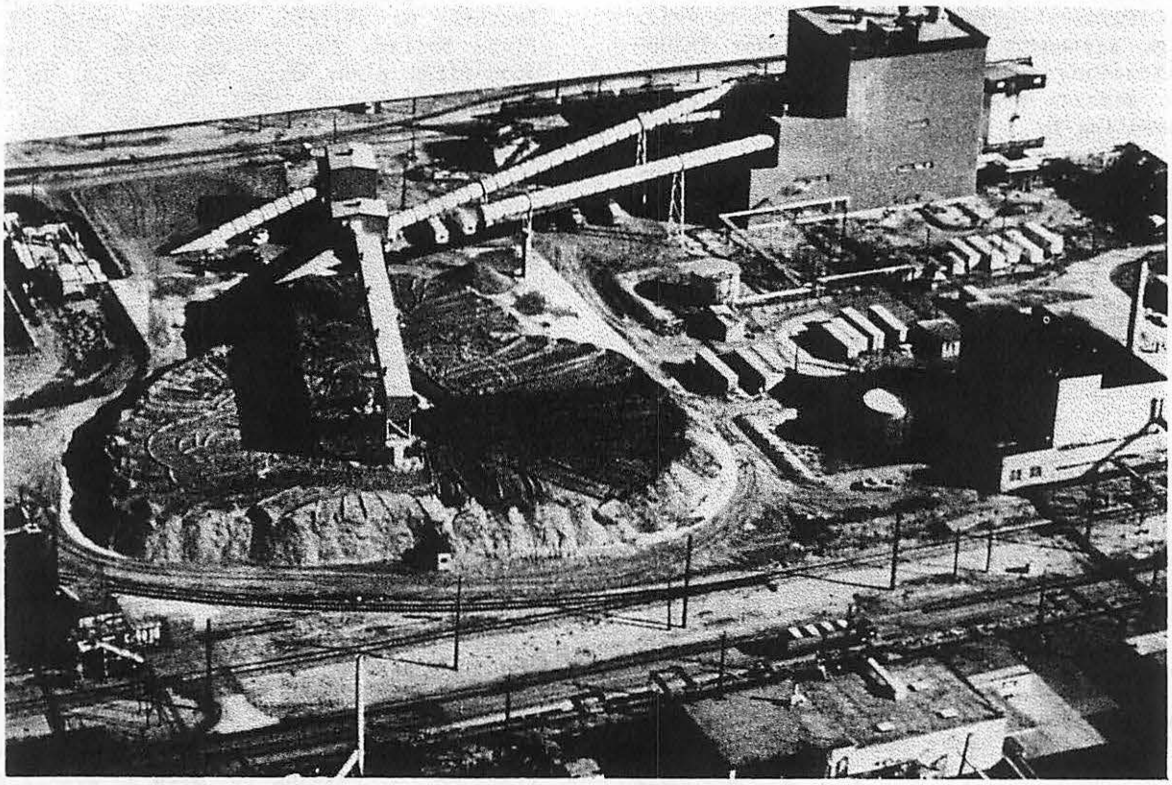

Figure 1.--Dow Corning's SECO power plant and the wood fuel storage pile.

3. Recommend a specific wood procurement system.

In a series of three reports, the forestry consulting firm presented their findings and recommendations. The Phase I report indicated that wood would be economical in comparison with fossil fuels (i.e., gas, oil, and coal). The Phase II report concluded that the potential supply of wood fuel material within a 75-mile radius of Midland is more than adequate to provide almost any desired mix of forest, urban, and industrially derived fuelwood in the quantity required by Dow Corning. The report recommends that

- Dow Corning need not purchase forest land or directly hire timber harvesters,
- Chips should be acquired through purchase contracts with independent producers,
- Brokers should be used to collect urban and industrial wood residues,
- Procurement efforts should be concentrated within 50 to 75 miles west and north of Dow Corning,
- Delivery of wood fuel should be by truck, and
- Prices paid for wood fuel should be based on dry tons.

The Phase III report identified and evaluated wood producers, forest products mills, and large forest landholdings within the procurement area.

The conclusions and recommendations of the forestry firm were supported by forest resource data and analyses presented in several federal and state government reports (Blyth and Hahn 1977, Chase et al. 1970, Manthy et al. 1973, Wood Energy Task Force 1981). Data were compiled on commercial forest land (by ownership and forest type), growing stock volume, net annual growth, timber products removals, logging residues, standing tree residues (i.e., rough, rotten, cull, small, and salvageable dead trees), and mill residues for counties within a 75-mile radius of the Midland plant site. Figures 2, 3, and 4 show pie graphs of commercial forest land ownership, annual forest growth versus removals, and mill residues, respectively.

Despite the limitations and uncertainties of available resource data, the potential fuelwood supply appeared to be adequate in terms of both the physical supply and competition for the resource. Annual forest growth exceeds removals by a wide margin, and the standing tree residue portion of the forest alone contains over 100 times Dow Corning's annual wood requirement. While there are about 80 sawmills of various sizes in Dow Corning's procurement area, the procurement of mill residues and lower-value forest material (e.g., pulpwood) for the SECO plant would offer little competition with major pulpwood purchasers in the Lower Peninsula of Michigan (fig. 5). The predominance of forest land to the north and west

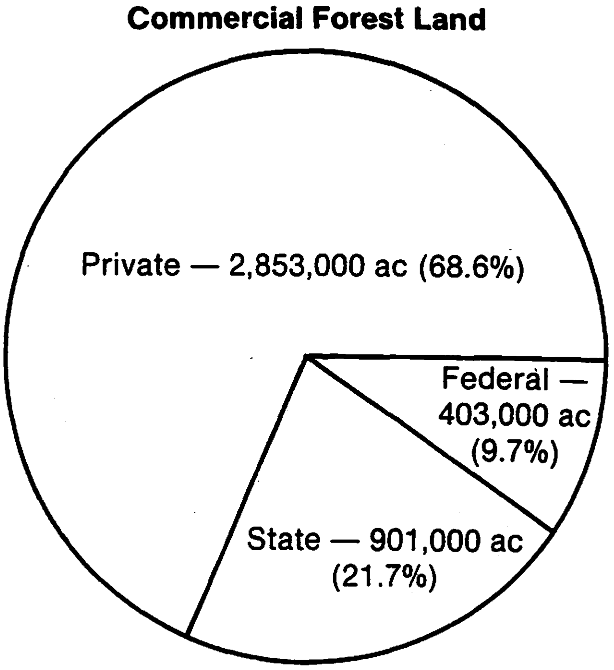

Figure 2.—Ownership of commercial forest land for counties within a 75-mile radius of Midland, Michigan.

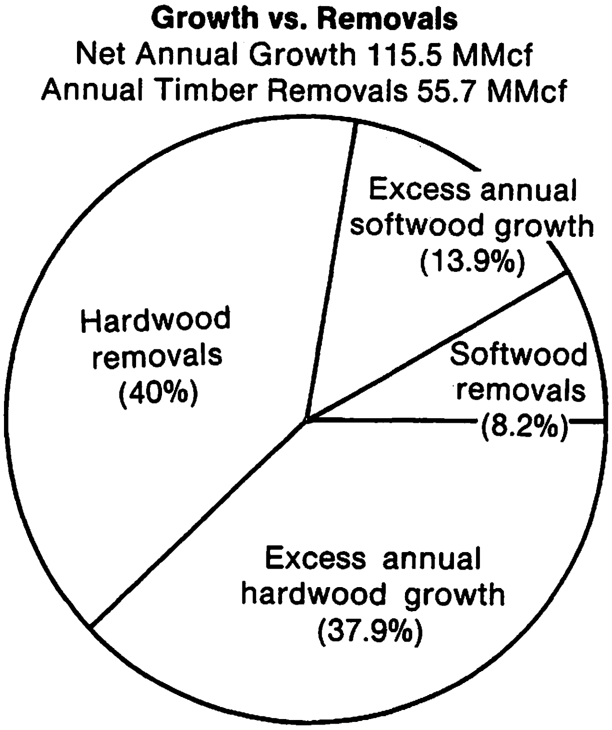

Figure 3.—Annual forest growth versus removals for counties within a 75-mile radius of Midland, Michigan.

of Midland (fig. 6) directed the focus of procurement planning to that area.

The forest stands in the vicinity of Midland consist of natural mixed hardwoods (e.g., aspen, maple, oak, and birch) and planted pines (e.g., red, Scotch, white and jack). In general, the hardwood stands became established following abandonment of agriculture during the 1930's. Much of the forest growth is underutilized and underproductive. Aspen stands, which regenerate from sucker sprouts, are typically clearcut. The pine plantations and hardwood stands are typically managed for pole and sawtimber production, as appropriate, by thinning. Though steep terrain is unusual in the area, site conditions that affect harvesting are soil texture and wetness, which vary spatially and temporally. Low and/or wet areas are, therefore, most accessible during the winter and summer months when the ground is frozen or dry.

FUELWOOD PROCUREMENT PROGRAM

Procedures for wood procurement are well established within the forest products industry. Utility companies and nonforest industrial firms considering the use of wood for fuel are often deterred by the apparent lack of a suitable infrastructure for continuous, long-term (e.g., 20 to 30 years) provision of wood at reliably constant prices. General guidelines for industrial fuelwood procurement are described by Harris and Helms (1981). The program developed by Dow Corning Corporation is offered here as an example of how, under a particular set of circumstances, it can be done.

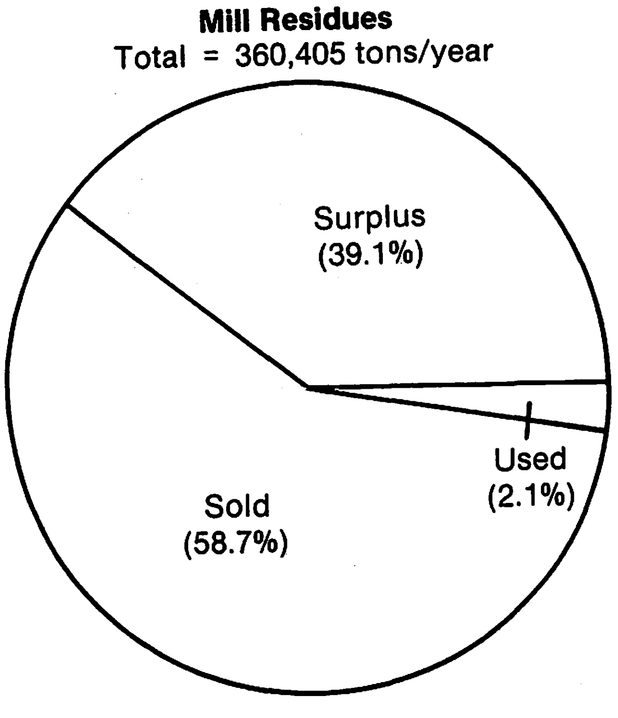

Figure 4.—Annual generation of saw mill residues for counties within a 75-mile radius of Midland, Michigan.

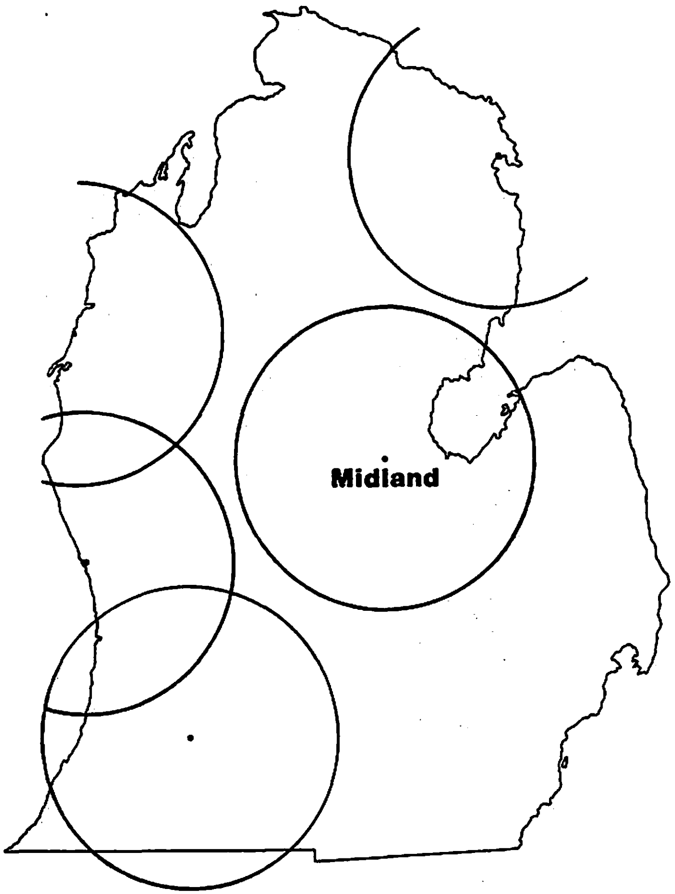

Figure 5.—Circles of 50-mile radius from Midland and from the locations of major pulpwood purchasers in the Lower Peninsula of Michigan.

The fuelwood procurement program for the SECO plant, in the form that it became established and operational, involves special arrangements with private landowners, logging and hauling producers, and waste wood suppliers—all managed by a small staff of natural resources and procurement professionals. The structure and procedures of the program were developed from investigations and plans over a 5-year period.

In addition to study and planning, effective communications with the public were highly instrumental to the development and success of the program. For example, audio-visual presentations were developed by Dow Corning's public relations department, in conjunction with natural resources and engineering staffs, to explain the power plant project within the context of sound natural resources management. By the time of plant startup, nearly 200 presentations to about 10,000 people had been made. All inquiries and requests for informational presentations were honored.

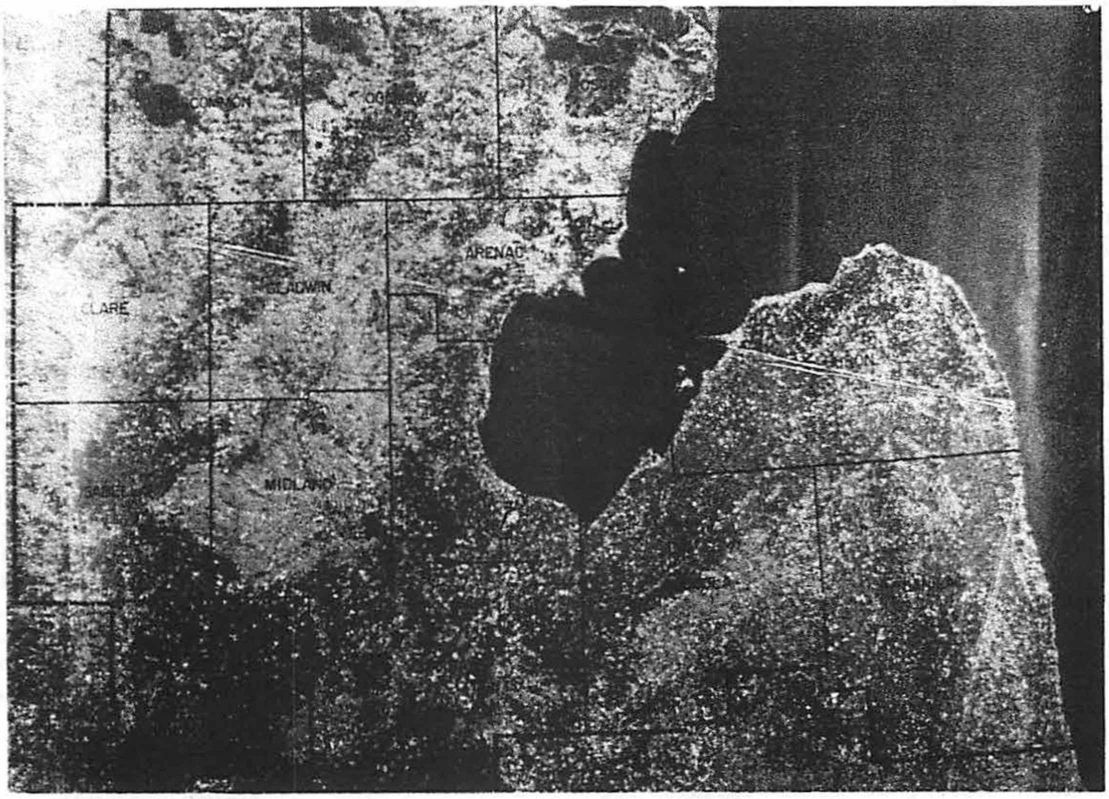

Figure 6.--Satellite image reproduction showing the occurrence of forest land to the north and west of Midland, Michigan, and agricultural land to the south and east.

Private Forest Landowners

The procurement program came to focus on private landowners as an alternative to initial plans for long-term contracts with state and federal land-managing agencies. Responses to a questionnaire sent to selected landowners in 1977, and subsequent contacts and discussion, revealed much interest in forest management, particularly for wildlife habitat improvement. The variety of landowner objectives and the need for individualized attention to ensure proper forest management induced Dow Corning to gradually enlarge the natural resources staff to include wildlife biologists and a field ecologist, as well as additional foresters.

The program with landowners involves land management guidance and assistance before money is exchanged for wood, excluding sawlogs. When a landowner contacts Dow Corning, a meeting is arranged with an appropriate staffperson of the Natural Resources Department to discuss the landowner's goals and how forest management practices can be applied. If in the judgement of the natural resources staff the landowner's tract of timber is suitable for Dow Corning's purposes and the landowner genuinely intends to manage it, an inventory is conducted and a management plan is prepared.

The management plan incorporates the landowner's goals within a framework of sound timber management, wildlife management, and soil conservation practices. The landowner's tract is characterized in terms of soils, vegetation, timber, and wildlife habitat using maps, tables, and descriptions. Management prescriptions include a harvest map and schedule, recommendations for locating access roads, and additional information as necessary for more specific landowner goals such as ruffed grouse management, turkey management, pine plantation thinnings, or special recreational needs.

The immediate intent of a management plan is to facilitate communication and understanding of natural resources management by the landowner. It is provided to the landowner without necessitating any obligation to Dow Corning. Upon negotiation of one or more contracts for Dow Corning to purchase pulpwood from the landowner, the plan provides prescriptions for harvesting that are understood and assumed by both parties. To ensure compliance with the plan, Dow Corning provides assistance by designating sale areas, marking trees to be removed or left, and locating access routes and landings. The plan's specifications are reviewed with the producer before harvesting and are also used as a basis for subsequent periodic inspections of the job.

Logging and Hauling Producers

The forestry consulting firm and the state department of natural resources developed lists of potential chip-harvesting producers for Dow Corning. Dow Corning selected 15 local producers and sent invitations to bid on contracts to harvest and haul Dow Corning stumpage (purchased from private landowners). The bid invitation package included (1) bid instructions and a bid form, (2) a sample contract, (3) general criteria for stumpage to be provided, (4) a form for information on the producer, and (5) a description of Dow Corning's safety requirements. Of the 15 producers contacted, 6 responded and 3 were selected.

This bid approach allowed the producers to specify their preferences for operating locations and tonnages of wood chips to be delivered. A major reason for bidding rather than specifying delivered chip prices was that the operators know best the economics of their own operations. To alleviate concerns about blind bidding on Dow Corning stumpage, criteria for the stumpage to be provided were established. Since the producer contracts are to be effective for a period of 3 years, the bid form and contracts incorporate provisions for adjusting the payment rates per dry ton or per dry ton mile in response to unforeseen escalation of fuel, labor, or other costs. The producers are paid on a dry ton equivalent basis to encourage practices which promote delivery of wood with a low moisture content.

Waste Wood Suppliers

As mentioned previously, a rather large number of sawmills operate in the Dow Corning procurement area producing substantial quantities of residues requiring disposal. Waste wood suppliers (currently mostly sawmills) were selected on the basis of sawmill size, quantity of residues available, and delivered price. Because the production of sawn wood products varies with demand, Dow Corning's contracts allow for 15% to 20% variation in dry tons delivered. Prices paid for mill residues are based on dry tons and a maximum permissible moisture content to encourage handling practices that minimize moisture content. The total amount of sawdust used is restricted by the capacity of the power plant and its wood handling systems to tolerate fine wood particles.

CONCLUSIONS

Dow Corning's industrial fuelwood supply is not absolutely secure in terms of sources and costs for the lifetime of the plant. However, contracts are now in effect with suppliers and landowners for the next 2 to 4 years. What is more significant is that flexible, responsive, and effective procedures are now established that should serve to maintain a continuous supply of fuelwood at reasonable costs in a dynamic market situation.

The apparent success of Dow Corning's fuelwood procurement program is attributable to several factors, not the least of which is a favorable location. Other factors are (1) the questioning and open-minded attitude of Dow Corning's management, (2) adequate allowance of time and expenses for planning, (3) implementation of effective public communication practices, and (4) incorporation of the expertise of natural resources professionals throughout planning and implementation of the project. Continued success of the fuelwood procurement program depends on maintaining an innovative and questioning approach in response to dynamic wood market conditions.

Dow Corning's fuelwood procurement program provides an example of how a nonforest industrial firm can ensure a reliable supply of substantial quantities of fuelwood in a manner that is complementary to the requirements and operations of the forest products industry. It also provides an example of how to facilitate productive management of nonindustrial private forest lands, a question which is often described as the major challenge to forestry in the United States for meeting future wood supply requirements (FPRS 1979, USDA Forest Service 1982).

RECOMMENDATIONS

During the first year of operation of Dow Corning's power plant, a need to improve control of fuelwood moisture content became apparent. Several mechanisms were identified (and are still being refined) which are summarized below as recommendations for industrial firms starting up wood-burning power projects.

- Wood purchases should be based on actual weight, including the moisture content, rather than on a dry weight equivalent--because the latter does not reflect differences of net energy value with moisture content.
- Evaluations of fuelwood resources in planning should also be based on the net energy, or usable Btu, values using relationships between costs and moisture content such as the ones illustrated in figure 7.
- Incentives and disincentives can be used to encourage delivery of low-moisture-content wood.
- Quick and accurate moisture content sampling procedures are needed for receiving and paying for delivered loads of fuelwood.
- The use of sawdust may need to be restricted and carefully controlled because of its tendency to absorb and retain moisture.
- Whole-tree-chipping operations can be planned and scheduled to minimize wood moisture content by considering species, time of year, and site conditions. In

addition, allowing a period of several weeks to elapse between the severing and chipping operations of a harvest reduces wood moisture content by transpirational drying when foliage is present.

General recommendations, drawn from the Dow Corning experience, for planning and developing an industrial fuelwood procurement program are summarized as follows.

- Publicize wood fuel needs early in project development so all sources can be identified.
- Develop an effective, comprehensive public communications program.
- Begin procurement planning and actual procurement as early as possible.
- Use bids in conjunction with specifications instead of fixed rates of payment in formulating arrangements with producers and suppliers.

Finally, two general recommendations are offered, based on Dow Corning's experience, regarding information that would be helpful to those considering industrial wood energy systems.

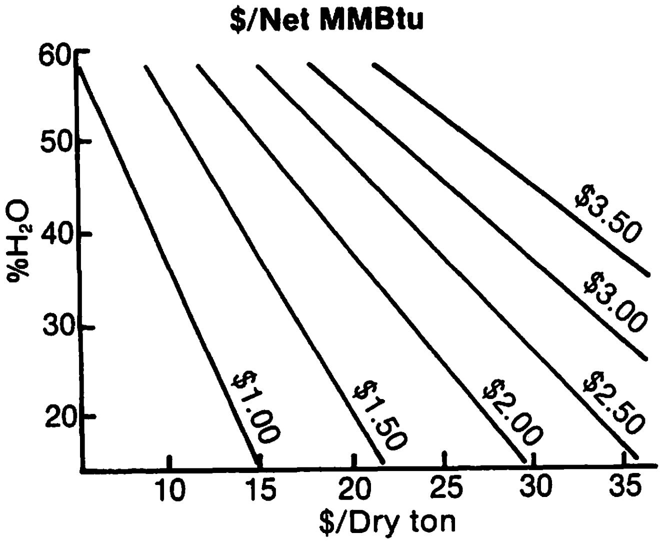

Figure 7.--Relationships between actual energy costs versus dry weight costs of fuelwood as influenced by moisture content.

- Reliable information and data are needed on the total biomass from any given forest and on the material available as wastes from wood utilization and disposal.
- Some central source of information on fuelwood resources, wood fuel characteristics, and energy conversion systems is also needed.

ACKNOWLEDGEMENT

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HEATING SYSTEMS IN SWEDEN
WITH ENERGY FROM FOREST BIOMASS

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I INTRODUCTION

Forest Biomass in Sweden is calculated to give 20-40 TWh/year* or 4-8% of the estimated yearly demand of energy in the 1990's.

Table 1. --Consumption of forest fuel for heating of buildings was in 1982 according to below (Skogsstyrelsen - SIND 1983).

	million m^3 solid
Villas	3.3
District Heating	0.3
Forest Industry	0.3
Others	0.5
	4.4 equal to about 6.2 TWh

Total demand of energy for heating of buildings was in 1982 about 100 TWh including district heating with 27 TWh.

One of the biggest obstacles for a fast development of Forest Biomass Energy has been the uncertainties with the economical competition between forest fuel, oil, coal and electricity. Other possible obstacles are soil acidification and nutrient losses. Here a fast increase in the use of forest energy presupposes utilization of the whole tree from cleaning, thinning and clear cutting.

Forest fuel is used today in Sweden with relatively well established techniques which in some cases have faced severe operational disturbances. These are mainly dependent on the forest fuel qualities. Some of the negative factors and problem areas can be listed as follows:

- high and variable moisture content
- contaminated fuel with snow, ice, sand, etc.
- oversized chunks of fuel
- high content of fine fractions below 5mm. Especially for logging residue
- storage and transport

The aim with this paper is to give an overview of Sweden's technical level for combustion of forest biomass in small scale systems and in district heating systems. The last two sections presents the results of a field-study on cooling of the fluegas and a study on burnout time for chunkwood.

II EQUIPMENT FOR COMBUSTION OF FOREST BIOMASS

The theme here is mainly limited to the technical construction of the grate which carries the burning fuelbed in the furnace. Some new combustion systems are discussed in the end (below listed points K-N). In the design of a furnace for forest biomass some of the following fuel properties must be considered.

Fuel Properties

Moisture content

The moisture content of the fuel is measured on green basis =

$$= \frac{\text{weight of the water}}{\text{total weight of the fuel}}$$

Combustion of wet fuel, with moisture content over 35%, can be done with good results in, for example, a furnace with refractory lining which dries the fuel before combustion. Forest fuels with moisture content over about 50% needs normally preheating of the air for good combustion. Maximum moisture content is below 65-70% that will support a good combustion.

Size

A high content of fine particles in the forest fuel can create an uneven air distribution over the grate and increase the amount of unburnt fuel which is carried with the fluegas to the boiler's convection part and the smoke cleaning equipment. The unburned material in the ash also increases with the amount of oversized chunks in the fuel. Uneven, "stringy" and "sticky" fuel can hamper the proper flow to and in the combustion bed.

Ash and contaminants in the fuel

The ash content is measured on the dry weight of the fuel.

High ash content in the fuel increases the risk for cindering. Sand and stones in the fuel increases the wear on the grates and on the materials handling equipment.

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* Heating of buildings 1 TWh = 10^{12}Wh $\approx 10^5 m^3$ heavy oil.

Variation

Variation in bulk density, moisture content, ash, contamination and size makes it difficult to maintain an even and high combustion efficiency with low smoke-emissions. Variations in the fuel causes adjustment of the fuel bed parameters, such as:
- speed and thickness of the fuelbed
- air preheating and distribution
- combustion temperature

The following briefly describe the most commonly used combustion systems in Sweden.

A. Plain fixed grate in a preoven or a water cooled furnace

This grate system is common for boilers below 1-5 MW and gives a safe operation except for fuel with a high ash content which gives problems with cinder formation. Fuel in the shape of billets are usually fed manually into the furnace whereas chipped fuel is fed with automatic equipment. The ash is normally removed manually.This is even done every day in one 30 MW district heating plant with a cyclone-preoven stoker fed on flat grate. The cyclone preoven has proven a reliable and efficient way of burning woodfuel.

B. Plain reciprocating grate

The plain aircooled reciprocating grate is not so often seen in Sweden but can be used as above for A, and for even bigger power demands. The grate can be used for bark, chips and logging residue with maximum ash content of 5-10% and moisture content 20-60%.

C. Inclined watercooled grate

This grate is normally used in big scale systems for chips and wood residue, sometimes even for bark. The grate works well for fuel with a low ash content - below 1-2% - and with a moisture content below 50-60%.

D. Inclined watercooled grate with reciprocating grate in the end

This combination grate type is used as C but with higher ash content (3-5%) in the fuel. The moisture content should be above 20% because of the air cooled movable grate.

E. Inclined aircooled grate

This grate has many different shapes including the conical type with or without the plain final combustion grate. The inclined aircooled grate is used as in C and D.

F. Reciprocating inclined grate

Reciprocating inclined grates are highly suitable for forest fuels with ash contents below 10-20% and moisture content in the range of 20-65%.

G. Rotating plain grate

This newly developed construction has a rotating grate where the fuel is fed from the perimeter. The fuel is then directed against the center of the inward sloping grate where the ash and the cinder is taken out. The rotating speed of the grate can be varied according to type of fuel. The surface of the grate is closed against ash downfall. The grate will then be suitable for fuel with a high content of fine particles. The grate is used in a preoven for fuel with a high moisture content of 55-60% and ash content of 10-20%.

H. Wander grate

Wander grates are used only in a few plants in Sweden mainly for coal. Some tests have been done with a mixture of wood and coal. Results so far have been on the positive side in reducing SO_2-emission. A large amount of wet wood can give difficulties with ignition and gasification of the fuel. A wander grate for only forest fuel needs certain special provisions to get higher combustion temperatures. Two examples are fluegas circulation and refractory heating surface. The moisture content should be less than 25%. A relatively large ash content, 10-20%, can be acceptable.

I. Spreader stoker with travelling grate

Spreader stokers are only used in a few plants in Sweden. This type of system has the advantage that mixing of different fuels can be done simultaneously during the firing. The moisture content ought to be below 50-55%. Relatively high ash contents, up to 5-15%, can be tolerated.

J. Small scale system

Small scale systems, below 100 kW, are usually fired manually with the billets on a plain grate in a water cooled combustion chamber. The moisture content of the logs are, for good firing, below 20-25%. Better combustion is achieved in a furnace with ceramic lined wood burning box. The ceramic furnace (fig. 1), can even be equipped with fluegas cooler. Total furnace efficiency, based on higher heat value, can then be increased from 60-70% to 85-95%. This furnace can use wood with moisture content within 15-50%.

The new limits for emission of tar, in small scale combustion, is set to 10 mg/MJ. This limit can today only be met in a handful of ceramic furnaces. Conventional furnaces with water cooled fire chambers often have tar-emissions in the range of 500-1,000 mg/MJ.

In small scale systems using wet chips, with moisture content of 35-55%, firing is done in a bricklined combustion chamber placed before or in the furnace. Feeding of wet fuel can be done with a gravity system or with an automatic stoker with retort. Dry chips, below 25%, are normally fed with an automatic stoker to the retort which is placed in a water cooled combustion chamber. The ash content in the fuel is usually low in small scale combustion system: - below 1-2%.

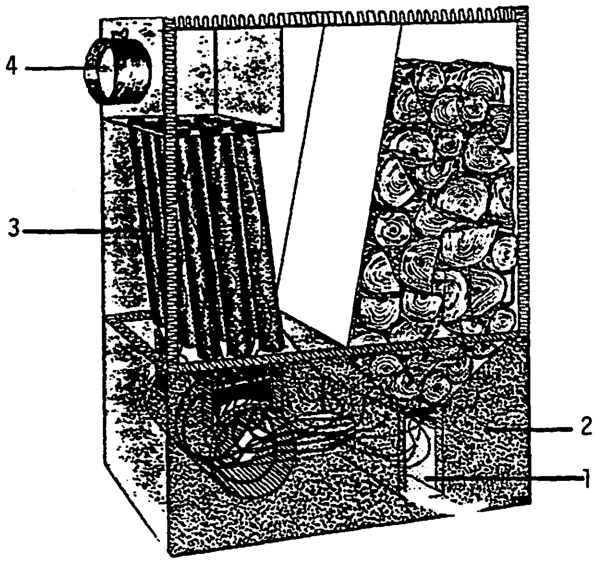

Figure 1. -- Ceramic furnace. 1. Fire chamber, 2. Ceramic, 3. Water cooled tubes, 4. Chimney.

K. Combustion of densified fuels

The most common products are briquettes and pellets. The first is used in ordinary combustion equipment for dry forest fuel, for example with an automatic stoker with a fairly oversized auger.

Pellets have proven to be difficult to combust. One reason is that the burnout time for pellets is 2-3 times longer than that of chips. Pellets also give problems with cinder formation. Combustion of pellets have been more or less succesful with some kind of moveable grate. One example is a rotation combustion basket (fig. 2). Another solution has a high temperature burner with an hydraulic pusher which removes the melted cinder and ash.

L. Combustion with wood powder

Firing with dried and ground forest fuel is used by only a few of the bigger heating plants for industrial and district heating. Powdered wood firing has an advantage because existing oilboilers can easily be converted to forest fuels. Disadvantages are the risks for explosion and the high cost for the wood powder.

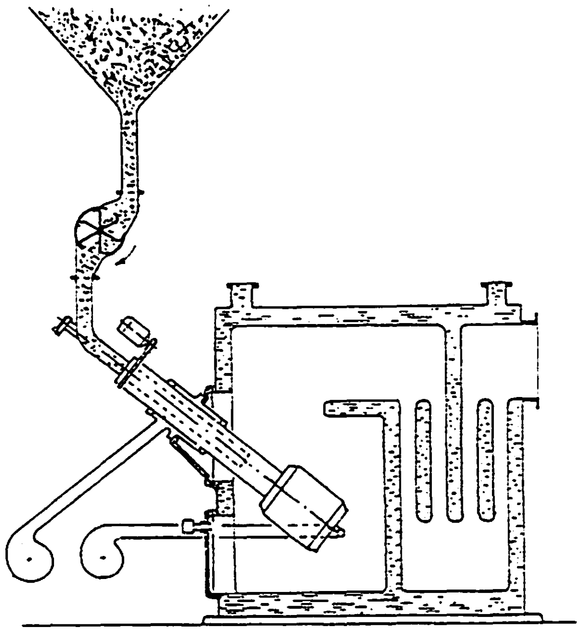

Figure 2.--Pellets burner with rotation combustion basket.

M. Fluidized bed

About a dozen fluidized beds have recently been installed in Sweden. The technical solutions differs from the simpler bubbling bed to the more complex fast circulating bed or double bed. The latter has the fuel supply in the lower bed with final combustion in the upper bed. Efficiency and smoke-emission with different woodfuels have shown good results but to the price of a complicated technical solution.

N. Bio turbo system

The Bioturbo system (fig. 3) is under development for burning of wet fuel. Combustion of the fuel and cooling of the fluegas is done under pressure. Hereby the water vapour in fluegas condenses at such a temperature that the main part of condensation heat can be used in a heating system.

Combustion air is compressed in two steps, high- and lowpressure compressors. Combustion takes place at a 7-8 bars overpressure in the fluidized bed. The air is blown in from the bottom and fuel feeding is from above the air intake. The fuel then floats on the air flow while it is being combusted.

The hot fluegases pass a couple of cyclones for dust separation before they are conducted into a gas turbine which drives the high pressure compressor. After the high pressure turbine the flue gases are conducted in a heat exchanger which heats water. All remaining energy in the gases is taken out in a second turbine which drives the low-pressure turbine. This system is technically complicated but its thermal efficiency, around 85-90%, is independent of the moisture content of the fuel up to about 80%.

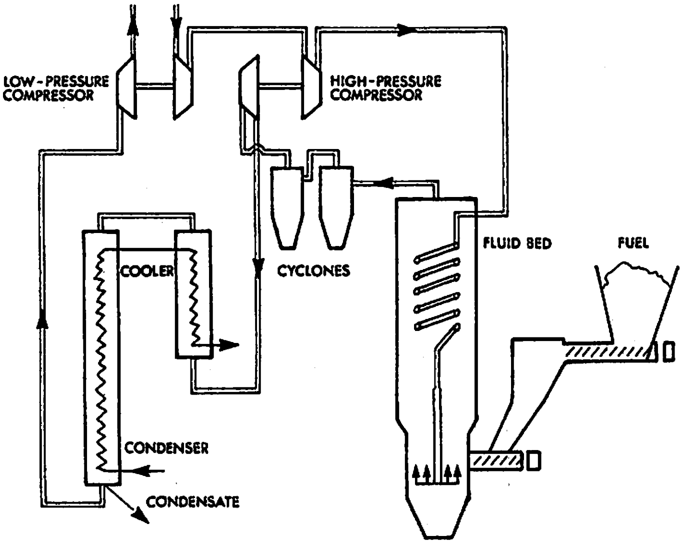

Figure 3.--Bioturbo system.

III FLUEGAS CLEANING, ASH REMOVAL AND SOOT CLEANING

A. Fluegas cleaning

The most common systems for fluegas cleaning in heating plants over 5-10 MW are:
- electrical filter has high efficiency with high equipment cost.
- textile filter with prefilter has the highest efficiency and high equipment cost. Combustion of forest fuel can result in increased risk for fire in the filter.
- multicyclones with secondary separator have medium efficiency with relatively low equipment cost. Fluegas cleaning in smaller furnaces below 1.0 MW is mainly done with multicyclones.

Small furnaces and stoves below 0.1 MW, often used in villas, farmhouses etc., have normally no cleaning of the smoke. Emissions to the air from a small billet furnace with watercooled firechamber are 10-100 times greater than a furnace with good combustion. Good burnout of heavier wood components, such as tar, demands a temperature above 800°C. This can be done in a combustion chamber with a refractory lining of bricks. In order to avoid smoulderfire, with high air pollution, a small furnace should be connected to an accumulation tank.

B. Ash removal

Outfeeding of slag and ash from bigger furnaces is often done through a waterbath in order to put out the live coal. Smaller plants use dry outfeeding system which have relatively low equipment cost. The smallest boilers use manual ash and slag removal. Materials handling equipment for slag and ash demands very heavy constructions in order to avoid shut down. Screw feeders should be avoided where there is a high risk of jamming and wear.

C. Soot cleaning

Sweeping of bigger boilers have worked best with steam. Some boilers accomplish sweeping with low frequency sound with good results. In smaller furnaces below 1-10 MW the sweeping is normally done manually.

Boilers with vertical tubes have less tendency for clogging by soot compared to those with horizontal tubes.

IV MATERIAL HANDLING

Shut down of materials handling equipment is mainly dependent on the properties of the fuel. Some causes are:
- oversized fuel
- valving
- freezing
- contamination (stones, sand etc.)
- varying moisture content
- varying bulk density
- varying primary product

A. Screening

Smaller plants for forest biomass which normally do not have screening device, often use fine comminuted shear-cut chips with a length under 50 mm.

Bigger heating plants normally have a screening device - for instance a disc screen - thus a coarser fuel can be used. Crushed fuels can have a length to 150 mm with some exceptional oversized pieces up to 300-400 mm. The fuel thickness for crushed fuel is normally within 50 mm diameter.

B. Valving

Forest fuels have a high tendency for hanging and valving. These phenomena usually occur in the transport system at changes in elevations for feeders and fuelbins. Sensitive parts for valving should be lined with low friction materials and the walls should, if possible, be inclined inwards against the fuel. Stirring equipment can be used to prevent bridging.

C. Freezing

The tendency for wood particles to freeze together into clumps or to freeze on the surface of piles increases for heating plants located in the north. Freezing can be reduced through a faster storage turnover.

The freezing of fuel to the walls in the storeage container can be reduced by lining it with a low friction material. Frozen clumps of fuel can also be crushed with a special roller with cutting teeth placed in the outlet of the store.

Some receiving silos have been equipped with heating. However, freezing can still occur when the fuel, with low turnover rate, is piled up in a high stack. The lowest risk for freezing is in a store with a low pile height with high turnover rate and heating of the walls and bottom.

Crushed logging residue is much more sensitive to freezing compared with chips from stemwood.

D. Conveyors

Safe operation of forest biomass heating plants are dependent on the construction of conveyors. This gives less reliability in an increase of:

- the length of transport
- the number of mechanical handling devices
- the number of changes in direction
- the speed of transport
- the amount of oversized fuel

Larger plants should be equipped with a small reserve feeding silo which is placed as close as possible to the boiler. The reserve silo can usually be filled with a tractor-loader.

E. Heating plant in Garpenberg

In Garpenberg, the Swedish University of Agricultural Sciences has installed a district heating plant for forest fuel. (fig. 4). The furnace is also intended for test firing with different wood- and peatfuel. The materials handling of the forest fuel in this plant is done after a new concept in Sweden -- an automatic crane equipped with a grapple bucket. This system gives possibilities for combustion tests with different fuel mixes.

The bricklined preoven has an inclined reciprocating grate. The speed of the grate, the feeding of the fuel and the combustion air with necessary preheating can manually be adjusted according to the moisture content and heat demand.

Heating power: 0.75 MW
Pressure - primary circle: 6 bar

Temperature - primary circle: + 140°C
secondary circle: + 90°C

Fuel moisture content: 25-60%

Fuel size maximum: 400 x 100 x 25 mm
or 150 x Ø 200 mm

Ash content maximum: 10%

V FLUEGAS COOLING IN A SMALL FURNACE

A. Background

During March/April 1984 a chip fired furnace with fluegas cooler, figure 5, was tested at a farm near Garpenberg. The chips were fired in a gravity feed brick lined preoven connected to an ordinary water cooled furnace with maximum power of about 25 kW. The heat transmission area in the furnace was 2.2 m^2. An oversized fluegas tube cooler - size $8m^2$ in stainless steel - cooled the gas down to about +30°C during the whole test period of 30 days. The furnace has been fired with chips since 1964. The fluegas cooler was installed 1980.

B. Testresults

Three different forest fuels were used during 10 days each:

Test 1 50% alder and 50% mixture of spruce, birch and aspen. Moisture content = 25%.

Test 2 100% birch. Moisture content = 35-40%.

Test 3 50% spruce, 35% aspen and 15% mixture of alder and birch. Moisture content = 30-35%.

Temperature

Outdoor temperature was on the average -3°C with variations (-15°C to +5°C).

Water temperature in the boiler averaged +80°C.

Fluegas temperature after the furnace before the fluegas cooler varied from +150°C to +320°C.

Gas analysis

CO_2 average 11%
CO average 0.04%

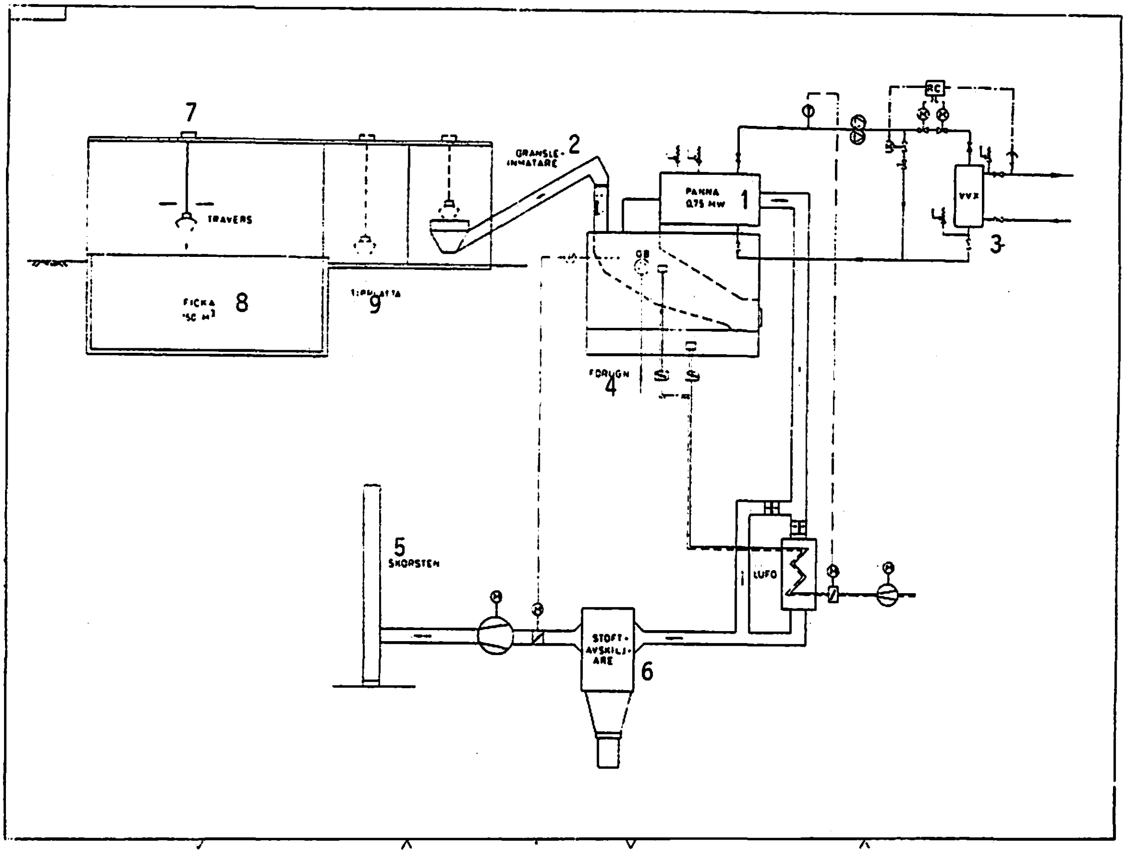

Figure 4.--District heating plant for forest fuel. 1. Boiler. 2. Fuel feeder. 3. Heat exchanger. 4. Preoven. 5. Chimney. 6. Cyclone. 7. Crane w grapple bucket. 8. Fuel store. 9. Test fuel store.

Power

The average output power from the furnace was 13.7 kW.

The average output power from the fluegas cooler was 4.5 kW.

Maximum estimated power from the fluegas cooler was between 7-8 kW.

Efficiency

Average efficiency for the period was:

furnace	63%	with variations from 52% to 73%.
fluegas cooler	20%	with variations from 16% to 26%.
total	83%	

The efficiency is measured on the higher heating value.

Moisture content and combustion

The preoven worked best with a moisture content above 35%. That was clear from the increase of fluegas temperature after the furnace. Test 1 with fuel moisture content of 25% gave an increase of around +120°C after 10 days following sweeping. Test 2 and 3 with moisture content 35-40% gave, during similar time, an increase of around +30°C to 40°C.

Sweeping

The importance of regularly sweeping the furnace must be pointed out. In spite of relatively good operation of the preoven, even a short period of 10 days following sweeping can cause a substantial decrease (5-15%) in efficiency.

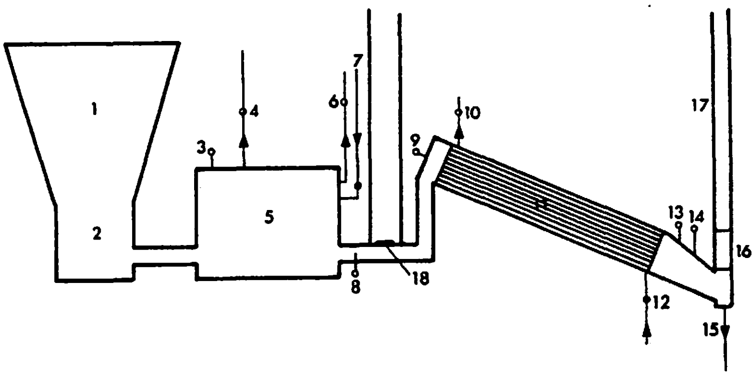

Figure 5.--Chipfired furnace with fluegas cooler. 1. Gravity chip feeder. 2. Preoven - bricklined. 3. Thermometer for furnace water. 4. Flowmeter for household hot water. 5. Furnace. 6. Energy meter for heating water to the house. 7. Return pipe from the house. 8, 9. Fluegas thermometer. 10. Energymeter for heating water to the stable. 11. Fluegas cooler. 12. Return pipe from the stable. 13. Fluegas thermometer. 14. Fluegas air pressure meter. 15. Condensate pipe. 16. Fluegas fan. 17. New chimney of sheet metal. 18. By-pass damper. 19. Old brick chimney.

Condensate water

The fluegas condensate water was tested (table 2) where some swedish standard values for drinking water and fresh sweetlakewater are included. The amount of condensed fluegas water varied 2 to 3.5 l/h depending on the moisture content in the fuel. The analysis showed low values except for nitrogen dioxid which was far above the limits for drinking water. However, this water will be accepted for a normal sewage system, and it would be more serious to make these emissions airborne.

VI BURNOUT TIME FOR CHUNKWOOD

A. Background

Chipped fuel from wet forest biomass has a big disadvantage in terms of maintaining good quality during long storage time. Wet chips should be consumed within 2-4 weeks in order to avoid disturbing losses in energy and attacks from hazardous fungi.

The long-term storage quality for comminuted wet wood improves with the size of the fuel. Bigger fuel particles have less area for oxidation and fungi and have a lower air resistance for the drying air. Chunkwood can, in small scale systems, even be sun- and winddried. Surface and volume proportion between chips - say 25 x 15 x 6 mm - and chunkwood - 150 x Ø 100 mm - is for the surface 1:51 and for the volume 1:524.

The use of chunkwood as a fuel for heating needs to be proved. In Garpenberg, chunkwood research programs have begun seeking answers to questions like:

- Which type of materials handling and combustion equipments are suitable? Can conventional chipfired plant layouts be used?
- How does the combustion process with chunkwood differ with methods of comminution? Can the influence of cracks in the chunkwood increase the combustion rate?
- What are the figures for efficiency and losses for combustion with different types of chunkwood in a conventional furnace? Will it be a heavy increase of the unburnt particles in the ash?

As a first step to answer the above questions, a burnoutest was started in the summer of 1984. Burnout time is an important design factor for the furnace. The burnout time of the fuel decides the speed of the fuel in the combustion bed. This speed gives normally, for chips, a stay on the grate of around 15-30 minutes.

B. Test oven

Our test oven (fig. 6) has a sheet metal case on an insulated combustion chamber. The lining consists of a ceramic casting for a maximum temperature around 1400 - 1500°C.

The undergrate air is introduced either with natural draft damper or with a fan. The temperature of the oven is measured in point A. Fluegas analysis is done in the beginning of the chimney at point B.

C. Testprocedure

The oven was heated to a temperature around +600°C in point A. Thereafter the oven was loaded with about 8 kg in dry matter weight of fuel. The test wood was set afire with a gas torch until full fire was obtained. This usually took about 5 minutes. The fuelbed was stired every 10 minutes to fully cover the grate. The CO_2 content was

Table 2.-- Analyse of fluegas condensed water

Description		Test 1	Test 2	Test 3	Limits drinking water	Limits sweetlake water
pH		6.8	6.2	7.4	7-9.5	6.5-8.5
Phosphorus P	µg/l	610	530	360	300	-
KMn04	mg/l	160	120	230	20	-
Ammonium						
NH4	µg/l	90	100	16	500	200
Nitrogen Dioxid N02	µg/l	8600	11000	13000	20	-
Nitrate+Nitrite (N03+N02)	µg/l	17000	12000	10000	10000	-
Nitrogen total N	µg/l	47000	31000	64000	-	-
Chloride Cl	mg/l	8	39	5	100	20
Sulphate S04	mg/l	103	56	73	100	200
Aluminium Al	mg/l	0.021	0.021	0.018	0.15	-
Lead Pb	mg/l	0.0014	0.0023	0.0014	0.05	0.01
Iron Fe	mg/l	0.02	0.11	0.027	0.20	-
Cadmium Cd	mg/l	0.0044	0.0092	0.0052	0.005	0.0002
Calcium Ca	mg/l	21	13.3	14	100	15
Potassium K	mg/l	72	29	75	10	0.5
Copper Cu	mg/l	0.0051	0.011	0.0079	0.05	0.02
Chromium Cr	mg/l	0.026	0.0089	0.030	0.05	0.02
Magnesium Mg	mg/l	5.2	2.2	2.5	5	-
Manganese Mn	mg/l	1.0	0.58	0.54	0.10	-
Sodium Na	mg/l	0.57	0.33	28	50	0.1
Zinc Zn	mg/l	5.6	5.0	2.1	1	-

checked before and after the stiring and necessary adjustments with the draft were done. Only primary unheated undergrate air was used. The CO_2-level was kept to about 7% during the main combustion when the wood was gasified. The air draft damper during final combustion of the live coals was kept unchanged from the rate in the end of the main gasification. That gave CO_2-levels in the final stages around 2-4%. For chunkwood with a diameter of 174 mm it was only possible to obtain CO_2-levels for the whole firing period of 4% depending on the big airleakage between the chunks. The burnout time was measured from full fire until most of the live coals passed through the 8 mm slots in the grate and the grate was covered to less than about 20%. The remaining ash and unburnt material was about 3-5% of the dry weight.

D. Results

The chunkwood tested was derived from stemwood of birch and produced with a hydraulic knife. The amount of shear cracks increased with decreasing diameter of the chunkwood, where the cross-section of 174 mm had almost no cracks and the section of 50 mm was covered with several small visible cracks.

Chipped sawmill spruce residue had an average size of 25 x 15 x 6 mm. The burnout test is in its beginning but the result so far (see fig. 7) indicate, as expected, a big difference between chips and chunkwood. This difference might be reduced with chunkwood from a new machine which gives more shear cracks.

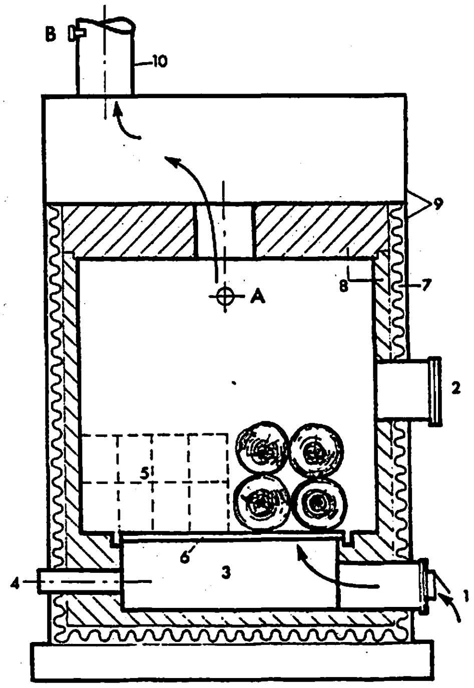

Figure 6.--Testoven. 1. Draft damper. 2. Charge door. 3. Ashroom. 4. Fan connection. 5. Bricks for space adjustment. 6. Grate. 7. Insulation. 8. Ceramic casting. 9. Sheet metal case. 10. Chimney.

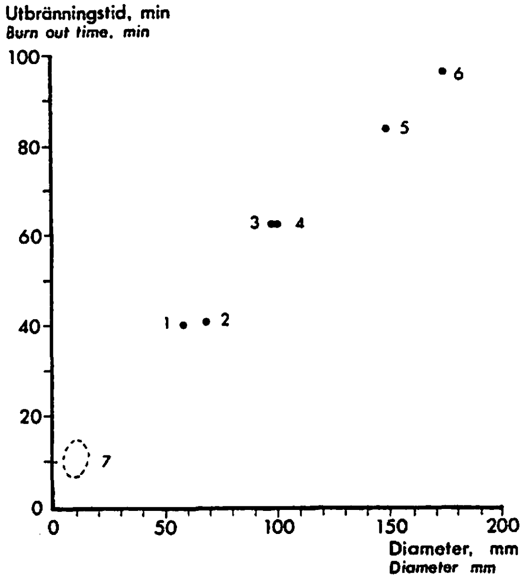

Figure 7.--Burnout time for chunkwood.

Test	Average size mm	Moisture content	Dry weight kg
1	Ø 58 x 158	35	8.07
2	Ø 68 x 148	36	8.12
3	Ø 98 x 146	35	8.34
4	Ø 99 x 148	40	7.58
5	Ø148 x 150	34	8.06
6	Ø174 x 152	36	8.73
7	25 x 15 x 6	33-40	7.84-8.37

VII CONCLUSION

A. Consumption of forest fuel

Consumption of forest fuel in Sweden for heating is still low and an increase of around 3 to 6 times is necessary in order to fulfill the target in the 1990´s. Today this seems to be unlikely, it depends on how heavy the competition will be in first hand from nuclear produced electricity.

B. District heating

District heating plants for forest fuel have, in Sweden, a large variation in the technical design from the simpler pre-oven to the complex double fluidized beds. Example on combustion systems with good operational results are cyclones, reciprocating grate and spreader stoker.

Materials handling of chips often will be done with hydraulic pushers and different types of conveyors and screening devices. A relatively new concept is materials handling with an automatic crane with a grapple bucket. This is even suitable for coarse fuel such as chunkwood.

C. Small scale systems

In early times the conventional log firing has been in water-cooled furnaces with low efficiency. A new development, for good combustion, is a furnace with ceramic fire-chamber. This furnace works best in connection with an accumulation tank.

Dry chips are stoker-fired in a water-cooled furnace. Wet chips are fired in a gravity fed or stokerfed pre-oven.

Combustion of briquettes can be easier done compared with pellets which need a higher technical level on the equipment.

D. Flue-gas cooling

One method to increase the efficiency in woodburning is flue-gas cooling. An increase in efficiency around 15-25% is possible even in small furnaces, below 100 kW.

The condensate water from the flue-gas seems to be acceptable for the normal sewage system.

E. Burn-out time for chunkwood

The relatively high time difference between chips and chunkwood indicate combustion difficulties for coarser fuel fed to a standard furnace for chips. However, improvements might in chunkwood comminution and -combustion equipment be able to solve the problem caused by the high burn-out time.

F. Recommendations for future research

In the field of forest fuel handling and heating some areas for future research needs can be recommended.

1. Basic studies of forest fuel in sizes from sawdust to logs and bales:
   - fall down angle
   - slide angle
   - freezing
   - bridging and hanging
   - filling rate of storage-bin in different transport systems
   - combustion: burn-out test, fuel-mixes, condensate rates etc.
   - corrosion
2. Continued or expanded studies of forest fuel in the follwoing areas:
   - health hazards
   - water- and smoke emissions
   - storage, especially for chunkwood, bales and bundles
   - combustion in district heating and small scale furnaces

- drying
- screening
- densified fuel
- comminution
- materials handling
- fuel specification and economical terms

3. Feasibility studies and test of whole fuel systems with:
   - chunkwood
   - bales and bundles
   - whole tree and logging residue fed to a furnace with an automatic crane system.

FOREST ROAD BALLAST & SURFACING ROCK[1]

William A. Johnson[2]

Abstract---Finding and developing quality rock quarries for Forest Roads is essential to orderly, cost-effective transportation planning and development. A methodical, systematic process that utilizes the technical skills of several professions can be effective in producing a Rock Development Plan. Environmental and cost benefits will be dramatic.

It is interesting to note the different disciplines the Forest Engineer gets involved in, and I can't help but recall the paper last year saying that the Forest Engineer should decide what aspect of engineering he will do and then do it well; cut out a piece and be the expert.

In the Pacific Northwest, the Forest Engineer is a specialist who works mostly with land boundaries, logging methods, road layout, construction and maintenance. He is an engineer who works in the forest and whose responsibilities require a working knowledge of roads, bridges, slope stability, pit development, etc. The Forest Engineer is like a small town doctor, handling all cases, and passing the more complex on to specialists.

Before I get into my topic, Forest Road Ballast and Surface Rock, I'd like to tell you of my organization, the State of Washington Department of Natural Resources. My agency is basically a land management agency. We manage 5 million acres of State-owned land. You will recall that upon becoming a state, the Federal Government gave each state sections of land, Section 16 & 36, in each Township. The new state of Washington also received lands to build a university, an agricultural and scientific school, capital buildings and penal institutions. We also manage tax-forfeited land for the counties. Some states sold this land and used the money for development. Other states, such as Washington, kept the land and held it in trust for specific uses, such as Common Schools, State Universities and Colleges, Capital Buildings, penal institutions, etc. We call this Trust Land Management.

The 5 million acres held by the State of Washington includes 2 million acres of forest land, 2 million acres of aquatic land (i.e. beds & shores of navigable rivers & lakes, tidelands and beds of the salt water and harbor areas) plus 1 million acres of commercial and agricultural lands. My agency conducts its proprietary programs from a precentage of the money received from the sale of materials from the land and from leases to use the land. The sale of timber is the biggest source of income, but leases for agriculture and aquaculture are destined to play a larger role in supporting our proprietary programs.

In the development of the 2 million acres of forest land, we have built about 12,000 miles of road. Each year we add approximately 200 miles. Most of these roads are all-weather haul roads that are constructed to support the hauling of large loads. Many areas receive 60" of rain per year and some in excess of 140" per year. This brings us to the point of my discussion "Forest Road Rock."

As you might imagine, we do not often have the rock where the roads are; or, if we do have the rock we need to wisely use it to prolong our source to get the most from it. Rock is one of the largest components of new road construction costs, quite commonly ranging between $35-$50,000 per mile. So, in order to reduce costs, effective planning, exploration, and use of rock resources is necessary. This may mean using soft rock that would degrade rapidly as ballast and then, covering it with harder rock as a wear course. We also use softer rock on one-shot spurs whenever possible.

So now we have the stage quite well set. I want to explain to you the process we are perfecting at the Capitol Forest. In our 80,000 acre Capitol Forest Area outside of Olympia, we have limited proven reserves of good rock, quite an extensive management program, including heavy timber removals, plus a large recreational program.. The forest manager needs good roads to move timber and the recreational public year-around, without degrading streams through road surface runoff, or damaging subgrades. The manager must

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[1] Paper presented at the conference of COFE/IUFRO - 1984. Orono, Maine, USA, 12-14 August.

[2] William A. Johnson is the Manager of the Division of Engineering Services, State of Washington Department of Natural Resources, Olympia, Washington, USA

do this while minimizing road construction and maintenance costs.

1. Rock Need Review

The Department's seven Area Managers ask for input from the local unit managers on surface and ballast rock needs. How many cubic yards of rock will be needed for construction of new roads and maintenance of existing roads each year for the next 10-15 years? Where are the existing pits? Will they meet the demand? In the Capitol Forest we had a problem. We had a large area with few proven sources, heavy construction and maintenance demands, long distances from pit site to delivery point, and several extremely sensitive streams near heavily used roads. In addition to timber hauling there was heavy recreational use. We had all of the ingredients of an expensive difficult problem.

The Forest Engineer was called in. The engineer sized up the problem and determined the assistance of a geologist and soil scientist was needed. Using Management input, a list was prepared identifying the location and volumes of construction and maintenance rock demand. Management then prioritized the list and identified areas needing further study.

2. Literature Search & Review

The engineer and geologist then searched for and reviewed existing geotechnical literature pertaining to the area in question. Additional information, such as well logs or aerial photographs were studied.

A thorough study of these source documents will be used to make a first cut of sub-regions for closer examination. By studying various geological characteristics, such as, structure (faults & folds); geomorphology (land forms); petrology and mineralogy (rocks & minerals); soils (mostly for overburden depth), and even vegetation, we can gather valuable information that will begin to identify areas of interest.

3. Sub-Regional Exploration

The office literature and map review will be followed by intensive sub-regional investigation and evaluations. Sub-regions will be explored on the ground by road, trail and cross country hikes. Continuity of potential rock source strata is mapped. Potential quarry sites are located using rock quality, developability and location as criteria.

Rock quality is estimated using field and lab techniques. Field methods are based mainly on the Uniform Rock Classification for Geo-Technical Engineering Purposes, by Douglas A. Williamson. Laboratory investigations include standard wear tests and petrographic analysis. The latter utilizes the petrographic microscope to study thin sections of rock and yields information such as the mineralogical (and consequently chemical composition) as well as important textural information.

Developability of a site is rated using such criteria as topography and overburden depth. A site should have room for crushing plant location, waste area, and favorable slopes for efficient excavation of rock and overburden.

Overburden thickness is determined by using a backhoe, portable seismograph, or small portable drills such as the cobra drill.

Location of rock sites is of course very important, as rock haul distances add up quickly and effect costs.

4. Site-Specific Investigation

Sites determined to have a very high probability of containing quality rock were examined intensively. Sample rock was sent to the Department of Transportation Materials Lab. Cobra-drilling and/or excavation were used to determine over-burden depth. More thin sections were sometimes made from promising outcrops. Finally, a large scale (1"-50' with a 5' contour interval) map was made. This topog map became the base for overlaying field-generated geological cross-sections that were run to predict rock unit boundaries. This procedure, the heart of the whole investigation, yielded very detailed preliminary geology maps of the potential quarry sites. The maps predicted the quality and extent of each rock unit in the formation. Recoverable base lines and bench marks were established, so that any future work could be tied to the original map.

With favorable lab results the sites were then scheduled for test core drilling. Staff geologists selected drill sites to yield maximum information with the fewest number of holes. Drilling generally indicated the practical operational limits of the site, the location of the optimal first entry, and the boundaries of each rock unit.

Drilling results were then used to confirm or modify the geologist's preliminary map. Core samples were tested for quality; again at the Department of Transportation Lab. Rock units were over-laid on the original topographic map, so that the feasibility of pit development could be evaluated. If the quality and volume of available rock were sufficient at an acceptable cost, a pit development plan was made again using the same topog map as a base. Overburden was also evaluated; what is the acceptable maximum stripping depth? Can overburden be handled and stored efficiently and safely? What are the environmental problems, i.e., streams, recreation site disruption, visual impact? Answers to these questions are relative to the availability of rock.

5. Overall Objective

The object was, and is, to identify rock sources that will yield large vulumes of quality rock at an acceptable cost, while disturbing the least amount of productive timber land. To avoid the "Quarry around every corner" problem, sites are finally selected on the basis of rock yield and area served. In the long-term this should minimize rock costs by:

1) Providing dependable, predictable rock sources.
2) Reducing development costs and land out of production by reducing the number of quarries.
3) Maintaining fewer total miles of road used for rock haul.
4) Providing rock of sufficient quality with better wearing characteristics, thereby reducing the volume of rock required for replacement.
5) Planning the use of poorer quality rock for ballast and one-shot spurs thus conserving the high quality rock for surfacing and high-volume roads.

We are developing a systematic approach to Rock Development that will be effective, efficient, and accurate for identifying potential quarries. The system should be repeatable, cost-effective and easily documented for future reference.

Accurate volume predictions pay off in another way, by keeping us from scheduling rock removal from an area that does not have rock. This is an extremely costly error that has been committed too frequently.

Cost saving resulting from professional exploration and documentation could be dramatic. The money we have spent has more than paid for itself. The Forest Engineer is providing a valuable service that could result in a 10:1 benefit to cost ratio as the system is refined.

CONSTRUCTION OF ENVIRONMENTALLY SOUND FOREST ROADS IN THE PACIFIC NORTHWEST[1]

Sandor A. Nagygyor[2]

Abstract: The "trench" method, in combination with endhauling to a safe disposal site is an accepted forest road construction technique. The method incorporates the old proven techniques with new ones that minimize soil erosion caused by road construction in the forest.

INTRODUCTION

The hazards to watershed values caused by forest road building and subsequent surface erosion were recognized early by forest managers and have commanded the attention of investigators since the early 1940s.

Road construction disrupts the basic equilibrium of steep-slope (over 65 percent or 33°) forest soils by altering slope drainage, slope loading (fig. 1), and slope undercutting. It has been identified as the greatest single cause of recent soil mass movements in the western states (Dyrness 1967, Swanston 1976).

During the 1964-65 Oregon floods which resulted from a 200+ year storm, 72 percent of the landslides on the Andrews Experimental Forest were associated with roads (Dyrness 1967), although roads occupied only about two percent of the area. The intensity of landslides was 315 times greater than that found in undisturbed portions of the forest (Fredricksen 1970).

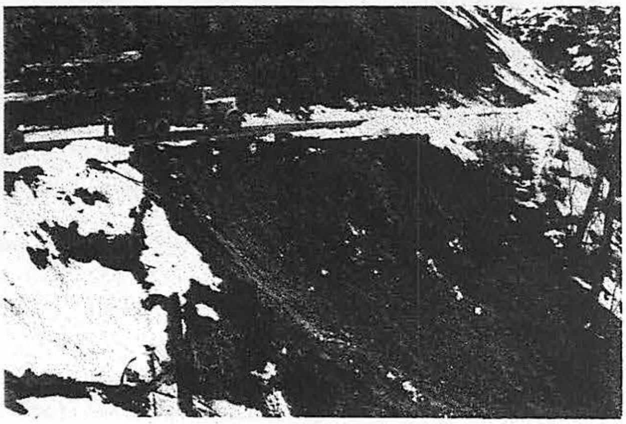

Figure 1.--Landslide caused by slope loading and side casting.

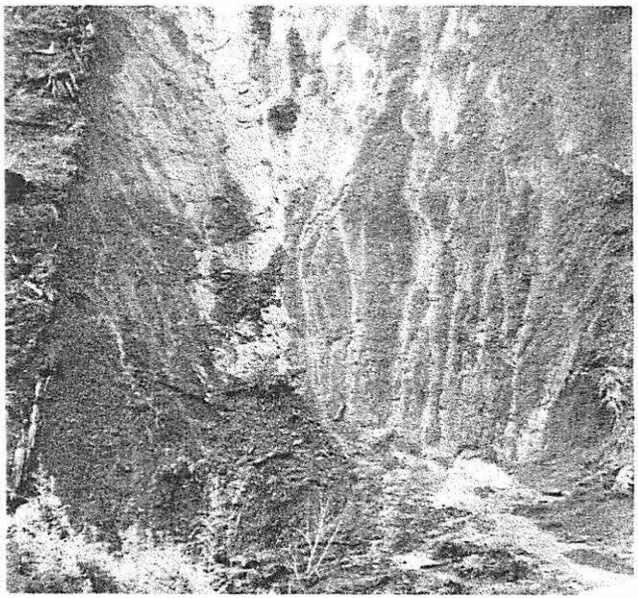

Figure 2.--Combination of translational - rotational slide caused by sidecasting and high pore water pressure.

Also in Oregon, a single road failure produced 40 percent of the total sediment yield for the year from a 303-hectares drainage containing 4 kilometers of roads constructed to permit clearcut logging of about 25 percent of the watershed (Brown & Krygier 1971). Similar results have been reported for forests elsewhere. In southern Idaho, 90 percent of the failures studied were associated with roads (Jensen & Cole 1965). In all these cases, roads had been constructed on steep slopes (fig. 2). These and similar findings have suggested that the forest manager minimize soil erosion and landslide risks by minimizing road mileage to the fullest extent possible, locating necessary roads on more stable portions of the landscape, and keeping road grades below 8 percent.

These methods, however, have been standard operating practice for road engineers. Attention has been focused on the more practical solutions of reduction of road width and endhaul of material to preselected safe disposal sites (Burroughs, Chalfant, Townsend 1973).

At present, however, almost none of the literature describes how these ideas can be implemented effectively in field conditions. That is why when these research findings were

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[1] Paper presented at the conference COFE/IUFO - 1984. Orono, Maine, USA, 12-14 August.

[2] Sandor A. Nagygyor is Chief, Branch of Technical Support and Assistance, U.S.D.I., Bureau of Land Management, Eugene District, Oregon, USA.

first presented, they were consistently rejected by forest managers, and little development of protective measures or construction techniques resulted. Managers' resistance came from: lack of understanding, rapid changes in woods labor and equipment that made some proposed techniques infeasible, and simply lack of economic incentives or "other motivations," such as strict rules and regulations.

By the early 70's, "other motivations" were strong enough to force most governmental agencies to develop new road construction methods previously not tried in forest management.

PROBLEM AND SOLUTION

When a road is constructed over stable ground, research and field observations have established that the causes of road-related landslides and/or siltations are:

1. Excess excavated material overloads the hillside, causing either sheet or rotational slides.

2. Excess material itself erodes away.

The apparent solution is simple: haul away all excess excavated material. On a 80 to 90 percent (38° - 42°) hillside, however, this is easier said than done. As engineers, our first step toward this solution was to determine a method which would contain the excavated material inside the right-of-way. We have devised the following steps to achieve such containment.

1. Directionally fall the right-of-way timber.

2. Eliminate clearing and grubbing of the right-of-way that typically occurs before the actual subgrade construction.

3. Start the excavation at the top slope stake.

4. Use the so-called 'trench method' to bring the cutslopes down to subgrade elevation.

5. Load and endhaul all excess excavated material to a safe disposal site.

Description of Work

1. Directional Falling

Directional falling of trees parallel to the centerline of the road is achieved by conventional falling methods, by use of tree jacks, or by pulling of trees. As the tree falls down parallel with the road centerline, it will roll against green trees or tree stumps and act as a temporary retaining wall. In western Oregon, generally, there are adequate numbers of trees in the right-of-way to do this.

2. Clearing and Grubbing

The elimination of the conventional clearing and grubbing has been easy since the contractor is happy to have one less chore to do.

3. Starting the Excavation

On hillsides 70 percent (35°) or over, the start of the excavation is the most critical step. To contain the excavated material, the excavation should begin at the upper slope stake (fig. 3). A small dozer, D7 or similar in size, can build a narrow pioneer road by drifting material against and on top of the fallen trees, logs and limbs. The logs and other woody debris act as a retaining wall so the initial excavation can be kept to a minimum. Usually, cuts two feet or less were adequate to construct a pioneer road 6-8 feet (1.8 - 2.4 m) wide (fig. 4). In this process, the use of the proper equipment is important because neither a Ford farm tractor or a TD25 can do the job. The right equipment will create a usable pioneer road without moving great amounts of material.

Figure 3.--Begin excavation at the upper slope stakes.

When rock is encountered, drifting dirt against or on top of the logs will form a temporary bridge to allow passage. The actual drilling and blasting will be done at a later time. I will explain the special blasting techniques in a moment.

The pioneer road can be constructed in segments, or to the full length of the road or progress simultaneously with the actual excavation.

Figure 4.--As excavated material is drifted on logs and other debris, it will form the pioneer road.

4. Using the "Trench Method"

To do the actual excavation, the trench system has proved to be a simple and effective method. The dozer should start about 30-40 feet (10-12 m) from the loader and work toward it. As the material is being drifted to the loader, the dozer will build a blade-wide trench. At first, some material will escape downhill, but logs and broken limbs will retain it inside the right-of-way. As the excavation gets deeper, the material from the outside wall of the trench will fall in front of the dozer and can easily be drifted towards the loader (fig. 5). As construction progresses, logs or other debris will be encountered. Debris can be either picked up with the excavated material or set-aside and hauled separately, depending on whether or not the excavated material is to be used for designed fills. If there is no designed fill, then only the usable logs need to be separated out. Broken tops and limbs can be buried in the waste area.

The trench method can also be used with the scraper. However, the pioneer road should be at least eight feet wide to give firm support for the scraper. Also, dozer help will be required to loosen the material to be excavated and to help the scraper to be loaded by pushing it. The excavation of common material by this method is fast and cost effective. However, most of the time solid rock slopes will be encountered, where the use of rock blasting is required.

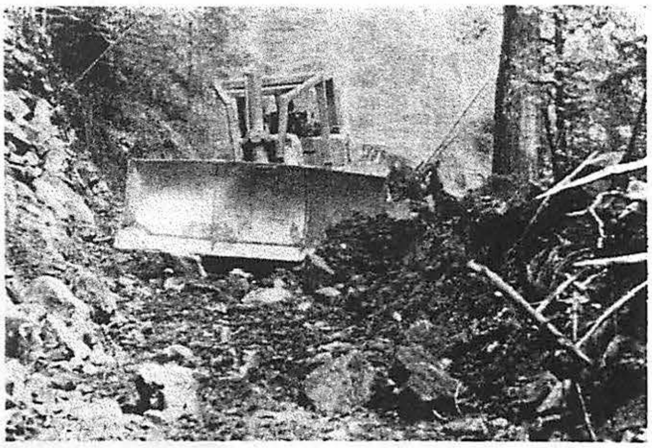

Figure 5.--Typical dozer excavation in the trench.

Rock Blasting

Several excellent books have been written on rock blasting (Langefors & Kihlstrom 1978). However, for many years the art of rock blasting on logging road construction could be summed up in the phrase: "if we shoot it heavy enough then we do not have to move it again" (Teller 1980). Until the early 70's, such terms as presplitting, sequential blasting, subdrilling, detonation velocity, and blasting plan had no place in forest road construction operations. These sophisticated methods were the domain of freeway construction and quarry blasting. But, the use of "lifters" was common since on steep slopes it is the easiest and most economical method.

Most of the time ANFO (Ammonium Nitrate - Fuel Oil) was used since it has larger detonation pressure, and is cheaper than most other explosives (Teller 1980).

The first time controlled blasting was used in our forest operations, our motto was "the smaller the better". It worked beautifully. We drilled 3 foot (91 cm) deep holes on 3 foot (91 cm) centers and loaded them with ½ lb. (0.23 kg) explosive per cubic yard (0.76 m^3), and the rock stayed in place. But this was time consuming and expensive. Slowly, the depth of the drill holes has increased with our confidence and experience. The process was educational for all of us. It was easy to convert the contractor to controlled blasting after he had been overcharged several thousand dollars by a charge-happy driller who blew the whole hillside over the hill and down the creek. Presently, excellent jobs are being done by presplitting and by using properly arranged delays (Teller 1980).

In a successful blast, we will have all the rock stay in place or neatly piled against the temporary cribs -- not in the creek. The excavation of shot rock is not different than hauling common material. The trench excavation method was used again. We found that the most effective method is first to drift the shot rock to a loading area and then load it into trucks (fig. 6). Shot rock is not picked up by scrapers easily. I have seen $1500 scraper tires destroyed within a month by the sharp rocks.

Figure 6.--In the trench, a dozer could easily push the shot rock to the loading area.

This new system is easy and simple, but much advanced from old times when only a dozer was needed to push the excavated material over the side and down the hill.

5. Loading and Endhauling to a Safe Waste Area

Loading and endhauling of the excess material was never difficult, although it was and is expensive. Hauling can be done either by trucks or by dumpsters, depending on the equipment available or owned by the contractor, but not on economic considerations.

The major problem is finding a safe waste area where 10-20,000 c.y. (7,600-15,200 m^3) of material can be hauled. The location of safe, environmentally sound, waste areas was a new challenge not only for the engineer but also for the soil scientist. Due to remote locations and lack of access, we don't have the luxury of core soil sampling and the consequent stability calculations. We have had to rely on surface samples, but mostly on intuition.

CONCLUSIONS

During the past 10-15 years there have been great changes in road construction techniques and in the construction equipment used to achieve them. The system I have described is presently being used in combination with other newer techniques. The use of hydraulic excavators (Somere 1984), for example, is an accepted construction practice. At any rate, we have seen the end of the traditional type of road construction, with its distinct sequence of right-of-way falling, pioneer road construction, clearing and grubbing, and road prism excavation (Krueger 1983). Although attempts have been made to develop foolproof methods and formulas, our advancements are still essentially trial-and-error propositions. Everchanging geology continues to challenge not only engineers and contractors, but also equipment companies. We can envision even more innovative equipment, such as tractors, loaders and trucks which will travel on an air cushions, and allow road construction to proceed all year around without causing environmental damage.

I am sure all of us are up to this challenge and the time will come when our roads will not be blamed, rightly or wrongly, for every slide or muddy creek. We will have an acceptable product not for only ourselves but for the public.

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QUALITY IMPROVEMENTS IN WORK STUDY USING HANDHELD COMPUTERS

Jan Thorn Clausen[1]

Abstract.-- In the Nordic countries a joint project concerning developing better work study techniques has been going for 2 years. The project deals with handheld computers and their use in Forestry Research. Several computers have been tested in the harsh Nordic climate. Programs have been developed following a joint design criteria concept. Study quality and control has been improved by the use of computer technology. Several Nordic Forestry institutions now use a British computer, the Husky, as standard time study equipment.

BACKGROUND

The Danish Institute of Forest Technology, a nonprofit institution with the object of improving forest operations, was formed in 1967. In our R&D we use work study as a tool for analysing the various study objects. The Institute is very small (Danish Forestry is small-scale!), 10-12 persons organized in one-man departments (weed-control, machinary-consultancy, thinning operations, harvesting techniques, short-term management etc.).

When a work study is required, the project leader does all the nescessary work: planning, work study, punching and analysing data, transfer of the results in reports, papers and demonstrations. With this system you concentrate all the know-how in one person, who afterwards as a consultant is better suited to deal with all management levels (owners, administration and workers).

WORK STUDY HISTORY

Back in 1967 a very advanced work study board was constructed: 3 standard stopwatches placed in a row and activated as one. The stopwatches were initialized in the 3 different modes (running, stop and ready), so the time elements could easily be read from one of the clocks, while another measures the time of the next element. All data was written down on paper and later analysed. On fig. 1 the later development of our time study technique is shown.

- 1967 Birth of the Institute
  - Study board with 3 stopwatches
  - Manual analysis on desk calculator
- 1976 - Analysis on programmable calculator
- 1977 - TTY terminal for ONLINE analysis (SAS) on computer center via telephone
- 1978 - Electronic stopwatch
- 1980 - Data entry on local micro computer
  - Transmission to computer center for analysis
- 1982 - Handheld computer for data collection
  - Transmission direct to computer center for analysis
- 1984 - Computer center as intermediate database
  - Retransmission to local micro computer
  - Local analysis (SYSTAT)
  - Bar code wand for data entry

Fig. 1. WORK STUDY HISTORY of Danish Institut of Forest Technology.

Analysis was done with the help of a normal calculator, summing rows and collumns and laborously making plottings on paper. In 1976 the summing was done on a programmable calculator, and this indicates our entry into the Electronic Age. A year later we bought a typewriter TTY terminal for ONLINE statistical analysis on a computer center via the telephone system. The punching of data was done by the timestudy personnel in order to avoid errors.
In 1978 we saw in a normal bookstore a cheap electronic stopwatch with a special lap function. Our fieldwork was now improved greatly by using one clock instead of three. The watch was later in use in Norway and Sweden, too.

In Scandinavia plus Finland we have govermentally financed joint projects. One of them deals with improvement of work study techniques in Forestry Research. One of the objects was to find improvements, which could be of common interest for all the Nordic countries. In 1980 a general Design Criteria for a handheld timestudy device and the software was developed. A systematic scanning of computer literature began.

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In 1982 we selected a British handheld computer, the HUSKY, which apparently met most of our demands. It was tested in all Nordic countries. A timestudy program for datacapture and -tranmission was developed and tested, too.

So the status now is that in Denmark and Sweden (and Norway soon) some Forestry institutions use computerized work study techniques all the way from the stump to the final report. I will in the following discuss the experiencies we have got so far.

DESIGN CRITERIA

SOFTWARE

Before getting into the 'Hardware Jungle' itself it is very important to specify precisely that you actually want the machines to do. That is a very classic and widely used remark, but difficult to follow. New machines are pouring onto the market almost every month - and they are always very interesting!

In Forestry Work Study dealing with R&D every study differs from one another with respect to lay-out, type, size, no. of elements etc. Some studies are continuous timestudies, some frequency studies. Some require extra variables measured during the study, such as diameter, lenght etc. Some consist only of numeric data (e.g. weed control studies). Work study programs must be able to handle all these study types.

Study Type
- Continuous time study
- GTT frequency study
- General data collection

Data Type:
- Time element + numeric variables
- One time element = One key
- Element code + time

Study Control:
- Dialogue system
- Informative messages

Data Transfer:
- "Handshaking"under program control

Study Evaluation:
- Print data
- Analysis of means
- Rough significance test

Fig. 2. Design Criteria of a work study program.

A point of practical importance is that the dialogue with and responses from the program must allow the studyman to be in complete control of the study. So statements as current observation number, name and time of last workelement and what the program expect from you next are important.

The work study program must handle the timemeasurement in such a way that the time of the current workelement is recorded along with the total workcycle time. All times must be recorded in a decimal form e.g. decimal minutes.

Allocating a time with a workelement may be done in several ways. One way is first to type an element code and then record the time, when the workelement is finished. Another is to allocate keys directly to workelements, so you only have to press one key. With the first lay-out you have a very flexible system, where you may have as many workelements you like. The one-key system require a more or less fixed definition of the study lay-out. However it is more simple to operate, especially in a complicated study.

The recorded data should be transmitted to a host computer under program control, either directly or via modem/telephone or tape/floppy disk.

We also find it important to be able - inthe field - to do some preliminary analysis. A simple calculation of element and cycle means is very useful. We also include a calculation of standard error of mean in order to test the study size (no. of observations against standard deviation).

HARDWARE

The portable computer must be able to work in the Scandinavian winters with temperatures down to minus 20 °C (-4°F) and in daylong rain (nobody is interested in the studyman!). It should be shockproof and have a max. weight of 1 kg.

Environment
- Max 1 kg
- Waterproof
- Temperature down to -20° C (-4° F)
- Shockproof

Function
- Display min. 2 lines
- Keyboard "foolproof"
- Internal clock
- Large and safe memory
- Safe power supply

Flexibility
- User programmable
- Standard communication
- Variable communication parameters

Fig. 3. Design Criteria of physical device.

The display should contain at least 2 lines, preferable 4 or more. The keyboard should be workable with gloves, but also as 'hit-by-accident-proof' as possible. The power supply must be very safe and with a backup system. Operation must be garanteed for at least 10 hours.

The memory must be able to contain at least one full days study. How big it should be in K bytes is difficult to say (depends of the program), but probably min. 32 K RAM.

We find it very important that the work study computer can be programmed by the user himself. Many studies defer so much in organization that the research institiution will need to design program concepts easily and inexpensive. We also find that a standard communication capability is most flexible. No institutions in the Nordic countries use the same computer system.

STATE-OF-ART

The work in the Nordic project is concentrated on getting practical experiencies about 1) handheld computers and their function in the Nordic climate and 2) different types of programs including development and programming.

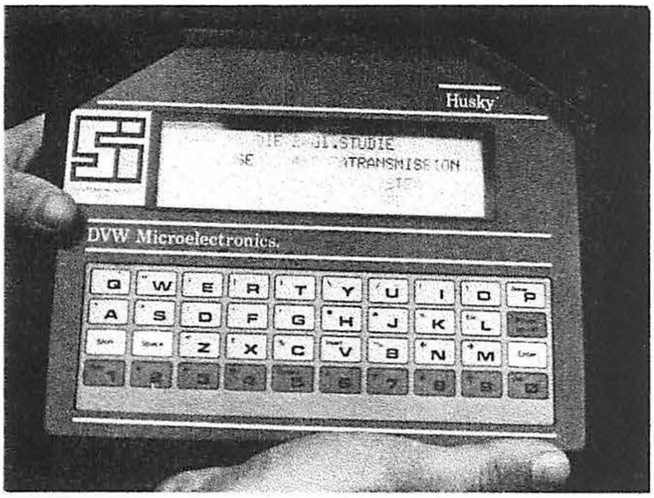

Fig. 4 HUSKY handheld computer.

In 1982 we bought a British computer, the HUSKY, which met most of our criterias. We developed a program package, HUSAS, which is able to perform both a continuous time study and general data collection - but at the moment no frequency studies. The machine and program was tested at all Nordic Forest Work Study institutions. The HUSKY computer and the HUSAS package is now the standard work study equipment at the Danish institute.

We found quickly that the main problem with the Husky computers is the Nordic winter. At temperatures below -5^{o} C Husky works clearly slower and not at all below $10-15^{o}$C. The computer itself is very useful and flexible, so we have tried several heating systems. The one that worked needed several kilos of battery power!

Computer
- Husky (64-144 K RAM)
- Husky Hunter (80-208 K RAM)

Design
- Standard Timestudy with 10 time elements + 5 numeric elements
- Element allocated keys (element+time=1 key)
- One cycle = one line with 15 variables
- General datacollection of up to 15 variables per observation

Analysis
- Print hardcopy/display
- Element means
- Cycle mean + standard error of mean

Data Transmission
- "Handshaking" with computer center
- Direct input in any host computer

Fig. 5. HUSAS Work Study System.

Recently we got in contact with the Norwegian Defence Research Institute, who has developed small, portable heating systems in order to keep wounded soldiers warm in arctic areas. The heat is provided from small charcoal burners, which produce a stream of hot air. In combination with the handheld computer stowed in an insulated bag and the input controlled by a bar code wand, we hope to have solved the crucial temperature problem.

The Nordic project also tested some other handheld computers and work study programs, mostly Swedish systems. The programs are based on the principle: element code + time measurement (2 to 3 keys). The computers (e.g. DATADON and MICRONIC) meet the climate criterias, but are more inflexible with respect to user programmability and communication.

STATUS

After about two years of practical use of handheld computers we have found both improvements and drawbacks. The system really cuts time handling the data. Errors are also reduced significantly. With a well planned study 50-80 % of the analysis can be done just after the study (Analysis of means). Off-days as rain and snow are used more efficiently with statistical analysis.

IMPROVEMENTS:

Timesaving
- No punching of data
- Analysis of means => 50-80% of total analysis
- Statistical analysis on "off-days"

Study Evaluation
- Standard Error of Mean => cuts fieldwork time
- Analysis of Means => involves study object more

General

- Improved observation of study object =>
  - = Better practical conclusions
  - = Complicated studies more simpel to perform

DRAWBACKS

- Studymen refuse to use "oldfashined" clocks
- Telephone connections must be "noise-free"

Fig. 6. Work Study Status 1984

We have found that the studyman has his eyes almost all the time on the object, because he only has to press one key to register the time element. More detailed practical information of the e.g. work method is collected in that way.

Earlier with the old technique the result of a time study was a pile of paper - sometimes wet and almost unreadeble. During a study the forest worker or tractor driver gets very interested in the study and a professional discussion often starts. But he is normally disapointed, because the studyman knows nothing of the result. With the computer you can read intermeadiate results out after each break - and the discussion at once starts at a high level - to the benefit of both.

Of course we have found some drawbacks. We have now no arguments against a study on a tractor in daylong rain, where the data and the driver are warm and safe indoor!
It is also very hard to get studymen to work with 'oldfashioned' equipment such as electronic stopwatches!
In the beginning we had strange disturbances during transmission via telephone to computer center. We used the normal telephone in the hotelroom, and it has a counter connected, which said 'beep' once a while - and our computers didn't understand that!

Talking seriously, the drawbacks are not of any importance. Our investment in handheld computers is generally a story of happiness.

FOREST WORK STUDY TECHNIQUES - A SURVEY OF CURRENT METHODS[1]

Benjamin F. Hoffman[2] and Morgan L. Cameron[3]

Abstract.--A survey of persons and organizations involved in forest work study revealed that most such work still relies on the conventional observer with stopwatch and clipboard, and Servis recorders. Most data are transferred to computing equipment manually. New developments include videotape and a variety of portable electronic data recording and storage devices capable of automatic transfer to computers. Most new devices are custom-built for research use. A tabulation of the results and a discussion of equipment is included.

INTRODUCTION

The collection, storage and retrieval of forest work study data is expensive and subject to several problems specific to the forest environment and the nature of forestry operations. Unlike other industrial operations, a single forestry operation, such as skidding, may cover a mile-square area of variable topography. Collecting data from the stump and landing, which may be half a mile apart, presents unique problems. In addition to the physical aspects of the operation, variables such as temperature, precipitation, insects and ground cover add to the complexity of such studies.

Further, the automation of data collection requires electrical power, which in turn necessitates portable power supplies. If the recording equipment and power source are to be carried by men, they must be small in size, light in weight and relatively immune to damage by dropping. If mounted on a woods machine, small size is desirable, and equipment must withstand constant vibration and frequent severe jolting.

For years, an observer with stopwatches mounted on a three-watch clipboard has been the standard in forestry work study data collection. Supplementary machine performance data have been obtained with automatic sensing and recording devices mounted on the machinery. In some ergonomic studies, workers have been equipped with devices to measure and record vital physiological data. In the past, most such information was manually entered into data processing machines.

Recent improvements in electronic technology have produced portable handheld microprocessors suitable for data entry in the field. Some units include timing functions so that time study data can also be recorded and retrieved. In most instances, information collected by electronic means can be automatically transmitted from the data logging device to a processing unit in the office or laboratory. With some devices data can be transmitted to a central computer by telephone modem at the end of the work day, and the completed analysis is on the desk the following morning.

Photography, both still and motion picture, is being supplemented or replaced by videotape, as picture quality can be verified on site to insure that it is adequate for later analysis.

In order to evaluate the changes taking place in forestry work study, the International Union of Forestry Research Organizations (IUFRO), Division 3, Forest Operations and Techniques, Working Party on Production, Labor and Wages (S3:04:02) planned a study in 1982 to ascertain recent changes and new developments in the collection, recording, storage and retrieval of work study data. In January of 1983, a survey was conducted to determine the "state of the art" in forest work studies.

METHOD OF STUDY

In January 1983, 210 questionnaires were mailed to persons and organizations known to have been involved in work study. As the mailing list was compiled from several different sources and was by no means complete, a statistical analysis of the results was not intended. In many cases, two or more persons in the same organization were questioned, and more than one person often replied. In those cases where the respondent might not be actively engaged in such work, he was asked to provide names and addresses of others who might be involved.

The results of this study would be useful only in determining the methods currently in use,

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[1] Paper presented at the COFE/IUFRO-1984 conference, Orono, Maine, USA, 12-14 August.

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without any definition of which were most popular. The questionnaire sought to determine:

1) How work is measured - methods for recording, storing and retrieving data.

2) The type of hardware used for measurement and analysis.

Figure 1 shows the questions which were posed.

WORK MEASURED:

How is the data recorded?
  Investigator in field -
  Equipment operator -
  Automatic machine recorder (mechanical, electronic) -
  Other?

How is the data stored?
  Data sheets -
  Electronic memory -
  Magnetic tape -
  Other?

Additional Comments?

HARDWARE:

Type of equipment used for recording data?
('Servis' recorder, stopwatch, etc.)

Type of equipment used for data analysis?
  Handheld calculator -
  Microprocessor -
  Mainframe computer -
  Other?

New design?

After two months, a tabulation of responses was prepared to show what methods are in use, with some indication of their frequency of use.

RESULTS

The survey was sent to 79 persons in 19 foreign countries, of whom 32, representing 12 countries, replied. Of the 131 forms sent within the United States, 56 were completed and returned. From the total of 88 responses, 32 persons were no longer involved in work study or did not provide useful information. Multiple responses were often returned from one organization, compiled into one response representing that organization. The basis for the results is therefore 56 persons and organizations which are actively engaged in work study of forest operations.

Work measurement concerned the methods of data collection, recording, storage and retrieval. Recording was accomplished by three principal means, the investigator, the operator or automatically by electrical or mechanical recorders (see Table 1). Many investigators used more than one method or a combination of several.

Table 1. Methods of work study data recording, by number of responses.

Investigator	Machine Operator	Automatic Recorder	Other Film or Videotape
31	8	17	6

Data were stored in several forms, but chiefly on conventional field data sheets, as shown in Table 2.

Table 2. Methods of work study data storage, by number of responses.

			Other		
Data Forms	Electronic Memory	Magnetic Tape	Film or Videotape	Recorder Disks	Computer Copy/Disks
43	18	12	8	13	3

As in the case of recording, some individuals used more than one of the above methods, or a combination, to store data.

Most respondents still performed data retrieval in the traditional manner - keypunching or otherwise manually entering directly into a computing device from field study sheets. Forty-four respondents used manual transfer, but 14 read data directly from magnetic tape or disks into the central processing equipment. Some data logging devices are capable of direct connection to computers or can have data transferred by telephone modem.

With regard to "hardware" in current use, the traditional stopwatches and board - conventional or digital - are still widely used, as is the Servis recorder. Motion pictures are also in use but video-cameras are being used increasingly. Tape recorders and portable electronic recording devices are also used, but in small numbers. Table 3 outlines the frequency of use found through the survey.

Table 3. Hardware used for the conduct of forest work studies, by number of responses.

Stopwatch and Board	Servis Recorder	Film or Videotape	Tape Recorder	Portable Micro-processors	Electronic Data Logs
38	16	10	1	8	5

Most respondents used several types of hardware, but there was a general absence of applications of small electronic devices to work study in the forest. Many of the electronic devices in use were custom made for the user. However, in the area of data analysis, most investigators are using modern computers, as outlined in Table 4.

Table 4. Type of equipment used for data analysis, by number of responses.

Mainframe computer	Micro-processor	Handheld calculator
37	25	26

DISCUSSION

The limited use of portable electronic data collection devices in forest work study is not really surprising. Most new developments in this field have been custom built, prototype units designed and fabricated for research work by organizations such as the Forest Engineering Research Institute of Canada (FERIC) and the Finnish State Research Center. The cost of such units makes them impractical for most industrial applications, but intensive and detailed research studies can often justify the cost.

For many industrial studies, traditional stopwatches and recorders produce adequate data for cost and production analysis. Here, the measurement of work elements within the nearest five seconds is adequate. However, for equipment design studies, greater precision in time measurement is required. For example, the felling cycle of a feller-buncher, normally a single work element for costing and production analysis, might be subdivided into several subelements. Many of these subelements of high-speed machine operation are too rapid for accurate manual recording. In cases such as these, automated data collection using electronic sensors, high-speed cameras and other sophisticated devices might be required.

As an example of the more advanced equipment in use, data-logging devices designed and built at two universities permit multiple, simultaneous, continuous monitoring of up to 16 events. The University of British Columbia developed a recorder for monitoring cable logging operations (Lawrence et al. 1982). Operation requires the yarder operator to insert a new cassette tape and recharged battery at the beginning of the day and turn the system on. The process is reversed at night. The University of Saskatchewan custom-built a 16-event recorder for FERIC (Heidersdorf 1983) which has been used for detailed recording of feller-buncher activity. Research scientists have developed and used some of these more sophisticated combinations of data collection and processing systems because much of the technology and expertise is readily available to them.

Videotaping is increasingly used for data collection, using both the video and sound systems for recording. Not only can elapsed time be read from the videotape, but the physical dimensions of the machinery and the number of pieces, size and quality of forest products can be measured from the image using a technique called videogrammetry (Cameron 1984).

Transfer of field data from tally sheets and recorder discs to computing equipment has been a tedious, manual task in the past, and a source of error. Portable data logging devices with time functions are now commercially available in Great Britain, Sweden, West Germany and the United States, at costs of $1,000 or more. By 1984, portable microprocessors were available at prices as low as $1,500 (Clausen 1984). In addition, for recording and analyzing site data which do not require time measurement, a variety of recording devices designed for agricultural and forestry use are also available. With such recorders, as well as with tape and video recorders, information can be transferred to data processing equipment by direct wire or telephone modem. In one instance, Servis recorder graphs were read into the computer using a digitizer.

CONCLUSIONS

Currently, the use of sophisticated electronic data logging and processing equipment for forest work study is largely limited to research studies.

Because of the cost considerations and the limited demand for specialized tools for industrial forest work studies, it is unlikely that such equipment will be widely adopted in the near future. As other applications of this technology take place, resulting in a wider variety of equipment, and lower prices, more general use can be anticipated. In the meantime, it is likely that highly specialized equipment development and use will be limited to intensive research into new machine designs and ergonomic studies where a high degree of precision is required.

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TOTAL TREE CHUNKWOOD AS RAW MATERIAL FOR FLAKE PRODUCTS[1]

Bruce A. Haataja, Roy D. Adams and Rodger A. Arola[2]

Abstract. This study evaluated the technical and economic suitability of flakes made from chunked aspen and soft maple wood produced by the Forest Service "chunking machine" as furnish for flakeboard, oriented strandboard and highly aligned products. Results indicated that structural panels can be produced with acceptable strength and physical properties. Analysis indicated that net raw material cost savings are possible with the chunkwood system.

INTRODUCTION

Structural flakeboards rely on engineered, high quality, bark free flakes in developing their superior strength properties at low resin levels and medium densities. This is true for both random and oriented strandboards. For the most part, the flakes for these products are made from peeled logs or pulpwood bolts. The logs are directly converted with disk, drum or lathe type flakers to produce the quality of flakes needed.

An alternate system for producing flakes is from forest residue and total tree material, which recovers 1.5 to 2 times as much wood per acre as conventional logging. Total tree harvesting is becoming more prevalent as a system for recovering wood for fuel, pulp and paper, fiberboard and particleboard. Forest residue and total tree material may be converted to flakes by first reducing it to chunks (chips that are 2 to 4½ inches long), processing the chunks into fingerlings (particles that are 2 to 4½ inches long by about 3/4 inches in cross-section) and then flaking in a ring flaker (6).

The key element in this process has been the system for producing the fingerling of proper geometry. Researchers (4,5,7) have reported that high quality flakes could be made from total tree material in a ring-type flaker if the material were first reduced to a fingerling size particle. In general, these researchers have noted that while disk flakes produce panels with improved properties, ring-flaked panels can exceed Canadian and American Standards. In 1972 Heebink (8) presented a challenge to the designers of chipping equipment to develop a machine to produce fingerlings.

The size and geometry of fingerlings are important for several reasons. The length of the fingerling controls the upper limit of flake length. It is necessary that flake length be substantially 2 inches or greater for structural flakeboard, therefore the fingerling should be 2 inches or greater in length. Since ring flakes rely on centrifugal forces to position the fingerling's long dimension parallel to the cutting edge of the knife, the fingerling should have about a 4 to 1 length to thickness ratio to insure a proper positioning with the knife. Fingerlings that are long enough but too thick in cross-section do not feed well through a ring flaker without plugging the machine. Further, the cross-section of the fingerling controls flake width. For oriented strandboard it is important to have long narrow strands rather than wide wafers.

The studies referred to indicate the need for equipment to produce a high quality fingerling. In addition to the drum chipper used by Heebink et al., other machines have been developed to produce large chips and fingerlings. Erickson (4) reported on a spiral-head chipper developed by the U.S. Forest Service, Forest Science Laboratory at Houghton, Michigan. This machine produced chips or blocks about 2½ inches long. The chips, when fed through a hammermill, broke down into fingerlings. Panels made from these ring flaked fingerlings had good properties. Recently, the Forest Science Laboratory at Houghton has developed a chunking machine reported by Arola et al., (1) which produces chunks from 2 to 4½ inches long with cross-sections often equalling the entire tree cross-section. Usually the chunk has longitudinal fractures which help in the subsequent breakdown of the chunk into fingerlings. The Institute of Wood Research at Houghton developed a prototype chunk splitting machine which is capable of reducing chunks into fingerlings while retaining the original chunk length. With these two machines, fingerlings 2 to 4½ inches in length by approximately 3/4-inch cross-section were produced.

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[1] Paper presented at the Symposium of the Council on Forest Engineering and International Union of Forestry Research Organizations - 1984. Orono, Maine, USA, August 13.

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A technology for producing a high strength composite wood material (CWM) from elongated wood flakes has been developed at the Institute of Wood Research. Structural products, such as utility poles and crossarms, have been manufactured from CWM and are undergoing service testing. The CWM technology currently uses species which would not usually be found as structural products. Although this material requires an engineered flake, i.e., size is restricted to fairly close tolerances, it is anticipated that these flakes could be produced from small trees and residue material, providing that suitable production equipment is available.

Under contract with the USFS, the Institute of Wood Research conducted two research studies involving chunkwood. The objectives of the studies were to evaluate the technical and economic suitability of flakes produced from chunkwood as furnish for flakeboard products. A particular objective of the second study was to determine the way in which board density and strength properties were affected by combining dense hardwood and aspen flakes.

The purpose of this paper is to describe the laboratory methods and equipment used to process bolts into high quality flakes using the chunkwood concept and to relate this to a commercial situation. A flow diagram outlining project steps is shown in Figure 1.

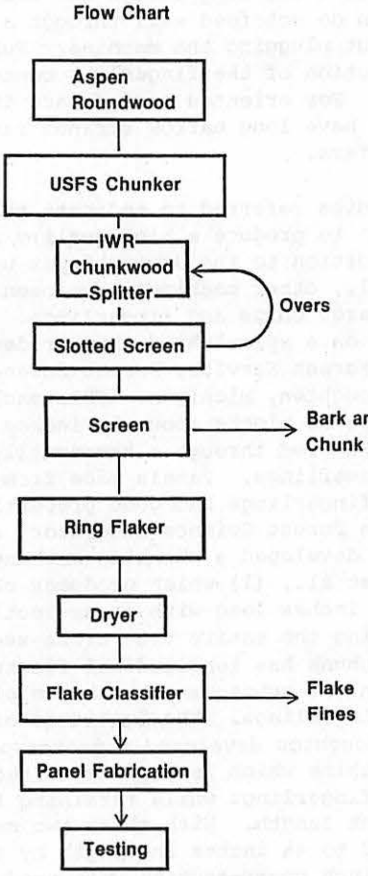

Figure 1.--Flow Diagram for Project

MACHINE DESCRIPTIONS

USFS Chunker

The USFS wood chunker was specifically designed for controlled laboratory testing to reduce roundwood bolts up to about 9 inches in diameter into chunks (Fig. 2). The flywheel and carrier for the cutting blades was a 1-3/4-inch-thick, 3-foot-diameter steel disk. The disk was mounted on a horizontal shaft running in a pair of bearings secured to a rigid frame. A diagram of the chunker is shown in Figure 3.

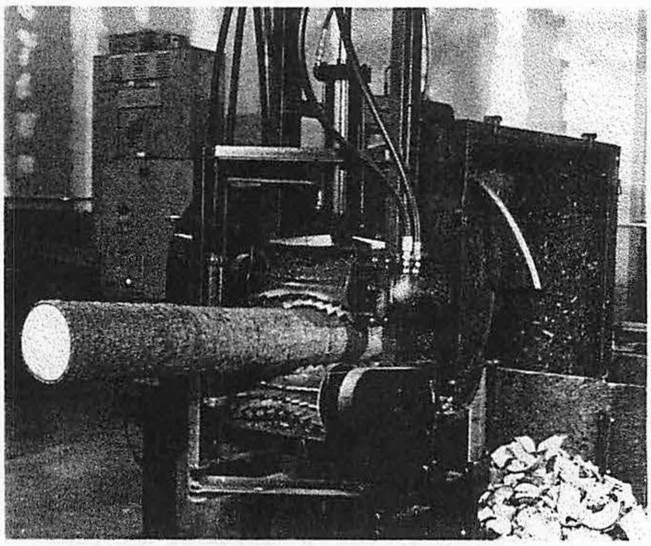

Figure 2.--USFS Chunker

Three curved, 24-inch-long, detechable blades, bent on an 18-inch radius, were mounted 120 degrees apart and positioned on the face of the disk so that the curved plane was at right angles to the axis of the workpiece. The leading edge of each blade was set at a greater radial distance from the center of shafting than the trailing edge. The blades were tapered so that the leading edge projected about 1 inch from the face of the disk, whereas the trailing edge projected about 9 inches (equivalent to the maximum diameter of cut). Two sets of blades for testing were fabricated - 1/4 inch and 3/8 inch thick - both with a 30 degree included angle double bevel.

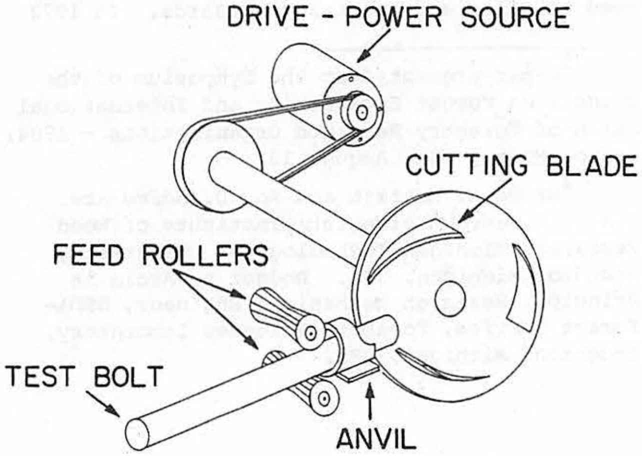

Figure 3.--Diagram of USFS Chunker

The workpiece was fed through a tubular anvil made from a 9.5-inch-diameter pipe horizontally secured to the infeed frame. The anvil tube was located near the rim of the disk, but offset from the plane of the disk, to match up with the cutting blades. The center of the anvil tube was positioned slightly below the disk center to obtain the desired entry and exit of the blades. The anvil tube was contoured to provide slight clearance between it and the blades as the chunks are severed from the workpiece.

Because the workpiece does not self-feed, a pair of hydraulically powered rollers was positioned immediately ahead of the anvil. The speed of the feed rolls was adjustable. To accommodate test bolts of different diameters, an air-operated cylinder was used to lift the upper roll to insert the bolt and to exert a downward force on the workpiece during test.

A 175-horsepower diesel engine provided power to operate the chunking machine. The disk was driven through a speed reducer and sprocket/roller chain drive system. The rotational speed of the cutter disk is variable.

IWR Chunkwood Splitter

When long wood chunks (i.e. 2-4" long) are produced, they usually have large transverse sections and may be as large as the cross section of the tree stem being chunked. Usually some longitudinal splitting occurs, but chips remain large enough in cross-section to cause flow problems through a ring flaker. Large cross-section chips also produce wider flakes than what is desired for flake alignment processes. Wide flakes can be reduced in width by subsequent operations but generally at the expense of additional "fines".

The IWR chunkwood splitter is based on a concept for splitting large chunks into fingerlings without producing an excessive amount of "fines" or damaging the chunks in ways which would produce excessive fines in subsequent flaking. The basic tool or bit employed by this concept is a hardened steel cone with a relatively sharp point. Splitting is caused by impaling the chunk with the cone shaped bit. The chunk may be pierced at any possible grain orientation. This will cause splitting along the grain. With a sharp point on the bit no cutting and little crushing of the wood fiber occurs.

While several machine designs are possible the IWR laboratory model chunk splitting machine was made using a jaw mounted with impaling bits. Figure 4 shows a sketch of the arrangement of jaw mounted with impaling bits, cleaner plate and bedplate. A photograph of the laboratory machine is shown in Figure 5. The features of of this machine include the following:

1. A hinged impaling head so that it works like a jaw with the bedplate.
2. A cleaner plate is included so that any chips that stick to the impalers are wiped off when the head rises.
3. A hydraulic cylinder which actuates the impaling head.
4. More numerous and smaller diameter impalers further into the throat of the machine to provide increasing chances of additional splitting as the chips move through the machine.
5. Impalers of simple configuration.
6. A sloped bedplate to allow gravity flow of material through the machine.
7. A gate at the lower end of the bedplate (not shown) which controls the flow through the machine when the jaws are open.

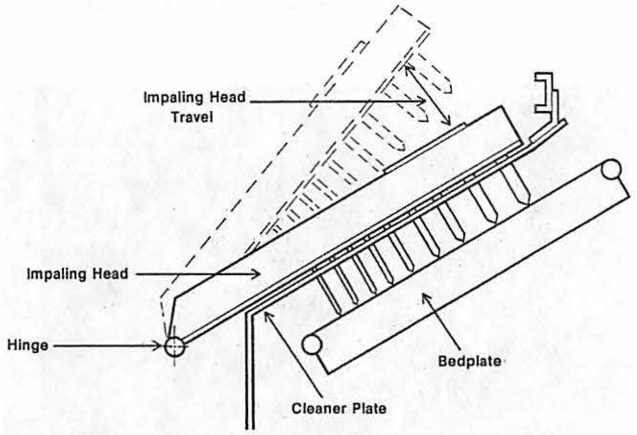

Figure 4. Section View of Impaling Head, Bedplate and Cleaner Plate.

This laboratory chip splitting machine successfully reduced large wood chunks produced by the USFS wood chunker into fingerlings that passed through a 3/4-inch slotted screen.

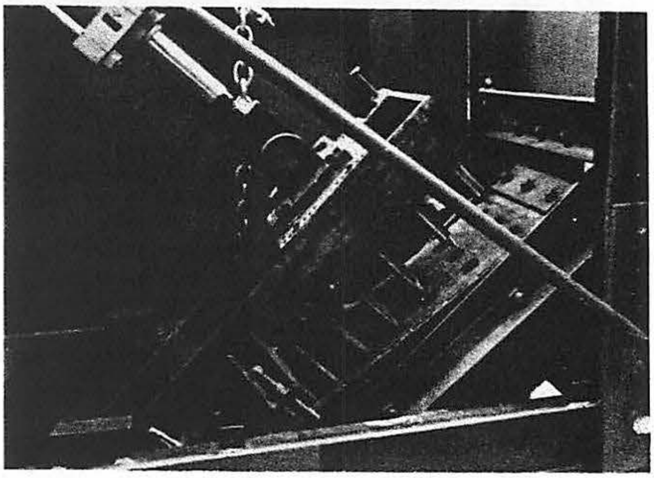

Figure 5.--IWR Chunkwood Splitter

FLAKE AND PANEL PRODUCTION

General Observations

Log quality was limited to sound logs and size to maximum capacity of the "chunking machine", i.e., approximately 8.5 inches in diameter. Sample bolts were reduced to 2 to 4-inch long chunks on the Forest Service's chunking machine. The aspen chunks shown in Figure 6 were too large for ring flaking and were subsequently reduced to fingerlings of 3/4-inch cross-section in the prototype chunk wood splitter. A 3/4-inch rotary slotted screen was used to accept only those particles meeting the required cross-section. All oversize material was recycled through the chunkwood splitter until acceptable in size. Figure 6 also shows some typical aspen fingerlings.

Figure 6.--Aspen Chunks Produced by the Forest Service Involuted Disc Chunking Machine, Fingerlings That Were Split From Chunks in the Institute of Wood Research Prototype Chunkwood Splitter and Ring Flakes Made From the Fingerlings.

The accepted fingerlings were flaked using a Black Clawson MKZ-14 ring flaker at the Institute of Wood Research. The flaker knives were set to produce a nominal flake thickness of 0.020 inches, and a sample of fifty flakes randomly selected, averaged 0.020 inches in thickness. The length of the flakes were determined by the length of fingerlings which ranged from 2 to 4½ inches long. Example flakes are also shown in Figure 6. The flakes were dried to 5 percent moisture content. Three flake classifications were then obtained, i.e., those retained by 1/8, 1/4 and 1/2-inch screens, referred to as +1/8, +1/4 and +1/2, respectively. These screen sizes approximately determine the minimum flake width retained.

Study No. 1

Sixteen panels 1/2 x 16 x 96 inches were fabricated at a nominal density of 42 pounds per cubic foot (pcf). Typical panels are shown in Figure 7 with a close up of a highly aligned (CWM) panel in Figure 8. Panel differences were based on flake classification and adhesive type/level. The adhesive type/level was related to the flake orientation method used. A 5 percent level of phenol-formaldehyde was used for random and oriented strandboard panels and an 8 percent level of isocyanate used in the highly aligned panels. The resin and flake classification choices were based on those used in commercial and experimental panels whose strength data can be used for comparison. The press temperature was 330°F and press closing was achieved in one to two minutes. The press time for the phenol-formaldehyde adhesive was 20 minutes and 15 minutes for isocyanate adhesive.

Study No. 2

In this work a dense hardwood species-soft maple (*Acer rubrum*)- was selected to be combined with aspen in the production of panels. Soft maple was chosen since it is overabundant in the Lake States, often has poor form on "off" sites and is frequently unsuited for sawmilling, and grows thickly on good sites allowing substantial thinning volume. Also, its texture and density are similar to paper birch (*Betula papryifera*) suggesting that similar results might be achieved with paper birch.

For Study No. 2, ring flakes were produced from chunkwood manufactured from aspen and soft maple bolts in the same manner as Study No. 1. The flakes used for test panel production were those retained on a 1/4-inch screen. Ninety panels 1/2 x 18 x 18 inches were fabricated at a target density of 42 pcf. As in Study No. 1, all random and oriented strandboard panels were blended with 5 percent liquid phenol resin. The highly aligned material was blended with 8 percent isocyanate adhesive. Other than board type, variables included the ratio of aspen to soft maple flakes and homogeneous mixtures vs. layering. Layering was accomplished by using one half of the total aspen component for a particular panel on each surface and soft maple was used for the cores. The press temperature was 350°F and press closing was achieved in one to two minutes. The press time was 12 minutes.

PANEL PROPERTIES AND DISCUSSION

Average values for bending strength (MOR), bending stiffness (MOE), material density and internal bond (IB) are given in Table 1 for the two studies. Data are given for random oriented panels, oriented strandboard (OSB) and highly aligned material (HAM); in addition minimum values required by Commercial Standard CS 236-66, (13), Forest Service Targets (4,12) and data from a study by Price (12) are presented. The MOR and MOE averages for the aligned material (i.e., OSB and HAM) are given parallel to the flake orientation.

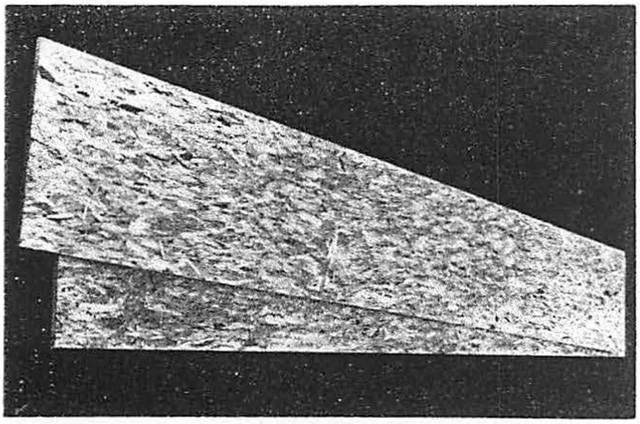

Figure 7.--Typical 1/2 x 16 x 96 Inch Panels Made From Chunked Wood.

As one would expect material density influences strength. Regression analyses were performed using the individual data points and we found that as the panel properties increased the density effects became more marked, so that a change in density of the highly aligned material has far more influence on properties than for the random panels.

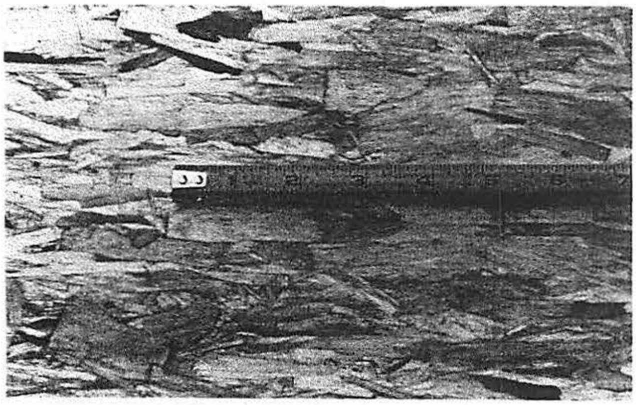

Figure 8.--A Close Up of a Highly Aligned (CWM) Panel.

The results of the two studies were comparable even though combinations of aspen and soft maple were used in Study No. 2. Data for the 50:50 mix are presented. In Study No. 2 the various aspen to soft maple ratios and homogeneous versus layered panel configuration appeared to have little effect on bending characteristics. The influence of flake classification in Study No. 1 was minimal and inconsistent therefore results are combined in the average values presented. The effect of flake orientation on bending properties is seen when comparing the random and OSB panels which were made with the same liquid phenol-formaldehyde adhesive levels. The use of higher levels of isocyanate adhesive and a greater degree of orientation is seen in the high bending strength results for the highly aligned material.

Table 1. Comparison of Test Results, Commercial Standard, Target Values, and Published Flakeboard Properties

TABLE 1

COMPARISON OF TEST RESULTS, COMMERCIAL STANDARD, TARGET VALUES, AND PUBLISHED FLAKEBOARD PROPERTIES

SOURCE	PROPERTY			
	MODULUS OF			
	RUPTURE (PSI)	ELASTICITY (PSI x 10^3)	DENSITY (PCF)	INTERNAL BOND (PSI)
Test Results				
Study No. 1				
Random Panels	4265	705	41.9	43.0
OSB-Aspen	8145	1365	45.9	78.3
HAM-Aspen	11680	1810	41.0	221.2
Study No. 2				
Random Panels	5605	730	44.8	81.4
OSB-50:50 Aspen/Maple Mix	7610	1195	40.9	65.6
HAM-All Mixes	12737	1770	42.3	301.8
Commercial Standard CS 236-66	2500	450	37 to 50	60
Forest Service Targets	4500	800	37 to 43	70
Published Study				
Random Panels	5300	800	47.5	83
Oriented Panels	6600	1090	45.5	82

The purpose of Commercial Standard CS 236-66 is to establish a voluntary standard of quality for particleboard and is intended to provide minimum property values. Those listed are for medium density material bonded with a durable adhesive and therefore suitable for certain exterior applications. The Forest Service Target values shown were developed for flakeboard, so that flakeboards meeting these goals should perform satisfactorily in structural applications.

Observation of the bending strength values in the two studies involving material made from ring flakes indicates properties much greater than the minimums given in CS-236. Except for the random panels in Study No. 1, MOR values exceed the Forest Service targets and results achieved by Price (12) using hardwood mixtures. MOE values of random panels were somewhat lower but manipulation of density and/or manufacturing techniques could increase the results.

The effect of the fairly high levels of isocyanate adhesive on internal bond strength can be seen in Table 1 which shows very high values for the highly aligned material. Internal bond values using the phenol-formaldehyde were low, however in most cases they approached or exceeded the values in CS-236 and the Forest Service target values. Again manipulation of density and production techniques should improve these values.

The results presented indicate that it is feasible to produce structural panels using ring flakes obtained from chunked wood using either aspen or aspen:soft maple combinations. Although strength properties of the highly aligned material were somewhat lower than those recorded for material produced from drum-type flakes the bending strength properties were exceptional and thus material produced from ring flakes has application in the IWR composite wood products.

Other hardwood species of the Lake States should be considered for furnish for composite products. Based on the results of this study, it is likely that paper birch and American elm could be substituted for soft maple because of density similarities. Other hardwoods such as red oak, hard maple, yellow birch and American beech are also potential species. Substantial volumes of all of these species are available in chunkable form, such as small diameter low grade trees, logging residue and thinnings.

PRELIMINARY COST COMPARISON

Estimates were made of the cost of producing flakes from roundwood and from chunks. These are shown in Tables 2 and 3 which indicate the cost of producing one ton (oven-dry basis) of +1/4 and +1/8-inch classification flakes from each system, respectively. Since fewer trees are needed to produce a given quantity of flakes from chunks than roundwood the cost of stumpage and harvesting wood for chunking is less. Also, the procurement radius for chunks would be less than for roundwood resulting in lower trucking costs.

The net cost differences are dependent on the classification of flakes desired after screening. The chunkwood system recovers the greatest volume of wood from each tree and the roundwood system recovers the most from the material actually brought to the mill when a +1/4-inch flake classification is sought. This balances out some of the previously mentioned gains from the chunkwood system and leaves it with a small cost advantage. However, if a +1/8-inch flake classification is used then the recovery from chunkwood improves so that the system has a cost advantage of about $24.05 per ton. Figures 9 and 10 illustrate material balances for +1/8-inch flake classifications. Should stumpage rates be increased to $15.00 per cord, as they are for some species in certain areas, then the +1/4-inch and +1/8-inch chunkwood systems would have $15.24 and $30.34 per ton advantages, respectively.

Table 2. Cost of Producing Roundwood Flakes From 1 Ton of Standing Timber (O.D. Basis)

1.	Stumpage - 0.57 cords (1 ton) @ 5.00	$ 2.85
2.	Procurement Fee - 0.57 cords @ 2.50	1.43
3.	Harvesting - 0.57 cords @ 19.00	10.83
4.	Haul - 0.57 cords @ 15.00 (50 miles)	8.55
5.	Yard - 0.57 cords @ 5.00	2.85
6.	Thaw - 0.57 cords @ 4.33	2.47
7.	Debark - 0.57 cords @ 12.00	6.84
8.	Flake - 0.485 @ 9.51	4.61
9.	Dry - 0.485 @ 17.76	8.61
10.	Classify - 0.485 @ 1.06	.51
	Total	$ 49.55

Cost per ton of +1/4 inch classification flakes

$$= \frac{\$49.55}{.403 \text{ tons}} = \$122.95$$

Cost per ton of +1/8 inch classification flakes

$$= \frac{\$49.55}{.415 \text{ tons}} = \$119.40$$

Table 3. Cost of Producing Ring Flakes From 1 Ton of Standing Timber (O.D. Basis)

1.	Stumpage - 1 ton (0.57 merchantable cords @ 5.00)	$ 2.85
2.	Procurement Fee - 1 ton @ 2.06	2.06
3.	Harvesting - 1 ton (0.57 merchantable cords @ 18.00)	10.26
4.	Chunk - 1 ton @ 10.00	10.00
5.	Haul - 1 ton @ 9.00 (40 miles)	9.00
6.	Yard - 1 ton @ 4.45	4.45
7.	Chunk Splitting - 1 ton @ 5.00	5.00
8.	Thaw - .949 tons @ 3.85	3.65
9.	Flake - .949 tons @ 8.44	8.01
10.	Dry - .949 tons @ 17.76	16.85
11.	Classify - .949 tons @ 1.06	1.01
	Total	$ 73.14

Cost per ton of +1/4 inch classification flakes

$$= \frac{\$73.14}{.647 \text{ tons}} = \$113.04$$

Cost per ton of +1/8 inch classification flakes

$$= \frac{\$73.14}{.767 \text{ tons}} = \$\ 95.35$$

The following calculations indicate the potential savings a 150 million square foot (1/2-inch basis) flakeboard plant could achieve by using the chunkwood system if it could utilize +1/8-inch flakes and had to pay $15.00 per cord for stumpage:

$$\$30.34 \times 150{,}000{,}000 \text{ ft}^2 \times \frac{.5 \text{ in-ft}}{12 \text{ in}} \times$$

$$\frac{42 \text{ lbs}}{\text{ft}^3} \times \frac{1 \text{ ton}}{2000 \text{ lbs}} = \$3{,}982{,}125 \text{ savings per year.}$$

Where specific cost elements are available, substitutions can be made to refine this estimate.

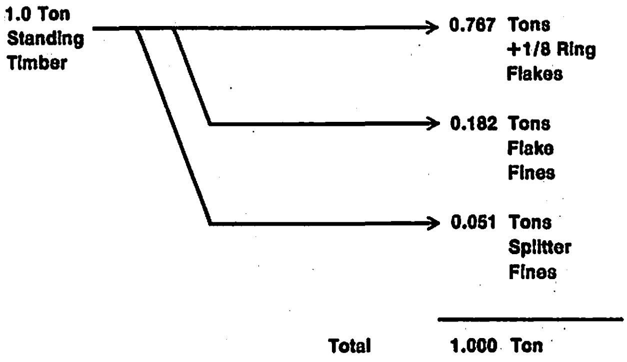

Figure 9. Material Balance for Producing Ring Flakes From Chunks From One Ton of Standing Timber O.D. (Oven-Dry) Basis.

CONCLUSION

Chunked wood, as produced by the U.S. Forest Service wood chunking machine, can be successfully used in the production of flakeboard. Mixtures of aspen flakes and soft maple flakes made from chunked wood can be utilized to produce random, oriented strandboard and highly aligned panels with strength and physical properties that meet or exceed commercial standards.

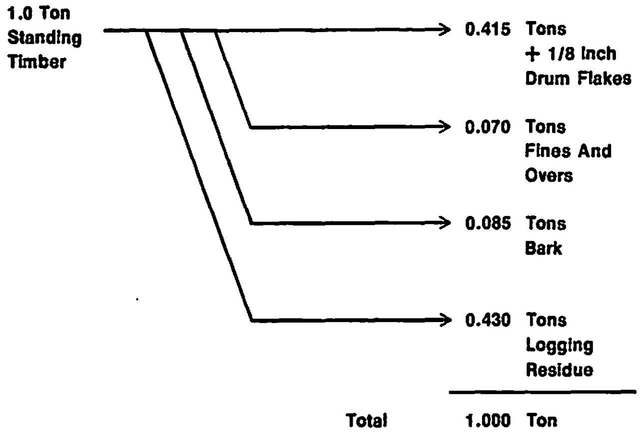

Figure 10. Material Balance for Producing Drum Flakes From Roundwood From One Ton of Standing Timber O.D. (Oven-Dry) Basis.

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TRENDS AND PROSPECTS IN TIMBER HARVESTING, TRANSPORT AND CONVERSION[1]

Jochen Wippermann[2]

Abstract.--For harvesting and primary conversion a wide variety of forest machines is in use, also with special applications to different forest conditions, mobile as well as stationary equipment, e.g. power saws, processors as single function- and multi-purpose-logging-machines, chippers, skidders and forwarders, winches and grapples, truck mounted loaders, cable cranes, skyline systems, long transport vehicles for short logs, tree-lengths and full-trees. Since about 20 years there have been introduced well mechanized centralized conversion methods by forest owners or wood-using industries. Finally sawmills have got a sophisticated technology for processing of timber.

MECHANIZATION OF HARVESTING AND PRIMARY CONVERSION

The concept for system design of mechanized harvesting operations should include technical devices to ensure a larger yield of forest biomass or at least to reduce harvesting losses. For the time being the technological development can offer some interesting progress as compared with the degree of mechanization 10 years ago.

- Working systems at the felling site: full-tree, tree-length and short-wood systems

Logging methods: mostly thinning, partly clear-cutting, felling and topping at 5 or 7 cm by chainsaw, delimbing tree-lengths by chainsaws usually, harvesting machines for felling and/or delimbing are still rarely used. The most important stands in this region are at present in age classes of 25 to 40 years; processors for delimbing and cross-cutting have come more into use in the last 10, especially in the last 5 years, the number of them exceeds not more than 30 in the Federal Republic of Germany.

- Skidding methods: mostly by wheeled tractors equipped with double-drum winches, sometimes with grapple, and at some places with crane, with normal or articulated steering; generally tree-length system or full-tree system is applied in two-man operations in felling and skidding, or tree-length skidding by tractors with radio-controlled drums in one-man operations (France and Federal Republic of Germany). In Austria the combined operation of cable cranes, grapple skidding and delimbing/cross-cutting by processors at the roadside are favoured in mountainous harvesting operations.

- Intermediate storage of full-trees or tree-length is usually done along roadside.

- Operation at the roadside

The investments needed for a mobile debarking machine handling an average of 40,000 m^3 of spruce, pine and other conifers per year amount to about 800.000.- DM to 1 million DM; in the Federal Republic of Germany such machines (62), with a total capacity of 2.5 million m^3 roundwood, which debark tree-lengths at the roadside at many conversion sites all over the country, are needed by sawmills without debarking facilities of their own. But the bark stays unused in the forest, or left in small piles at the roadside.

- Operations at a central conversion site

The idea of rationalizing timber conversion by installing central conversion sites (CCS) is fostered by technological improvements of the last two decades and by the demand for intensive wood utilization. Highly developed forest industries need a well-managed flow of assorted timber from stump to mill.

The mechanization and centralization of primary conversion should be seen as part of a comprehensive system which includes stages of harvesting trees or logs and the subsequent stages of transport, storage and processing (secondary conversion) of timber.

The technological concept for centralized conversion with highly mechanized equipment finally evolved owing to the introduction of improved mechanical and hydraulic devices for the internal timber flow at landings, as well as of electronic devices for scaling timber volume, process regulation and operational control.

Such installations with high capital investments are becoming increasingly interesting from the energy point of view and help to make the high investments more advantageous although more

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electrical power is used. The advantages are as follows:

- conversion of tree-length logs or even of full trees
- higher value due to optimized grading of the log assortment
- direct marketing of any specially requested assortment
- use of residues, partly as wood chips and partly as fuel chips
- concentration of residues favours installation of CCS, but is more attractive to wood-using plants than to forest owners without utilization facilities of their own.

GENERAL EXEMPLIFICATIONS OF THE DEVELOPMENT TO CCS

The technical terms 'Central Conversion Site' (CCS) or 'centralized conversion landings', 'centralized processing yards', 'timber terminals' or 'lower landings' stand - according to a wood-utilization concept - for the concentrated conversion of timber, due to ECE/FAO/ILO-basic concepts and terms. This may be intermediate or permanent installations. Within a certain forest district, timber is harvested at various logging sites, accumulated in one place, converted at this 'central' point and afterwards distributed to linked plants or marketed over long distances. As many work elements as possible should be performed by machines - controlled by a few operators or skilled workers - at such a place, where the conversion of large masses of timber is concentrated from the point of view of transport lines or of the timber market. Thus the CCS can functionally be installed by the forest owner or forest products industry.

A vital factor in the successful use of the capacity and technology at a central conversion site - bearing in mind the very high investment costs - is the raw material itself. The following should therefore be defined in advance: whether the type of the surrounding forest is suitable for logging; whether the continuity of timber delivery from that catchment area is guaranteed; and last but not least whether the quality of the timber makes the production of a variety of assortments worthwhile.

At the end of such a process line convenient assortments of roundwood may accrue, e.g. saw and veneer logs, masts, poles, stakes, pitprops, pulpwood, wood for fibre, sometimes fuelwood, the number of assortments being determined by wood species, dimensions of trees, utilization features and, finally, the local or regional market.

Work has been facilitated by the reduction of time-consuming and physically hard manual work; therefore, the labour-force in forestry, sawmills and other timber industrues favours this mechanized working system whose design features ensure good ergonomic results.

In the Federal Republic of Germany the greater part of the mechanized conversion is carried out by stationary equipment than by mobile equipment, while in Austria the highest mechanization degree in harvesting operations is achieved at upper landings, mostly roadside places, when full-trees or tree lengths are brought by skyline systems in combination with grapple skidders.

RECOVERY AND HANDLING OF WASTES AT CCS

Centralized conversion not only meets the interests of production managements but also encourages wood industry plants more than the forest owners, who, in the Federal Republic of Germany, do not commonly run mills to utilize the residual material where it accrues in concentration. Branches, tops, bark, needles and occasionally leaves are turned into fuel for kiln drying facilities or power stations in timber industries. Up to 100% of the mass delivered to CCS or landings or mill yards may be used. Foresters and industry have gained sufficient experience to reach a surplus in recovery of about 6% timber volume by log length and full-tree logging.

In the last five years the interest in wastes has grown so much, at least for energy purposes, that the residues from conversion sites no longer have to be taken to a dump at considerable cost, but are collected by different conveyors and containers at the CCS. This method of waste recovery entails fairly high investments. The mechanical and hydraulic residual recovery system should be evaluated at not less than one tenth of the complete installation value. In the light of technical, ergonomic and economic criteria, it may be assumed that this investment outlay will be rapidly recovered.

For the construction of a new CCS with a yearly capacity of 20,000 - 30,000 m^3 spruce, delivered in tree-length with diameters between 16 and 24 cm and up to 22 m long, an investment of at least DM 150,000 should be calculated for all the conveyors and collecting system required to handle an average of 3,000 t wet weight of bark. The whole investment for the new CCS exceeds DM 1.5 - 2 million; in other words, the mechanical residue recovery system should be evaluated at not less than one tenth of the complete installation value.

YIELD BY VOLUME AND QUALITY

There are several advantages in transferring work elements of timber harvesting from the felling site to the CCS.

- better working conditions and technical facilities allow accurate scaling and cross-cutting, thus avoiding losses in volume and

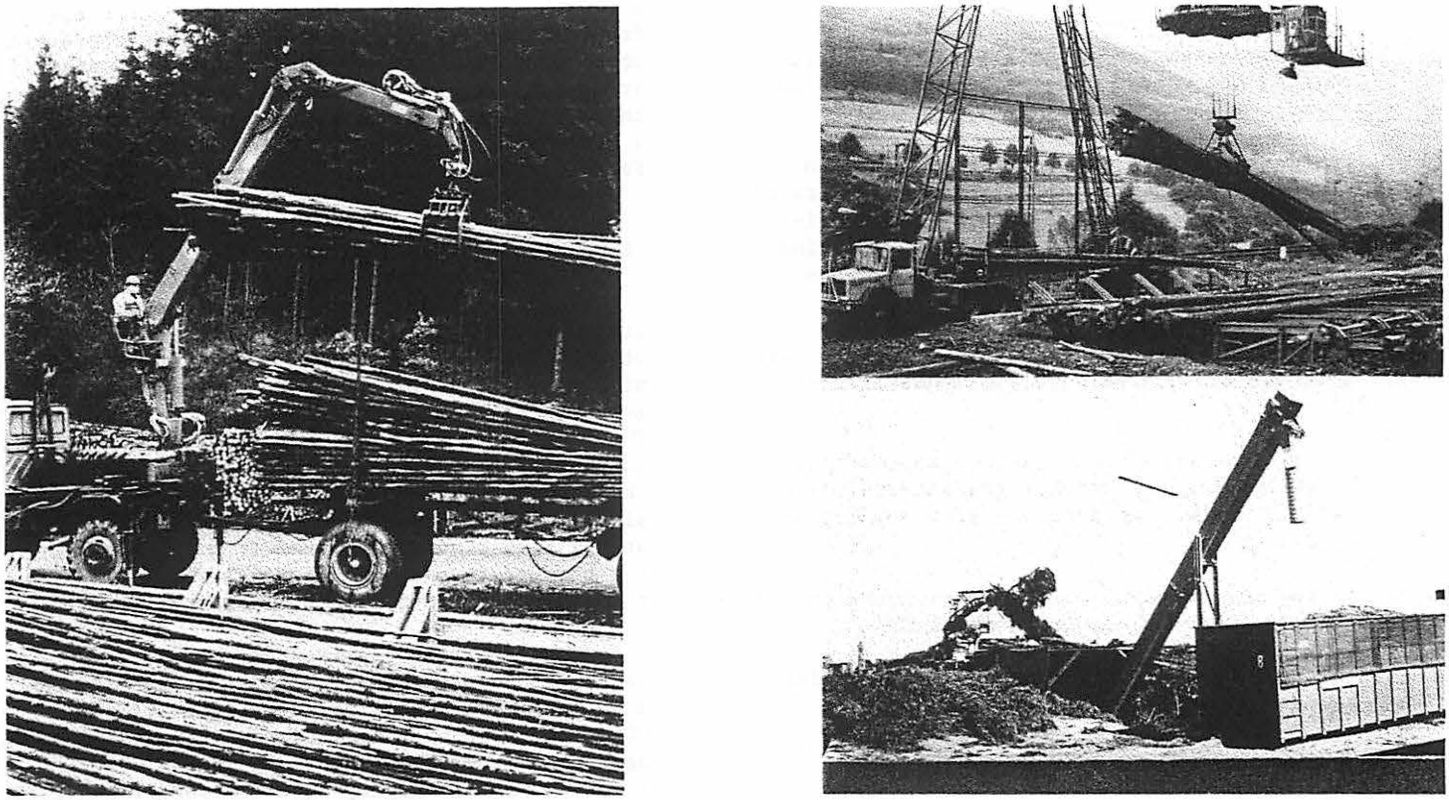


Figure 1. Infeeding operations at central conversion sites for tree-lengths and full-trees from thinnings.

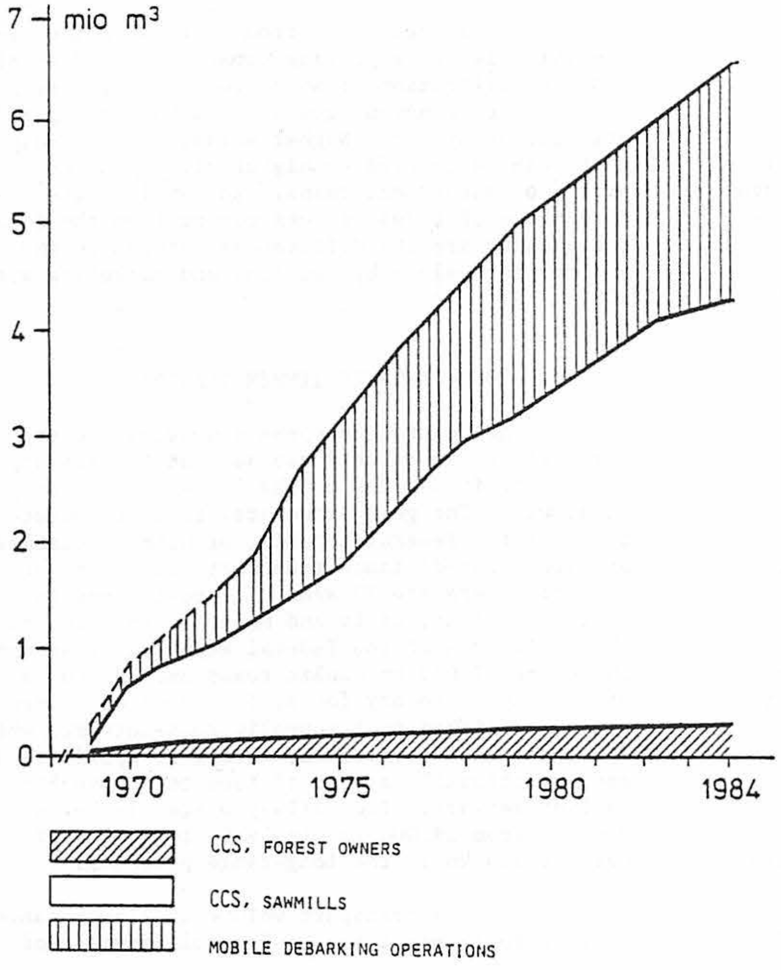


Figure 2. Mechanized debarking at central coversion site and at roadside in the Federal Republic of Germany.

grading;

- the forest owner will have more volume after selling the graded logs rather than the log stems;
- residual pieces at butt or top end remain unused when cut off in the forest, but are of some use as an offcut length on the longitudinal conveyor at CCS, where it will find a use anyway; only 2 to 3% of log lengths as cut-offs go to waste;
- even partly diseased logs can be marketed as lowgrade fibre, fuelwood and industrial or fuel chips;
- all small pieces of conversion residues can be gathered as industrial raw material or as fuel (branches, woodchips, bark, sawdust and needles);
- in past years bark and slabs had to be dumped, causing costs of between 3 and 6 DM/m^3;
- the residues get homogenized by introducing hammer-mills or drum-chippers;
- the bark can be sold to gardeners or to chemical industries;
- finally there is a yield by computing the grading in dynamic programming.

APPLICATION IN FOREST INDUSTRIES

The establishment of central conversion sites meets the goals of forestry and of the managements of wood-using industries for rationalization production processes. For many years now, a remarkable increase in the number of mechanized CCS can be observed in conjunction with sawmills. There are today about 250 yards and landings functioning as CCS in the Federal Republic of Germany. Most central conversion sites '(about 90%) work in connection with wood-using industries; less than 5% have been set up by forest owners, and another 5% by timber dealers, preferably for small dimensioned timber.

Methods of centralized conversion have not yet changed, but the technology has been steadily improving. The capacity of CCS in the Federal Republic of Germany has grown, so that it is nowadays possible at some places to convert 100,000 to 200,000 m^3 (3 shifts) roundwood/year. At first CCS processed only spruce/fir but others were opened later for pine, especially in the northern part of the country.

Also in Austria several sawmills have been installed in the last few years, processing short saw-logs from spruce stands in the mountains with a yearly capacity of up to 100,000 m^3, in one place up to 300,000 m^3 roundwood. In France the biggest sawmill is processing up to 150,000 m^3, with primary conversion of tree-lengths in front of the mill. In the Netherlands there are some modern but smaller sawmills than in Austria or Germany which get tree-lengths and short logs; there the handling and sorting at a CCS linked to a mill are similar to the conditions in the Federal Republic of Germany.

ECONOMICAL CONSIDERATIONS OF HIGH CAPACITY CCS

Continuous delivery of log assortments facilitates rationalization of timber processing, while at the same time improving wood utilization in mill operations. The mills want roundwood assortments for all housing and construction purposes. There are only a few standard lumber measurements in the Federal Republic of Germany, France and the Netherlands, while Austria has standard dimensions for export markets. Expensive installations at the timber yards are needed in order to meet the requirements of conventional sorting and to reach high productivity at the conversion site.

However, with the increasing capacity of combined conversion and processing systems, e.g. a small-dimensioned timber line with trees on the CCS and lumber by the chipper-canter installation, new economic problems are cropping up at the timber market in highly industrialized countries, with a great density of sawmills.

To summarize, apart from increasing the yield possibilities by employing demand-oriented grading and the utilization of so-called wastes, there appear further advantages of this harvesting and utilization system. Higher skidding and transport costs can be covered by higher yield and net profit of assortment gains. The smaller the dimensions of trees or logs coming from the forest, the greater are the differences between buying and selling values by handling and marketing with CCS.

LONG-DISTANCE TIMBER TRANSPORT

In the Central European countries the transport network is quite dense so that forests and wood-using industries can be linked in a nearly ideal way. The good structural traffic connections of the Federal Republic of Germany enables excellent far-distance transport conditions of timber: there are 30 m/ha of forest roads in average of flat, hilly and mountain terrain, on the whole area of the Federal Republic of Germany there are 17.000 km public roads and 29.000 km of railways. So any forest is opened up by truck-roads and linked to the public road-network, while all industries have direct access to public roads and traditionally a part of them to the public railway network. The railway system is being reduced from 29.000 km (in 1980) to 18.000 or even 16.000 km in the long-range planning.

The yearly transport volume of timber ranges from 12 to 15 mio t in the Federal Republic of

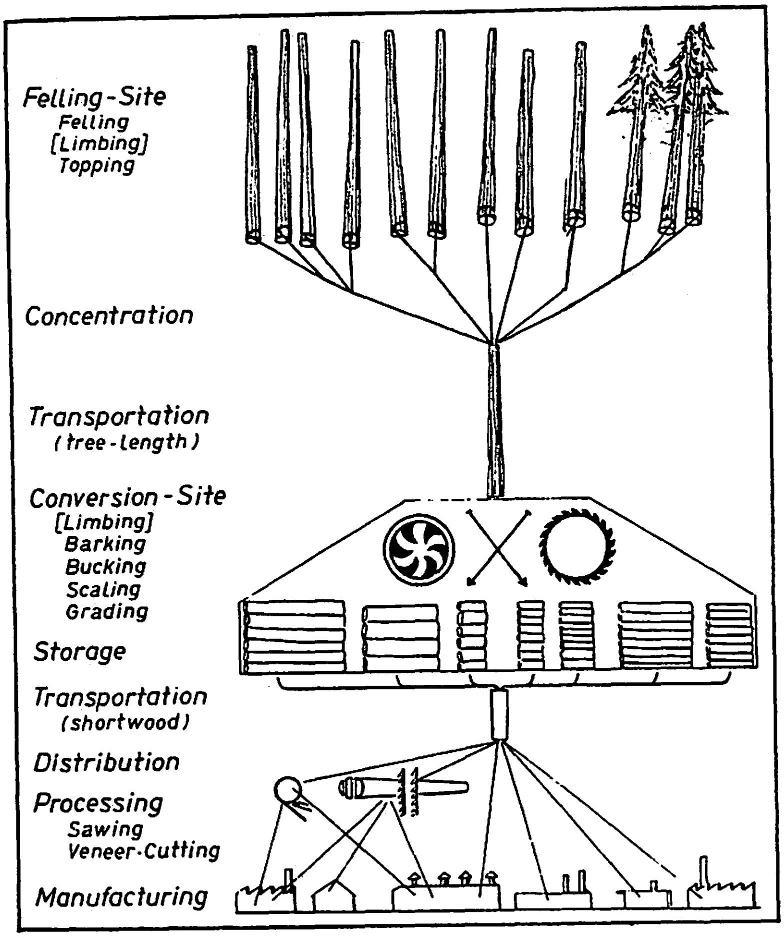


Figure 3. System of centralized and mechanized conversion.

Table 1. Harvesting costs for small-dimensioned timber from thinning stands, selected operations in spruce and beech in the Federal Republic of Germany.

Arbeitsverfahren	Holzart Sortiment	HEK-freier x) Erlös bei BHD cm m.R.	Holzerntekosten bei BHD 14 cm m.R.
EST-Standardverfahren	Fichte 2 m lg.	14-15	100,00
ROTTNE-SNOKEN-Processor	Fichte Abschnitte	14-15	95,23
Seillinien-Verfahren mit Kranprocessor auf Waldstraße	Fichte lang und Abschnitte	14-15	91,10
KOCKUMS-GP 822-Processor	Fichte 3 m	13-14	81,50
Schwedisches Bank-Verfahren mit Langkran-Tragschlepper	Fichte 3 m	12-13	79,84
Schwedisches Bank-Verfahren, manuelles Vorrücken	Fichte 2 m	13-14	79,64
Modifiziertes Goldberger-Verfahren	Buche lang	13-14	64,75
Winden-Durchforstungsverfahren	Buche lang	12	62,94

x) HEK = Holzerntekosten; HEK-freier Erlös (Variante mit 80% Lohnnebenkosten -LNK)

Germany, the smallest part of it (5%) is carried by inland navigation, 25% by the railway-system and 70% by road transport.

The timber transport by train is declining more and more, because of closing down unefficient and uneconomical branch lines of the railway system; on the other hand any interruption in the material flow rises the costs of transport. The timber has to be loaded on trucks anyway, because no direct access of train to forest exists. Today any transport distance up to 400 km is more economically to be overcome by truck than by train, though the investment for truck and semi-trailer has grown from 75.000.- DM to 300.000.- DM and fuel costs from 0.44 to 1.30 DM between 1968 and 1984.

The long-distance transport on the roads usually runs over 10 - 100 km, full trees over shorter distances (5 - 70 km) than tree lengths (up to 200 km in the Federal Republic of Germany mostly by short truck and semi-trailer, up to 27 m transport lengths for tree-lengths or up to 22 m truck-lengths for full trees).

The truck-transport of timber - full trees, treelength and shortwood - is possible and well managed in the following way today:

- 5-axles-truck and semi-trailer for highest possible transport capacity
- hydraulic loaders (cranes) for shorter cirlces of loading and unloading
- higher motor-capacity for shorter driving time
- technical devices to reduce time of maintenance, unproductive time, breaks, etc.
- loading at the roadside by mounted cranes
- one-man-operation (driving and loading)

There are many small companies of which the owner is mostly driving the truck himself. The payment system is based on t x km, the payment is done in DM/m^3 net weight.

RECOVERY SYSTEMS FOR RESIDUES AND UNCOMMERCIAL WOOD

The arrears in thinning stands, residues at most felling sites, growing demand for raw materials by the wood-using industries as well as the increase in wood prices and in energy costs are challenging for new operational way of recovery. Predominantly the biomass above the ground should be utilized to a greater degree.

Very high costs of harvesting timber in dense young stands, particularly felling and extracting trees from thinnings as labour-intensive operational elements in conventional residual recovery systems call for more productive working methods and better economic results. The conversion of residues after the normal logging process is the most expensive part of the whole harvesting operation in terms of m^3 of chips at the forest road side.

A process for recovering residues will be adopted by forest owners and workers as well as contractors and industrial managers if it works well; the feasibility of such an operation presupposes good design and productivity, ergonomic aspects, safe work and - last but not least - reasonable production costs. Fuelwood should be harvested and delivered with as much efficiency as industrial wood. But the propagation has to take into account the development of the timber market and fuel prices. For the time being in rural areas the interest in energy supply by the forest has grown up rapidly, while chipboard as well as pulp and paper industries are still sufficiently supplied with thinning material and industrial wood residues.

OPERATIONAL DESIGN FOR RATIONALIZATION OF CHIPPING

For the utilization of small trees or tree segments from thinnings and residual material from older stands different working methods have been applied. The unsatisfactory productivity and the moderate prices obtained for these scarcely-used raw materials demand for the use of machines which do not entail high investment and not acceptable operational costs. Intensive studies have therefore been carried out under different forest conditions in small-scale operations with special emphasis on private forest ownership, which accounts for 44% of forests in the Federal Republic of Germany now. More than one-half of the small estates scattered all over the country deliver fuelwood for residential wood-energy purpose. The fuelwood consumption for home-heating has been steadily increasing over the last years.

If the forest workers split or chip the fuelwood from thinning or other forest operations, residual recovery needs efficient motor-manual techniques and good organization of work, primarily for the working methods in the poorly mechanized private forest estates. On the other hand it should not be neglected that there rises the creation of employment opportunities through woodfuel harvesting. The conceptual ideas for these comprehensive studies since summer 1980 originated from the consideration to mobilize machines and men of farms or contractors for removing forest residuals by chipping in the forest.

TECHNICAL EQUIPMENT FOR A COMBINED CHIPPING AND FORWARDING SYSTEM

For the operational design it was hoped to develop a mechanized system of high mobility for carrying the chipper to the stump and forwarding

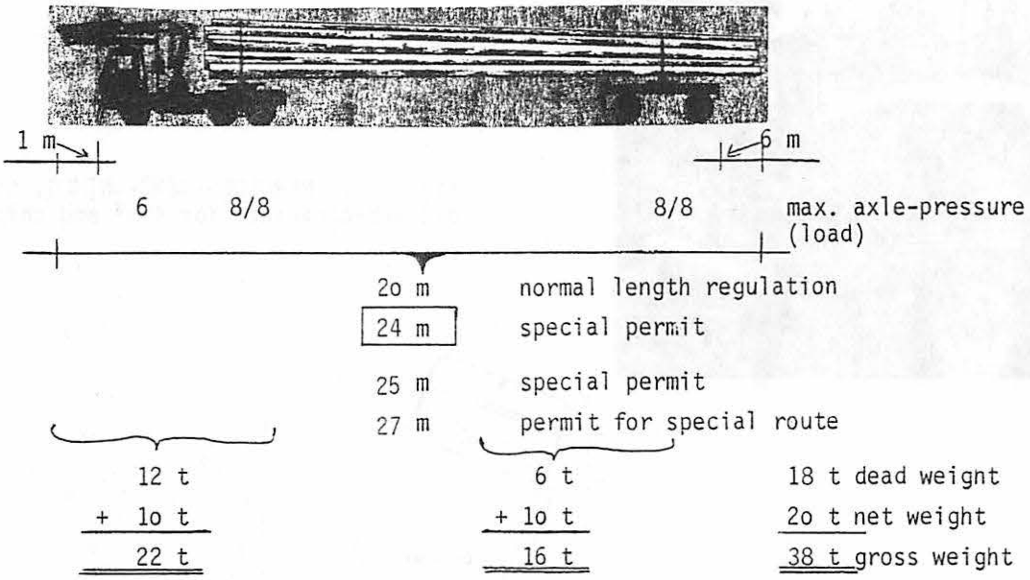


Figure 4 : Loading capacities and transport regulations for timber transport

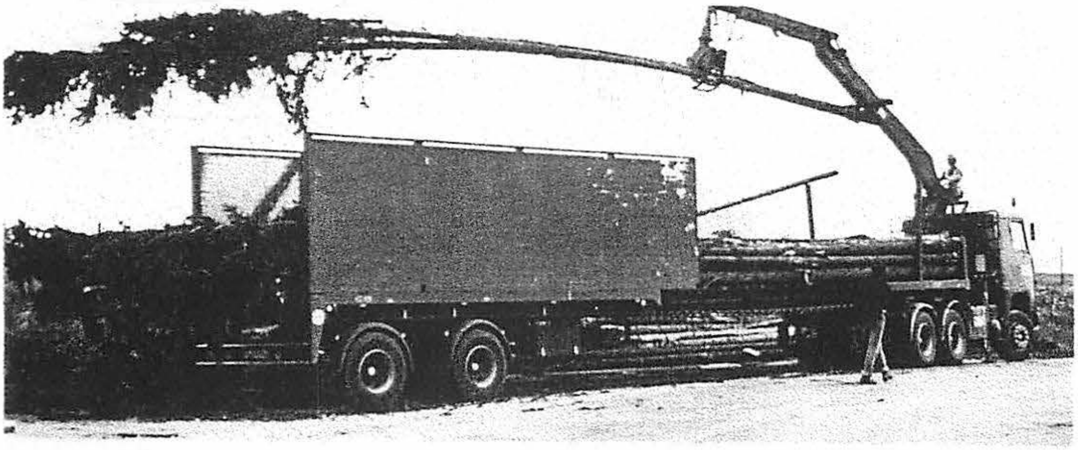
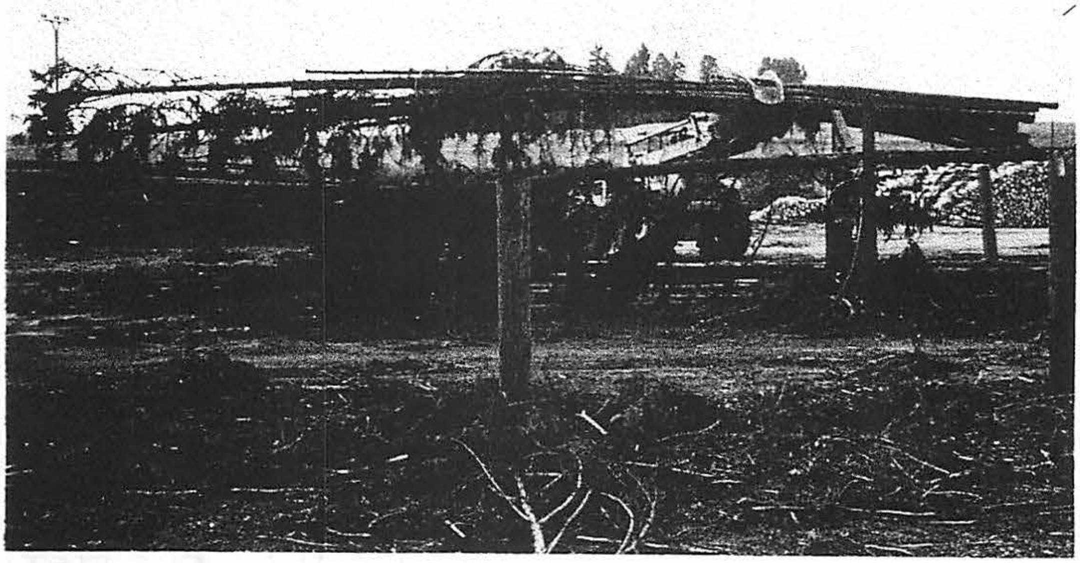


Figure 5 : Long-distance transport of full trees on public roads



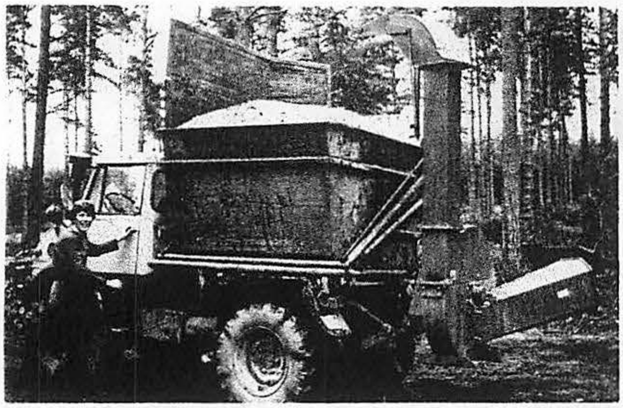
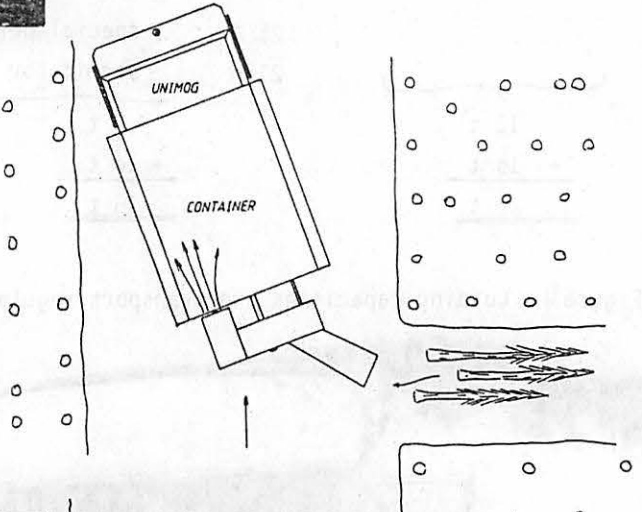


Figure 6. MERCEDES-BENZ-UNIMOG, tipping pick-up-container for 4 m³ and chipper.



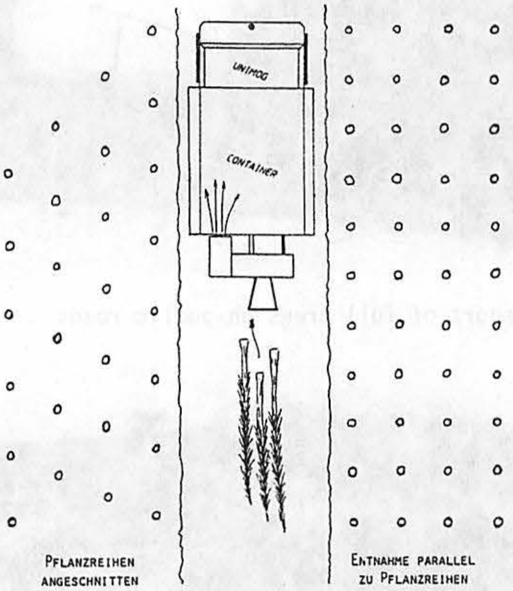
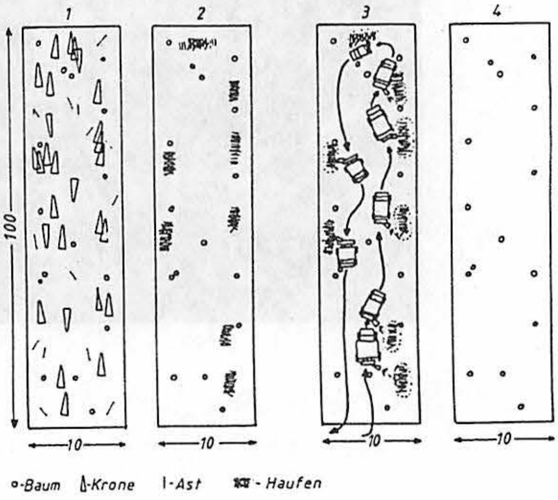


Figure 7: Machine combination in the skidding trail of pine stands

(above) operation for selective thinning

(left) chipping after stripwise felling

(below) chipping residues under old-growth



the chips. The single machine should be a regionally widespread skidder or tractor, owned by farmers or even better by an association, equipped with a pick-up container and a chipper linked with power transmission in the rear. The machine which served for most of our studies is to be seen in the pictures beside.

Of the skidders available for driving the chippers and forwarding the chips in one single operation, only machines with more than 50 kW were regarded and proved as sufficiently powerful. Especially those skidders which could carry a container (2 to 4 m^3) besides the chipper were preferred (MB-TRAC, BM-UNIMOG, DEUTZ, WELTE, FENDT, etc.). It is very convenient to have a container catching the chips and to drive only with a two-axle vehicle on the skid trails as well as within the stands. Because of small operational areas in the size-class typical of private forest ownership, small-dimensioned, manually-fed disc-, helical- or drum-chippers should be used, with power transmission from the tractor.

PERFORMANCE OF THE MAN-MACHINE SYSTEM

The technical productivity of the studied and designed systems is measured under different working conditions and expressed in m^3 chips as quantity of reference to productivity or production costs.

In spite of most sales-promotion activities the hourly capacity of those small manually fed chipping machines does not reach 10 to 25 m^3 of chips/h but roughly 3 to 7 m^3/h, including feeding with prepared material, chipping and forwarding to the truck road. The lowest capacity is reached by removing residues under old growth, the best rate in the spruce stand where whole trees or segments of them have been utilized in a precommercial thinning operation. All experiences refer to two-men crews as well as in the preconcentration as in the chipping operation.

COSTS OF CHIPPING OPERATIONS IN THE FOREST

The most expensive work is the removal of residues under old growth stand at a cost of 41. - DM/m^3; the best results are achieved in spruce stands of about 20 to 30 year old beech (26. - DM/m^3), all data referring to the social cost situation and lower machine operating costs in private forestry. These costs appear very low compared to studies in other operations, which range from 30.- to 50.0 DM per m^3 chips delivered to the truck road; reasons for this are special design of the working system and its application in private forest ownerships.

The wages for forest workers and machine operators range from 12.- to 16.- DM/h, they differ among forest owners in the Federal Republic of Germany, especially there are beg differences in social costs, ranging from 70% in private enterprises to 130% in state forest enterprises on the wages. The private forest owner uses his farm tractor for harvesting work, while the state forest has a great number of special machines and this entails higher operational costs. Roughly speaking, in the state or municipal forest 40% can be added to the costs per m^3 chips mentioned above.

Generally fuelwood is coming from thinnings and clearcutting residues, which are removed by the consumers themselves from the stump in the most cases, paying about 30.- DM per m^3 at the felling site or 60.- DM per m^3 when it is already split and stacked at the forest road. Normally residuals are left back because of no economical value up to now. So long they are not processed to split pieces or chips they are not used as industrial raw material or fuelwood. On the other hand the returns from selling industrial roundwood for pulp and paper or chipboard industries cover scarcely the costs of harvesting and skidding in thinning operations.

STORAGE AND DRYING OF CHIPS

Biomass destined for fuel chips should be as dry as possible before delivering to storage or burner; in the optimal way it should be dried in the forest even with leaves before being chipped (leaf seasoning promises good results between May and September); when the biomass has been seasoned for some months at the felling site it should be chipped and go to storage. Wooden constructions for chip storage under roof but with open sides of a wire entanglement are recommended.

YIELD OF BIOMASS UTILIZATION

Especially in unthinned stands between 20 and 30 years a relatively high yield of biomass has to be taken off consisting of residues and small-dimensioned timber of no commercial interest. Many forest ownerships hold a considerable percentage of unthinned stands of which the biomass potential must be taken into account when normal silviculture methods and well-managed stands are aimed for.

Different silvicultural methods and harvesting intensities yield large amounts of biomass in each case; the following quantities which have been removed and chipped in the stands are to be seen in Table 2.

PROCESSING LINES FOR SMALL-SIZED TIMBER

The foreseeable development in the forest products industries allows a steadily growing utilization of small-sized conifers for sawn goods to be expected. The method of processing and the capacity of the processing line are influenced by factors such as supply of raw material, integrated production in combination with centralized primary conversion, accurate pre-sorting of well-graded timber, technology of processing, capacity, yield requirements, programme of sawn goods, investment needs and stresses at the working places. In addition to usual frame and circular saws, profile chipper-canters and bandsaws are in use now, as well as combinations, to set up efficient production systems.

Beech	- 58 years, naturally regenerated, selective felling	74-11o m^3 HS/ha
Beech	- 26 years, naturally regenerated, selective felling	6o m^3 HS/ha
Poplar	- 17 years, planted, clear-felling (2 sites)	37o and 72o m^3 HS/ha
Pine	- 76 years, naturally regenerated, selective felling	74 m^3 HS/ha
Pine	- 25 years, planted, strip-wise and selective felling	6o m^3 HS/ha
Pine	- 17 years, planted, strip-wise	14o m^3 HS/ha
Pine	- 25 years, planted, clear-felling (after forest fire)	45o m^3 HS/ha
Spruce	- 27 years, naturally regenerated, strip-wise and selective felling	18o-2oo m^3 HS/ha
Spruce	- 3o years, planted, strip-wise felling	7o m^3 HS/ha

Table 2: Yield of biomass from different stands - species, operational methods, age-class, yield - (Aspen/Poplar, beech, spruce and pine)

Figure 8: Centralized conversion site (CCS) for conifers

SIMULATION OF MECHANIZED FELLING IN DENSE SOFTWOOD PLANTATIONS[1]

Sharon A. Winsauer[2]

Abstract.--Computer simulation of a feller-buncher operation was used to develop a regression model relating machine attributes to productivity while thinning dense softwood plantations. Factors most affecting productivity were machine travel speed, shear speed, accumulator head size, back up distance, bunch distance, and accumulator head size times shear speed.

INTRODUCTION

Throughout North America and Europe hundreds of thousands of hectares of closely spaced (1.5 to 2.75 m) softwood plantations need cleaning or thinning. Traditionally, the high cost and scarcity of skilled labor, combined with the fact that such thinnings produce little or no merchantable timber, have often made such thinning uneconomical. Recently, however, the development of machines such as chippers and chunkers have made it possible to reduce small trees to marketable products. These machines, along with the rising demand for wood energy and fiber, offer hope that the thinnings needed for stand improvement can break even or even make a profit.

To match the technological gains in processing machines, efficient techniques and machines for harvesting these small, closely spaced trees must be developed. Because of the close spacings and the possibility of bole and root damage, these harvesting machines must be small, lightweight, and maneuverable in addition to being efficient (Berg et al. 1975, Evert 1971, Low and VanToi 1974. Oswald 1974).

To develop new machines or harvesting concepts for these dense softwood plantations, the relation between machine design and productivity needs to be determined. As a step in this direction, we used a computer model to simulate a feller-buncher thinning a softwood plantation and to develop a regression model for productivity (fig. 1) (Winsauer and Bradley 1982).

The feller-buncher modeled has a chassis-mounted shear so it must be driven to each tree, and the shear head must be accurately positioned. The assumptions used in the simulation are typical for small machines of this type. Thus, results are realistic, and data trends and comparisons should be valid; however, the specific numbers such as "172 trees/hour" may not match the production rate of any specific machine. Moreover, the theoretical study was limited to ideal, closely spaced softwood plantations so the results cannot be extrapolated to other stands or machines.

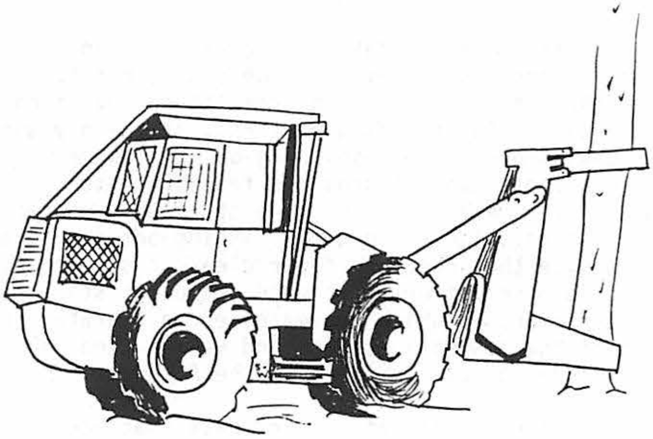


Figure 1.--Typical feller-buncher with chassis-mounted shear.

PROCEDURES

Feller-buncher productivity (trees/hour and/or tonnes/hour) is influenced by the following machine factors:

- Use of an accumulating head shear
- Shearing speed
- Machine travel speed

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[1] Paper presented at the conference COFE/IUFRO - 1984. Orono, Maine, USA, 12-14 August.

[2] Sharon A. Winsauer is a mathametician at the Forestry Sciences Laboratory, North Central Forest Experiment Station, USDA Forest Service, Houghton, Michigan, USA.

If the trees are to be removed from the stand, the number of trees the feller-buncher collects into a bunch affects machine and system productivity. Small bunch sizes may result in high feller-buncher productivity but low skidder or forwarder production, so the system must be balanced accordingly.

This simulation study was limited to plantations of small-diameter, uniformly spaced softwoods. Spacings were from 1.0 to 2.5 m. All stands were assumed to have an initial basal area of 35 m^2/ha, giving an average tree diameter of 6.7- to 16.7-cm dbh. Work with slash pine (Collicot and Strickland 1968) showed the best growth to be in stands thinned to a residual basal area (BA) of 100 sq ft/acre (23 m^2/ha), so a thinning intensity of 33 percent (one-third of the initial trees) was simulated.

It is almost mandatory to clear a strip or machine corridor to get into the stand, but it is felt that thinning by strips results in poor form and growth. Two thinning patterns, strip-only and strip-with-herringbone-thinning-between, were tried. These two patterns are feasible alternatives for mechanized thinning of closely spaced plantations. The strip-with-thinning-between is a compromise that requires fewer clearcut strips and leaves a more uniformly thinned stand but still has corridors in which the machine can operate. A list of the assumptions made and values used in the simulation can be found in the Appendix.

Earlier investigations indicate that accumulating shears, faster shear rates, and faster travel speeds increase feller-buncher productivity (Newham 1970, Winsauer et al. 1984). To develop equations relating machine productivity (trees/hour) to these and other significant factors, simulation runs were made using various machine rates and stand spacings. Trees/hour, tonnes/hour, trees per bunch, and percent of total time spent shearing, traveling, etc. were recorded for each run. Then regression models were proposed and equations developed. Finally, test runs were made to verify the equations and refinements made as necessary.

The simulation model was written in the simulation language GPSS (General Purpose Simulation System) (Schriber 1974). The simulated thinnings were carried out on the Sperry 1100/80 at Michigan Technological University, Houghton, Michigan.

PRODUCTIVITY REGRESSION MODEL

For a feller-buncher with a chassis-mounted shear, the following prediction equation for productivity while strip thinning was developed based on 55 simulation runs:

Productivity
(trees/hr) = 22.9
\+ 8.45 ave. travel speed (k/hr)
\+ 3.17 ave. shear speed (trees/min)
\+ 37.9 accumulator size (trees/load)
\- 3.27 accumulator size^2
\- 4.74 backup distance (m)
\+ 2.52 acc size x shear speed
\- 1.31 bunch distance (m)

Multiple correlation coefficient - R^2 = .95

Standard error of estimate (S.E.E.) = 18.16

Sample Calculation -
For Strip-Only Thinning

Productivity (trees/hr)	= 22.9	22.9
	+ 8.45 x 5 k/hr	42.2
	+ 3.17 x 5 trees/min	15.8
	+ 37.9 x 4 trees/load	151.6
	- 3.27 x 16 (trees/load)^2	- 52.3
	- 4.74 x 10 m	- 47.0
	+ 2.51 x 4 x 5	50.2
	- 1.31 x 10 m	- 13.1
		= 170.3 trees/hr

As you can see, the feller-buncher productivity rate was about 170 trees/hr for average conditions. The production rate ranged from less than 50 trees/hr (no accumulator head, slow travel speed, and long backup distance) to more than 400 trees/hr (accumulator holding eight trees, fastest shear, and no backup distance).

Productivity in terms of tonnes/hr can be determined from the trees per hour and the size of the trees; for example, 170 trees/hr would be 4.3 tonnes/hr for 6.7 cm trees, or about 15 tonnes/hr for 16.7 cm trees.

DISCUSSION

Several interesting facts came to light while testing and refining the prediction model.

1. Although tree spacing is a significant variable where wide spacing is used (Ashmore et al. 1983, Bradley 1984), adding a tree-spacing term did not improve the fit of the model to the data. Because of the close spacings in the stands considered (1.0 to 2.5 m), tree spacing had little effect on productivity.

2. Tree diameter did not directly affect trees/hr felled. The trees are small enough (maximum 16.7 cm) that positioning and shear time depend upon the hydraulic capacity rather than stem diameter. Tree diameter does have a major, indirect effect--for a given accumulator head size, the average number of trees/load depends upon average diameter at breast height (dbh). The same size accumulator may collect eight small (6.7 cm) trees for a load of 200 kg but average only 3.3 large (16.7 cm) trees per load (approximately 300 kg).

3. As the sample problem shows, the trees per accumulator load greatly influenced the production rate. It is not a linear effect, however--a change from no accumulator head (one tree/load) to two trees per load can increase production rate by 50 trees per hour while a change from 7 to 8 trees per accumulator load shows little improvement.

4. Another significant effect on production rate is the strong interaction between shear speed and accumulator capacity (fig. 2). Although productivity would be expected to improve with a higher shear speed or with the addition of accumulating ability, I did not expect such a great cumulative increase.

When an accumulator head is used, travel is reduced; therefore, a greater percentage of the time is spent actually shearing trees. And of course, the more time spent shearing, the greater the effect of changing shear speed.

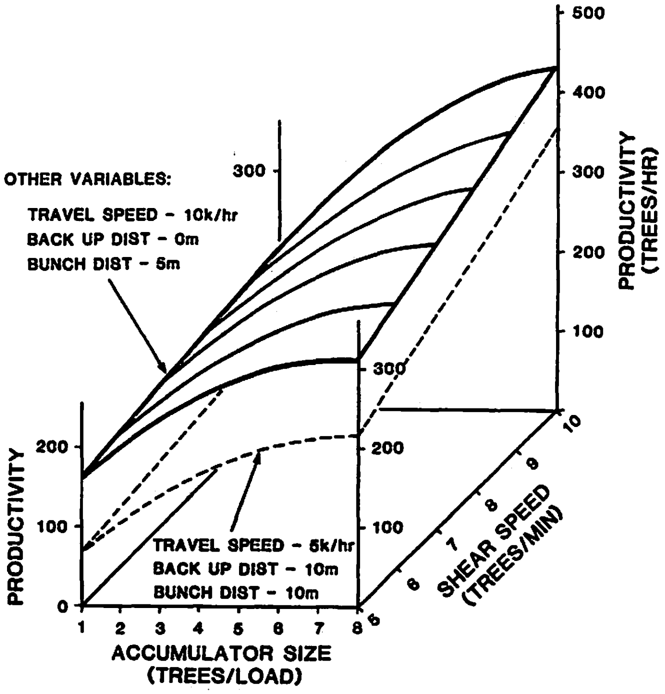


Figure 2.--Feller-buncher productivity--strip thinning in dense softwood plantations.

Accumulator size (trees/load)	Average travel per tree (m)	Travel time (percent total)	Shear time (percent total)
1 (no acc)	30.8	51.9	23.4
8	4.5	20.6	70.8

Although it may not be possible to develop a machine that can reach the theoretical 8 trees per load and still operate without damaging the closely spaced remaining trees, it is important to note that an increase in shear rate along with an increase in the number of trees per load would be much more effective than an increase in either factor by itself.

5. Another variable that was more important than anticipated was the "backup" distance. The original assumption in the model was that the machine working in the narrow strips would shear the tree(s), "back up" one tree length (10 m), drop the tree(s), then drive forward over the downed tree(s) to the next tree. If this backup distance could be reduced or eliminated by a new machine design, productivity would be increased. On the other hand, as the "backup" distance gets longer, it becomes more and more important to have an accumulator head.

6. A slightly higher correlation coefficient, R^2, could have been obtained by adding other terms involving combinations of backup distance, accumulator size, shear speed, and travel speed. However, these additional terms did not increase the R value sufficiently to warrant the increase in model complexity.

7. The last factor in the equation, "bunch distance," is the extra distance the feller-buncher operator will travel to create larger bunches for the skidder or forwarder. The extra "bunch distance" was selected as a variable to make it independent of stand spacings and other variables. In small-tree stands where it is costly to remove the wood, it would help to have the stems bunched and ready to skid. The feller-buncher can do this, but at what cost? To determine the effect the operator's decision has on productivity, runs were made simulating various "bunch distances." A regression equation was developed relating the number of trees/bunch the feller-buncher collected for the skidder to the choice of bunch distance. Two other major factors affected bunch size--stand spacing and accumulator head size.

$$\begin{aligned}\text{Trees/bunch} = {} & 7.13 \\ & - 3.56 \text{ spacing (m)} \\ & + 0.527 \text{ accumulator size (trees/load)} \\ & + 0.613 \text{ bunching distance (m)}\end{aligned}$$

$R = .91$ S.E.E. $= 1.46$

Test runs were made varying "bunch distance" from 0 to 20 m. Trees per bunch varied from one (no bunching) to 22; the largest bunch was in the 1-m stand thinned with a machine with a large accumulator head and an operator willing to back up an extra 20 m to increase the bunch. This increase in bunch size can decrease feller productivity by 25 trees/hr.

THINNING IN A STRIP-WITH-HERRINGBONE PATTERN

The strip-with-thinning-between pattern selected for simulation was to cut a strip every sixth row and to thin the intervening five rows in a herringbone pattern.

The distance traveled per tree is greater when using the herringbone pattern, making travel time greater and overall productivity less than for strip-only thinning. When no accumulator head is used, the distance per tree increased about 10 percent, while productivity (trees/hr) decreased 5 percent (table 1).

The greatest loss in productivity is caused by the lack of full utilization of the accumulator head. The machine must leave the strip, and it would not be feasible to try to maneuver into the between-strip areas with the accumulator head already partially loaded. Therefore the accumulator loads are only 60 to 70 percent as large as those in the strip-only thinning. This results in a net productivity loss of up to 50 trees/hr.

At the same time, the number of trees collected in a bunch for removal from the stand is much larger when thinning between. Because of more trees to be cut from any strip location when no accumulator head is used, the bunches are twice as large as in the strip-only situation, and are 50 percent larger when a large accumulating head is used. The possibility of more efficient skidding could offset the slightly higher felling costs, particularly in the case of a non-accumulating head feller-buncher.

The bunch size when thinning between strips depends upon stand spacing and backup distance but not upon accumulator size for the stands and machines simulated. Some care would have to be taken, particularly in the closest spacings, to prevent the bunches becoming so large as to obstruct the passage of the feller-buncher.

CONCLUSIONS

New and better ways to mechanically thin closely spaced softwoods need to be developed. In addition to the need for small, maneuverable machines, the most important machine concepts to explore and develop appear to be ways of cutting and/or collecting multiple stems at once. If this can be developed in conjunction with a faster cutting head, the production rates could be greatly increased.

Another area of possible improvement would be to find some way of stacking the stems or dropping them immediately at the stump and yet not hinder forward motion of the feller. If the backup and/or positioning travel the feller goes through to drop and/or bunch the felled trees can be eliminated, efficiency would noticeably improve. Still another possibility would be to have the felling machine do no bunching other than what is done while cutting, followed by a "clearing" machine that could sweep through the strip rows and remove the felled, unbunched wood from the stand.

APPENDIX

Tables 2 to 4 contain the assumptions and data used in the simulation model. For a more complete discussion of input values, see Winsauer *et al.* 1984.

Table 1.--Comparison of thinning in a strip-with-herringbone and strip-only pattern.

	Productivity		Bunch size		Average acc load		Total Travel distance	
	Herr	Strip	Herr	Strip	Herr	Strip	Herr	Strip
	(trees/hr)		(trees/bunch)		(No. of trees)		(m/tree)	
No acc head[1]								
1-m spacing	72	76	20	10	1.0	1.0	33	30
2.5-m spacing	69	73	9	4	1.0	1.0	36	32
Large acc head								
1-m spacing	172	221	23	15	5.0	8.0	9	5
2.5-m spacing	120	152	9	6	2.5	3.3	18	11

[1] Other parameters values - shear speed = 5 trees/min, travel speed = 5 k/hr, backup distance = 10 m, and bunch distance = 10 m.

Table 2.--Initial stand characteristics.

Assumptions	
Species	Softwood (generalized)
Stand structure	Plantation - square spacings
Terrain	Flat
Strip length	100 m
Basal area (before thinning)	35 m^2 ha (150 sq ft/acre)
Tree volume	
(m^3)[1]	0.021 + 0.00048 x dbh^2 cm)
(ft^3)	0.73 + 0.109 x dbh^2(in)
Tree height (m)	10
(ft)	33
Wood density (green basis)	
(kg/m^3)	600
(lb/ft^3)	37
Thinning intensity (% trees removed)	33

Variables	Range
Tree spacing[2]	
(m)	1.0 to 2.5
(ft)	3.3 to 8.2
Ave. tree dbh[3]	
(cm)	6.7 to 16.7
(in)	2.6 to 6.6
Stand density	
(trees/ha)	1,600 to 10,000
(trees/acre)	648 to 4,050

[1] Volume equations were developed from combined data of several softwood species (Winsauer and Steinhilb 1980).

[2] For each stand spacing, average tree dbh selected to give a B.A. of 35m^2ha.

[3] Individual trees dbh selected from a distribution with a range average stand dbh ± 2 cm.

Table 3.--Operational factors.

Assumptions

Chassis-mounted shear:

Feller must move to each tree to fell it.

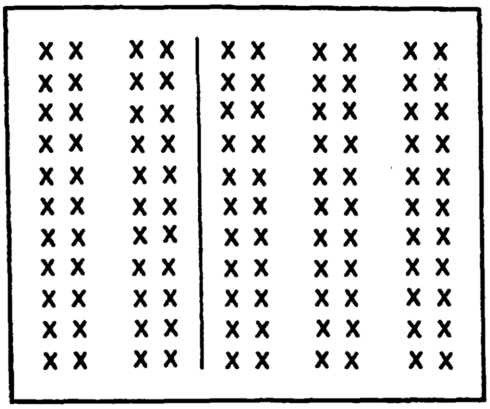
To reach a tree outside the strip, it must back up an equal distance for maneuvering.

All felled trees will be laid in the strip. The feller will back up, drop the trees, and drive over them.

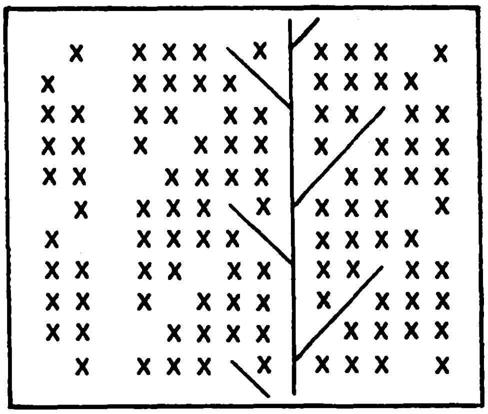
Maximum distance the feller will back up to add to a bunch is 20 m (65 feet).

Desired bunch size for economical skidding (sum of tree diameters)	
(cm)	200
(in)	80

Thinning patterns: Strips-only or strips with herringbone thinning between strips (fig. 3).



SINGLE ROW CLEAR CUT STRIPS



HERRINGBONE THINNING OF FIVE ROWS BETWEEN CLEAR CUT STRIPS

Figure 3.--Thinning patterns to achieve a 33 percent tree removal.

Table 4.--Machine characteristics.

Variables	Range
Shear accumulator Capacity - total sum of tree diameters (dbh)	
(cm)	No accumulator to 55[1]
(in)	No accumulator to 22
Average travel speeds[2] Chassis-mounted shear	
(k/hr)	2.5 to 10.0
(mph)	1.5 to 6.0
Average position and shear time[3] (min/stem)	.1 to .2
Average drop time (min/load)	.2

[1] Maximum size accumulator can hold up to 8 small, but only 3 to 4 large trees.

[2] Individual travel speeds taken from normal distribution.

[3] Individual shear times selected from normalized empirical distribution multiplied by average.

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RECENT ADVANCES IN OFF-ROAD FOREST VECHICLE DEVELOPMENT IN SCANDINAVIA [1]

Esko Mikkonen [2]

Abstract. Due to historical background and forest ownership structure, the shortwood harvesting systems have been prevalent in Scandinavia. Research and development work in mechanization of harvesting has therefore been concentrated on the machines and methods applicable to the shortwood systems.

The future development in the short run seems to follow the same line, though there are new materials and technologies being introduced; e.g. aluminium frames, advanced hydraulics, electronics, automation and robotics.

New requirements are set, however, for decisions regarding productivity and costs of the machines for harvesting thinnings. These are environmental issues, working conditions and safety. They will affect the machine design in the future, as will the ever increasing internationalization of the forest machine manufacturing business.

INTRODUCTION

Shortwood systems have been traditionally used in the logging and transportation of timber in Scandinavia. This is due to the large number of forest owners and the small size of their woodlots where extensive large-scale operations cannot be performed. The number of wood sales have thus been large. The timber measurement procedure applied to shortwood systems is widely accepted. Labour intensive logging methods have been used because the unit costs of the manual methods were lower than those of the mechanized methods till the late 1970's.

Logging and transportation operations have been managed and performed either by the timber buyer or the seller in many farm forest operations.

Forestry was traditionally a part of the farm economy. Only in Sweden a larger share of forest land is owned by the forest industry companies. State forests are generally located in remote and environmentally sensitive areas where full-scale operations are not allowed. The forest ownership structure has changed. There are more urban forest owners who obtain their living from other professions than agriculture and forestry.

Another reason for the wide use of shortwood systems has been limited capability of the mills to handle tree lengths or full trees. This has restricted the development of new logging methods and machinery.

Finland and Sweden are countries where shortwood systems have reached a pre-eminent position.

The research and development of equipment and machinery as well as methods has almost entirely supported shortwood applications.

One can find two clearly different lines of mechanization in logging and hauling of timber. The other is based on the use of typical farm tractors in forest operations and farmers' wood deliveries. In the other, almost everything, from whole tree logging for stationary wood handling terminals to small tractor operations, have been tried. Here, the shortwood logging with processors, harvesters and forwarders has established itself as the prevalent method. The share of the last mentioned line has increased during recent years.

Other features typical to Nordic logging are the large share of selective thinnings, vast areas of bogs, snow problems caused by the long and often severe winters, etc.

In the next chapters I will try to outline the present situation of hauling wood and its mechanization in Finland and Sweden. The logging is also dealt with as long as the off-road machinery is concerned.

Finally, the effects of new technology on Nordic off-road forest machine design will be discussed.

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1) Paper presented at the joint conference COFE/IUFRO -1984. Fredericton, New Brunswick, Canada, August 17.

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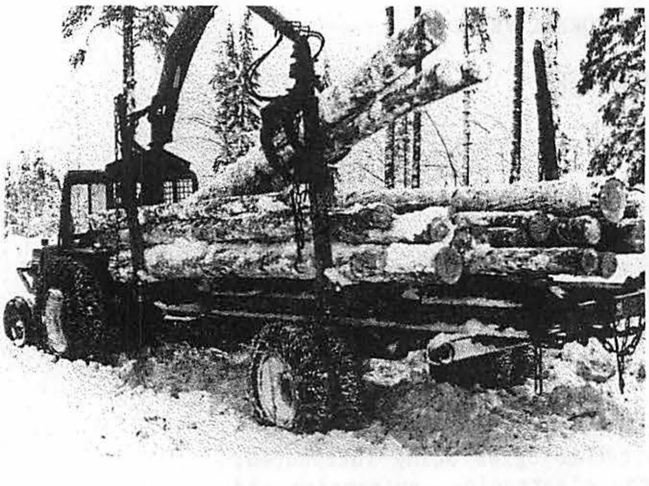


Figure 1. A Typical farm tractor of the early 1970's in forest operation

Figure 2. Modern Valmet 802 farm tractor equipped for forwarding wood

CURRENT METHODS AND MACHINERY

Farm tractors in forestry

As earlier mentioned there are two separate lines of mechanization. First, a few words about farm forest operations.

There are nearly a half million farm tractors in use in Scandinavia. A great number of them are also used in logging operations every year. The following methods are applied.

(1)	Felling, delimbing and bucking in the woods	+	Forwarding by farm tractor			
(2)	Felling and delimbing	+	Tree length skidding	+	Bucking at landing by power saw	
(3)	Directional felling	+	Delimbing and bucking by farm tractor mounted processor	+	Forwarding by farm tractor	

Figure 3. Valmet forwarder of the early 1970's

Method 1 is most common. A farm tractor can be equipped with a winch, skidding grapple, hydraulic loader, and a forest trailer which can have driven axles and boggies. During winter time a timber sledge can be used.

These methods are applied in about 20 - 25 per cent of the total volume harvested yearly in Finland. In Sweden the figure is somewhat smaller.

Farm tractors are bigger than earlier, they have four wheel drive, a turbocharged engine, power shift transmission and a safety cabin. Regardless of development, farm tractors are still primarily designed to be used on fields and not in the woods. Therefore, they can be used in good terrain only under favourable conditions if high productivity is maintained simultaneously. This is not the case, however, in many farm forest operations where a farmer tries to get extra work hours for his otherwise underemployed tractor.

Figure 4. Modern Bruunett mini 572 forwarder is equipped with double boggies

Farm tractors are not used in forestry for other tasks than hauling and transportation of wood. In the picture review one can see the recent development of the Nordic farm tractor for forestry (Fig. 1 and 2).

Off-road vechicles in harvesting

The most common off-road vechicle in Scandinavian forestry today is the forwarder. Other vechicles such as skidders, excavators, bulldozers, snowmobiles, etc., are rather rare. The design of the forwarder is based on a wheeled construction. Other design principles such as tracks or air cushions are not generally used.

As such, forwarders are used for hauling logs and short pulpwood. They are basic machines for several applications like feller-skidders, processors and harvesters. Forwarders are used to pull forestry equipment; e.g. planting machines are built on forwarders, etc.

For hauling timber, three size classes of forwarders can be found. Classifield by the gross vechicle weight, heavy forwarders weigh 25 - 33 tonnes, medium sized 15 - 25 tonnes and light weight forwarders 10 - 15 tonnes, when fully loaded.

Forwarders are used in the following logging methods:

(4) Manual shortwood cutting + Forwarder

(5) Manual felling + Processor at strip road + Forwarder

(6) Feller-buncher + - " - + - " -

(7) Harvester + Forwarder

(8) Feller-clambunkskidder + Delimber at landing (Forwarder frame)

(9) Manual felling + Forwarder equipped with a grapple saw

Feller-bunchers are the only specially built machines in which forwarder chassis are not used as the machine base.

Methods number 4, 5 and 9 are also used in thinnings if the forwarder size is approriate.

Medium sized and heavy forwarders can be equipped with a long-reach hydraulic loader.

Typical features for a modern forwarder are articulated steering, hydraulic-mechanical transmission, boggies both in front and rear, hydraulic loader with long reach, and ergonomically designed safety cabin in which all the operator functions are easy to perform.

The modern forwarder is a highly specialized machine which has undergone tremedous development to become the versatile machine it is today. The picture review features some of the development trends during the past years (Fig. 3 and 4).

CHALLENGES OF THE FUTURE

The social environment for forestry is changing rapidly. The number of urban forest owners is still increasing and for them, other aspects, other than wood production, are more important in forest owning. If wood is to be harvested it has to be done more carefully than to-date. This creates an urgent need for development of lighter and environmentally acceptable harvesting technology. The volume from thinnings will increase greatly if all the activities needed for the right forestry measures and achievement of production goals are to be met. For this reason there is a special need to develop selective thinning technology.

The costs of human labour have increased fast due to high social security costs. It has been profitable to mechanize logging. Another reason has been the effort to make the logging work more productive and easier, and also to raise the safety of the forest work.

Energy crises have created requirements that the wood raw material has to be utilized better than earlier. New technology applicable for it, is to be developed. The optimization of raw material utilization requires full trees or at least tree lengths, to be transported to the mill.

The huge increase in productivity of forest machines has decreased the home market for the machines during recent years. This in turn means that the forest machine manufacturing business must internationalize its activites in order to maintain the same volume of sales. The problem is how to fit the production for the international market. The next question is whether the shortwood systems widely used in Scandinavia, but not elsewhere, are the right ones.

According to the facts above the following requirements for the forest machines of the future can be set:

(1) Machines must be lighter and their transport payload has to be increased

(2) Thinning machines have to be smaller and lighter

(3) Damages to the growing stock caused by the machines have to be minimized

(4) Forest work must be safer than earlier, i.e. less accidents and not cause permanent injuries or diseases i.e. back injuries, white finger disease, etc., to the workers

(5) Increase in real machine costs has to be stopped i.e. the productivity must be raised

(6) Methods and machines to be developed must not prevent better utilization of the raw material

HOW TO MEET THE CHALLENGES

Forest machines can be constructed lighter and their transport capability increased in two ways:

- to design them better
- to use lighter materials

For the first task the use of the CAD/CAM will provide good help for the designer.

New construction materials such as vacuum steel, aluminium (Fig. 5), modern plastics, carbon fibers and ceramics will decrease the weight of the machines considerably. It is estimated that the forest machines could weight 30 - 40 % less than today. Some experiences of the new materials are already now available. The decrease in weight will increase the load by the same amount (fig. 6).

For thinnings a wholly new machine size must come into use. Its dimensions must fit the thinning instructions of various stands. The ideal new machine could be designed for all types of harvestings, including clear cuttings.

If the machine is equipped with tracks (Fig. 7) or wide profile tires the ground damages will be negligible.

The movements of a long reach loader can be controlled by a microprocessor with programmes applied in robotics. A microprocessor controlled transmission will allow even traction and thus minimize tearing of the ground surface.

Figure 5. Aluminiun frame of the Ponsse forwarder has reduced the gross weight considerably

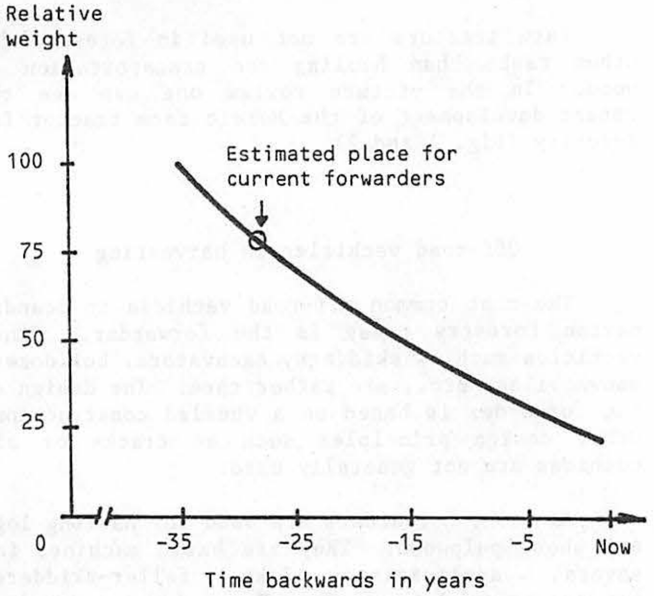


Figure 6. Relative weight reduction curve of the professional chain saw and the weight reduction possibilities for forwarders

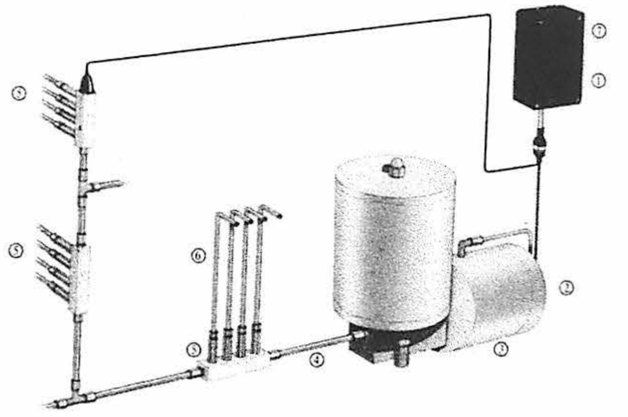
Redesign of the cab and its better suspension will decrease whole body vibrations. Better ergonomic design of the operator seat, panels and lever positions will prevent fatique.

The increase in machine costs and thereby the unit costs of harvesting can be slowed down by utilizing automation. Applications in forest machines are for instance

- automatic lubrication systems (Fig. 8)
- microprocessor controlled loader movements
- remote control and automatic driving systems

The machine prices can be kept down by manufacturing longer series. This requires internationalization, however, because the home markets

Figure 7. Farmi-Track is a modern tracted forwarder for thinnings



1 Control unit
2 Magnetic valve
3 Hydraulic pump
4 Body pipe
5 Dosing modules
6 Lubrication pipe
7 Signal light

Figure 8. An automatic SAFEMATIC^{TM} lubrication system for vechicles

are shrinking due to faster productivity increases, than the growth of the business. The international marketing must be taken into account in designing special methods and machines, as forest machines are.

A good example of a new application of the proven method and machines is the part tree method with forwarders equipped with a grapple saw. This combination utilizes the raw material much better than earlier methods.

CONCLUDING REMARKS

There will be no drastic change in the Scandinavian harvesting technology in the short run. Shortwood systems will stay dominant. They will be developed toward utilizing more part tree methods. Special machines and applications of the current machines (Fig. 9) for this will be developed according to the facts stated above.

Figure 9. Forwarders of the future will be lighter and smaller. Norcar is one example of them

In the longer run the use the tree length or full tree systems, at least in some part of the harvesting, will be reconsidered. Better utilization of the trees will require all the parts of the trees to be transported to the mills.

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FOREST OPERATIONS IN NORTHERN CHINA

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SUMMARY

Beginning in the 1950's, Northeast China's logging operations achieved significant successes in the development of improved systems and technology for logging. The logging operations changed from manual/animal to mechanized, from short-wood to tree-length, from seasonal to year-round. After decades of exploitation the surviving forests are limited mainly to the more inaccessible steep regions. Tractor skidding has been preferred in the Northeast, but cable yarding is getting wide use. As terrain transport distance is getting longer (1-1.5 km), more than one type of extraction has to be used for log transport from the stump area to the roadside landing. Existing combinations of off-road transport are described. The trees to be harvested are getting smaller and the plantations are maturing, equipment for thinning is under development.

China contains about 120 million ha (296.4 million acres) of commercial forest, 16 million ha (39.5) of thinly stocked forest and 4.5 million ha (11.1 million acres) of plantation. The forest cover is only about 12.7% of the total land area. Most forests grow on inaccessible mountainous areas, unsuitable for agriculture. In 1949, the timber production amounted to 5 million cubic meters. However, as economic construction developed, the need for timber increased rapidly. During the last ten years, the annual timber production in China has been estimated at 40 million cubic meters. This figure represents only that part of timber distributed by the special state-owned company. The actual annual cut is much more, perhaps three or five times.

Being one element of an integrated forest management plan, forest harvesting in China is mainly undertaken by state-owned enterprises, called forestry bureaus, with annual harvest quotas of 100,000-500,000 cubic meters, while the collective farmers in South China also cut timber on a smaller scale. The timber production has been concentrated in Northeast China, including Heilongjiang and Jilin Provinces as well as the Inner Mongolian Autonomous Region, where most of China's forests, about 60% of total forest resources, grow. Timber production in the Northeast accounts for about 40-50% of the total. Mature and overmature mixed coniferous-broadleaved stands constitute the main part of the forest resources to be harvested with red pine, birch and larch being the dominant species. Most terrain of this region is gentle with an inclination of less than 25 degrees. The stand yield is about 100-200 cubic meters per ha with the average tree-length volume 0.3-0.7 cubic meters. The frost-free period amounts to 120-140 days per year. Due to continuous intensive harvesting, the annual cut has exceeded growth, and timber harvesting has been transferred from gentle to more steep terrain.

Before 1954, logging operations in Northeast China were carried out manually, felling with one-man curve-handle crosscut saws and axes, delimbing with axes, crosscutting with saws and skidding with horses and oxen. All logging operations were conducted only in the cold season, taking advantage of the frozen ground covered with ice and snow to use sledges for timber extraction. The timber was loaded onto a rail car manually and then transported to concentration yards by narrow-gauged railway cars. From 1955 crawler skidders (KT-12 and later TDT-40) were introduced from the Soviet Union which made possible tree-length harvesting and year-round operations. Since then, manual shortwood harvesting and seasonal operations were almost replaced in the Northeast. Chainsaws were used for felling and bucking while axes were still used for debranching. Winches with stationary wooden booms were employed for cross-hauling loading. During the period from the end of the 1950's to the beginning of the 1960's, ice-snow chutes were widely developed due to lack of fuel for skidders. About 50% of the timber was extracted manually from the stump area by gravity along these chutes in 1960. Afterwards, the fuel supply improved and machinery operated again. In 1980, the proportion of mechanized extraction amounted to 97% in Heilongjiang Province. From 1982, however, animal skidding has risen again, constituting 11.2% in Heilongjiang, because in some difficult terrains the animal skidding cost is lower than tractor skidding. The proportion of seasonal logging has also increased rapidly. Timber, produced in the cold season, amounts to more than 80% of the total of the annual cut in some enterprises. The productivity of skidders in winter is 50% higher than that in summer when the bearing capacity of forest ground is low, and muddy skidding roads have to be filled with branches or even timber crossties to strengthen them. Timber consumption on skidding roads is figured at 0.3 cubic meters per cubic meter of log produced. Although in some forestry bureaus logging operations are carried out seasonally, long distance transport continues year round. The tree-lengths skidded to the roadside landings must be piled, which results in value loss due to deterioration of wood quality and tieing up of funds. Logs are usually not debarked and transported in tree-length form to depots.

All logging machines used in the Northeast are made in China. The first chainsaw was introduced in 1959, model 051, and now four models (051, GJ85, CY5, YJ4) are manufactured in China. In spite of the high level of noise (110 decibel) and vibration (20-25g), the 051 chainsaw is popular with the loggers of Northeast China. It is distinguished by its' high offset handle bar which enables the operator to fell trees without bending down, reducing fatigue significantly. The wire rope recoil starter can be removed and stored in a pocket after use. The chainsaw is powered by a 2-cycle 3-hp gasoline engine and is hand oiled. It weighs 11.5kg (251 lbs). The sawbar head can be rotated 360 degrees each way, so it can be easily changed from felling (horizontal) position to bucking (vertical) position or vice versa without rotating the whole saw body. However, it cannot be used for limbing, which is still done by axes. Models CY5 and YJ4 are conventional chainsaws with short handles.

In Northeast China, tractor skidding is preferred. Two types of skidders are used. One is the Jicai 50 crawler, the other is the Jicai 80 wheeled skidder. The crawler skidder, most popular in this region, is powered by a 50-hp diesel engine through a five-speed transmission. Equipped with a single drum winch and frame bunk on the rear, which can be raised and lowered hydraulically to carry the front end of the tree-length off the ground, this machine has been widely used for more than 20 years. It was specially designed for skidding in forest terrain, and has a skidding capacity of 8-10 cubic meters in the winter. The Jicai 80, a 4-wheel drive skidder, was introduced in recent years by the same plant. Equipped with an 80-hp diesel engine and 10-speed transmission, as well as bunk and winch on the rear, this articulated skidder travels much faster than the crawler and is mainly used for long distance skidding or secondary offroad transport on modulate terrain (less than 20 degrees), while the crawler works on steeper terrain. Both crawler and wheeled skidders use chokers to attach tree-lengths to the winch cable. Logs are usually skidded downhill to the valley floor, where the forest roads are located. Cable yarding has also been increased in recent years, as the forest resources located on gentle terrain has been largely harvested and the cutting has moved to steep slopes (more than 25 degrees) where the remaining stands grow. All yarders used in China are semistationary, mounted on sledge legs and powered by engines ranging from 25 to 70 hp. Both skyline and highlead systems are used for extraction, with priority given to the first one.

Although over 10,000 km of narrow gauged railways and thousands of forest roads have been built during the last decades, the density of the forest road network is still limited due to the difficult terrain and lack of capital investment. This resusits in extremely long offroad transport distances (1-1.5 km). To solve this problem, some forestry enterprises have employed measures such as relay or secondary off-road transport. Timber is transported from stump area to roadside landing by combinations of 2 or 3 types of terrain transport. The existing combinations of off-road transport can be described as follows:

(1) Skyline + wheeled skidder
(2) Crawler skidder + skyline + wheeled skidder
(3) Crawler skidder + wheeled skidder
(4) Highlead cable system + wheeled skidder
(5) Highlead cable system + crawler skidder + wheeled skidder
(6) Crawler skidder + cable-railway*
(7) Skyline + cable-railway

Although China has manufactured front end loaders, due to their lack of adaptability the main log loading equipment in the Northeast is still the simple stationary devices. A set of blocks is hung in two gin poles supported in an inclined position by

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*The cable-railway operates like a pendulum. When the loaded car goes downhill, the empty car is pulled uphill.

guylines. Cable from the winch of a tractor or yarder is used for cross-haul loading, with the mainline attached to the winch cable. In some places simple cable cranes are also used for log loading. A winch-operated overhead cable is strung between two wooden spars across the road. A carriage rides on it and lifts logs to be loaded.

After loading, tree-lengths are hauled by narrow-gauged railway cars or trucks 30-100 km to log yards, where they are unloaded, bucked, sorted, stacked and distributed to users. Log yards are actually rail reloads. Facilities in log years are more permanent. The level of operation mechanization is higher than that of forest operations. Winch-operated spar-cable systems or gantry cranes are used for unloading. Portable electric chainsaws are widely used for bucking, while a set of fixed circular saws is also used. Most yards use conveyors for log sorting. Winch-operated A-frames and bridge cranes are used for stacking and loading onto railroad cars.

The forestry enterprises in the Northeast are all comprehensive, undertaking planting, tending, silviculture, harvesting and sawmilling. Most forestry bureaus have sawmills nearby log yards, consuming 10-50% of timber produced by the bureaus. There are also plywood and wood-based panel mills in some forestry bureaus.

Attention has been paid recently to utilization of logging residue, which were left in the site in the past. Utilization of branches, twigs and leaves has just begun. Some are used to support local fuel needs, while large branches are turned by mobile chippers into salvage materials suitable for pulp and fiberboard. Utilization of logging residue will be expanded in the near future, because the forest resources to be harvested are declining.

Most of the logging machines used in the Northeast were developed more than 20 years ago. Their technical-economic indexes are behind modern standards. These machines cannot meet the needs of ergonomics and operation safety. For instance, the 051 chainsaw, designed in 1959, has an excessive weight and relatively low cutting efficiency. The level of noise and vibration is much higher than that of overseas chainsaws. The Jicai 50 skidder, developed in 1964, has a poor cab, where the operator suffers severe cold and heat in the winter and summer respectively. In particular, there is no protective structure, such as ROPS (roll-over protective structure), FOPS (falling object protective structure) or OPS (operator protective structure). These machines need to be replaced. Forestry machinery plants have worked on developing new machines, which are going to replace the existing old ones. The new modified model GJ85 chainsaw's vibration has been decreased from 25g to 5.29g. A mobile yarder with tower is under development to meet the need in harvesting timber on steep slopes. Equipment for thinning has also been developed, such as the Yinglin 35 and Yinglin 55, both articulated wheeled skidders. The Yinglin 35 is equipped with a hydraulic grapple.

In 1976 and 1980 a small amount of modern logging machines was imported from Finland and the United States, including feller-bunchers, feller-skidders and processors, which have been tested in Northeast China. Results indicated that this expensive sophisticated machinery is not suitable for the present stage of development in China despite its high efficiency. China is a developing country with abundant labour resources and extremely low labour cost (about 40-50 times lower than that in industrialized countries). Considering the social and economical point of view, for the time being it is not desirable to develop such complicated machines. However, economic construction in China has been developing rapidly since 1980, the employment situation is improving and the wage rate is increasing, so the time for using these machines will come eventually.

The tree-length harvesting system, i.e. both skidding and hauling in tree-length form, will remain predominant. However, in some particular places, where the forest resources are scattered and terrain is difficult, short-wood animal skidding and skidding by ice-snow chutes may be used to a certain extent. Because the period, when economic profitability was neglected, has gone never to return. Both seasonal and year-round operations will remain.

Forest roads are essential not only to log hauling, but also to all forestry activities. Silviculture and management cannot be undertaken without roads. The density of the forest road network in Northeast China is expected to increase from 3.5 to 10 m/ha. The existing narrow-gauged railroad will be maintained while truck roads will be built.

The main problem in silviculture involves cutting and regeneration. Emphasis had been put on cutting in the 1950's and 1960's, while regeneration had been neglected. Afterwards selective cutting took the place of clearcutting on the majority of areas harvested while natural regeneration was relied upon in many areas. However, selective cutting is falling into disfavour because of misapplication and unsuitability. Often noncommercial species tend to take over in preference to the desired commercial species, and regeneration is difficult. Therefore, the preferred system is now clearcutting, followed by planting. Clearcutting is often done in strips ranging from 50-200 m with an area restriction of 5-10 ha. Even with planting, it is difficult to get the desired species to dominate the young stands. This is particularly true in the broadleaved-coniferous mixed forest because birch and other species quickly invade the cutover areas and compete with planted trees. So the predominant planted species is not the well-known red pine, but larch, which is easier to regenerate though not as commercially important as the red pine. Many forest scientists are working on regeneration of the valuable species - red pine.

THE FELLER FORWARDER CONCEPT AND ITS APPLICATION[1]

John Kurelek, P. Eng.[2]

Abstract. The feller-forwarder concept has been implemented into a well-developed full-tree logging system particularly suited to poor stands and rough terrain. It offers a very high man/day productivity and a tidy operation at a low level of mechanical complexity. Its application requires close attention to stand and terrain characteristics.

Intensive development of the feller-forwarder was begun in North America in 1976. By 1980, it was making inroads as a preferred full-tree system. This growth has now been almost stopped as machine costs have jumped, labour is generally easily available, and wood harvest volume needs reduced.

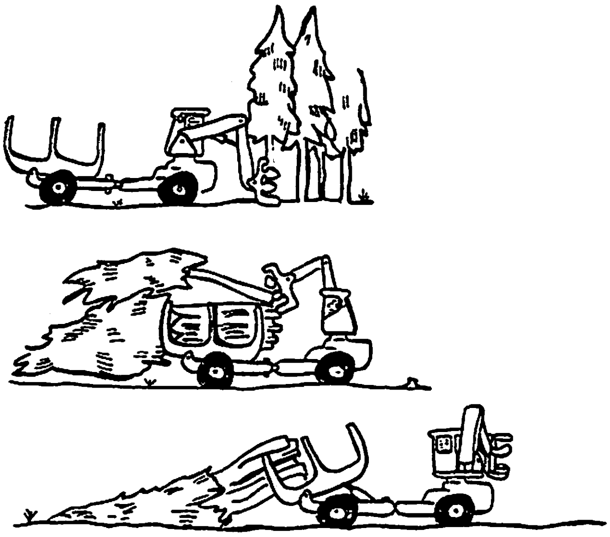
There are approximately 75 machines out in the field, some now six years old, and most users consider the concept to be their best system. They would seriously consider it for additional capacity or equipment replacement.

Its proferred advantages are listed as:

- a high man/day productivity
- low wood cost
- clean wood
- low biomass loss
- clean, low disturbance site effect
- good worker job quality
- simple mechanization

If we accept the SAE definition for our purposes here, then the operation is simply to drive to the tree, fell it onto the machine, and haul it to roadside.

The practical applications to date embody a fairly large four-wheel drive vehicle, a multiple tree-collecting felling boom, and a dumping container.



Although it is a simple procedure requiring the introduction of little complexity into the woods, it did require some components that were not available, namely, a multiple tree-gathering head, and an off-road vehicle capable of carrying full trees off the ground. Early experiments hence usually persisted in felling the tree into a holding rack for the butts only, allowing the tops to drag. Such ideas offered small machines and good manoeuvrability, but, unfortunately, never solved the problems of having to break static sliding friction with every tree-to-tree move and the load disturbance of repeated arm opening and closing. The needed componentry came during the early 70's in answer to the impetus for stump area harvesters and feller-bunchers. Trees could be accumulated in a swinging boom-type felling head, and large wheels were operating to the stump.

The intrinsic advantage of a feller-forwarder, at first, seems to be that it saves material handling; but, besides that, it probably does well at both the felling and the wood transport functions as well.

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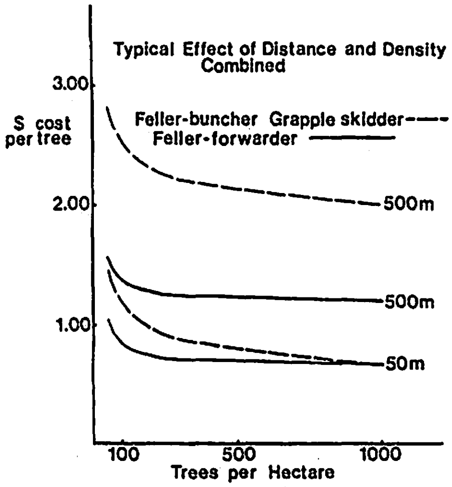
[1] Paper presented at the COFE/IUFRO Symposium - 1984. Fredericton, New Brunswick, Canada, 15-18 August.

[2] John Kurelek is a mechanical engineer doing forest-related equipment analysis and design in independent practice in Brantford, Ontario, Canada.

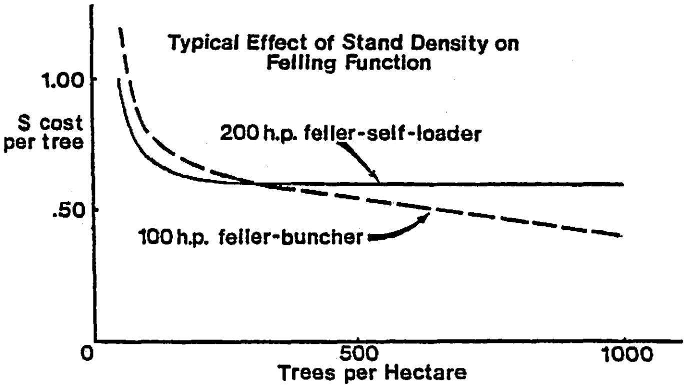


A good way to examine the economics of this sequential multi-function machine is to look at it separately, first, as a feller-buncher, and then, as a self-loading forwarder. The machinery provided can be identified as: that for felling only; that for forwarding only; and that which works at both.

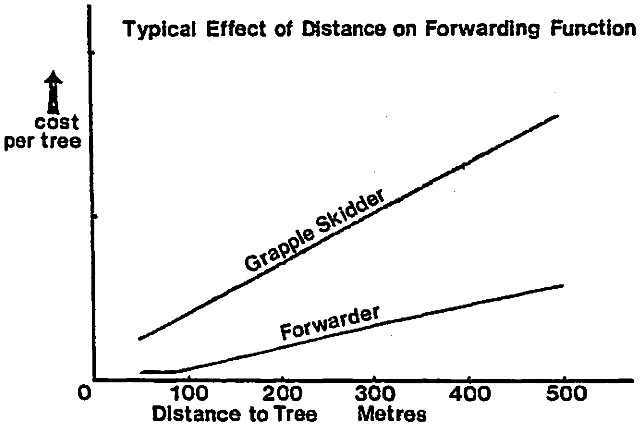
	Felling	**Forwarding**
Engine	✓	✓
Wheels & Drive	✓	✓
Chassis	✓	✓
Cab & Controls	✓	✓
Boom	✓	✓
Felling Head	✓	—
Bunk	—	✓
Dump	—	✓

As we get into this, we see that there is very little that does not work at both operations; and, even then, the temporarily extraneous components or abilities are sometimes of advantage. For example, the bunk would not be needed if bunches were built on the ground, but, particularly in sparse stands, it assists felling in that the operator always has a place to put his trees.

We may question whether felling requires the amount of installed power that forwarding does, but this can be answered by balancing the design: very adequate felling capacity can be used as the guide to horsepower while letting the load size and forwarding speeds follow.

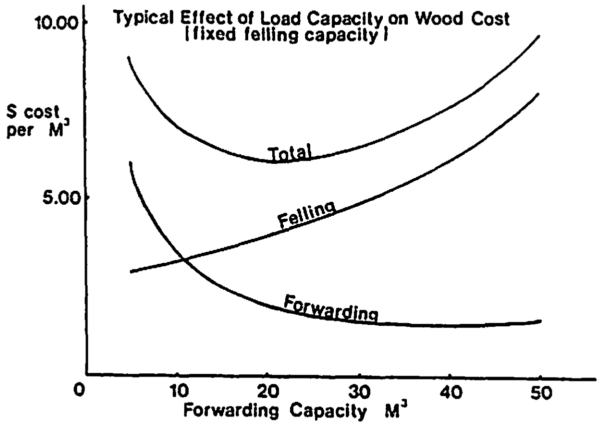


The forwarding functions demand a large machine, not only long enough to hold at least one tree, but with space to take the trees from a long strip and haul them at a low man/day rate. The forwarder should be made of tough components and be physically over-powering in its surroundings. Thus, forwarding stipulations would lead us to a very large machine, stopping only as its components become special and exorbitantly expensive.

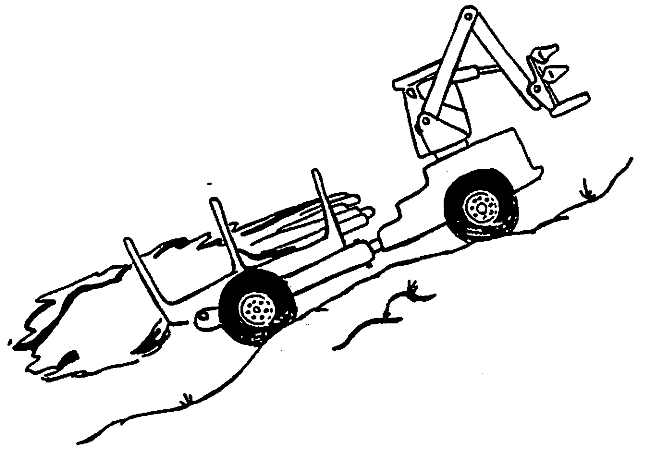


The felling function can often be done by a very small machine, but, as evident in the feller-buncher business, the larger the trees, the more rugged the terrain, and the more we want to help subsequent operations with large well-placed bunches, then the bigger the felling equipment needs to be.

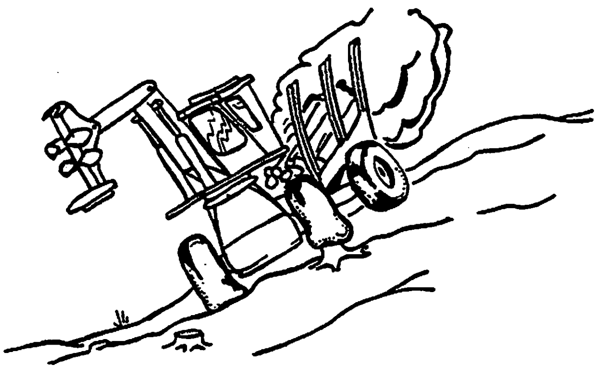
The relative importance of these factors is not easily pinned down, and at this stage we can only observe that the optimum machine size would vary with locations. In addition, small plots and frequent moves often stipulate size to be kept at the minimum that can be made to work. Fortunately, many areas with rough terrain do not have road width restrictions, and to some extent, machine width can be varied to suit at the time of application.

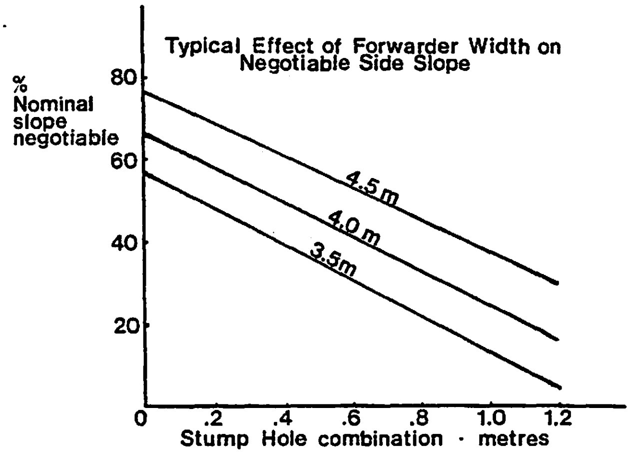


Feller-forwarders handle grades and side slopes better than was proposed at the beginning of their development. The relatively long wheel base helps neutralize short pitches when working up and down grades; and such operation is usually limited by the coefficient of traction on the way up, and the operator discomfort at perhaps 40 percent on the way down.



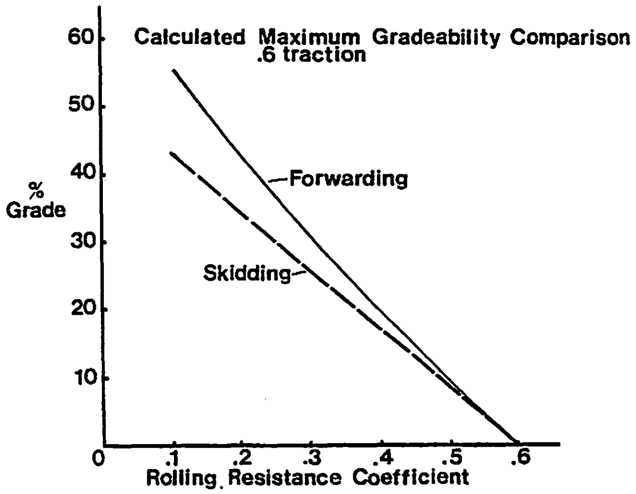
Side slopes are more detrimental to feller-forwarder operation and, for oscillated chassis configurations, what can be handled depends on roughness and how well the machine balance is arranged in the fore and aft direction.





Tailoring wheel base to tree height, reference to stump hole combinations, machine width, and experience are all important in making side slope applications. Of course, just like any other stump area logging machine, feller-forwarders need to be designed to quickly go back to work after taking a tumble.

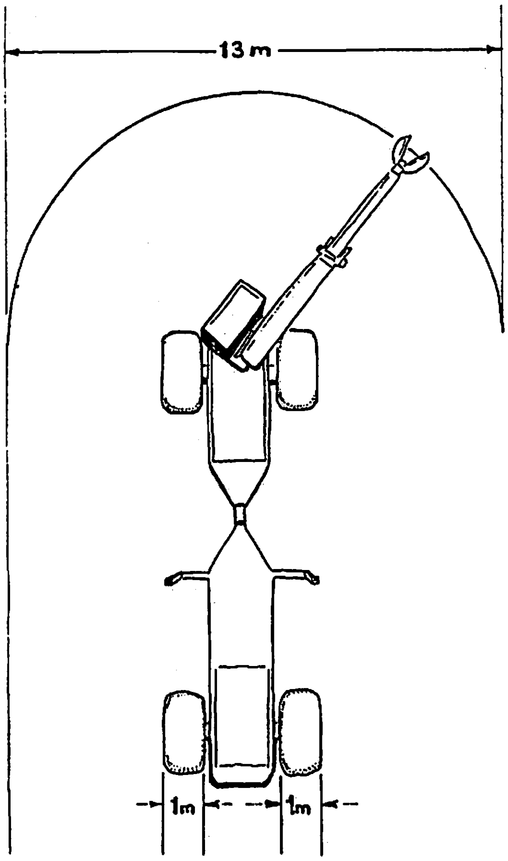
Rolling resistance and flotation are very pertinent to feller-forwarders, especially when we make comparisons with skidder systems.



Since we would like to move the product from stump to roadside with a minimum of energy expended, the load is carried on rubber-tired wheels rather than allowed to partly drag on the ground. The numbers are clearly favourable when making comparisons with grapple skidders.

To be competitive in mobility with other systems, feller-forwarders have relatively large wheels. The large diameter deals more easily with terrain roughness, logs, and stumps. The larger cross section means that the carcass can be made more robust for traction transmission and puncture resistance while achieving ground-conforming contact better than most smaller tires.

A typical feller-forwarder with a 13-metre boom swath width would have a total tire width of two metres, and, except for locations near the road, would travel a given swath area only twice.



The feller-forwarder, with its long-reach boom and easily controlled travel, is mechanically suitable for thinning and sorting operations. Calculations indicate that there will be little productivity loss if at least 200 trees per hectare are taken, and provided the remaining trees are in straight strips, or number 150 or less per hectare.

Work on sorting suggests that the felling head can pick out randomly located trees, sorting for size or species with little productivity loss, provided all trees are taken. Bearing in mind that the felling head has two compartments, simply throwing accumulations to one side or the other can be a good start toward subsequent sorting at the landing. Ideas for separating bunks and clamps have also been proposed.

The product needed affects the viability of feller-forwarders as well. Full-tree chips are the best follow-up. Chipper knives run much longer between changes, almost no limb and top material is lost; if cut, even very small trees always come to roadside, and a large forwarder load equals a trailer load of chips.

If trees are to be delimbed and processed, it is necessary to have mechanized equipment capable of feeding from the large well-packed piles put down by the feller-forwarder. If the forwarder is working close to the delimber, much wood can be concentrated in a small area by continually feeding the delimber with more full trees as it piles its output of delimbed trees.

In most cases, the felling and forwarding is followed by delimbing and bucking.

The recent availability of disc saws has altered feller-forwarder mathematics by allowing a smaller machine to take lumber-size trees, and by theoretically reducing the felling and loading portion of each cycle. The relatively high engine horsepower installed is useable by the disc to sustain rapid tree cutting.

Feller-forwarders are operating mainly in the Canadian boreal forests and in the North Eastern U.S.A. Some operations have also been carried on in the U.S. South East.

Feller-forwarder operators are usually taken from skidder crews, since that is what they are replacing, and they like the concept. Except for serviceing and maintenance, men are not required to work outside of the cab, and it is a comparatively safe job. Man/day productivity is often high: 100 to 200 cubic metres per 8-hour shift. Job satisfaction opportunities are good.

CENTRALIZED TREE PROCESSOR SYSTEM FOR OPTIMIZING THE VALUE OF OUTPUT PRODUCTS[1]

C-G Wachtmeister[2]

INTRODUCTION

Sweden is not well-known for its longwood logging operations. In fact the using of full tree- and stem methods in large scale forestry has dropped from 15 % in 1970 to 1 % in 1982 (Brunberg 1984). The extraordinary development of our logging operations has been undertaken within the shortwood methods. Our shortwood harvestors are now in action over a wide variety of conditions and the performance is high.

There have, however, been serious attempts to question this development. Those who have criticized the massive investments in shortwood systems have the following main reasons to support longwood logging:

1. Longwood logging with central processing makes it possible to handle logs with flexible sorting and highest possible output value.
2. Central processing makes it possible to work in an industrial environment with high rate of production away from difficult terrain- and weather conditions.
3. It is easier to introduce modern equipment such as scanners, computers and robots in a central plant than in mobile systems.
4. Full tree methods utilize valuable forest residues better than shortwood methods.

Approximately 1/3 of the Swedish clear-cut area is located where conditions are suitable for longwood systems. Less than 10 relatively small processing plants are in operation in the southern part of the country. I would like to present some results from four years of operation with a plant built by the Swedish Forest Service. My presentation will focus on how we technically try to optimize the value of each stem.

I also want to put forward a few experiences concerning the marketing and distribution of lumber further down the market channel.

LOGGING SYSTEM AND MARKET CONDITIONS

The plant is located in the centre of a forest district with an annual clear-cut volume of 140 000 m^3s 3). Pine and spruce account for 95 % and the medium stem volume is 0.40 m^3s. The trees are felled, logmadelimbed and transported 35 km to the plant. Our maximum net truck load is restricted to 32 m^3s.

The organization of the work at the plant is built on a high degree of self-supervising. It is of great importance that close contact is established between the logging units, the plant and the marketing of the produced products. To a certain extent we try to let the demand of logs direct the selection of logging areas so that species and tree-size suit current markets.

The idea of this plant is to meet and extend the demand of custom-made deliveries to the saw-mill industry in the area. Pulpwood and special assortments (veneers, poles, sleepers) are sold to various customers. In figure 1 are shown the principles of shortwood and central processing systems.

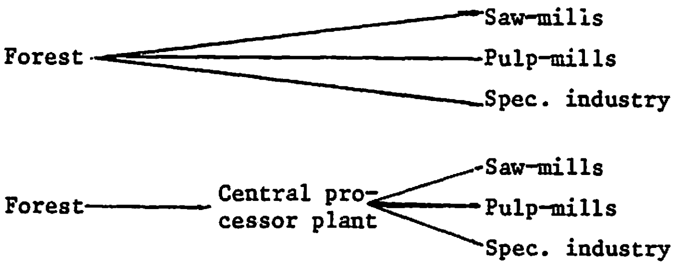


Figure 1. -- Principles of shortwood and longwood systems.

The plant is located in an area in the south with a heavy concentration of wood processing companies. Within 35 miles there are 50 mills and approximately half of the Swedish prefab-house capacity. The mills have to a great extent specialized their production, and they have in many cases found profitable market shares. Accordingly the demand for sawlogs in the area is high and differentiated. We account for about 10 % of our customers' requirements.

The saw-mills can order logs from the plant which suit the demand of their lumber customers. The possibilities to produce these specified logs are restricted only by plant productivity and forest conditions (quality, volume, species). Two examples of specifications from our saw-mill customers are shown in table 1.

Table 1. -- Two types of specifications from saw-mill.

	Specification easiest to meet	Specification more difficult to meet
Type	Sawlogs, spruce	Sawlogs, pine
Quality	V or better	Max 40 % VI, remainder V
Length	49 dm	30 %, 31 dm 40 %, 36 dm 30 %, 45 dm
Top diameter	16-21 cm (ub)	14-15,9 cm (ub)
Quantity	1 000 m^3	500 logs
Delivery time	As produced during season	1 month

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1) Paper presented at the IUFRO Conference - 1984. Fredericton, N. B. Canada.

2) C-G Wachtmeister is research assistant at Linköping Institute of Technology. S-581 83 Linköping, Sweden.

3) m^3s = solid wood under bark.

In these cases the saw-mill has taken advantage of the possibilities concerning the quality, the diameter, the length and the delivery time of its raw material. The delivery time is not the least essential as direct trucking of lumber to customers in Europe is frequently used nowadays.

THE HJÄLTEVAD PLANT

Now back to our plant. It consists of three main sections:

- feeding table
- scanning and bucking section
- sorting line.

The duty of the operator at the feeding table is to keep the plant supplied with fault-free timber stems. Using a grapple saw he can, for instance, cut off decayed portions and larger root buttresses. Small diameter or decayed pulpwood stems can be sorted out at the feeding table and handled in a separate bundle cutter.

Lengths and diameters are measured automatically in the scanner. The accuracy is as high as that obtained in wood value measurement of logs, namely ± 2 mm in diameter and ± 15 mm in length. The conveyor moves at a speed of 60 m/min, and the average length of the stems is 16 m.

The bucking process is controlled and monitored by two operators who releive each other in 2 hour periods. The operator determines the quality of the stem in the bucking section. As it moves transversely towards the operator the stem can be made to roll to allow examination of the whole of its outside surface.

In order to mark the length of the measured, but not yet cross-cut stem, there is a row of lamps. As the operator looks for the quality limits the lamps light up above it. In our plant crooked stems are best observed from the root end in a mirror.

The operator can either decide what each stem will yield by combining length- and diameter values, presented in front of him, or confine the decision to the electronic optimizing equipment. More of this later.

Cross-cutting by two saws, and subsequent sorting, is controlled by a process computer. Position of the cutting point is controlled by slowing down the conveyor from 60 m/min to 6 m/min just before the predetermined length is reached, at which point the conveyor stops. A photocell starts a pulse counter by means of which the trimming allowance can be varied. The sorting line allows sorting into 18 pockets. The logs are then placed in stacks, one for each customer.

The plant is served by a 17 ton high-lift truck which unloads the incoming trailers and empties the sorting pockets. The production capacity of the plant, operating on one shift, is 250 000 stems per year or 75 000 m^3s.

Operating experiences

The cross-cutting accuracy - which in the beginning was not quite satisfying - has now stabilized at ± 10 mm after complementary installations. The mechanical breakdown time of the plant is 20 %.

When designing the bucking section, where the main value is produced, the following should be kept in mind. The operator must sit close to the stem - not further than one metre away. While a close view is needed for judgement of quality he must also have a certain perspective view of the stem in order to see crooked ones properly, if these are not observed in any other way. We have not yet found a satisfactory answer to the problem of these two opposing requirements. The lighting in this section of the plant must be uniform and without reflections. A perfect environment would, therefore, involve carrying out this work indoors, with the operator able to move freely along the length of the stem.

The technical design of the plant has not limited flexibility of operation. On the contrary, we can commence production of a special size or quality the moment an order is received. Information is routed quickly to very few people, a foreman and an operator in fact, and this is where the strength och the central processing lies.

Product output

The system has now been in operation for four years. During this time we have closely followed output of production and prices. It is of interest to what extent the customers have utilized the possibilities to order custom-made sawlogs, and if the central processing system is profitable to the forest owner. It is natural to compare central processing output to those volumes produced from the forest district with other logging methods, i. e. manual chainsaw- and mechanized shortwood systems.

The revenue from logging of coniferous forests is highly dependant on how flexibly different assortments can be produced. From figure 2 we can learn that during a period before the plant was built the same forest district produced 3/4 of the volume as bulk-sawlogs. The rest was delivered as pulpwood and special assortments. During the period after the plant was taken into operation the mobile systems have produced less sawlogs and more special assortments. The installation of the central processing system has in fact partly influenced operators and supervisors of the other logging systems to produce products of a higher value.

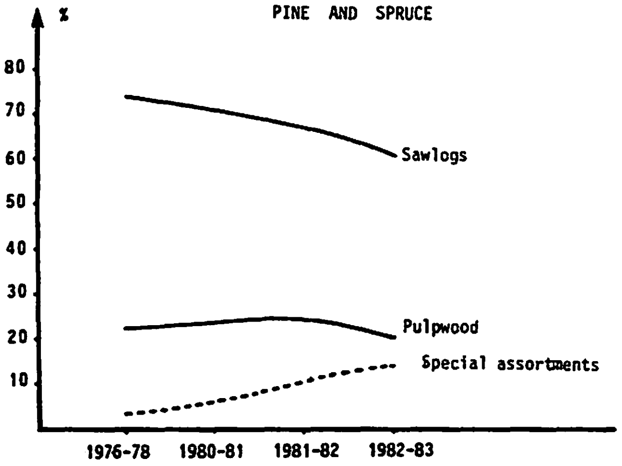

Figure 2. -- Product output from sorting in forest logging, 1976 - 1983.

The product output from the plant has developed with the changing demand for specifications. Figures 3 and 4 show product output for pine and spruce respectively. Bulk-sawlog volumes have dropped to 1/4 of total volume, and they have been replaced by specifications. The demand for these products has been steady and rising. At present (spring 1984) they account for about 50 % of total output. Specifications of spruce are more frequent than of pine because end-users in the building industry can easier utilize special lengths of spruce. The local industry for poles, veneers and sleepers has been ablo to order raw material in bigger lots and with easier access than at forest roadside. The differences in pulpwood output over the years are due to fluctuations in price and decayed sprucewood (delivered as pine pulpwood).

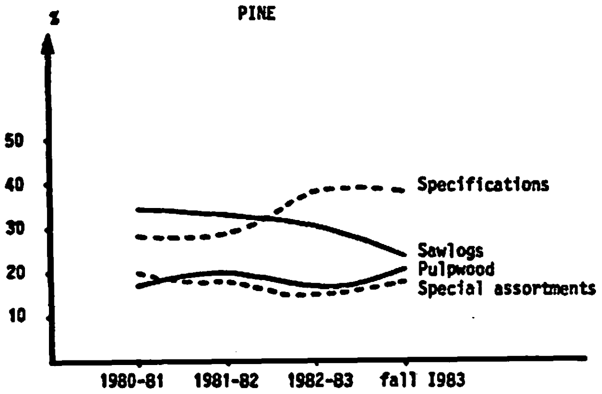

Figure 3. -- Product output from central processing, pine.

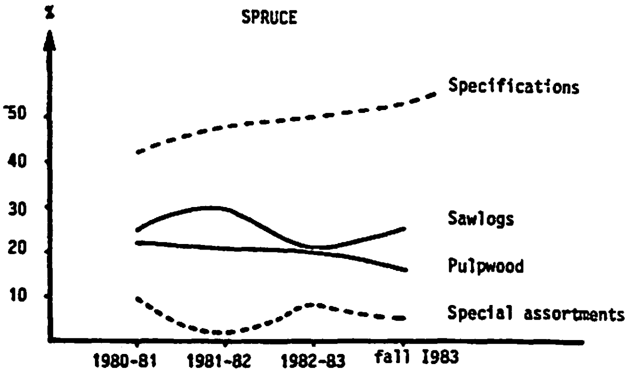

Figure 4. -- Product output from central processing, spruce.

One question of interest can now be risen. Has the "picking out" of specifications influenced the value of bulk-sawlogs so that the total value is equal to or lower than without specifications? Our analysis shows only one significant difference in value-setting factors, namely the diameter distribution of sprucelogs. Figure 5 shows that the "picking out" of specifications has been more frequent in middle diameter classes which means that output of small and big bulk-logs is slightly higher than in normal logging. The value of this deviation has only a marginal negative effect on total output value.

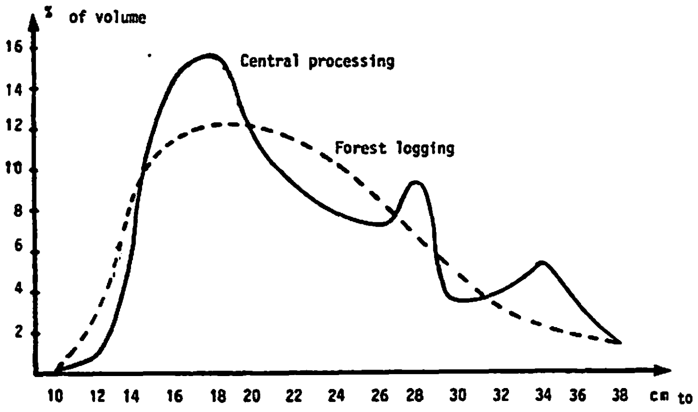

Figure 5. -- Diameter distribution of sawlogs from central processing and forest logging, 1982 - 1983.

Is central processing beneficial?

Of course, this question cannot be answered in general. An easy way out would be to list the advantages and disadvantages of longwood and shortwood logging without talking of econimic results. I want to try the other way.

In Sweden there are two different situations in which central processing is used:

1. Forest owner operated plant with diversified product output.

2. Saw-mill integrated plants.

The Hjältevad Plant described above belongs to the first category.

All other longwood systems (about five) are built in integration with saw-mills. One of these plants, with a similar annual production to Hjältevad, is described in literature (Eliasson 1983). Full tree systems with processing at upper landing or at a central plant have been comparatively analysed at Skogsarbeten (Jonsson 1982).

Regardless of market situation or owner objectives it is a fact that central processing systems, working with one tree at a time, need

- large coniferous trees, > 0.30 m^3s and
- short transportation distances, < 50 km

to economically compete with shortwood harvestor systems.

In the Hjältevad case we have compared the economic result with that from the forest logging operations of the same district. It is important to observe that the volumes delivered at roadside in this case are paid with comparatively high prices due to large volumes and intensive marketing. The economic output shows a small deficit of about CAD 0.75/m^3 during the first years of operation and a zero result at present times. Our experience is that the system is more profitable to the forest owner during lumber market depression times because saw-mills then need to specify their products better. We have also found that many saw-mills have an inadequate knowledge of the end-use market of lumber, due to a complicated distribution system.

If a co-operative of forest owners would set up a system similar to Hjältevad (as in a few cases in Norway and W Germany), and use its advantages properly, the system would be profitable if compared to today's logging forms and log prices.

In the above mentioned report (Eliasson 1983) from a saw-mill integrated central processing operation, stems have been processed for nearly 20 years. The main issue of the report is to calculate the economic result of full tree processing. The full tree system is estimated to be profitable under current conditions as compared to mechanized harvesting. The author points out that costs for log handling and inventories can be reduced when the plant is integrated with the mill.

The residues (about 20 % of stemvolume) are calculated at a zero result which means that the revenue comes from a better utilization of saw logs. This value, obtained by central processing, is divided into three categories:

1. High technical precision (cross-cutting accuracy, elimination of crooks).

2. Optimization of raw materials.

3. Integration values through flexibility to market conditions.

In his analysis, Jonsson (Jonsson 1982) states that full tree logging with central processing costs about 60 % more than if the processing is done at the upper landing. For the conditions used in the analysis it is unlikely that higher wood output value would cover these costs. Jonsson discusses a combination of shortwood and longwood methods in which a shortwood harvestor processes the small trees beforehand so that the plant only handles the valuable trees. In the Swedish Forest Service we have made promising studies of this idea, and we expect to generate more results this year.

Optimized sorting

Compared to mobile systems central processing plants can utilize modern electronic equipment more effectively. It is primarily due to the fact that the computer receives correct data from the entire stem and not only an estimation of taper etcetera. In Hjältevad we are faced with an extremely diversified production with over 50 possible assortments to combine for highest possible output. Regardless of how skilled the operators are it is impossible to beat a computerized calculation as a means of improving the sorting.

Our program has not yet been in regular operation due to technical difficulties. It is based on linear programming and uses a specific logic to minimize the processing time. When the maximum alternative is calculated it is presented to the operator on a monitor and by the lamp row above the stem. Thereafter a pocket-search program destinates the different assortments. As specifications sometimes overleap each other we have a system of priority where the delivery time of each specification influences the sorting. If two specifications have the same delivery time (time left to contract deadline) and volume they will be chosen every other time.

In our tests of the economical output of the optimization equipment we have found that in comparison with our extremely skilled operators it increases the total wood value by 2 - 4 %. However, the electronic equipment can in no way replace the operators. We regard it as a complementary support.

It is especially suited for "difficult" stems where the calculation of the cutting points is tedious for the operators. In difficult and rare situations, e. g. large pines of high quality, the program is slower than the operator to come up with an acceptable solution.

2 - 4 % does not sound so much, but it means in fact that such equipment, with our production capacity, has a pay-off time of less than a year.

DISCUSSION

It is a fact that the development of logging equipment in the 60-ies and 70-ies to a great extent has been focused on the pulpwood assortment. This means that we have developed shortwood machines which in the same operation and with the same speed have processed the tree into sawlogs and pulpwood. The pulpwood, being the low-value assortment of the two, has therefore forced the productivity with suboptimal results for the sawlogs.

Today new and cheaper methods are developed such as tree-section logging (bucked tree-sections with limbs on) for the pulpwood- and energy-fraction of the tree. Various concepts of bundle-delimbing of small trees and tree-sections are tested today. This development is interesting, but dependant on the pulpwood industry and its flexibility to handle trees. Restrictions on full tree methods are introduced today in certain areas because of biological reasons.

In 1982 the shortwood harvestors accounted for 21 % of the final felling volume in large scale forestry. This method is predicted to increase its efficiency by 3.5 % per year and account for over 50 % of the volume in 1990 (Ericson and Rådström 1984). The recently introduced one-grip harvestors have captured the minds of many production-oriented forestors. Unfortunately these machines are not as suitable as the traditional two-grip harvestors concerning the treatment of wood value. One-grip harvestors are extremely efficient in thinning operations but should at present not be used in stands where sawlogs are produced. The development of equipment to improve output value on mobile machines has for the moment stopped. Let us hope temporarily.

This line of development ought to bring new solutions to the logging of sawlog assortments.

In this work we have to carefully penetrate where and how the crosscutting should be done. A better definition of forest stand population with respect to quality and size is a primary condition. It should be possible to correctly determine the stem form (taper, crook) and quality. The development of X-ray or computed-tomography equipment for this purpose is interesting, but at present only suited for research purposes. Precise cutting with flexible allowance must also be possible.

It is obvious that longwood methods and central processing have lost all practical importance in Sweden. The economic results have not been good enough to convince forestors and machine manufacturers. It has been much easier to develop equipment to increase productivity rather than product value.

Another factor is that the saw-mill industry has not forced forestry to produce specified and high quality logs. Competition for sawlogs has been too strong to raise questions about product quality and length specification. The saw-mill structure is, however, changing, and there are already areas where mills do not have to buy every log produced. If this development continues there is a value for the future in the alternative logging systems.

We must not proclaim that central processing is the only solution to increase forest product value, but it is a valuable and future-oriented method to develop further. Therefore it is necessary to build new plants and to document and discuss their results.

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RATIONALIZATION OF WOOD DELIVERY BY ROAD, RAILWAY AND WATER IN SOUTH-EASTERN FINLAND[1]

Reino E. Pulkki[2]

Abstract. A paper briefly outlining a project dealing with the coordination of wood procurement and water transport. Factors which had to be taken into account are covered. A heuristic simulation system used for aiding long-distance transport decision-making is also introduced.

INTRODUCTION

This paper briefly outlines a project currently in progress dealing with the coordination of the variations in wood procurement and water transport. As viewed from the firm, wood procurement begins with wood purchasing and ends with delivery of the wood to the mill. Millyard handling and inventories can also be held as a part of wood procurement. Wood can be purchased as standing trees, at roadside or delivered to the mill. When viewed by a Finnish firm, the wood procurement courses of action open to it are shown in figure 1. The courses of action open to the forest owner, whether State or private, are presented in figure 2. During the 1982-83 harvesting year the distribution of all industrial cuttings was as follows: stumpage sales from private forests 52.8 %; delivery sales from private forests 26.2 %; company forests 9.0 %; and State forests 12.0 %. Almost all wood harvested from State forests was by the delivery sale method; 95 % during the years of 1982 and 1983.

What do we mean by rationalization? Hakkarainen (1978) states that rationalization is orderly and continuous development meant to increase productivity and to make work more meaningful. It is achieved through scientific and technical means. Rationalization helps in keeping pace with development, adapt to changes in the environment and means orderly development of operations.

Long-distance transport is limited in the study to cover the transport of wood raw material from the forest, at roadside, to its place of utilization. It includes all possible combinations of transport methods irrespective of the distance, and includes all terminal operations and intermediate storages. Extended primary transport from the forest to a long-distance transport terminal or directly to the mill is also held as long-distance transport. Long-distance transport can also include the transport of finished products to the market, however as apparent from above, it is not included in the study. The possible combinations of long-distance transport methods available in south-eastern Finland are also presented in figures 1 and 2. In the study initial transport to the water or railway network and terminal operations are included in water and railway transport.

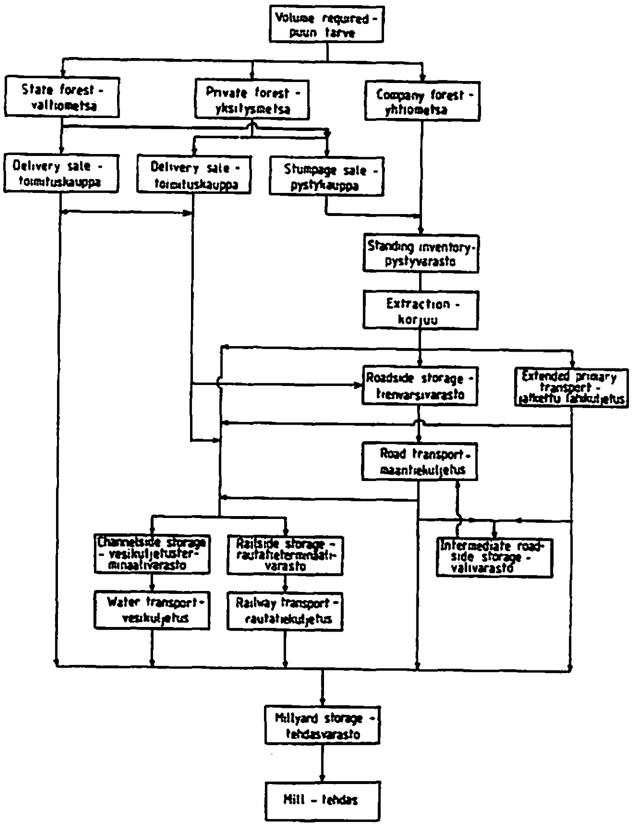

Fig. 1. Wood procurement courses of action open to a wood purchaser in Finland.

The study is limited to the Vuoksi, Jänisjoki, Kiteenjoki-Tohmajoki and Hiitolanjoki watersheds and is referred to as the Saimaa area. The Saimaa area is very similar to the south-eastern Finland wood procurement area, with the exception that the latter area follows municipal and not watershed boundaries. The total area of the Saimaa area is 56 075 km^2, while that of the south-eastern Finland

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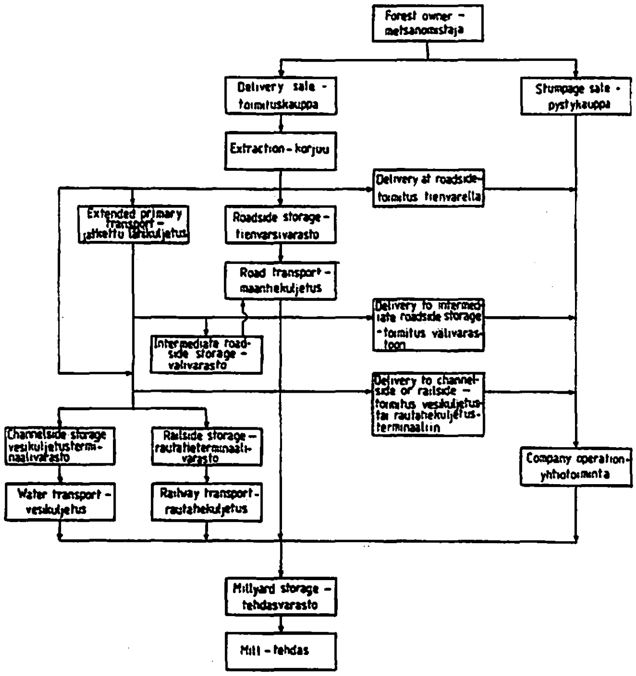

Fig. 2. Courses of action open to a wood seller in Finland.

wood procurement area is 56 490 km^2. Although this paper deals with south-eastern Finland, the Saimaa area, which is the area under study, can be held as being more or less the same area.

The purpose of the study is to develop a system which can be used in solving transport problems and in formulating transport policies in an ever-changing environment. Since we have seasonal and multi-year cyclical variations, combined with developments in the forest industry, transport networks, harvesting techniques and the forest itself, we see we have a very complex problem. The problem is further aggrevated when you have many different wood purchasers with plants at many locations competing for the same wood and a very large number of wood sellers: for example, there are more than 340 000 private and company forest holdings in Finland, with the average size being about 48 ha. If only private forest owners are taken into account the average size is about 33 ha. Since there are so many variables which must be accounted for, it is inconceivable to use linear programming or other such related operations research methods. Due to this, a heuristic simulation system had to be developed. A set of models were formed of the transportation environment in the area. The models were tested and then used to mimic (i.e. simulate) wood transport in the area. The results were used as a heuristic tool to stimulate further discussion and finally to aid in decision-making. Simulation itself is not an optimization tool. However, information gained through simulation can be used in optimization models. In the study we are striving to minimize the cost of wood procurement in a dynamic environment, while also accounting for its impact on the wood processing costs and product yield.

FOREST INDUSTRY IN THE AREA

In the area we have a wood industry ranging from small portable sawmills using a few hundred m^3 of wood for domestic use, to large integrated wood processing complexes capable of using in excess of 2 M(m^3)/a. If sawmills using in excess of 5 000 m^3/a are only accounted for, we find that there were 40 sawmills in operation in the area in 1983. There were also 19 wood-based panel mills (13 plywood, 5 chipboard and 1 particle board mills) and 10 pulp and/or paper mills in operation in the area. Wood processing mill locations are shown in figure 3. In all, we can locate 37 separate wood processing centres/points requiring various volumes of wood. Wood volumes used by the forest industry in the area since 1979 are shown in table 1. The majority (57 %) of the centres/points use less than 100 000 m^3/a. The mills in the area account for about 25 % of industrial wood consumption in Finland. During a peak year, total annual consumption of industrial roundwood and forest chips is now slightly greater than 13 M(m^3). Mill residues are also used to a large extent but are not included in the study.

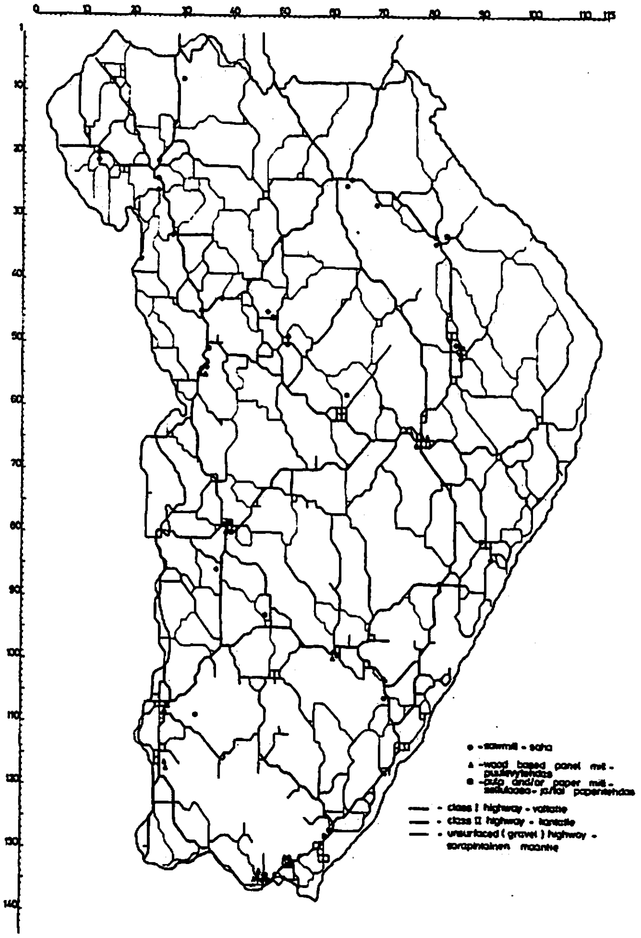

Fig. 3. Major road network in south-eastern Finland and mill locations.

Note: - m^3 is solid volume, bark included
- M(m^3) is mega (million) cubic metres

Table 1. Volumes of wood delivered to mills in south-eastern Finland by wood assortments (includes imported[1] wood).

Year	Mill delivered wood volume, (1000) m^3						
	Soft-wood logs	Hard-wood logs	Other soft-wood	Other hard-wood	Forest chips	Indus-trial residue	Total
1982	3 752	692	3 297	1 742	787	1 351	11 621
1981	4 130	805	3 293	2 618	192	1 186	12 224
1980	5 063	834	3 422	2 449	39	1 699	13 506
1979	4 800	684	2 896	2 170	37	1 319	11 906

[1] Volume of imported wood in 1982 was 1.296 M(m^3).

WOOD PROCUREMENT CHARACTERISTICS

The total land area in south-eastern Finland is 45 243 km^2 and the lake coverage is 19.9 %. From the 7th national forest inventory (Kuusela and Salminen 1983, Uusitalo 1983), the annual allowable drain for the area can be estimated to be about 15 M(m^3). Total drain (industrial, fuelwood and domestic consumption, wood export, logging residues, floating losses, and mortality) in the area during 1981 was 13.88 M(m^3) (Huttunen 1983).

In Finland, 98 % of the volume logged is by the shortwood method (Salminen 1983). In the shortwood method the various wood assortments are cut in the stump area and in most cases a forwarder is used for forest (primary) transport. The use of agricultural tractors is more or less restricted to farmers who harvest their own wood and sell by the delivery sale method. Forwarders account for about 88 % of forest transport, while agricultural tractors and skidders account for about 10 % and 2 %, respectively (Vesikallio 1981). At the end of 1981 about 20 % of the annual volume harvested by companies and the State was by mechanical means; about 16 % of the total harvested volume (Vesikallio 1981).

The average composition of wood costs by wood assortments delivered to the mill in south-eastern Finland is presented in figure 4. Stumpage forms the major part of the wood cost at the mill for logs, while extraction and long-distance transport form the major part for pulpwood. The average stumpage rates for the area during the 1982-83 harvesting year were as follows:

- pine logs - 160.81 FIM/m^3
- spruce logs - 131.34 "
- hardwood logs - 153.45 "
- pine pulpwood - 78.52 "
- spruce pulpwood - 78.01 "
- hardwood pulpwood - 60.46 "

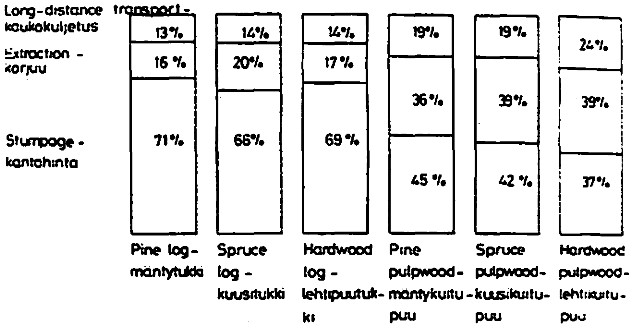

Fig. 4. Average composition of wood costs by wood assortments delivered to the mill in south-eastern Finland.

LONG-DISTANCE TRANSPORT INFORMATION

Table 2 presents the volumes delivered to mills in south-eastern Finland from 1972 to 1982. As can be seen, the variations in the volume of wood delivered to mills in the area have been quite large in past years. This is due to market conditions, with cycle peaks occurring during 1974 and 1980. The largest change between successive years occurred between 1974 and 1975; a reduction of 6 M(m^3) or 38 % from the volume delivered during the preceding year. Also apparent is that the volume delivered by tractor has decreased steadily and is more or less insignificant in the area today. The volume delivered by water transport has remained fairly steady and the annual variations in total wood requirements have not had too much effect; the coefficient of variation (CV) is only 7 %, compared to 30 % for both truck and railway transport. The variation in railway transport is due to the combined effect of annual wood requirement variations and tariff policies; if the tariff schedule overly increases compared to the other methods, wood is easily transferred to truck transport. Truck transport seems to be the method which picks up or looses wood most readily, with changes in wood requirements.

The average transport distances and average direct transport costs for the long-distance transport methods available are presented in table 3. The values given in table 3 do not include initial transport to railway or water transport terminals. The per cent and absolute cost increases in average direct transport costs, excluding initial transport to the terminals, from 1972 to 1982 were as follows:

- tractor transport - 18.2 %/a 116.4 p/(m^3·km)
- truck " - 10.9 " 22.8 "
- railway " - 11.5 " 6.9 "
- water " - 11.6 " 4.8 "
- wholesale price index - 12.8

When transport distance is also accounted for we obtain the transport output. Since the average transport distance is longer for both water and railway transport, their share of the transport output is larger than for mill delivered volume. During 1982, the shares of transport output for truck, railway and water transport in the area can

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Note: - 4.40 FIM equals about 1.00 CAD
- 1.00 FIM equals 100 p

Table 2. Volumes of wood delivered to mills by transport method.

Year	Transport method									
	Tractor		Truck		Railway		Water		Total	
	1000 m^3	%	1000 m^3	%	1000 m^3	%	1000 m^3	%	1000 m^3	%
1982	2	0	5 761	50	1 340	11	4 518	39	11 621	100
1981	3	0	6 202	51	1 742	14	4 277	35	12 224	100
1980	31	0	6 689	50	2 264	17	4 522	33	13 506	100
1979	25	0	5 685	48	1 764	15	4 432	37	11 906	100
1978	26	0	4 406	47	1 155	12	3 896	41	9 483	100
1977	35	0	4 004	40	1 663	16	4 430	44	10 132	100
1976	43	0	3 368	35	2 338	24	3 899	41	9 648	100
1975	79	1	3 413	35	2 066	21	4 246	43	9 804	100
1974	122	1	8 306	52	2 623	17	4 778	30	15 829	100
1973	259	2	4 880	42	1 447	13	4 896	43	11 482	100
1972	210	2	3 936	41	915	10	4 514	47	9 581	100
$\bar{x}$	78		5 150		1 756		4 401		11 383	
s(+/-)	86		1 540		528		312		1 981	
CV		110		30		30		7		17

be calculated to be 23, 22 and 55 %, respectively. For the country as a whole the corresponding values were 46, 21 and 33 %.

In water and railway transport, initial transport by truck or tractor is required in almost all cases. In south-eastern Finland the average minimum distance to a water transport terminal is 25 km, while to a railway terminal it is 26 km. There are 88 water transport and 88 railway transport terminals servicing the area. Figures 3, 5 and 6 present road, water and railway transport networks and infrastructure available.

Inland waterway channels are classified into four classes:

- Is deep channels depth ≥ 4.2 m
- IIs main channels $2.4 \text{ m} \leq$ depth < 4.2 m
- IIIs side channels depth < 2.4 m
- IVs floating channels specified under floating regulations for each watershed but unmarked on inland waterway maps

The shallowest marked channel can be held to be 1.2 m in most cases. All channels have a 0.6 m safety margin, which can be added to the above values to get the actual channel depth. The channel depth in inland waterways is measured from the lowest water level during the navigation season (NW_{nav}). The minimum water depth required in bundle floating is 3.0 m. However, a depth of 2.5 m is generally sufficient in the upper reaches of the waterway. Of all marked inland channels in Finland, 48 % lie in the Saimaa area, while the corresponding value for all inland channels is 35 %. The distribution of channels by classes in the Saimaa area is as follows (TVH 1979):

- Is	(≥ 4.2 m)	755.4 km
- IIs	(2.4 - 4.1 m)	1 123.1 km
- IIIs	(0.0 - 2.3 m)	1 036.7 km
- total marked channels		2 915.2 km
- IVs	(0.0 m -)	317.9 km
- total channel length		3 233.1 km

Table 3. Average long-distance transport distances and average direct transport costs[1] in Finland.

Year	Tractor		Truck		Railway		Water	
	km	p/(m^3·km)	km	p/(m^3·km)	km	p/(m^3·km)	km	p/(m^3·km)
1982	10	143.2	74	35.3	297	10.4	226	7.2
1981	13	101.7	75	34.2	289	9.7	249	6.5
1980	17	64.2	81	26.1	225	10.1	253	6.6
1979	14	75.5	84	23.0	246	9.0	236	5.0
1978	21	51.3	88	19.7	248	7.4	239	4.5
1977	16	48.7	81	20.2	250	7.2	231	4.7
1976	19	61.1	82	19.5	232	6.9	249	4.3
1975	16	66.2	72	19.8	178	7.3	243	4.2
1974	17	46.3	71	16.9	174	5.6	205	2.8
1973	18	34.8	67	14.0	237	3.6	211	2.8
1972	22	26.8	64	12.5	214	3.5	209	2.4

[1] The direct costs for railway and water transport do not include initial transport to terminals.

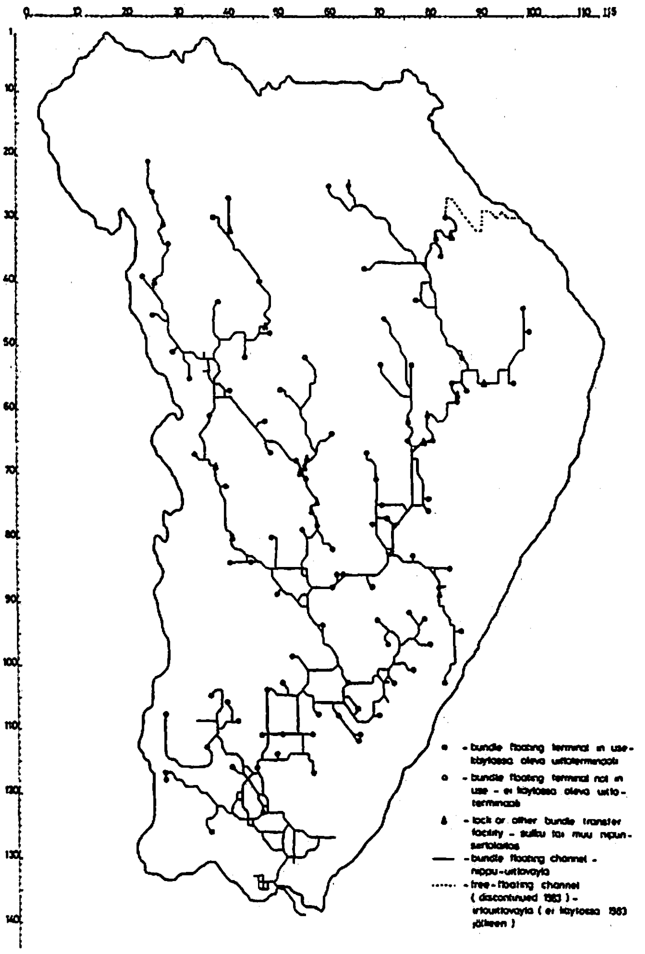

Fig. 5. Water transport network in south-eastern Finland.

The total length of mainline railway servicing the area is about 1 400 km. The length of public roads in the area in 1982 was 14 531 km (TVL 1983). Unfortunately, an accurate estimate of the length

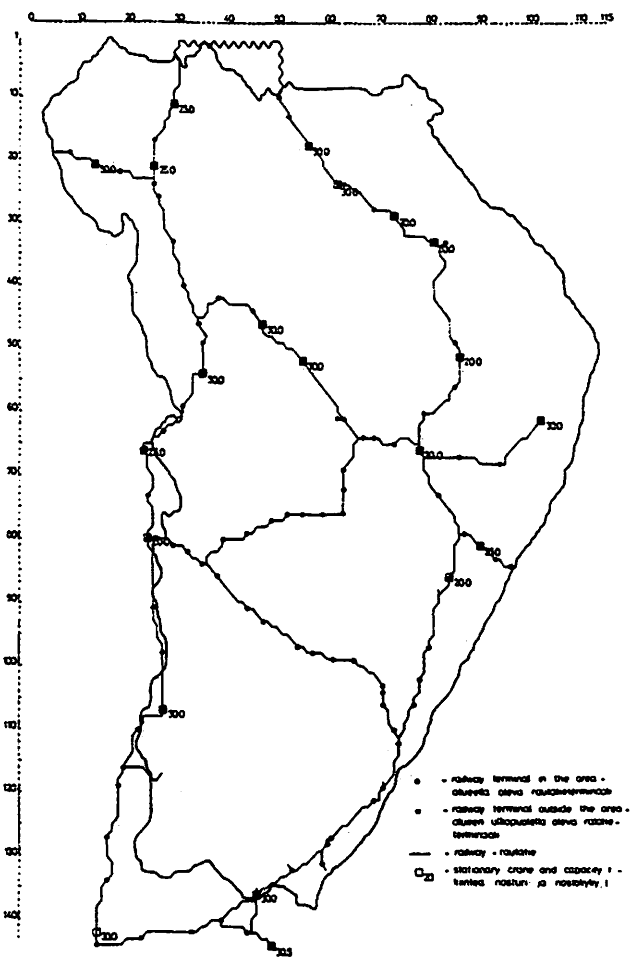

Fig. 6. Railway transport network in south-eastern Finland.

of private roads in Finland today is lacking. Wiiala (1962) estimated that there were 375 000 km of private roads in Finland in 1961. If we add to this forest roads built since 1961 (about 75 000 km), we obtain a private road estimate of 450 000 km. If we assume that about 20 % of private roads have been built in south-eastern Finland, since 20 % of public roads lie in the area, we can estimate that the total road length is about 105 000 km. This gives us a road density of 23 m/ha. Wiiala (1962) stated that the average road density in Finland in 1961 varied from 10 to 30 m/ha, with public roads forming 10 to 15 % of all roads. Calculated from above we get the share of public roads in the area to be 12.6 %.

From the above we can see that the area is well serviced by all three transport methods. For wood harvested in the area, truck transport is used mainly for road distances from 4 to 120 km. With present tractor payment rates, extended primary transport should not be used for distances greater than 5 to 8 km, depending on wood assortment. Depending upon wood assortment and time delay factors (e.g. interest cost), bundle floating in the area begins to be competitive with truck transport once a truck transport distance of 40 km is reached. This exceptionally short distance is due to the dense water transport network in proximity of the larger wood using centres. On the other hand, small sawmills rely only on road transport. Vesikallio and Salminen (1978) state that in Finland on average, the transport of logs by truck transport and water transport compete with one another over distances of 90 to 200 km, after which floating is cheapest in all cases. For pulpwood the corresponding distances are 60 to 120 km, after which floating is cheapest.

In south-eastern Finland, railway transport is not used to as great an extent as truck or water transport to delivery wood harvested in the area to mills in the area. Of railway delivered wood, 25 % was imported wood (mainly from the Soviet Union) and 30 % was from other watershed areas. Similarly, of wood dispatched from railway terminals in the area, the majority (64 %) was transported to mills outside the Saimaa area. In the area, railway transport cannot compete with truck transport in any situation where the road distance is less than 130 km. Railway transport is more expensive than water transport in all cases.

FACTORS AFFECTING LONG-DISTANCE TRANSPORT POLICY

General

When choosing the optimum employment of transport methods, a firm wants to achieve the best overall economic result over the long-term. The inventory policy has a direct effect on the transport methods applicable. For example, if a firm wants to take a large risk of running out of wood, but keep holding costs at a minimum, it would choose minimum inventories and thus hot-logging techniques; for which road transport is most appropriate. In any decision on the most appropriate inventory the following factors must be accounted for:

1) holding costs - i) interest costs
   - ii) storage costs
   - iii) handling costs
   - iv) insurance cost
   - v) depreciation/deterioration cost
2) set-up costs or ordering costs
3) shortage or penalty costs
4) production costs and purchase prices
5) lead-time (e.g. for raw materials the period between order and arrival)

Unfortunately, in past years too much attention has been focused on on interest costs alone and thus the favouring of minimum inventories and hot-logging techniques. As will become apparent, hot-logging techniques are only applicable where we have certainty in wood procurement.

Although it is best to view the available transport methods as forming an integrated transport system, it is also beneficial to view the methods as competitors. In this way competition is stimulated between the methods and thus costs are kept better in line. If one method becomes more competitive, the others must follow suit or loose their share of the transport volume. When deciding on the most appropriate share of transport methods we have both business economic and national economic factors which must be taken into account.

Business economic factors

Since private forests form the major source of wood used by the forest industry, the timing when wood becomes available is an important factor. Most wood sales occur during the fall and it is difficult to predict how wood sales will develop in the next harvesting year. This is the case today where the industry requirements are much larger than the volume of wood coming up for sale. Wood shortages at the mill are common at many Finnish mills today. The problem of stimulating the desire of private forest owners to sell wood is under serious scrutiny nowadays. A general observation has been that companies which have resorted to the use of minimal inventories have been the ones most susceptible to wood shortages; excluding mills with small wood requirements. Mills which have relied largely on water transport and thus larger inventories, have been able to draw on wood stored in water storages. Living hand to mouth also results in transport without regard to cost, since wood must be transported directly to the mill once it becomes available.

Although in past years there has been an attempt to schedule harvesting operations uniformly throughout the year, 68 % of commercial cuttings still occurred during November to April in the 1982-83 harvesting year: i.e. during the winter season. During the 1981-82 harvesting year the corresponding value was 63 %. The spring break-up period in April-May also has its effect on uniform wood supply. Also, wood must not be stored in the forest during late spring and summer due to insect damage directly to the wood and to surrounding stands, and damage due to blue stain fungi. If wood must be stored, water storage is generally held as the best method. Also, due to the above variations in wood supply, the difference between average size of inventory required for 100 % road transport and, for example a 50/50 mix of road and water transport, is only about 1.5 months.

The harvesting methods in use also have an effect. All solutions in wood procurement should fit into the entire chain and not cause unreasonable cost elsewhere. In most cases transport forms a service function and must meet the demands imposed upon it by the wood assortments required at the mill and the conditions prevalent at the forest end. Seldom is wood harvested in a form to minimize only transport costs.

Due to the many factors mentioned above, the transport method giving the lowest direct cost is not always the one chosen. However, direct cost forms one of the basic criteria in transport method choice. The direct cost of truck transport to the mill is straight-forward; we have costs of loading, transport to mill and mill receiving. When dealing with railway or water transport we have many additional cost components. In both methods we have the additional cost of transport from the forest to the terminal, as well as terminal operational and maintenance costs. In bundle floating we also have the additional costs of bundle bindings, bundling and raft formation.

In bundle floating 40 to 60 % of the total direct cost is due to initial transport to the terminal, while terminal operations account for 15 to 20 %. The actual bundle towing operation only accounts for 20 to 30 % of the total direct cost, while the corresponding value for mill receiving is 5 to 10 % (Uiton kehittämisryhmä 1980). From the above we can see that 70 to 80 % of the total direct bundle floating cost occurs over approximately 15 % of the total distance for the method.

Road transport is the most flexible of the three methods. This is because we are dealing with small truck-load units. In railway transport, discounts can be achieved by dispatching larger volumes of wood at a time (e.g. 1 000 m^3 per train load) and throughout the year. Time is also spent in transporting the wood to the railway terminal. Water transport has the largest delay time of the three methods. One reason is due to seasonal factors; the waterways freeze over during winter and floating is only possible for 5 to 6 months between May and November. The navigational period for water transport can be extended through the use of barges.

As mentioned earlier the additional cost due to interest on the wood investment has been given considerable attention. For small unintegrated operations road transport is solely relied on. For small firms only a small buffer inventory is required and they are flexible to market demands and wood supply. Since they have a low capital investment, as opposed to a pulp and paper mill, wood shortages do not pose a serious consequence, when compared to a pulp and paper mill. Also, the area from which wood is procured is quite small and thus suited to road transport. The cost of interest thus forms a much larger criteria for smaller firms.

When dealing with a large mill complex and thus large wood requirements, the importance of solely interest cost decreases. A buffer storage is required to ensure against wood shortages. Wood storages are also helpful to even out discontinuity between wood demanded and wood available on the market. Trying to juggle 340 000 forest owners to sell or not sell an additional 5 or 10 M(m^3) from one year to the next is near to impossible, as apparent from the recent difficulties experienced in wood sales from private forests. As mentioned earlier, the seasonal nature of cuttings also results in wood inventories. Another point to remember when dealing with large wood volumes is that, even though truck transport is the quickest method to get a load of wood to the mill, the movement of an entire inventory by the other methods can be competitive with truck transport. For example, the average raft size on Lake Saimaa is slightly larger than 20 000 m^3: i.e. over 500 truck loads. To ensure against wood shortages Eskelinen and Peltonen (1977) state that the optimal inventory for a Finnish firm is 40 to 45 % of the annual wood requirement: i.e. 4.8 to 5.4 month wood supply. Assuming uniform purchasing and harvesting operations throughout the year, the majority (about 90 %) could be stored as standing inventory. Since there is usually limited space at millyards, bundle floating allows an excellent opportunity to eleviate millyard congestion.

The choice of a long-distance transport method in south-eastern Finland also assumes that the method services the point of dispatch and the destination. Once wood is transferred from road transport to railway or water transport, it should be delivered by that method to the destination. This is due to the high interface costs when transferring from one method to another. For example, lifting bundled wood out of water and onto truck costs from 7 to in excess of 10 FIM/m^3, depending upon the conditions. This is equal to about a 30 to 40 km marginal increase in truck transport distance. Generally, road transport can be used in all cases except when extraction occurs in island or shoreline forests accessible only by water.

Certain poorly floating wood assortments, for example chips, fresh hardwood pulpwood, birch logs and small diameter fresh softwood pulpwood, limit the use of bundle floating if additional buoyancy or barges are not used. The extent of wood deterioration has a direct effect on the final product value and processing costs. Generally, if wood must be stored, it should be stored in water to minimize deterioriation due to fungi and insects. Wood stored on land (i.e. at roadside, railway terminal or millyard) would have to be continuously sprinkled with water or chemically treated. In bundle floating 10 to 15 % of the bundle is above the water's surface and thus subject to wood damaging agents. Storage also has effects on barking, pulping processes, chemical requirements, pulp quality and yield, and yield of side products (e.g. pine oil and turpentine). Direct delivery of wood to the mill would give the best results, but if storage is required, water storage gives the best results (Vesikallio 1979).

By service we mean the period when a method can be used. As mentioned earlier, the use of water transport is limited to the navigational season. Dependability reflects the susceptiblity of a method to environmental and external factors.

National economic factors

When examining transport methods from a national economic point of view one must account for the investment required to establish, maintain and operate the different transport networks. Other factors which must be accounted for are: productivity of labour and capital, consumption of fuel and lubricants, effect on the environment, domestic share, dependability, etc.

Heikkerö (1979) makes a comparison between the balance of expenditure and income for the State by transport method. According to Heikkerö (1979), in 1977 70 % of the State's expenditure on truck transport was recovered through taxes directly related to truck transport. To cover expenditures fully, truck transport tariffs would have had to been increased by 5 %. The corresponding values for railway transport and floating were 40 % and 20 to 40 %, respectively. Table 4 gives the net costs to the State by transport methods. It must be pointed out that the cost for floating is larger than it would be if the channels were only used for floating. This is because channels are built to a higher standard to accomodate inland vessel transport.

Table 4. Net costs to the State by transport methods after expenditures and revenues.

Method	Net cost to State, p/(m^3 · km)	National economic accident cost, p/(m^3 · km)
Truck transport	1.2	0.50
Railway transport	5.8	0.04
Inland vessel transport	1.0	--
Bundle floating	1.0	--

(Pertovaara 1982)

Uiton kehittämisryhmä (1980) and Pertovaara (1982) give the additional information listed below, comparing the transport methods from a national economic point of view:

- depending upon conditions, the man-day productivity in floating is 7 000 to 25 000 m^3· km and for truck transport it is about 5 000 m^3·km; a corresponding value for railway transport is not available
- the productivity for capital invested in floating equipment in 1980 was 265 m^3·km/1.00 FIM, while for truck transport it was 35 m^3·km/1.00 FIM and for railway transport (capital cost of railway cars only included) it was about 28 m^3·km/1.00 FIM
- the use of fuel in actual transport by truck is 10 times greater than for bundle floating per m^3·km, while for railway transport it is 3 times greater
- when taking into account energy required for actual transport, transport network construction and maintenance, and building the actual transport equipment, the energy requirements (oil equivalent, kg/(m^3·km)) for truck and railway transport, and floating are 0.042, 0.040 and 0.003, respectively
- a decrease in the trade balance of 20 million FIM/a would result if 5 M(m^3)/a were transferred from water transport to truck transport; inflated to today's costs about 30 million FIM/a
- the domestic share of floating is 85 %, while for truck transport it is 30 %
- the environmental effect is only significant in free-floating; in bundle floating little water surface area is required and loss of bark and leeching of chemicals into the water is minimal due to bundling, however there is a local effect

at large dumping terminals and millyard storages
- transferring wood to roads, from either railway transport or bundle floating, would result in greater environmental effects and roadways would be further stressed near built-up areas, thus resulting in increased traffic risks and road wear
- land storage of unbarked wood in the summer can cause damage to surrounding stands, while water stored wood generally has little effect, unless large quantities are stored unbarked near coniferous forests over a long time since 10 to 15 % of the bundle volume is susceptible to insect damage unless the bundles are rotated or sprinkled with water
- the majority of waterway channels are usable for floating with little or no improvements required; also maintenance of waterways is minimal since they do not wear with use
- a waterway transport network is the most dependable method in times of crisis; e.g. energy supply problems

RATIONALIZATION WOOD TRANSPORT IN PRACTICE

As mentioned in the introduction, there are many firms with mills at different locations procuring wood in the area. In floating, the irrational operation of many different firms on the same channels became apparent quite early in industrial wood procurement as we know it today. Thus, the Kymi Floating Association was formed in 1873 (Seppänen 1937). In the Saimaa area, Pielis Elfs Flötnings Aktiebolag Oy was formed in 1886 by two companies floating on the Pielis River. Gradually, a number of floating associations and companies were formed in the area. In 1930 the Savo Floating Association and Northern Karelian Floating Association were formed, and are still in operation today. The two associations are responsible for floating in the northern half of the area and at two channel bottlenecks in the southern half (cooperative floating). Rationalization of private floating in the southern half of the area has also occurred and only two companies, Tehdaspuu Oy and Enso-Gutzeit Oy, have floating operations today. Floating associations are non-profit organizations who transport wood in an area and distribute costs to the member companies according to their share of the transport output. In the private floating area, contracts are made between companies with floating operations and other companies with wood to be transported.

Tehdaspuu Oy, which started operations in 1968, was another step in rationalization of wood procurement in the area. It is responsible for procuring wood for four separate companies. This cooperative venture allowed the elimination of overlapping organizations. Cross-hauling by the four companies could also be eliminated.

Tehdaspuu Oy and Enso-Gutzeit Oy, the two largest wood procurement organizations in the area, also employ optimization models for aiding long-distance transport decision-making. The decision areas are generally based on municipal areas and employ average costs from the areas to mills. Metsäteho, the Forest Work Study Section of the Central Association of Finnish Forest Industries, has also developed a number of mathematical methods for wood procurement optimization (Eskelinen 1984, Eskelinen and Peltonen 1982, 1980 and 1977). Although the methods give valuable information and are helpful in long-distance transport decision-making, they are subject to the limitations mentioned in the introduction. To make the methods operational, since they are based mainly on mathematical programming techniques, simplification of the problem and averages for areas must be used. Gillam (1969) states that mathematical programming is only applicable to hypothetical problems and is of little use in practice. Also, a clear picture of the overall transport situation is not easily available from the above methods.

Other rationalization has occurred, resulting through practical experience and research. There have been major developments in truck transport to keep it competitive. This is apparent from the section on long-distance transport information. Although railway transport and floating should be less susceptible to inflationary pressures than truck transport (Vesikallio and Salminen 1978), the rate of increase in truck transport from 1972 to 1982 was slightly less. In railway transport, special cars have been developed and unnecessary terminals discontinued. Improving the condition of terminals in use has also been another important development. In water transport, floating operations have been concentrated into the main channels, and terminal, towing and transfer facility operations developed. The use of redundant terminals have been discontinued and today, based on average minimum distance to terminals, the optimum terminal distribution has been reached. Only in some individual cases are terminal location improvements required. Any reduction in the number of terminals today would result in excessive increases in initial transport distance, while additional terminals would have no significant effect on reducing the average distance to terminals. Increasing the flexibility of water transport through the use of barges is also under investigation.

DATABASE FOR SIMULATION EXPERIMENTS

This section briefly introduces a database based on the uniform coordinate system. The uniform coordinate system is a grid system (perpendicular intersecting lines) based on the Gauss-Krüger map projection. In Finland, one projection corridor is used to cover the entire country. The centreline of longitude for the corridor is 27°E. This corresponds to the grid central meridian which is 500. Lines of latitude of 60°N and 64°N intersect the grid central meridian at grid lines 6710 and 7100. By using the uniform grid coordinate system, all grid squares have the same area since the effect of the earth's curvature is eliminated. Storage of data at uniform coordinates is simpler and its use in simulation models made possible.

A grid with a 2.5 km interval between grid lines was chosen in the study. The scale of the map mosaic covering the area was 1:200 000; the distance between map grid lines was 1.25 cm. Each grid square covers an area of 6.25 km^2 and it forms the basic unit of each information matrix having dimensions of 144 x 114 (l x w). Due to the shape of the watersheds under study, 9 048 of the total 16 416 squares lay in the study area. Figures 3, 5 and 6 were drawn from hard copies of information matrices. The Y and X axes of the computer printouts are not of the same scale due to the difference between character density per line and line density. Thus, figures 3, 5 and 6 show the area to be more elongated than it actually is.

When registering the transportation system information the map area covered by each grid square was examined. If it did not lay in the study area it was labled according to whether it was in another area of Finland or in the Soviet Union. Otherwise the presence of the following features was recorded:

1. roads
    11. highway network
        111. class I (primary national) highway
        112. class II highway
        113. unsurfaced highway
    12. community road
        121. bound surface
        122. unsurfaced
    13. private road
2. railway network
    21. actual railway
    22. railway terminal
        221. terminal with stationary crane
        222. terminal without stationary crane
    23. railway spur
3. water transport network
    31. water transport channel
        311. bundle floating channel in use
        312. bundle floating channel not it use
        313. free-floating channel
    32. bundle transfer facility
        321. bundle crane/track
        322. lock
    33. water transport terminal
        331. bundle dumping terminal in use
            3311. dumping ramp only
            3312. ice storage area only
            3313. dumping ramp and ice storage area
        332. bundle dumping terminal in sporadic use
        333. abandoned bundle dumping terminal
        334. harbour
4. watershed
5. water coverage percentage
6. mill
    61. sawmill
    62. wood-based panel mill
        621. plywood mill
        622. particleboard mill
        623. chipboard mill
    63. pulp and/or paper mill
7. district forestry board
8. municipality

Additional information relating to the area was also gathered: for example, annual allowable drain by wood assortments and district forestry boards, wood volumes dispatched from terminals, industrial cuttings, wood consumption at mills, channel costs, etc.

The storage of the above data for each grid square is only possible with a computer. With the data readily available in digital form, information matrices could be developed. Simulation models and experiments could be easily devised and used in a heuristic manner to help in long-distance transport evaluation and decision-making. A set of transport route search algorithms were devised for the system. A series of costing subroutines also allows the determination of actual transport costs. By entering the grid coordinates of the source and destination, and the wood assortment to be transported, transport between the two points by all transport methods is simulated and pertinent information produced. This is done with the aid of a master program combining the above mentioned information and subroutines.

Due to the nature of this paper, further explanation of the above heuristic simulation system is not possible. A major report dealing with the above will be published by the author in the near future.

SUMMARY

Since long-distance transport occurs in a dynamic environment with the presence of uncertainty, decision-making is very difficult. Rationalization of wood delivery has occurred in many areas; from the consolidation of wood procurement operations, to the actual development of each method. When deciding on the proper use of long-distance transport methods there are both business economic and national economic points of view. Generally the following business economic factors must be taken into account:

1) availability of wood for purchasing
2) harvesting schedule (i.e. availability of wood at roadside)
3) harvesting methods in use and costs
4) direct transport costs
5) time required for transport of wood from forest to mill
6) technical factors in regard to presence of suitable transport routes and effect on wood quality
7) wood holding costs at the mill
8) dependability and service provided by each method
9) wood demand at the mill

In regard to national economic factors, the competitiveness of each method depends mainly on the productivity of various resources: for example, labour, energy and capital. A transport method´s effect on the environment is another factor. The ratio between domestic and imported materials required by each method is also important. The dependability and applicabiltiy of each method in uncertain conditions should also be accounted for.

Mathematical programming techniques have been used to a wide extent in aiding transport decision-making. However, use of the methods is limited due to the very large number of variables involved and uncertainty.

This paper has outlined the environment and factors which had to be accounted for in a study dealing with the development of a system to help in the coordination of the variations in water transport and wood procurement. The system, a heuristic simulation system, was briefly introduced. A detailed description of the system was not possible due to the nature of the paper. However, since all information relating to the transport system in the area is readily available, transportation problems can be readily simulated, and the information used in problem solving and decision-making. A system of this type is also applicable in solving other problems related to forestry or in fact, any other field with a geographical distribution.

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CONTROL OF WOOD DELIVERY AND ASSOCIATED WOOD INVENTORY IMPLICATIONS IN NEW ZEALAND[1]

J.E. Galbraith[2] R.N. O'Reilly[3]

Abstract. - The experience of controlling wood deliveries and managing log inventories at the N.Z. Forest Products Limited, Kinleith mills is described. There are a number of geographical, organisational and climatic factors which allow close control of wood flow and minimal wood inventories at Kinleith. Operations research techniques were first applied to aid the management of the wood flow in 1965 and there have been a number of studies since to further refine control of the system.

Minimal inventories, equivalent to only a few days of usage, offer significant advantages in fresher wood, reduced handling costs and capital servicing. However, the resulting flow system is very dynamic and requires considerable short term control effort.

Key components of successful wood flow control were found to be :

- understanding the variability of the wood supply and demand and, where possible, improving forecasting.
- a system of short term (weekly) review and control.
- reasonably accurate estimates of inventories.

In the final analysis, control actions are a compromise between the need to return the system to target as soon as possible and the need to preserve some stability in wood production and delivery rates and hence maintain efficiency.

INTRODUCTION

The management of wood flows in a forest harvesting and utilisation operation has many similar characteristics to the management of any material supply, handling and processing system :

- there must be an overall balance of inputs to outputs.
- there are a number of processes within the operation, working at variable rates, and these too must be balanced.
- buffer stocks, or inventories, are held between the different processes to allow them to operate as independantly of upstream or downstream variation as possible. But the levels of the inventories must be economically examined and justified.

Many of the common business techniques of simulation, linear programming, inventory control, queuing theory, etc., can be applied to help improve the management of wood flows.

The experience in the use of some of these techniques, plus some basic control theory, in managing wood flows at the N.Z. Forest Products Limited Kinleith mills is described. Aspects of research to identify the factors that affect the efficiency of planning and control are also described and the implications for management discussed.

THE WOOD SUPPLY SYSTEM

The wood supply system at Kinleith has a number of characteristics which allow for, and demand, close control of wood flow and minimal wood inventories.

- Geographical location. The mills are located within the Kinleith forest, the main source of supply, and other sources of wood are relatively close. Average transport lead distance is a little over 30 km with a maximum of 120 km.
- Eighty to ninety per cent of the wood comes from Company owned or controlled sources.
- There is a close integration of growing, harvesting and utilisation functions.

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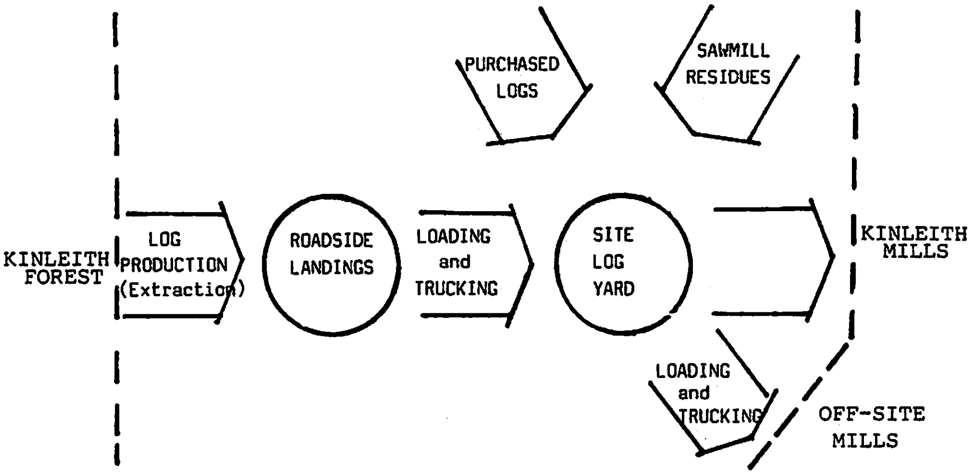


FIG. 1 - KINLEITH WOOD FLOW SYSTEM

- The climate is favourable for year round work.
- A single species, Pinus radiata, dominates the wood supply. Minor pine species and native hardwoods make up only 5% of the mix.
- The fast-grown radiata experiences quick deterioration after felling, by way of fungal and insect attack and drying out.

For the benefit of North American readers, the control of the wood supply organisation ("woodlands") extends through to the mill input, i.e. logs on the sawmill or chipper infeed chain or purchased chips on the outside chip storage slab. Thus the wood supply organisation manages the mill site log storage and handling, as well as delivery. Wood supply totals 2.5 million tonnes per annum.

INVENTORY CONTROL

Kinleith first took a scientific approach to setting target log inventory levels in 1965. By direct mathematical comparison of log supply and usage variation and by considering the costs of holding inventories, the following policy levels of site inventories were struck:

Pulpwood 3,800 tonnes
(equivalent to 1.3 days usage)
Sawlogs 1,900 tonnes
(equivalent to 0.5 days usage)

These were minimum safety levels; site log inventories were built up on top of these levels Monday to Friday each week to cover five-day supply, seven-day usage pattern, and also built up to cover long holiday and Christmas periods. Thus the safety levels applied to the log inventories which should be on site on the next 'normal' Monday morning.

Wood inventories were also held in the forest at roadside landings and on the mill chip piles.

These first studies reported that the costs of handling inventory and of running out of wood, had only a small influence on the optimum minimum inventory level.

In 1974, following a doubling in pulpmill capacity and massive increases in finance interest rates (and therefore the cost of holding inventories) the log inventory policies were re-examined. This time a simulation approach was used. Historical distributions of log supply and usage, the costs of holding inventory, the costs of running out of wood and the costs of taking extraordinary measures to maintain supply, were combined in a stochastic simulation model. As a result, the recommended optimum safety levels for site log inventories (pulpwood and sawlogs combined) were:

7,000 tonnes
(equivalent to one day's usage in total).

And the chance of running out of wood was estimated as being once every four years. Despite the major changes in the magnitude of some of the inputs to the calculations, there was remarkably little change to the total inventory policy levels as a proportion of usage. The sensitivity of the optimum inventory level to changes in the various inputs was tested. It was found that the optimum levels were primarily a function of the patterns of variation in supply and usage, and were not at all sensitive to the cost of capital, the cost of running out, or the cost of handling excessive inventories.

A similar simulation approach to setting optimum inventory levels was subsequently applied to an Eastern Canadian pulpmill and similar principles emerged, i.e. that optimum inventory levels are primarily a function of the variations in supply and usage (Galbraith, 1977, Galbraith and Meng, 1981).

These findings are not too difficult to rationalise. For a reasonably balanced wood flow system, there will be a level of buffer inventories which will reduce the chance of running out of wood, and of overstocking, to an acceptably low level. At this level, the costs of such consequences are reduced by the same low level of probability.

Returning to the Kinleith experience; policies for log inventories were then set as:

Site:	
Pulpwood	4,000 tonnes (1.4 days usage)
Sawlogs -	
summer	1,875 tonnes (0.5 days usage)
winter	2,500 tonnes (0.7 days usage)
Forest:	
Pulpwood	15,000 tonnes (2.6 days usage)
Sawlogs -	
summer	5,000 tonnes (1.4 days usage)
winter	7,000 tonnes (2.0 days usage)

The forest log inventories were not set by scientific means, but rather by experience. At levels below those set, it was found that loaders spent an excessive amount of time shifting, and truck utilisation dropped off. Any loss in efficiency in loading and trucking would quickly negate the relatively small gains in reducing capital invested in inventory at this lower cost stage.

In addition, buffer stocks of chips were held on site on outside chip storage slabs.

PRODUCTION CONTROL

Classic inventory theory speaks of 'inventory control', i.e. the direct management and manipulation of inventories. In the wood supply system however, inventory control is a misnomer. Since wood inventories can generally not be manipulated by selling off excess or buying in to make up, it follows that the only effective action is to deal with the cause, not the symptom.

Fluctuations in inventories are a result of imbalances in supply and demand. Since the wood supply manager can generally not influence demand, if he is going to try to adhere to inventory policies he must have an effective method of production control.

A formal system of log production control was introduced at Kinleith in 1976. The basic planning horizon was set at one week. Log inventories in the forest were estimated at the end of each week and inventories on site were estimated daily.

The simple arithmetic basis for determining target log production for the week was:

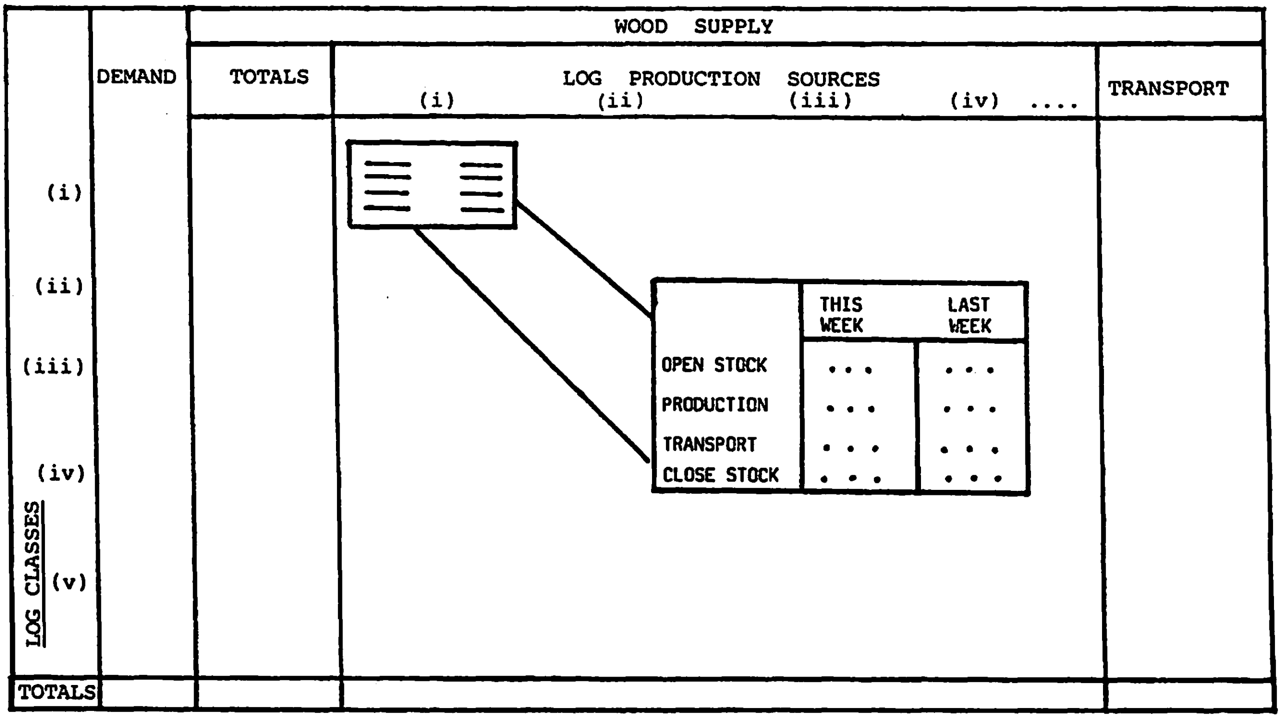


FIG. 2 - PRODUCTION CONTROL MATRIX (for weekly planning and control)

> Forecast demand, plus target (policy) site and forest inventory, less actual beginning inventory.

and for determining target log transport (delivery) was:

> Forecast demand, plus target site inventory, less actual site inventory.

These targets were then entered on a production control matrix board (fig.2). The matrix was broken down into the different log classes and log sources and discussed among the wood supply management people at the beginning of each week. At the same time, using measured delivery information and inventory change estimates, the actual productions and deliveries for the previous week could be compared to the plans for the previous week.

The advantage of the system was that it very closely linked forecast demand and planned supply, and kept log inventory targets as objectives each week. It also gave quick assessment of the effectiveness of control. The feedback loop linking supply and demand was very short and reactive.

Experience showed that the system was just too dynamic to be controlled this closely. Fluctuations in demand in particular sometimes caused actual inventories to move significantly away from target within a week. Target inventories (particularly on site) were quite low compared with weekly demand, and it didn't take much of an imbalance in flow to cause a major inventory movement.

When this happened, it became unrealistic to expect the system to be returned to target in the next week.

At each processing stage of a wood flow system, the general objective of its management is to achieve stability and security. Apart from the fact that people generally like to be stable and secure, it also helps to improve efficiency. A logging crew, for example, cannot be expected to operate efficiently if it is constantly being required to move its output up and down, and jump from area to area. As noted before, losses in efficiency can quickly negate gains in e.g. inventory costs.

Yet if wood flows are to be kept in reasonable balance, and if the obvious benefits of optimum inventory levels are to be achieved, some degree of production control must be exercised.

The compromise was to move away from the objective of returning to target inventory levels necessarily in one week and to take a longer time horizon, appropriate to the size of the adjustment required.

This introduced another level to the planning process; a set of programmed productions and transports which were an agreed plan of action, often different to the target. The program figures represented the compromise of moving the system back toward target, but at a pace acceptable to the production management.

In summary, the three levels of weekly production planning and control data were then :

> Target - a strict arithmetical calculation of demand, plus or minus an inventory adjustment to return inventories to target.
>
> Program - an agreed plan of action, often different to target, but normally reflecting a move toward target.
>
> Actual - the actual productions and deliveries at the end of the week, which could be compared to program to test the ability of area management to adhere to agreed plans.

EFFECTIVENESS OF CONTROL

In 1978 author O'Reilly began studying the wood flow system at Kinleith to identify its particular relationships. As an outside view it gave an interesting assessment of the effectiveness of the production control.

While numerous texts describe the techniques used in modelling (e.g. Daellenbach and George, 1977), there are few examples of the application of such techniques to the modelling of wood flow. Lönner (1968) and Newnham (1975) both applied linear programming to a wood supply problem to minimise the total cost of wood supply; however, both assumed a fixed mill demand situation. Hewson (1960) studied the dynamics of inventory using simulation in a variable demand situation, although his model allowed only restricted variation in both supply and demand. The above studies also suffer from a fault common to most forest operation models, which is to emphasise planning, with little thought to control: "To a considerable extent, control of operations has been left to operating personnel. The result is that planning and control have largely been done in isolation from one another, with little feedback from control personnel to planning personnel and even less attention by planners to the special problems of operational control" (Dykstra, 1981). The important characteristic of this operation is that the planning and control are purposefully linked, and thus in the research into the system, this connection is of prime importance.

The wood flow system at Kinleith was modelled to represent the planning and control activities under normal conditions (i.e. no major strikes or mill shutdowns). In the models, the relationships between the various stages in planning and control (i.e. demand → target → program → actual, for both wood production and wood transport) were derived; measures of variability were included in the models to reflect the real-world variation experienced.

Historical data was used to validate the model and then to study the significant relationships within the system.

Some important results of the study were :

The major inputs to the planning and control system are :

- The estimated log inventories in the forest and on site at the beginning of the week.
- Forecast demand for the different wood classes, expressed on a weekly basis.

(i) Estimates of inventories :

The accuracy of the estimates of log inventories are important on three counts :

- log inventories are a component of the formula for calculating required log production and deliveries for the week ahead.
- log deliveries are measured by weight coming on to the Kinleith site. Mills on site are fed directly from trucks or from stockpile. Therefore the actual input to a mill is assessed from the daily haul plus a stock adjustment.
- log inventories are also a component of the formula to calculate actual production and delivery.

Estimates of log inventories on forest roadside landings were known to be coarse and prone to error, depending on the experience and skills of the 20 or so different people making the estimates.

Log inventories on site were also estimated by eye but generally by the same one person and were independantly surveyed each month by volume measurement of the log piles.

Although there was more confidence in the estimates of the more critical site log inventories, there was a general requirement to improve estimating, as errors could not only result in incorrect planning, but also compound the problems of control.

(ii) Estimates of demand :

Each week the wood-using mills provided estimates of log demand for the coming week. For most of the mills the model showed that there was reasonably good correlation between actual usage and forecast demand. However, for one mill, unfortunately the largest user, forecasting was very poor and the model in fact showed little correlation between what it actually used and what it said it would need. Forecast demand was often set at or near mill capacity and so variation was normally in one direction - down. Being such a big user, the result was that log inventories in that class would often move very rapidly up, certainly at a faster rate and to a level beyond which the weekly control system could cope. The downward fluctuations were due to internal mill factors which are not within the control of the wood supply personnel.

Wood supply was then faced with an extended period of production control to try to bring the system back to target, often taking many weeks. The study added weight to the long term complaint of the wood supply people - the need for more reliable forecasting of demand.

In recent years forecasting improved as mill production became stable and as more realistic mill production targets were set.

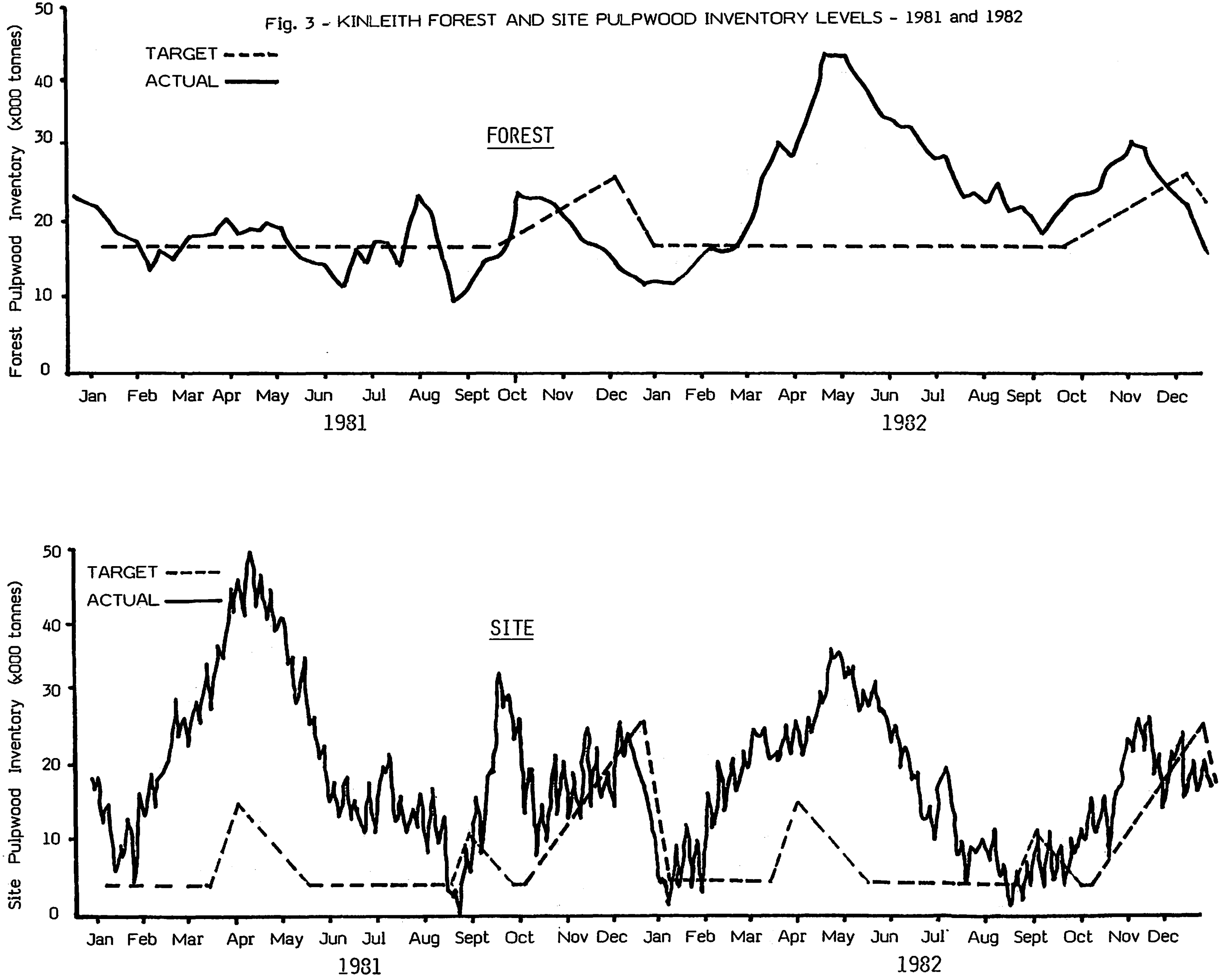
Another interesting use of the modelling was to assess the effectiveness of wood flow control. As an example, the general finding was that there was reasonable correlation (though lower than expected) between actual and programmed log production. However, the performance of the transport phase was more significantly influenced by the forest log inventories, i.e. the wood <u>available</u> to haul, than the program, i.e. what was <u>required</u> to haul.

The transport phase, despite planning targets, was tending to work to move forest inventories, particularly if they were above target, and this in turn encouraged log production. This latter was a natural tendency of the production crews - somebody obviously wanted their wood!

The result was that the site inventories would build up and not until the log yard filled would transport slow and in turn slow production. The system was being driven by the supply end, not the demand end. Reaction to variation in demand and to inventory fluctuations was too slow as a consequence.

The solution was to put a lot more attention into requiring transport to hold to plan. If transport was reacting more quickly to demand this in turn would demonstrate, quickly and practically, the demand pattern to the producers. This helped reinforce, in a practical way, the message coming out of the weekly production control planning meetings. This was successful and, apart from taking a lot of inertia out of the control system, tended to push more inventory fluctuation out to the lower

Fig. 3 - KINLEITH FOREST AND SITE PULPWOOD INVENTORY LEVELS - 1981 and 1982



cost forest end.

Figures 3 and 4 show the actual pulpwood log inventory levels in the forest and on the site for the years 1981 to 1983. Some observations :

(i) Three planned inventory buildups occur each year :

- in December to cover the reduced deliveries during the holiday period
- in April and either September or October as a result of planned maintenance shutdowns on pulpmill equipment.

These planned buildups are superimposed on the target inventory levels and the objective is to get inventories back to target as soon as practicable after the event.

(ii) The shape of the inventory profiles shows the tendency for the inventories to build up rapidly, generally due to a shortfall in usage, and then taking a considerably longer period of production control to bring the inventories back to target.

(iii) Comparing years 1981 and 1982 illustrates the effect of using transport more effectively in the control procedure. In 1981 a series of mill production problems in February and March, followed by an extended maintenance shutdown in April, caused a significant drop in usage. Because the transport phase did not react quickly enough to the reduced demand, site inventories continued to build up to the point where the mill yard was full. Through all this the forest log inventories did not move much at all. Thus the problem was carried at the highest cost stage, and incurred significant costs of handling excess stockpiles on site.

In 1982, when a similar pattern of reduced demand occurred, transport was controlled more effectively to match demand on site and most of the buildup in inventory was taken at the forest end.

As a final word on the effectiveness of the overall wood control system; the mills have never (barring major industrial action) run out of wood, and the system has operated with a site log yard which will hold at most only five days usage.

SUMMARY

Over the past 19 years at Kinleith, a process of scientific investigation, evolution and experience has produced a production control system which has successfully maintained wood supply with minimal log inventory holding facilities. The basis of control is a weekly planning and control procedure involving management directly concerned with wood supply. A series of optimum log inventory levels have been calculated which minimise the expected total cost of holding inventories (including the costs of running out of wood) and these optimum levels are used as planning targets. The procedure moves through the stages of :

TARGET = Forecast demand
+ target inventory
- actual inventory

PROGRAM = Agreed plan of action, moving toward target

ACTUAL = Actual performance at week end which can be compared with program.

Key inputs to the procedure are forecast demand and inventory estimates and it is important that these are as accurate as possible.

Close control of the transport (delivery) phase proved to be the most effective way of controlling the higher cost site inventory levels and influencing log production.

With the above procedures it has been possible to maintain a log supply of 2.5 million tonnes p.a. of a variety of different log classes, with a safety site inventory of only one day's log supply and a maximum site log yard capacity of only five days supply.

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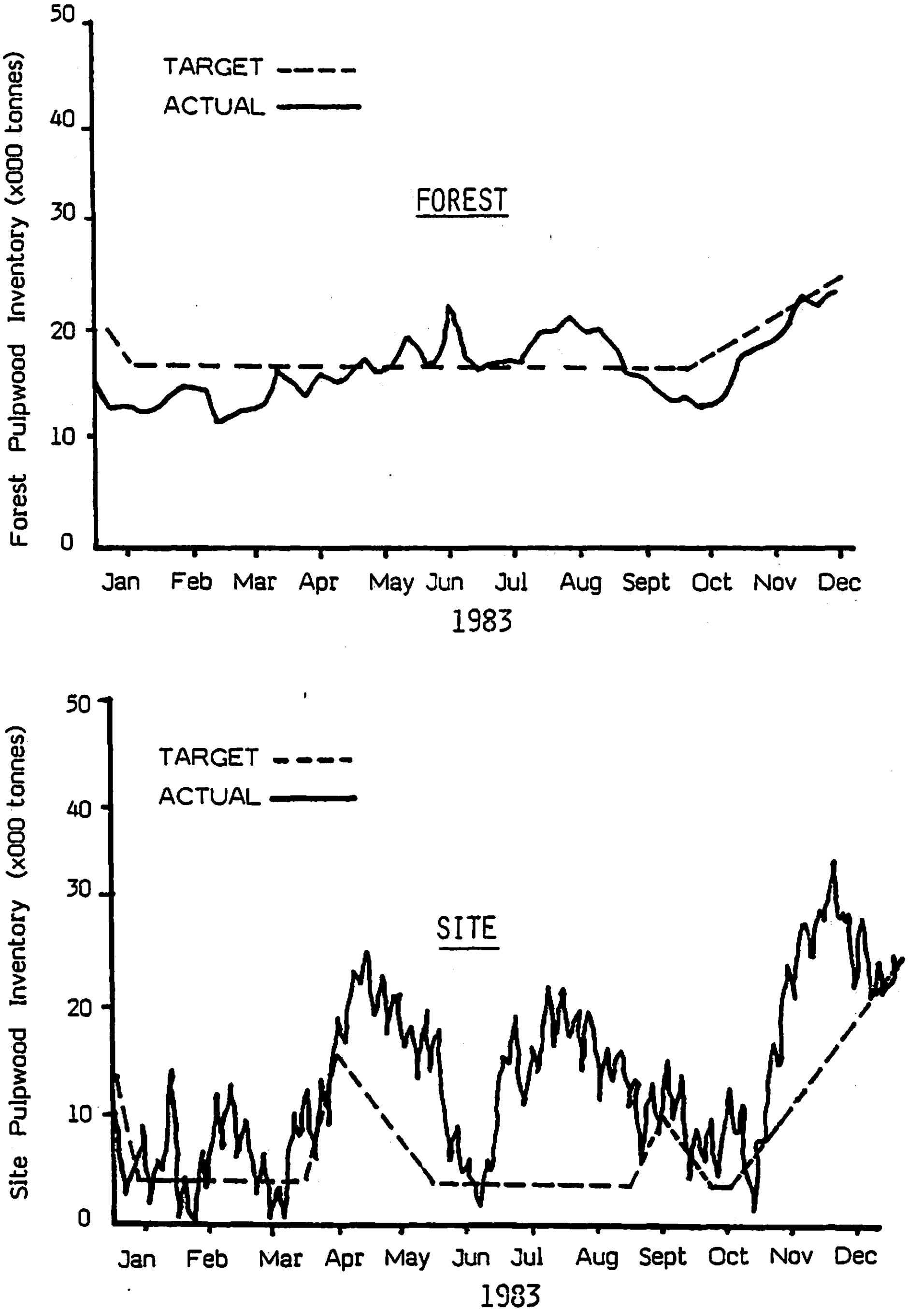
Fig. 4 - KINLEITH FOREST AND SITE PULPWOOD INVENTORY LEVELS - 1983



EFFECTIVE FOREST ROAD PLANNING FOR FOREST OPERATIONS AND THE ENVIRONMENT[1]

Yasushi Minamikata[2]

It is now the most important to minimize the influence of forest road construction on the forest environment. In this paper, methods to estimate the total length of forest roads in a planning area, to locate the roads as a networks, and to select the optimum route of the main forest roads etc. are presented.

INTRODUCTION

About sixty seven percent of the land area of Japan is covered with forest from the sub-tropical zone in the south or at low altitudes to the sub-frigid zone in the north or at high altitudes. The average temperature in the summer season is fifteen degrees and the average annual rainfall is 2,000 millimeters. Such a warm and rainy climate favors the growth of trees and the appearance of artificial forests might be traced back to about 400 years ago. Thirty nine percent of the forest area is now made up of artificial forests and the dominant species are japanese cedar, cypress,and larch. The Forest Agency in the long-range plan intends to enlarge this to fifty two percent by 2,025 A.D..

It takes more than two centuries for forest to recover from the damage caused by harvesting and revert to useful softwood forest again. In contrast the regeneration periods if artificial methods are used in less than seventy five years. However, in comparison with natural regeneration, artificial regeneration requires a lot of labour for planting, weeding, pruning and thinning. Usually, 200 to 400 men per hectare are said to be required through the entire regeneration periods, though this varies with tree species, regional customs, etc..

Generally speaking, the greater the labour required in stand establishment and the higher the labour cost, the more significant will be the road network in the forest. The Forest Agency therefore, in the long-range plan, calls for the opening up 440,000 kilometers of roads in the forest area, equivalent to eighteen meters per hectare when public roads passing through the forest area are included. But so far this has not been achieved and the present densities are very low compared to the target. In such circumstance, the demand for the expansion of the forest road system becomes greater.

On the other hand, there is a tendency to emphasize the influence of forest road construction on the ecosystem or natural environment of the forest. Opening up forest roads occasionally causes land slides sometimes on a large scale, so that it is very important to assess not only the economic effects of road construction on forestry but also the various impacts acting on the environment of the forest before building a dense road network.

DETERMINATION OF THE TOTAL LENGTH OF FOREST ROADS

There are three kinds of forest road in Japan, first, second and third class. The former two classes are forest roads for ordinary logging truck use. First class roads are trunk roads within the forest road network. Second class roads are the most popular and the total length constructed annually is far greater than that of first class roads. Third class roads are roads for the use of light types of vehicle with engine capacities less than 500 cubic centimeters. The main standards of the geometrical design are shown in table 1.

Table 1.--Standards of main geometric design of forest roads in Japan.

Road class	Design speed	Width	Shoulder	Radius	Grade
	(km/hr)	---------(m)---	-------------	----------	-(%)--
1st	40(30)	4.0	0.5	60(40)	7(10)
2nd	30(20)	3.0	0.5(0.25)	30(20)	8(12)
3rd	20	2.0	0.5(0.25)	15(12)	9(14)

The figures in parenthesises are allowable values under the special conditions respectively.

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[1] Paper presented at the conference COFE/IUFRO - 1984. Fredericton, N.B., Canada, 15-18, August.

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Forest owners, including The National Forest Service, wish to increase the total length of road in their forest area as quickly as possible, so the length of third class roads opened annually is equivalent to or greater than the total length of first class and second class roads. The reasons are that low class roads are not expensive to construct and, if necessary, they can be upgraded in the future.

Under such circumstances, it is considered that it is time to introduce a new idea into the road network system, i.e. the compound road system which is composed of more than two kinds of forest road, not only high class roads but also low class roads (Minamikata 1977,1983). In this system, two kinds of forest road densities should be calculated first. One is the density of high class roads(d_C) at which the production costs of the two logging systems shown in figure 1 are equivalent to each other. The road system should be changed from the high class to the low class one once this density is reached. The other is the target density (d_l). The formulae to calculate forest road densities are as follows and include various factors such as the average volume to be harvested in cubic meters per hectare (V), labour costs in yen per hour (C_W), labour consumption in men per hectare during the plantation period (N_W), and non-productive wage owing to the lack of forest roads, e.g. to account for the walking time from the road side to logging site.

$$d_l = 50(\alpha_l \cdot V \cdot (1+\eta) \cdot (1+\eta'_l)/r_l$$
$$+ k \cdot (1+\eta) \cdot C_W \cdot N_W/500 \cdot S \cdot r_l)^{\frac{1}{2}} - d_0$$

$$d_C = (p^2/4 - q)^{\frac{1}{2}} - p/2$$

where $p = d_0 + (\beta_H - \beta_l)/(r_H - r_l) \cdot V$

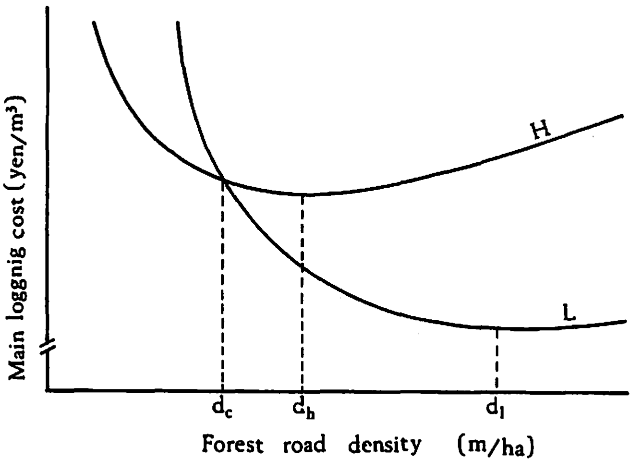

Figure 1--Concept of compound road network system. H : logging system with high standard roads and long span cable yarding. L : logging system with low standard roads and short span cable yarding.

$$q = (p - d_0) \cdot d_0 + (2500\ V \cdot (1+\eta) \cdot (\alpha_H \cdot (1+\eta'_H)$$
$$- \alpha_L \cdot (1+\eta'_L)))/(r_H - r_L)$$

r : unit cost of road construction (yen/m), S : walking speed of labours (km/hr), k : the coefficient of the increment of the walking distance, and α ,β : coefficient related to the prehauling cost, d : density of public roads in the forest area.

The length of each class of road to be planned should be calculated from the densities of forest roads. From the point of view of the expansion of the forest road network, high class roads should be constructed until the point (d_C) attained. After that, the construction of low class roads should be continued until the target density (d_l) is reached.

COMPUTER LOCATION OF ROAD NETWORK IN OUTLINE

The overall planning of the forest road network consists of two main processes. One is the determination of the forest road length to be constructed, and the other is the location of the optimum route of the network. The former can be obtained by calculating the densities of each road class. As for the latter, there have until recently been no theoretical methods. Therefore, route location is left to the individual engineer in charge of the planning of forest roads. This ought to be a person of experience as it is desirable that route location is entrusted to an expert. But it seems to be almost impossible to maximise the effect of forest roads throughout the planning area.

A theoretical method to locate forest roads has been developed recently (Kobayashi 1983) and has proved to be applicable to network planning in mountainous regions. The operational flow chart of the planning system for route location using a computer is shown in figure 2. "A" in the figure represents the preparation of the data and is divided into three parts. The first is the process to produce a digital terrain model of the planning area and to define values such as the construction cost of roads, the cost of prehauling and the cost of the unproductive labour. The second is the process to prepare data concerning the condition of the existing road system in the planning area. The third is the process to obtain the data such as the timber volume to be harvested and the amount of labour per hectare needed for stand establishment. "B" is the process to calculate the road length required and to estimate the investment effect of road sections. "C" outputs the results.

The planning system for route location is based on the mesh analysis method. Using this method, the forest road is extended section by section. Extensions consisting of roads along the sides of the grid or along the diagonal except the direction along which the route has already been laid are considered and road section which has the highest economic effect will be selected as the next route section to be extended. The procedure is then

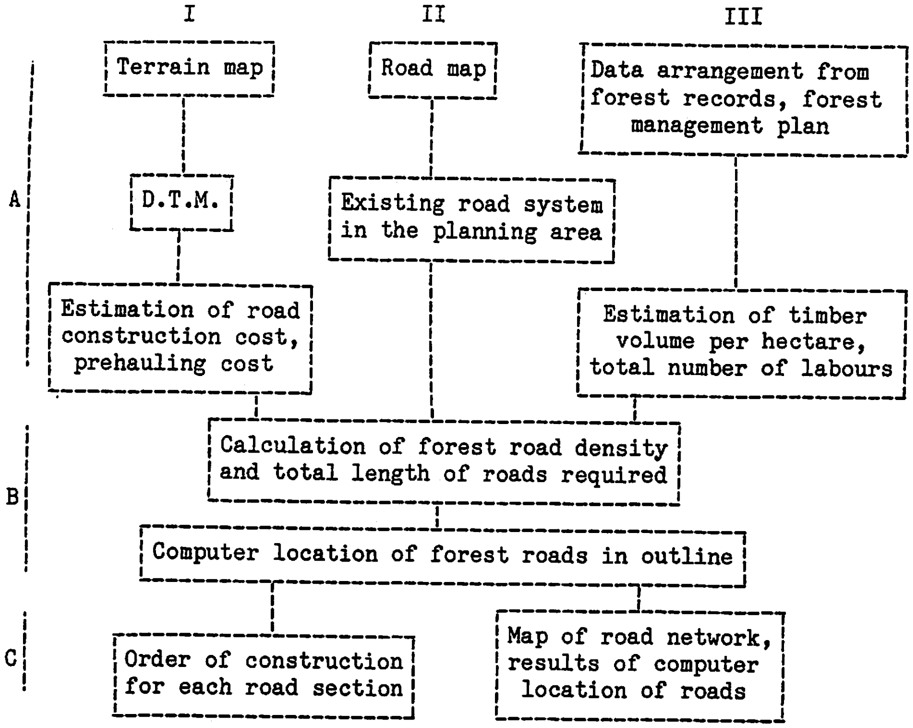

Figure 2.--Operational flow chart for planning system for road-route location with an electronic computer

repeated from the new starting point. The route location, using a computer as mentioned above, will be continued until the length of the forest road is equal to the target length in the planning area. As a result, this method can provide the planner of the forest road network with an optimum location for the road route.

The results of this method may not be accurate enough due to the limits imposed by using mesh analysis. But the planner, using the results shown in figure 3, will be able to make a plan confidently or objectively on a terrain map of the planning area to the scale of 1/50000 or 1/25000. This is the great merit of a computer aid for route location.

ROUTE PROJECTION FOR TRUNK ROADS

Long forest trunk roads often pass through two or three water-sheds. As a matter of course, there is a high probability that they will pass through high altitude and cross steep mountain slopes and have a serious impact not only on the forest environment but also on the scenery.

Until about ten years ago, forest road engineers did not pay enough attention to the environmental damage caused by opening up forest roads or to construction techniques designed to minimize disasters. A lot of damage occurred to the forest environment. This led to or stimulated the move-

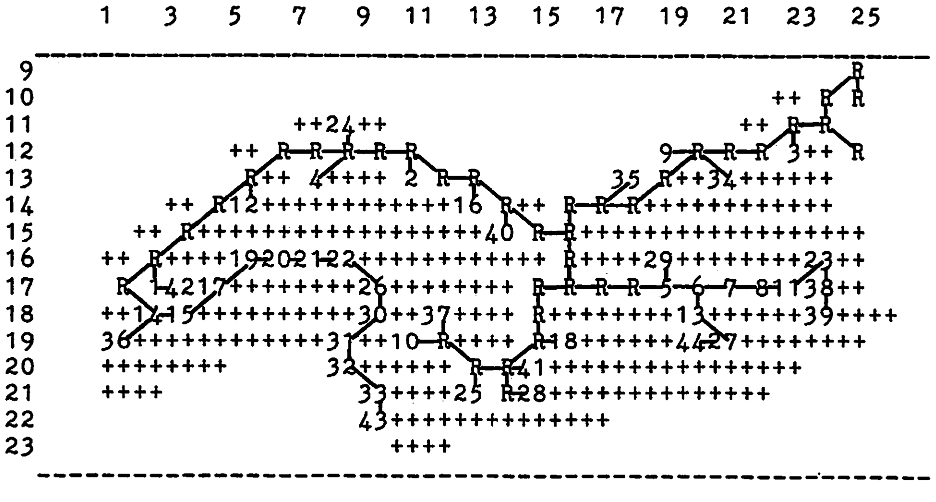

Figure 3.--Results of computer location of road network. R:existing roads, Figures:order of construction.

ment for nature protection, and made us realize the necessity of establishing new methods to find the best route which might cause minimum damage to the forest environment.

Nowadays, route location for long trunk forest roads is carried out using the mesh analysis method as follows (Minamikata 1983).

The planning area, which might be the service area for the road, is covered with rectangular grids 500m by 500m and each grid is numbered. After this process, the following items are estimated and scored for every grid.

Estimation category A : factors related to the conservation of forest land, such as the land slope, calculated from the altitude of the grid corners, classified into five grades (less than 15°, 15° - 25°, 25° - 35°, 35° - 45°, more than 45°), the area ratio of landslides to the grid area, classified into three grades (less than 2 %, 2 - 10 %, more than 10 %), existence of fault lines or a fracture zone, classified into three grades (none in or around the grids, none in the grid but around, in the grids) and the existence of creeping land classified into the same grades the previous factor.

Estimation category B : factors related to nature conservation such as the designation of protection forests, National or Prefectural Parks, and existence of significant species of floura or fauna. Scoring of these factors is adjusted according to the type of forest in the grid. For example, in a grid containing National Park forest the scores for the category would be increased, etc..

Estimation category C : factors related to forestry such as the volume of timber per unit area, artificial forest or not, and stand age.

The next step in the route projection is the calculation of a total score for each road section from the mesh i to j which are connectable.

Defining $(E_e)_{ij}$ and $(E_f)_{ij}$ as the sum of scores included in category A and B, and category C for grid i and j respectively, the total score for the same road section from grid i to j, $(E_t)_{ij}$, is given by the following equation.

$$(E_t)_{ij} = ((E_e)_{ij} \cdot k_e + (E_f)_{ij} \cdot k_f) \cdot (D_{ij} \cdot (1+S_{ij} - M)/M)^{k_r}$$

where k_e: the weight for categorys A and B (environmental factors), k_f: the weight for the category C (forestry factors), k_r: the weight for the construction cost of roads, D_{ij} : distance from mesh i to j (rectangular direction : 500m, diagonal direction : $500\sqrt{2}$m), S_{ij}: the average gradient between mesh i and j in percent, and if S_{ij} is less than M, then $(S_{ij} - M)/M$ is taken as zero.

The optimum route for the forest road is shown as a series of grids by using the shortest path algorithm from the theory of graphs (Iri 1976). Up to five terminal points of the road may be preappointed. As a result, routes equal in numbers to the combination of the start points and end points will be generated. It is also possible to appoint some points through which the road has to pass. The final route will be chosen from these alternative routes, which will have the minimum total score for $(E_t)_{ij}$.

Figure 4 shows the series of grids as an outlined location of the forest road. The dotted line shows the result in the case that intermediate points are preappointed. The topographic map overlapped with the series of the grids as an outlined location of the forest road will be very helpful for the road engineer to make a route projection within or along the series of grids or in adjacent grids on the contour map. This method is useful and sufficiently accurate for route location on the map.

If the final route passes through grids with high scores, attention must be payed to the design and construction of the road sections and it must be made clear what kinds of countermeasures should be adopted. Furtheremore, some countermeasures to maintain scenic beauty should also be indicated for those places which can be seen from several view points within a four or five kilometer zone on both sides of the final route.

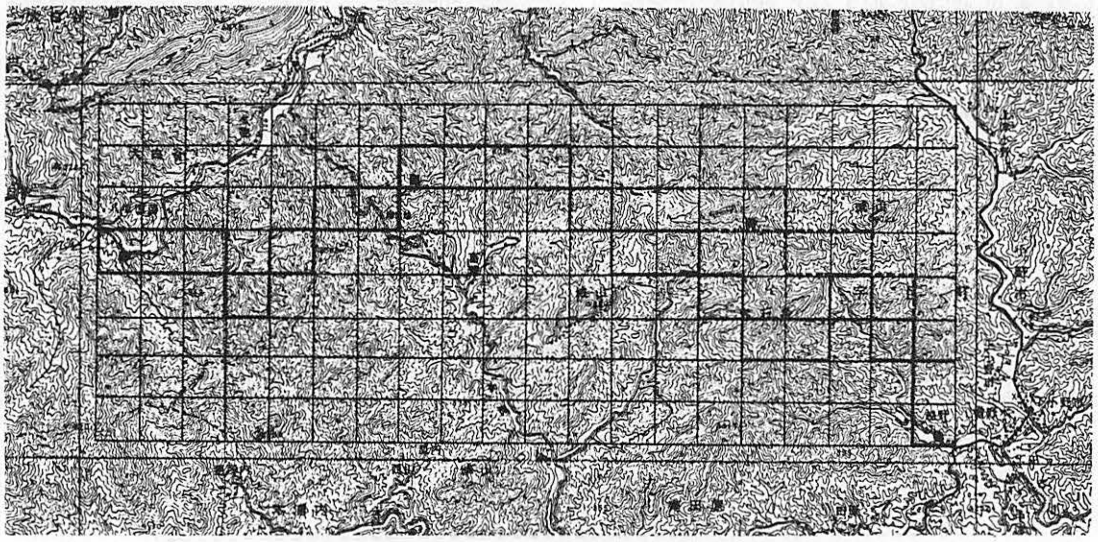

Figure 4.--Contour map overlaped with the series of grids showing the best route for the forest road.

SOME CONSTRUCTION TECHNIQUES FOR PREVENTING THE FOREST LAND FROM DAMAGE

The main machine for the earth work

The construction of high standard forest roads is often accompanied by a large amount cut and fill works, especially in steep terrains. It usually results in a lot of waste material being produced along the route. Until recently an angle-dozer had been the major machine for earth work of this type and it could only push the residual soil or rock outside the right of way to the down slope, the vegetation on the mountain side below the formation line of the road was injured or killed by the dumped material. This aroused a lot of emotion.

About six or seven years ago, the angle-dozer was replaced with the back-hoe, which is nowadays the most important machine for earth work and it can treat waste material efficiently without the accompanying serious damage to the forest environment. Cutting works on steep mountain sides are carried out with this machine and the waste materials are removed by dump truck to a special disposal area on a gentle slope (figure 5). The angle-dozer is only used as a supplemental machine for earth work at present.

The road side and occasionally the foot of the disposal area are strengthened by concrete or concrete block wall.

Slope seeding

Grass seeding has become a very common treatment for slope stabilization during the final stage of forest road construction. Usually, grass seeds are sprayed by compressor on the slope together with a base material which consists of wood fibers, adhesive and fertilizing materials, or the slope is covered with many sheet of wood fiber mat holding grass seeds and the fertilizer (figure 6).

The surface erosion control is indispensable from the view point of land protection in order not only to prevent the slope from erosion, such as the formation of small gullies, but also to improve the appearance of the road side.

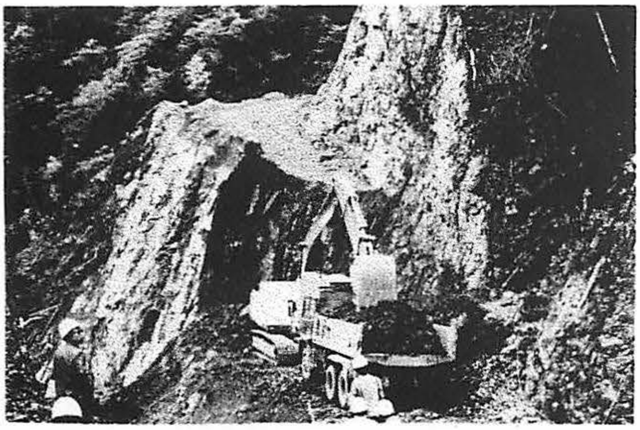

Figure 5.--Earth work with the back-hoe and dump trucks.

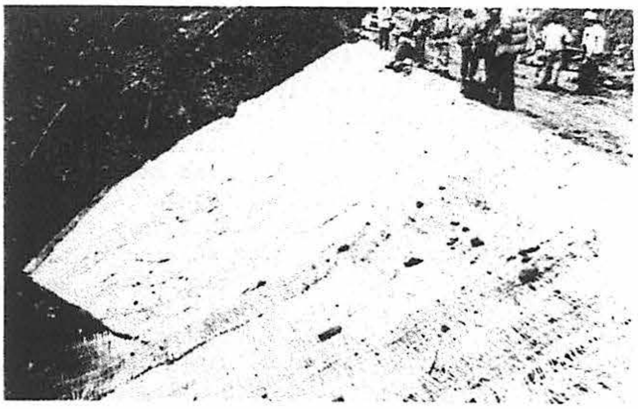

Figure 6.--Slope seeding covered with straw blind.

Cut slope in rocky places are usually left alone, but they are covered with cement mortar reinforced with metal net if there is the possibility of dangerous stone fall in the winter season. The bank slope of the disposal area is also sprayed with mixed grass seeds to protect against rain-wash.

Drainage

The control of both stream water and run-off flowing down the road surface is very important to keep the road base and road surface in good condition. The road surface should be periodically reshaped with a motor-grader to reshape dips. But in Japan, the resources for road maintenance are often not enough to keep forest roads in good condition. Therefore the control of water or the road surface becomes more and more important, especially in view of the high rainfall in Japan.

Various type of open-culverts have been developed and are coming into wide use. They are usually installed at about a thirty degrees angle down grade. They have proved to be very effective for intercepting runnoff flowing down the road surface. The open-culvert on the road sueface might be spaced in accordance with the grade of the road as shown figure 7.

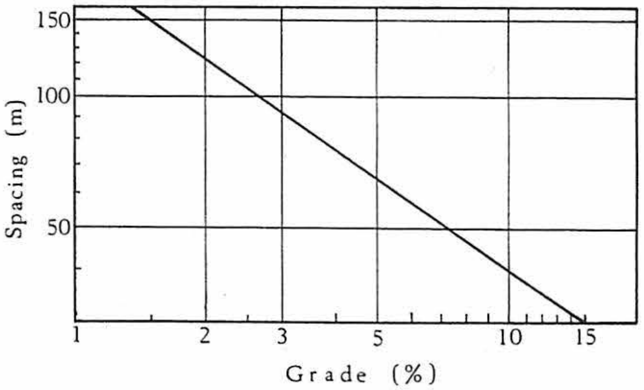

Figure 7.--Spacing standard of the open-culvert on the forest road surface.

LONGITUDINAL GRADE OF ROAD

In order to build up a road network as quickly as possible, it is practical to construct branch roads of a low standard. The standards of road grades at present in force are shown in table 1. This shows that the lower the road standard, the steeper the longitudinal grade of the road which can be adopted. In keeping with such a standard, most low standard roads, which must be in the majority, may be constructed with a steep grade. This results in the erosion of the road surface or the road bed, and land slide of the slope along the route is frequently caused by water flow running down the road surface along wheel dips. This is especially so in places where precipitation is high and terrain is steep. It indicates the necessity to reconsider the standard of the longitudinal grades of forest roads, considering that sixty five percent of damage to forest roads in mountainous areas is brought about by water flow on the road surface.

Low standard forest roads should not only be in low cost but also should be highly resistant to erosion. These conditions will be satisfied by keeping the longitudinal grade gentle for low standard forest roads, for example under five percent. On the other hand, steep grade as are adopted for low standard roads i.e. ten to fourteen percent may be permitted for forest roads of high standard, if necessary because of terrain conditions, and in exchange for using steep grades, the road surface of high standard roads should be paved in order to prevent the erosion or destruction caused by rain-wash on the road surface. Because high standard roads are to be permitted to budget the necessary funds for their construction.

Considering that about ten percent of forest roads with high standard have been paved, the paving of the main forest roads are no longer only a dream, on the contrary, it seems to be an essential treatment for main forest roads from the view point of land protection.

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INTERACTION OF HARVESTING AND STAND ESTABLISHMENT IN HARDWOODS IN EASTERN NORTH AMERICA[1]

John C. Lees[2]

Abstract.—Harvesting methods affect the ease or difficulty of subsequent hardwood forestation. The trend in eastern North America is to clear-cutting and mechanization. There are problems associated with the existing, often decrepit hardwood forest and the new forest for the next rotation, and with a seeming overabundance of natural regeneration to less valuable species. New designs for logging equipment are required if thinning and shelterwood systems are prescribed.

INTRODUCTION

Silviculture is the art and science of growing trees in forests to fulfill a management objective. Harvesting is a silvicultural treatment that usually meets such an objective and yields a wood product. Other objectives that may be met are improvement of wildlife habitat, salvage of damaged stems, control of snowmelt, creation of recreation opportunities such as skiing and hiking, and wood fibre production.

In production forestry, when the object of management is a sustained yield of wood products, harvesting methods interact most importantly with the relative ease or difficulty of stand establishment and reestablishment. Delays are costly. Instant forestation is the ideal, so that the annual allowable cut effect may be applied and more mature merchantable timber cut. When considering hardwood harvesting in the mainly mixed forests of eastern North America, an understanding of ecological succession and the silvics of species (pioneer, successional, and climax) permits certain predictions about stand establishment to be made, and to be made confidently.

In industrial forestry, and to a lesser extent in private nonindustrial forestry, the harvesting method of choice is clear-cutting, whether in large blocks, small patches, or strips (Marquis 1965). What is not merchantable is left standing, cut and left lying, or moved to trailside or landing and left lying. These residues from harvesting interact with stand establishment.

In general, it can be predicted that

1. Cutover hardwood and mixedwood stands will regenerate naturally to a higher proportion of pioneer (intolerant) hardwoods.
2. In the altered state of a clear-cut, advance growth regeneration will begin a recovery from logging damage.
3. Sprouting species will regenerate from cut stumps and root suckers.
4. Sprouts and surviving advance growth seedlings will dominate the regeneration scene at first.
5. Viable seed stored in the organic soil layers will germinate.
6. Light seed will be dispersed from the uncut stand margin and from standing residuals.
7. Heavy seed will be dispersed on the uncut stand margin and under standing residuals.
8. Competing ground vegetation will proliferate vegetatively and then from seed.
9. Aggressive pioneer species quickly invade unoccupied areas. Successional and climax species, which are nonsprouting and not present in the surviving advance growth, will follow later.

There should be no mysteries here. These sorts of predictions can also be made for forest types on the other side of the world. The silvics of the species harvested and to be reestablished, (table I) interact with stand establishment. This information from Leak et al. (1969), for example, would be a useful prediction tool in this region. It was collected for use in a guide to the silviculture of the northern hardwoods and forms the basis of the guide as modified for Maritime woodlot owners (Lees and Embree 1983).

Harvesting methods change as advances are made in forest engineering technology. The trend in the Northeast is to greater mechanization and to shorter rotations. The new hardwood forest will be managed as if it were a plantation, but the old hardwood forest still creates many harvesting problems. (Today's new felling head on a mechanical harvester may be on tomorrow's scrap

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[1] Paper presented at the conference COFE/IUFRO - 1984. Maine, USA and New Brunswick Canada, 12-18 August.

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Table 1. Silvical characteristics of the important species in the beech-birch-maple and associated types*

Species	Shade tolerance	Relative growth rate	Seeding frequency, good crops	Effective[1] seed dispersal	Minimum seedbed requirements	Sprouting vigor	Delayed germination
			Years	Tree heights			
Sugar maple	Tolerant	Medium	2-5	2-3	Light litter	Moderate	Possibly a small proportion
American beech	Tolerant	Medium	2-3	0-1	Light litter	Abundant root suckers	None known
Yellow birch	Intermediate	Slow to medium	2	2-4	Mineral soil or mixed mineral-humus	Very low	None known
Paper birch	Intolerant	Fast	2	2-4	Mineral soil or mixed mineral-humus	Moderate to low	None known
White ash	Intermediate	Medium to fast	3-5	2-3	Light litter	Moderate to high	Up to three-fourths germinate second spring
Red maple	Intermediate	Medium to fast	1	2-3	Light litter	Very high	Small proportion germinate second spring
Aspen	Intolerant	Fast	4-5	-	Continuous moisture	Abundant root-suckering	None
Red spruce	Tolerant	Medium	3-8	2-4	Moist humus or mineral soil	-	None known
Eastern hemlock	Tolerant	Medium	2-3	2-4	Moist humus or mineral soil	-	None known

[1] Effective seed dispersal means that roughly 50 to 75 percent of the seed falls within the given distance.

*Reproduced from "A silvicultural guide for northern hardwoods in the Northeast" with permission of the authors (Leak et al.).

heap, and the harvester retooled as a self-loading forwarder.)

In the Canadian Maritime Provinces, Rowe (1972) describes 13 Forest Sections of which 11 have an important hardwood component. Hardwoods comprise one-third of the forest resource. In New Brunswick, there are about 170 million m^3 of hardwoods (Baskerville 1976[3]) with a theoretical annual allowable cut of 2.8 million m^3 of which only 45% is currently harvested. In Nova Scotia, there are 75.6 million m^3 of hardwood of which only 40% of the annual allowable cut is currently harvested. Hardwoods occur in predominantly mixedwood cover types which when logged for softwood production tend to regenerate to the increasing proportion of pioneer hardwoods previously mentioned. Thus, while Maritime hardwoods are underutilized, quality is rapidly declining and softwood and hardwood managers are now faced with increasing areas of decrepit high-graded hardwood, damaged hardwood residuals, and increasing areas of vigorous pioneer hardwoods, many of stump sprout origin.

Lack of orderly use of the hardwood forest for production, protection, and amenity in the Maritimes; low demand levels; unreliability of markets; distance between quality hardwood use and quality hardwood producers, or between low quality hardwood use and pulpwood stands are recurring features of problem analyses (West 1976[4]; Lees 1982). Short-term production demands are unpredictable. Short-term utilization trends of even the traditional quality forest products

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[3] Baskerville, G.L. 1976. Hardwood research in the Maritimes. Unpublished manuscript. Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, N.B.

[4] West, R.C. 1976. The New Brunswick hardwood problem. Report to Maritime Section, Canadian Institute of Forestry, (Unpublished). 8p.

depend on widely fluctuating markets, transportation costs, and costs of woods operations. Long-term demands can be ranked with only vague predictions of unprecedented world consumption of hardwood products and the sustained importance of quality. Better markets would mean more complete utilization, a better integrated woods operation, and better silviculture. There are management and silvicultural problems associated with the existing, slow growing hardwood forest and also with the new forest to be established for the next and future rotations.

Research and development work now underway in eastern North America includes those problems of utilization of logging residues, natural regeneration responses to complete clear-cutting, and growth responses of hardwoods to juvenile spacing and fertilizing of overdense natural sapling stands.

Logging Residues

In a review of literature about hardwood silviculture and management, it was reported (Lees 1978),

> "The hardwood logging residue following conventional hardwood sawlog operations in the Appalachians is described in a case-study by Craft (1976). His example will serve to illustrate the sorts of materials generated by conventional logging in hardwoods:
>
> After the merchantable timber (12 inches dbh and over) was felled and removed, a typical acre within the 18-acre sample block was selected for close study. The first treatment was the removal of all topwood residue. All sound material that would give a straight or nearly straight piece at least 6 inches in diameter by 4 feet 3 inches long or longer was removed and decked for sawing. The remaining topwood material was stored for chipping. The second treatment was the felling and skidding of all residual trees that were 6 inches diameter at breast height or larger. The final treatment was the felling and skidding of all trees below 6 inches dbh which were weighed and piled for chipping. The total weight of all residues recovered from one acre was 69.3 tons! Topwood residue yielded 11 tons of sawable logs. Residual trees yielded 14.9 tons of sawable bolts and the weight of merchantable logs harvested from the 18 acre unit was about 40 tons per acre. Thus, for every ton of merchantable logs harvested about 1.8 tons of residue remained. The test sawing operation produced 8.2 tons of chippable slabs and edgings and 2.6 tons of sawdust. The chip yield was not assessed."

The problem of generating logging residue in hardwood and mixedwood stands is so serious that Martin (1976) prepared a logging residue yield table. Martin reports that the independent variables i.e., type of cut, products removed, basal area per acre, and stand age explain 95% of the variation in residue volume per acre. The yield table was prepared to show the probable residue volumes for different cutting practices at various levels of residual basal area, and stand age.

Logging residues are also being studied in New Brunswick by B.S. Chisholm, Valley Forest Products, and G.D. van Raalte, Maritimes Forest Research Centre (1980). Four logging intensities have been sampled

(a) Koehring feller forwarder (no clean-up)
(b) Koehring feller forwarder (clean-up)
(c) Conventional cut and skid (no clean-up)
(d) Koehring feller forwarder + conventional cut and skid oversize hardwood and softwood (clean-up) (table 2).

Table 2. Summary of logging production and costs

Treatment	Production	Cost/tonne
(a)	419.7 tonnes (chips)	$ 7.44
(b)	424.7 + 8.4 tonnes (chips)	8.26 + 13.92 (clean-up)
(c)	319.2 tonnes (round wood)	6.95 + 3.70 (estimated chipping cost)
(d)	367.7 + 22.9 tonnes (hardwood round wood) + 14.5 tonnes (softwood round wood)	7.99 + 12.57 + 4.50 + 13.61 (clean-up)

Clean-up (b) $13.92 and (d) $13.61 was costly. Because the roadside chipper has a screen for twigs, leaves, and loose bark, this discarded material was measured for one vanload of chips. It amounted to about 5% of the total feed. This is a significant proportion of the total biomass produced on these hardwood sites, and lost through processing in this way.

Regeneration Responses

My silvicultural studies in the Canadian Maritime Provinces include some examples of the sorts of interactions with which we are concerned today. Contemporary industrial clear-cuts were sampled beginning in 1977. When 10 clear-cuts were assigned to three original stand types; i.e. shade tolerant hardwoods, intermediate, and shade, intolerant, a large proportion of the natural regeneration (25-90%) was composed of the less valuable pioneer and successional species such as red maple, grey and white birch, and poplar (table 3).

A further examination of this regeneration in 10, 4-m^2 quadrats under the uncut stand, on the stand margin, and in the open clear-cut showed significant ($\underline{P} = \leq 0.05$) differences in numbers and origin. Regeneration of the more valuable shade tolerant sugar maple, ash, and beech in the open was mainly vegetative, (fig. 1). The heavy-seeded sugar maple germinated on the stand margin, the light-seeded birches also in the open, and red maple and white ash were intermediate.

Regeneration responses to pulpwood logging systems at Pokiok, N.B. are compared in table 4.

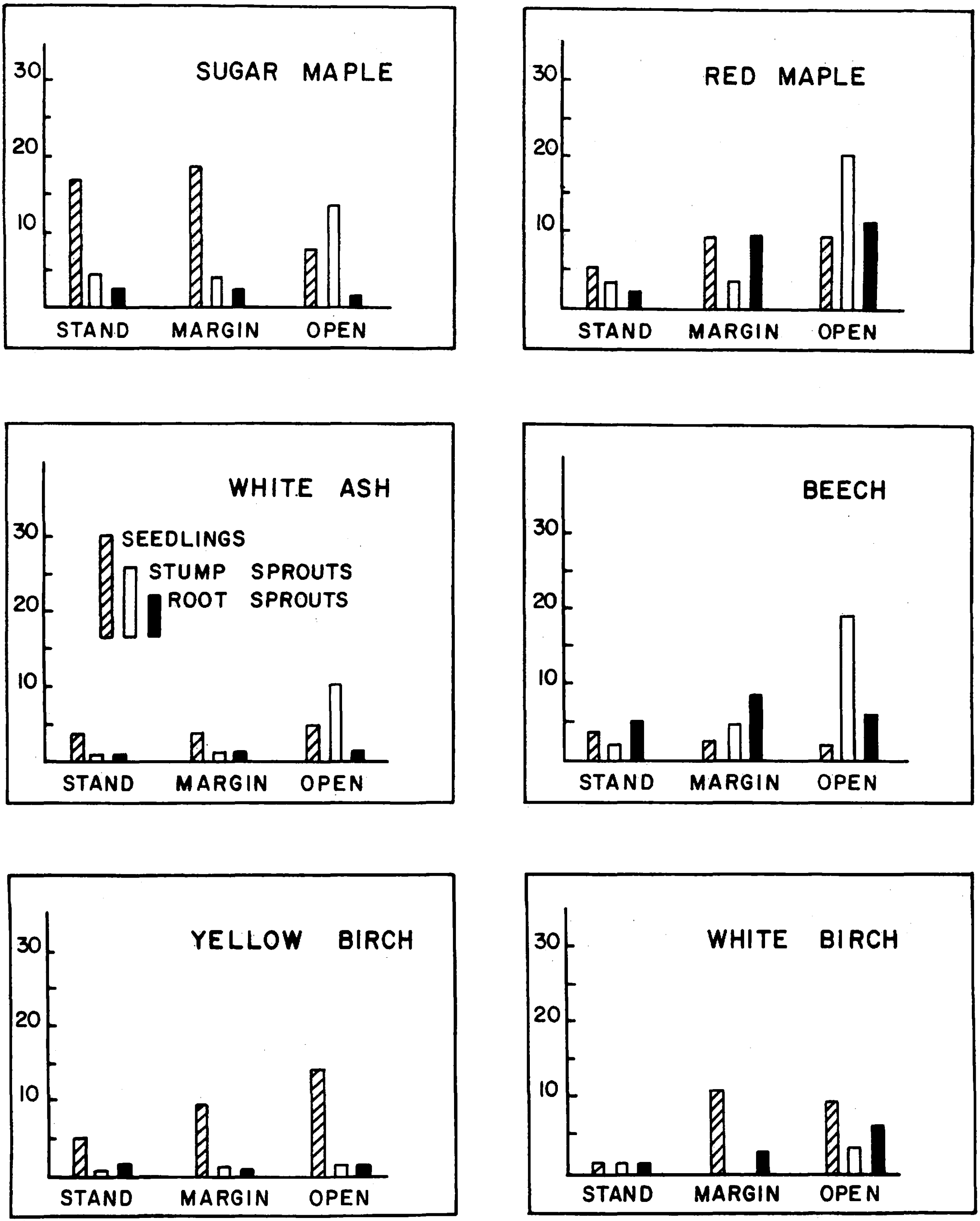

Figure 1. Number of stems and their origin per 40-m² transect (0.004 ha).

Table 3. Proportions of regenerating species (percentages)

Stand type	Location	Sugar maple	Red maple	Yellow birch	White birch	White ash	Beech	Poplar	Grey birch	Black ash	Total
Tolerant	Nashwaak	3	40	7	8	20	17	1	-	4	100
	St. Croix	18	8	29	1	8	29	2	-	5	100
Intermediate	Crowhill	8	21	15	36	-	20	-	-	-	100
	Acadia	-	59	-	22	-	-	-	19	-	100
Intolerant	Coles Island	-	73	-	1	-	-	16	10	-	100
	Anagance	-	40	-	-	-	-	27	33	-	100

Table 4. Percentage composition of natural regeneration by species and sprouts, Pokiok, N.B. June 1979 (n, 100 4-m^2 quadrats)

	Harvesting system			
	Conventional chainsaw cut		Koehring machine cut	
	%		%	
Species	Regen.	Sprouts	Regen.	Sprouts
Sugar maple	2	100	10	95
Red maple	51	44	20	93
Yellow birch	3	44	5	60
White birch	18	15	23	58
Beech	-	-	10	92
Poplar	1	25	4	8
Softwoods	20	-	5	-
Pin cherry	6	-	23	-
All	100	28	100	54

A Koehring feller-forwarder produced a 54% sprout regeneration component after two years, the conventional chainsaw-and-skidder operation only 28%.

On another Valley Forest Products Koehring operation at Napadogan, N.B. a sample of 30 stems were chainsaw-cut and paired with machine-cut stumps. Subsequent red maple stump sprouting was monitored for six years, to 1982, and is illustrated in figures 2-4. The sprout drop-out rate for both chainsaw and machine-cut stumps is now stable, but early differences were the cause of some concern. Mean values (1984) are

	No. sprouts per stump	Height tallest	Diameter tallest
		cm	cm
Chainsaw-cut	17	95	3.2
Machine-cut	18	260	3.2

Height differences are now attributed in large measure to deer browsing.

Logging Damage

A logging damage study is underway in advance growth seedlings on a conventional chainsaw-and-skidder operation in mixed northern hardwoods near Canterbury, N.B. One hundred 4-m^2 quadrats in units of 10 were examined before and after logging in summer and fall 1982. The tallest seedling of each species in each quadrat was marked on the ground before logging began and mapped as the seedling most likely to survive. Logging resulted in several changes in seedbed and slash cover. Four slash types, degrees of cover, and disturbance type were recognized. The commonest condition was skidding disturbance (26%), with a light (50%), hardwood (47%), slash cover. However, 62% of the 100 quadrats were undisturbed by skidding or slash redistribution. Mortality because of drying out of the organic soil layers was common. Many sugar maple seedlings with only 2-4 leaves, on undisturbed sites did not survive the increased exposure following logging. Of the 375 identified tallest seedlings only 103 survived the logging operation. Of the 272 losses;

48% were "missing,"
12% were "dried out,"
10% were "smothered in slash,"
28% were "skidded over," and
2% were "damaged in felling."

Eighty-seven percent of the losses were in the height range 0-50 cm.

The results of these and other studies are provided to the Cutover Response Subcommittee and the Hardwood Technical Committee of the New Brunswick Forest Research Advisory Committee, and to the Hardwoods Working Group of the Nova Scotia Forest Research Committee. In this way it is hoped to fine-tune predictions of the interaction of harvesting and stand establishment. A minimum acceptable height class of advance growth seedlings should be determined.

Logging and Season of the Year

The timing of harvest cutting affects hardwood regeneration. Some species disperse seed earlier in the summer (red maple), others later (sugar maple), and some throughout the fall and winter (white birch). Summer logging may inhibit stump sprouting while winter logging may produce more vigorous sprouts and suckers from reserves stored in the roots at that time.

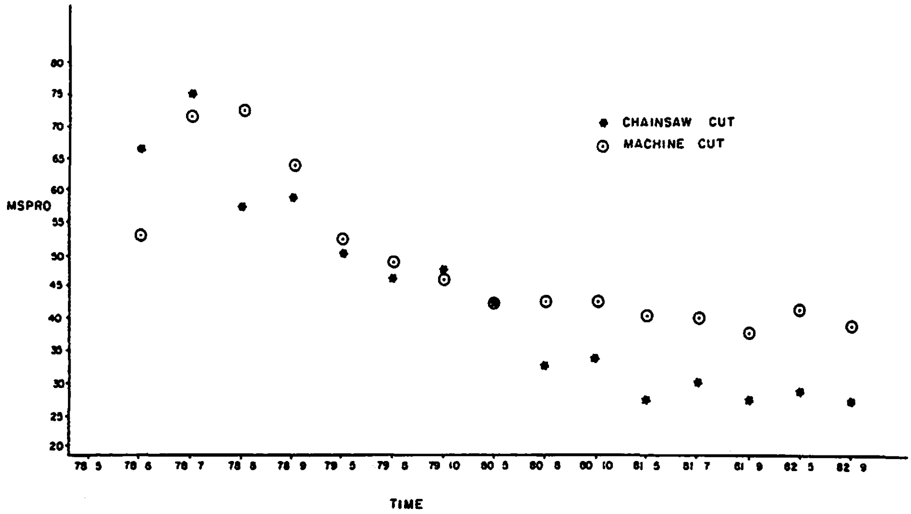

Figure 2. Mean number of sprouts per cut stump, over time.

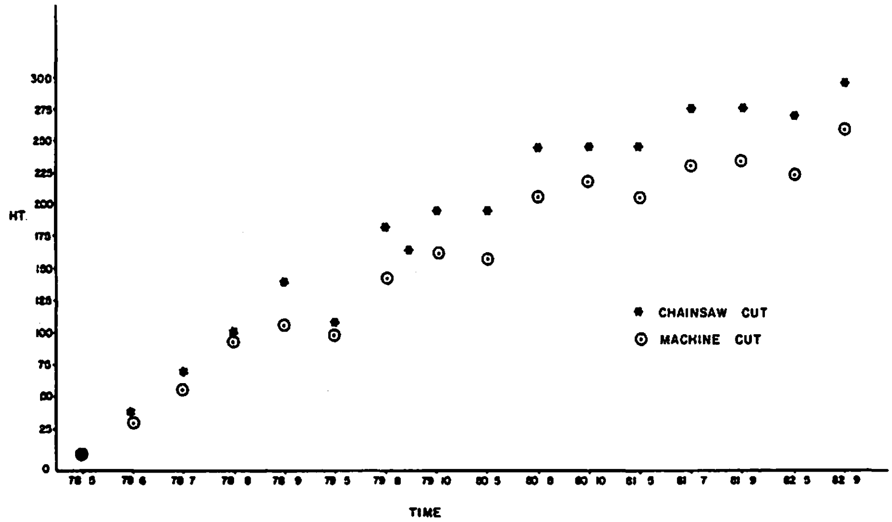

Figure 3. Mean height of tallest sprout per cut stump, over time.

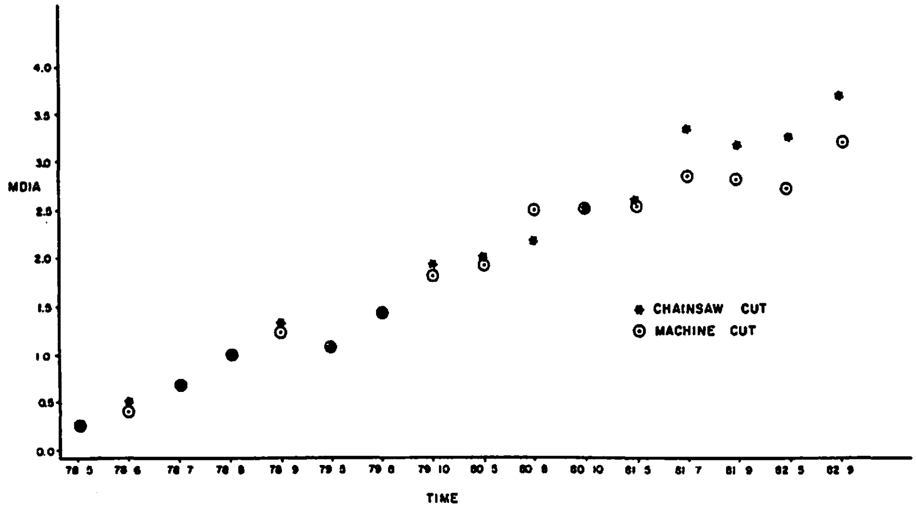

Figure 4. Mean diameter of tallest sprout per cut stump, over time.

Tubbs and Reid (1984) report that winter logging in northern hardwood stands resulted in better stocking to seedling sugar maple, yellow birch, and white birch. Summer clear-cuts were not well stocked with birch, and maples increased proportionately so that all cutover areas were fully stocked. Seed-trapping studies in Nova Scotia and New Brunswick on birch seed-tree areas and strip clear-cuts confirm the phenology of seeding of these species and may support Tubbs and Reid's observation of seed dispersal under a shelterwood, degree of seedbed disturbance, and season of logging.

DISCUSSION

Where such predicted responses to clear-cutting are unacceptable, alternative harvesting methods may be prescribed. Alternative stand establishment treatments may also be required. The problems are those of a seeming overabundance of natural hardwood regeneration to less valuable species. This creates a need to manipulate the proportions of species and their origin (sprout or seedling).

The valuable, denser-wooded tolerant hardwoods (sugar maple, yellow birch, ash), often require a shelterwood for reestablishment. The shelterwood systems developed by Tubbs and Metzger (1969) for birch in the Lake States are now commonly prescribed for mixed northern hardwoods in the New England States and Nova Scotia. The selection system, at first applied to tolerant hardwoods in Ontario, may be attractive to the small private woodlot owner in the Northeast and suitable for beech-maple types in Quebec and the Maritimes. Narrow strip clear-cutting is chosen in some regions of Quebec, Maine, Nova Scotia, and Prince Edward Island to obtain satisfactory regeneration of more tolerant species.

The implications for harvesting equipment development, of management trends to thinning, and "partial cutting" are far-reaching. A new generation of small maneuverable machines will be needed. The private nonindustrial forest manager (and there are thousands of them in every jurisdiction in the Northeast) will ensure a market for such harvesting equipment, but what will be the impact on advance growth, seedbed, planting site, and ground vegetation competition?

These new harvesting systems will clearly interact with stand establishment costs. Research and development trials, field demonstrations, and economic analyses are now due.

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Tubbs, C.H., and B.D. Reid. 1984. Logging season affects hardwood reproduction. North. J. Appl. For. 1:5-7.

Species names

American beech	Fagus grandifolia Ehrh.
Eastern hemlock	Tsuga canadensis (L.) Carr.
Grey birch	Betula populifolia Marsh.
Largetooth aspen	Populus grandidentata Michx.
Pin cherry	Prunus pensylvanica L.f.
Red maple	Acer rubrum L.
Red oak	Quercus rubra L.
Red spruce	Picea rubens Sarg.
Sugar maple	Acer saccharum Marsh.
Trembling aspen	Populus tremuloides Michx.
White ash	Fraxinus americana L.
White birch	Betula papyrifera Marsh.
White elm	Ulmus americana L.
Yellow birch	Betula alleghaniensis Britton

INTERACTION OF HARVESTING AND STAND ESTABLISHMENT IN CONIFERS IN NORTHEASTERN NORTH AMERICA[1]

Maxwell L. McCormack, Jr.[2]

Abstract.--Harvesting systems in spruce-fir forests have been primarily dependent on advanced regeneration. Minimum disturbance of sites is important to reduce disruption of drainage and establishment of undesirable vegetation. Trends toward mechanical full-tree harvesting are causing problems of soil disturbance, logging residue reduction, and nutrient removals.

INTRODUCTION

The northeastern conifer forest occurs on shallow glacial till soils, often with a compact layer at 40 to 60 cm which impedes drainage and root development. Many sites have relatively poor drainage resulting in very high organic matter content and excessive moisture. Irregular terrain, numerous drainage channels, and boulders often impede harvesting. Many sites are relatively flat and favor mechanical harvesting. In some regions fire has been a significant natural disturbance.

Silvical characteristics (Fowells 1965) and silvicultural systems (U.S. Department of Agriculture 1983) for major conifer species (Table 1) have been summarized. A silvicultural guide for spruce-fir (Frank and Bjorkbom 1973) is available. Most past management has been dependent on natural regeneration with interest in plantation culture, requiring some site preparation, developing in recent years. Advanced regeneration of the spruces and fir establishes readily in partially shaded understory conditions. However, the short-needled species are sensitive to exposure during the post-harvest establishment stage and need good conditions for satisfactory early growth. Pine and fir seed crops are fairly regular and reliable; those of the spruces are intermittent with limited dispersal. No significant viable seed is stored in the duff layers.

Pines may seed in effectively following harvest, but successful spruce-fir regeneration must be established before the overstory is removed. Where there is unsatisfactory stocking of spruces, those species are reestablished best by planting immediately after harvesting. Evenaged management is the rule, but spruce-fir stands can also be managed under the selection system (Frank and Blum 1978).

The spruce budworm [*Choristoneura fumiferana* (Clemens)] has made an impact on this forest. Defoliation of dominant trees, mortality of fir, reduced seed crops, and establishment of undesirable vegetation in defoliated stands have complicated harvesting operations and scheduling. There are very few pure stands except on poor sites and in plantations. Consequently, postharvesting conditions usually include a period of development by aggressive pioneer broadleaf vegetation which interferes with conifer regeneration, especially on good sites. Species which pose serious problems include red raspberry (*Rubus idaeus* L.) which forms a dense uniform cover. Red maple (*Acer rubrum* L.) and mountain maple (*A. spicatum* Lam.) are vigorous stump sprouters. Aspen (*Populus tremuloides* Michx.) and beech (*Fagus grandifolia* Ehrh.) produce large quantities of root sprouts, and the birches (*Betula papyrifera* Marsh., *B. populifolia* Marsh.) are prolific seeders. Stored seeds of raspberry and pin cherry (*Prunus pensylvanica* L.F.) frequently provide rapidly established cover which excludes conifers. These competitors have been characterized by Leak *et al.* (1969), and Lees[3] provides pertinent insight.

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[1] Paper presented at the conference COFE/IUFRO-1984. Fredericton, New Brunswick, Canada, 17-18 August 1984.

[2] Maxwell L. McCormack, Jr. is Research Professor of Forest Resources and Leader, Cooperative Forestry Research Unit, University of Maine, Orono, Maine, USA.

[3] Lees, J.C. Interaction of harvesting and stand establishment in hardwoods in eastern North America. Draft paper prepared for conference COFE/ IUFRO 17-18 August 1984.

Table 1. Selected regeneration characteristics of important conifer species in northeastern North America.

Regeneration method		Species	Effective advance regen.	Consistent seed supply	Easy to establish
Nat.	Plt.				
●	◦	Red spruce (*Picea rubens* Sarg.)	●	○	○
●	●	Black spruce [*P. mariana* (Mill.) B.S.P.]	●	◑	◑
●	◑	White spruce [*P. glauca* (Moench) Voss]	◑	○	◑
●	○	Balsam fir [*Abies balsamea* (L.) Mill.]	●	●	◑
◑	●	Red pine (*Pinus resinosa* Ait.)	○	◑	●
○	◑	White pine (*P. strobus* L.)	◑	◑	●
◦	◑	Jack pine (*P. banksiana* Lamb.)	◦	◑	●
○	◑	Tamarack [*Larix laricina* (DuRoi) K. Koch]	◦	○	◑

◦ = Little or no use

○ = Low use, weak characteristic

◑ = Moderate use and characteristic

● = High use, strong characteristic

Presence of shade tolerant undesirables in the forest understory, combined with their potential for rapid establishment following disturbances, results in an explosion of competing vegetation which effectively prevents conifer establishment or suppresses development of advanced regeneration on the better sites. Partial cuts often result in sufficient ground disturbance to facilitate early establishment of undesirables. The shallow rooting of spruce and fir makes lateral root systems vulnerable to machinery damage and windthrow. Partial cut harvests in older, well-developed stands can, thereby, result in losses of residual, future crop trees and the turned up soil provides seedbeds for advanced development of undesirable species. However, properly timed entries for partial, light removals from below can be successful. Shelterwood cuts, administered in a way to retain the best quality and spacing of residuals, provide good potential for establishing natural regeneration.

HARVESTING SYSTEMS

Years ago, horse logging with water transport was common. A transition has taken place from shortwood to tree-length systems and, more recently, to full-tree removals by large feller-forwarders and in-woods chipping. Different postharvesting site conditions and vegetation dynamics have accompanied this transition. Trials with high lead cable systems have provided some biological advantages, but high costs have deterred their development in the region. As we proceed with equipment development and modification, programs to improve operator knowledge and understanding become an essential component of total harvesting systems.

When considering establishment of the next crop we must consider impacts of mechanical harvesting on the natural systems and consequences of residue redistribution. All appraisals and projections must recognize differences in site quality. Changes in the natural system and subsequent silvicultural needs depend on the extent of harvesting (i.e. partial cuts of various intensities vs. clearcutting) and management objectives for culturing residual stands, or for establishing regeneration naturally or artificially.

Much depends on the characteristics of the stand to be harvested and it is important to anticipate future stand development prior to harvest. Special attention must be given to existing and potential vegetation problems. Also, a careful appraisal of physical site conditions is essential.

Moisture relationships, especially drainage, are critical determinants of site quality. Disruption of drainage patterns in shallow soils by equipment ruts can cause serious, long-lasting damage. Though some benefits to regeneration from full-tree harvesting have been described (Saltarelli 1980), recent trends toward full-tree removals and roadside mechanical delimbing have prompted concerns about harvesting residues and their management. The values of residues fall into three general categories:

(1) Providing desirable microhabitat and protection for seedlings,

(2) Adding organic matter (OM) directly to the soil, and

(3) Composing an important part of the nutrient cycle.

Advanced regeneration of spruce and fir has high value and provides an opportunity to have the next stand in place before final harvest. One of the most valuable assets in the Acadian spruce-fir forests is a bountiful supply of desirable advanced regeneration (Smith 1981). If regeneration in place immediately after harvest is compared to the cost of site preparation and planting, significant efforts to retain natural advanced regeneration are easily justified. Well-distributed slash can play a major role by protecting regeneration from browsing animals, dessication, and frost heaving. Transient shade provides desirable temperature and moisture conditions. Though not quantified in detail, these relationships have been observed over long periods of time.

The loss of natural regeneration can be replaced through intensive planting programs when the necessary investments are made. However, the loss of OM has longer-term implications. OM is a source of N in the surface horizons, but its physical involvement is also very important. OM plays a role in soil bulk density, formation of macropore space, cation exchange capacity, and moisture retention.

More detailed nutrient cycling information which is directly related to specific site conditions is needed. Kimmins (1974) expressed a need to define rotation length in terms of an "ecological rotation" where soils are permitted to return to the preharvest ecological condition. Whole-tree removals break the nutrient cycle by a drastic redistribution of living biomass. This change is not readily remedied by simply replacing the nutrients lost by applying fertilizer.

Bengston (1981) described residue removals in terms of dollar values of the nutrients being removed. The increase in harvest yields through more complete removals have a much higher cost per unit. Some costs are difficult to define. For example, small litter components (branches, leaves, twigs) may serve as important initial sources of nutrients for regeneration. This same basic relationship is thought to benefit residual crop trees from slash remaining after thinnings or shelterwood cuts.

Alleviating nutrient losses by not removing the large nutrient capital in foliage might be accomplished through harvesting techniques which leave foliage on the site. Bjerkelund (1984) has proposed a compromise which would leave valuable nutrient-rich components on the site by employing a "trimmed whole tree" harvest.

STAND ESTABLISHMENT INTERACTIONS

As experience is gained with mechanical systems, valuable lessons are learned. For example, there is better appreciation of the significance of leaving unmerchantable paper birches during a summer mechanical clearcut of spruce-fir. The apparent cost saving becomes a costly expense in regenerating the site to conifers. Timely removals of a prolific, undesirable seed source in the presence of an ideal seedbed would be a judicious move during harvest.

Planned concentration of machine traffic provides residual undisturbed areas. Advanced regeneration can be retained on undisturbed portions while the concentrated machine disturbance provides effective site preparation to be planted immediately after harvest. Bunching of felled stems within feller-buncher trails which are also used by grapple skidders demonstrates how this basic technique can be employed[4]. Lack of disturbance is a desirable feature. It enables advanced regeneration to develop after harvest. Machine disturbance damages, or eliminates, desirable seedlings. Also, it benefits undesirable pioneer brush species.

Observed relationships of harvesting with site and stand conditions are being substantiated through scientific documentation (Case and Donnelly 1979, College of Environmental Science and Forestry 1979, Freedman 1981, Freedman *et al.* 1981, Lyman 1982, Smith 1984a, Weetman and Webber 1972, Weetman and Frisque 1977, Weetman and Algar 1983). Northeastern spruce-fir site conditions were recently appraised on 190 transects comprising 3.6 miles of samples across seven townships in northern Maine[5]. Conditions were studied on sites which had been mechanically clearcut between 1973 and 1982.

Harvesting systems they studied included the use of a large, rubber-tired feller-forwarder; feller-bunchers on rubber tires; and feller-bunchers on lags. Grapple skidder disturbance was an integral part of the feller-buncher systems.

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[4] Observed operational procedures, Georgia-Pacific Corp., Washington Co., Maine, USA.

[5] Unpublished preliminary data. 1983 Maine landowner study of site disturbance by mechanical harvesting equipment.

Table 2 summarizes site disturbances across the study. Surface disturbances were differentiated between those confined to organic layers and those reaching mineral soil. Less than half of the area was left undisturbed.

Table 2. Summary of site disturbance by mechanical harvesting done during 1973-1982[5].

Disturbance classification	Area affected
	---(%)---
UNDISTURBED	47.7
SCARIFICATION	
Organic	12.2
Mineral	1.9
RUTS	
Organic	8.7
Mineral	5.7
SLASH	9.7
OTHER	14.1
TOTAL	100.0

Relatively thorough removal of residues and mechanical delimbing at roadside is reflected by only 9.7 percent of the area covered with slash. Table 3 presents selected results comparing winter and summer harvesting. As expected, there is less disturbance from winter harvesting and a possible additional benefit of more area covered with slash. My observations of mechanical harvests across northern Maine consistently show best development of new spruce-fir stands where there has been well-distributed slash, especially when harvested during winter. The best young stands were usually attributable to harvests by a Beloit Tree Harvester which delimbed at the stumps and travelled on lags. The landowner study indicated that snow cover alone was not always sufficient as a protection to site. A confounding factor in data collection appears to be distinguishing true winter conditions from the beginning of spring breakup. With respect to the latter, aspect of site appeared to be important.

Table 3. Selected comparisons of summer and winter mechanical harvesting during 1973-1982.[5]

Season	Undisturbed	Scarification		Slash
		Organic	Mineral	
	----------(% of area affected)---------			
Summer	39.3	13.7	2.3	8.3
Winter	66.1	8.9	1.0	12.7

The three types of equipment involved across the study period are compared in Table 4. Heavier equipment tends to cause deeper ruts than lighter equipment and ruts can cause serious disruption of drainage. Recent trends seem to be toward somewhat lighter, better balanced equipment carried on wider tires.

Table 4. Selected categories of site disturbance by equipment used for harvest in northern Maine during 1973-1982.[5]

Equipment	Un-disturbed	Scarification		Ruts		Slash
		Organic	Mineral	Organic	Mineral	
	--------------% of area affected-------------					
Feller-forwarder	35.0	14.3	2.5	8.3	8.2	12.5
Feller-buncher (tires)	25.8	19.5	2.5	9.5	7.9	10.2
Feller-buncher (lags)	66.0	8.5	1.6	9.4	2.9	5.0

Conifer regeneration was growing best on good, undisturbed areas. Disturbance of sites appeared to cause some loss in productivity and, where it disrupted the organic pad, resulted in barren ground which eventually developed into undesirable brush cover rather than useful tree species.

A study initiated in 1979 to evaluate mechanical full-tree removal, residue management and nutrient cycling on a spruce-fir watershed (Smith 1984a, 1984b) indicates trends similar to data from other studies in the region (Freedman *et al.* 1981, Weetman and Webber 1972). An intensive evaluation was made of harvested biomass and nutrient content. Soil solutions have been sampled on a regular schedule to monitor the active nutrient cycle.

In evaluating the disposition of residues, the distribution of biomass within merchantable trees is important. Table 5 shows a typical breakdown for a merchantable red spruce. Considering green organic matter benefits and nutrient values of residues, it is important to note the proportion of the tree in small branches and foliage. The harvesting system studied involved mechanized roadside delimbing which resulted in residues piled at the landings. The

Table 5. Biomass distribution for a red spruce in north central Maine, b.h. age = 112, dbh = 33.6 cm, total height = 19.3 m, live crown ratio = 44% (Smith 1984b).

Component	Oven dry weight	%
	(kg)	
BRANCHES		
<0.25" + Foliage	47.35	11.0
0.25 to 1"	15.47	3.6
1 to 3"	16.94	3.9
Dead	32.60	7.6
TOP (4" Merch.)	2.91	0.6
MERCH STEM	312.92	73.1
TOTAL	428.19	

fact that these residues were removed from the site is important. Estimated amounts per unit of land area are in Table 6.

Table 6. Estimated above-ground biomass for a harvested spruce-fir stand in north central Maine (Smith 1984b).

Stand Component	Oven dry weight Metric	 English
	(T/ha)	(T/a)
Preharvest (trees)	230	102
Harvest removal	209	93
Merchantable material	152	68
Roadside residue	57	25

Three residue management alternatives were applied on the treated watershed:

(1) Complete removal of residues;
(2) Residues chipped and scattered, and
(3) Residue scattered intact on the site.

Porous cup lysimeters at depths of 25 cm and 50 cm have been used to obtain soil solution samples. Nitrate (NO_3) concentrations before and immediately after harvest are illustrated in Figure 1. Three seasons later, concentrations have returned close to preharvest levels. Soil drainage classes were more important than residue treatments (Table 7). This emphasizes the need to consider site characteristics carefully. Most of the NO_3 change following harvest took place on the better drained locations. As expected, a more dynamic situation exists on the better sites.

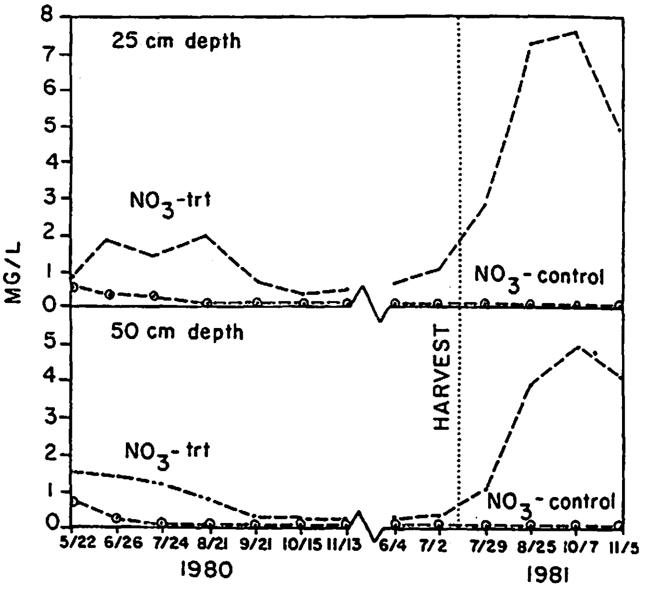

Figure 1. Nitrate (NO_3) concentrations of soil solutions collected from two depths before, and immediately after, clearcutting a spruce-fir watershed in north central Maine Maine (Smith 1984a).

Table 7. Soil solution nitrate concentrations by soil drainage class, three months after clearcutting a spruce-fir watershed in north central Maine (Smith 1984a).

Sample depth (cm)	Soil drainage class Moderately well (N=4)	 Poorly to somewhat poorly (N=8)	 Average all plots (N=12)
	-------------	NO_3 (mg/l)	------------
25	18.36	0.18	7.76
50	12.3	0.12	5.12

This same clearcut watershed study measured nutrient quantities and removals in a spruce-fir full-tree harvest. Using tree component data, comparisons can be made between full-tree and bole-only harvests (Table 8).

Table 8. Estimated soil nutrient reserves and harvest removals for a spruce-fir stand in north central Maine (Smith 1984b).

	N	P	K	Ca	Mg
	(kg/ha)				
FOREST FLOOR PLUS MINERAL SOIL (54 cm) NUTRIENT POOLS					
Total[1]	6709	2770	10063	10668	36483
Exchangeable[2]	--	217	159	392	211
HARVEST REMOVALS					
Whole tree	322	46	192	423	44
Bole only	98	12	94	215	17

[1] Technicon block digest for N and P; nitric-perchloric extractable K, Ca, Mg.

[2] 1N NH_4 OAc, pH 7.0, extractable K, Ca, Mg; Bray-Kurtz extractable P.

When examining the data as ratios of nutrient reserves to harvest removals (Table 9), it is possible to speculate on available nutrients for future rotations. This study (Smith 1984b) estimated roadside residues to be equivalent to 13 percent of extractable Mg, 16 percent of exchangeable P, 53 percent of exhangeable Ca, and 61 percent of exchangeable K. If these nutrients were to be replaced by fertilizing, increased yields through harvesting branches and foliage result in relatively high per-unit costs for the additional biomass removed. The nutrients in the residues could help to replenish the exchangeable soil nutrients as they are released through decomposition.

Table 9. Estimated ratios of nutrient reserves to harvest removals (i.e. number of rotations to deplete total or exchangeable soil nutrient reserves without additions of nutrients from other sources) for a spruce-fir stand in north central Maine (Smith 1984b).

	N	P	K	Ca	Mg
	(ratios)				
TOTAL NUTRIENT RESERVES					
Whole Tree	21	60	52	25	829
Bole Only	68	231	107	50	2146
EXCHANGEABLE NUTRIENT RESERVES					
Whole Tree	--	5	0.8	0.9	5
Bole Only	--	18	1.7	1.8	12

Nutrients could be conserved on sites where they are needed by removing only merchantable stems, since full-tree harvests removed two to four times as many nutrients as a bole-only harvest would have.

SUMMARY

Harvesting systems in northeastern conifer forests have been primarily dependent on natural regeneration. Successful spruce-fir regeneration must be established before the overstory is removed. Harvesting systems should result in minimal site disturbance and the maintenance of advanced regeneration. Where necessary, planting should be done as soon after harvesting as possible.

Especially on good sites, postharvesting conditions usually result in dense growth of undesirable broadleaf vegetation which requires silvicultural consideration. Physical site conditions must be carefully appraised before operations are initiated. Properly timed and executed shelterwood cuts provide good potential for establishing effective advanced regeneration of spruce and fir.

Trends toward mechanical full-tree harvesting are causing problems concerning soil disturbance, logging residue distribution, and nutrient cycling. Disturbed soil surfaces can disrupt drainage and provide seedbeds which benefit regeneration of undesirables. Removal of residues, such as small branches and foliage, from sites results in loss of beneficial microhabitat for desirable seedlings, lost benefits to soils from organic matter additions, and nutrient removals.

Exchangeable nutrient reserves are depleted more by full-tree harvests of spruce-fir than by bole-only harvests. The availability of adequate quantities of Ca and K for a subsequent rotation is questionable. Conservation of nutrients and benefits to regeneration through use of harvesting systems which leave nutrient-rich residues distributed across sites is recommended.

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HARVESTING FULL TREES IN THINNINGS

- SHOULD THE LOGGING RESIDUE BE REMOVED?

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Abstract.--Some companies are today harvesting full trees in thinnings. In a short-team perspective this method offers certain advantages; in the long term, the scientists do not know for sure. There is, however, a definite trend. Certain losses of increment of growing stock apparently can be expected if the logging residue is not left on the ground. This is what Sven-Olof Andersson concludes in the following account of investigations made by himself and other Nordic scientists.

INTRODUCTION

Logging of full trees in thinnings has been practiced by a number of Swedish companies for some years. This method can be profitable on a short term basis. The yield is larger compared to thinnings where only industrial roundwood is utilized. The economic outcome of the thinnings will also be more favourable. One important question remains however, how will the growth be influenced by the fact that no slash is left on the ground?

NORWEGIAN PILOT TRIAL

As early as 1928 a pilot study was made in Norway to find an answer to this question. A sample plot situated close to the Swedish border was established in a 90-year-old pine forest on sandy soil covered by lichens. The sample plot consisted of two subplots. They were both thinned but the slash from one subplot was transferred to the other which consequently received a double layer of tops and branches. In the course of time, several light thinnings were made in series. Here too the logging residue was transferred.

The results were analysed by Professor Alf Brantseg in 1962. The average annual volume growth during the 32 year observation period was 0.3 m^3sk* higher her hectare on the subplot with slash than on the subplot from which the slash had been removed. The difference corresponds to approximately 20 %. The greatest growth increase amounted to 1 m^3sk and occurred after 18 years. The growth was then approximately 3.5 m^3sk as compared to 2.5 m^3sk on the subplot without slash.

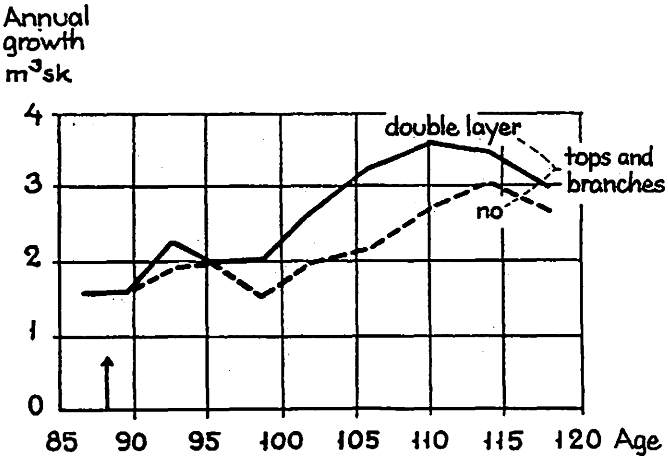

Figure 1.--Volume increment on plots with and without logging residue in the Norwegian experiment established in 1928. The arrow shows the year of first thinning.

The subplots varied slightly as to volumes before and after thinning and the trial contained no replications. Brantseg points out that the growth estimates are somewhat uncertain on account of some difference of site class between the subplots. However, he is still of the opinion that the results show that removal of logging residue in pine stands may cause a loss of increment amounting to approximately 10 %.

In order to study the effects of full-tree methods in young thinning stands, the author (Professor Andersson at the Swedish college of forestry) established a thinning experiment in western Dalecarlia in 1964. The subject was a 42-year-old sowed pine stand (Pinus Sylvestris), cleaned 11 years ago, and ready for a first commercial thinning. The number of stems were 1750 per hectare and the

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* m^3sk=Cubic metres of forest (volume of the entire stem above the stump, including bark).

volume was 170 m^3sk. It is located on a mesic blueberry shrub vegetation site and the soil is rather fertile.

The experiment included 3 blocks, each containing 3 different treatments or plots. During the thinnings, pulpwood was logged in the ordinary way and from one plot in each block, branches and tops were removed and spread out on another plot as in the Norwegian experiment. Moreover, there is one plot in each block on which slash has neither been removed nor added to as in normal logging operations. The volumes felled in the thinning averaged 52 m^3 sk/ha. The three plots within each block were thinned to the same basal area so that no such differences would influence the growth. At a second thinning, 10 years later, the removal amounted to 45 m^3 sk/ha. The logging residue was handled in the same way as before.

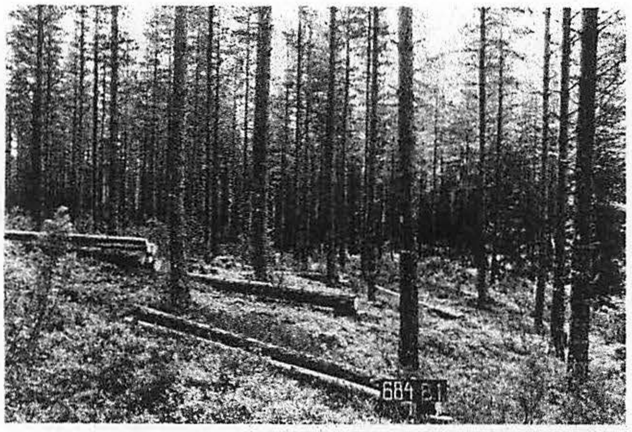

Figure 2.--The mentioned sowing of pine in Dalecarlia at 52 years of age, immediately after the second thinning. The logging residue was removed after both thinnings.

Pulpwood, 3 m in length and with a 7-cm (o.b.) minimum top diameter was cut in the first thinning. On one of the plots the tops and the living branches left as slash were weighed. The volume of the pulpwood was 52 m^3 (o.b.). The residual tops amounted to 9 m^3/ha, green weight 8.1 tons. The living branches, needles included, weighed 6.3 t after drying. The total dry weight of tops and living branches is estimated to be something like 10 t/ha.

In the second thinning pulpwood was cut to a minimum top diameter of 5 cm (o.b.). The volume of the pulpwood this time was 44 m^3 (o.b.) and the volume of the remaining tops 2.3 m^3 (o.b.). The dry weight of both tops and living branches totaled approximately 4 t/ha. The entire dry weight of logging residue of this kind from the two thinnings then amounted to 14 t/ha.

YIELD 10 % HIGHER

Measurements after 5 years showed that the stemwood growth on all the blocks had been higher on the plots where a normal amount of slash remained than where it had been removed. The same applied to the following 5 year period and also to the whole 16-year period up to the latest measurements which were made in 1980.

During these 16 years the yield per hectare has been 12 m^3sk higher where branches and tops were left. This corresponds to an approximately 10 % higher production. Where there was a doubled cover of slash, the growth had also been higher, but here the results vary more.

In 1964 a similar experiment was started by Professor C.O. Tamm in an 80-year-old pine stand of low density at Gällivare (northern Sweden). The growth after thinning was low because of poor site quality and a low standing volume, but during a period of 17 years the plots with slash remaining have shown a higher percentage of growth here also. The difference was 7 per cent.

Figure 3.--From the experiment in north Sweden. On this plot a double cover of slash was left at the thinning 17 years earlier.

GROWTH LOSSES ALSO ON FERTILE SOILS

A series of experiments, dedicated to the same problem, was established by the Department of Forest Research in Norway in 1972 - four of them in pine stands and four in spruce stands (Norway spruce). According to Björn Tweite, leader of these experiments, the trend is the same here as in Sweden. So far it is most obvious in the spruce stands.

The four Norwegian thinning experiments in spruce stands are established on good sites. The growth losses amount to 1.5 m^3/hectare, which corresponds to 11 %. This difference is strongly significant.

Many foresters believe it is a small risk of yield loss in harvesting full trees on good sites. Obviously it is not so.

AMOUNTS OF NUTRIENTS IN SLASH FROM THINNINGS

The slash from these Norwegian experiments in spruce stands contained on an average 113 kg of nitrogen, 108 kg of calcium, 14 kg of phosphorus and 57 kg of potassium. The slash from the youngest stand contained as much as 147 kg of nitrogen which, in Sweden, is an ordinary quantity when fertilizing in practice.

This problem has been investigated in Finland also. Mälkönen has examined the amount of nutrients lost during the first thinnings if the slash, including needles, is also removed. He has the average figures from 8 experiment plots in pine forests on a whortleberry vegetation site where the removal was 62 m^3 stemwood/ha. The residue of tops and branches was the equivalent of 8 t of dry weight. It contained an average of 26 kg of nitrogen, 3 kg of phosphorus, 14 kg of potassium and 16 kg of calcium. In spruce stands he has made similar studies on a more fertile site with blueberry shrubs and wood sorrel. Here the volume logged by thinning was 93 m^3sk/ha. The residue equalled 17 t of dry matter, containing 74 kg of nitrogen, 9 kg of phosphorus, 25 kg of potassium and 82 kg of calcium. This shows that considerable amounts of the nutrient are removed with the logging residue.

Research on biomass and the nutrient content of the different parts of the tree has been carried out in Sweden. In thinning stands, between 29 and 100 years of age, Albrektson has found that branches and needles together contained nitrogen amounting to 79-109 kg/ha.

COMMERCIAL FERTILIZER IS INFERIOR

There have been discussions as to whether or not the losses of nutrients may be compensated for by fertilizing. According to several ecologists the nutrition found in the logging residue is of considerably higher value than in the corresponding amount of fertilizer. The residue promotes the activities of the soil organisms as well. Furthermore, the shading by the slash may have a favourable effect on the moisture content of the soil which is valuable especially on dry soils. In forestry it is agreed that the traditional logging residue should be left on such soils.

A new series of experiments has now been started in thinning stands where the effect of utilizing full trees is being studied. The project includes fertilizing in connection with such logging. In late cleanings too it is possible to extract considerable amounts of biomass. Experiments in cleaning stands where the felled trees are left on the ground or removed, respectively, are still too few but new ones were carried out during the summer of 1983.

Summing up, I have to admit that there is, unfortunately, too few experiments that can explain the long-term effects of utilizing full trees in cleanings and thinnings. The tendency is, however, rather obvious in the case of thinnings. There definitely seems to be a loss of growth if the traditional logging residue is not left on the forest floor.

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IMPACTS OF WOOD HARVESTING ON STAND ESTABLISHMENT IN THE WESTERN EUROPEAN SCENE [1]

W. Heij [2]

ABSTRACT

A survey is given of the harvesting and the stand establishment methods, which are in use in Western Europe. There are many impacts from harvesting on stand establishment but not very many exact figures are known. The author is making a plea for a system analysis of the whole system of harvesting and regeneration, i.e. of the chain of activities from the mature stand up to the growing young stand. Except of a comparison of costs a study should be made concerning the decision making with respect to the choice of methods.

INTRODUCTION

Foresters in Western Europe are thinking in terms of stands which are generated in some way, tended and thinned during many years and finally harvested. By then we start a new cycle again. Trying to plan the management and the operations during the rotation of the stand, has an impact on the generation of the stand and forest, on the spacing of the trees, on the spacing of the roads, etc. For example forests in the Netherlands have been planted in a time that horse traction was still very important and the result is there are nowadays too many roads per ha, moreover of low quality. Especially, if the period between afforestation or reforestation and harvesting is large, it is difficult to plan so far ahead, since the labour circumstances, the methods and the equipment are changing. To be more specific, we can not oversee such a large period.

Harvesting and reforestation - in that following order - are much closer. It must be possible to have a young growing stand within a four years or even shorter period and this period can be overseen. There is, of course, an impact of stand establishment on tending, thinning and harvesting of the stand, but to make the situation less complicated it is not considered in this article.

In the present experience both operations, harvesting and stand establishment, are disconnected. Very often the operations are arried out by different people and no coordination takes place; this is even the case within a group of operations, for example between felling and skidding. The logger is interested in how to harvest the timber in the most efficient way without looking forward to the next stage. There after the planter has to find his way through a mess of logging waste to generate a growing stand within the shortest time possible and as cheap as possible. Decisions made concerning harvesting, have an impact on stand establishment. For example, what the reason may be, if large stumps are left behind on a clear cut, it is much more difficult, or even impossible to mulch the logging slash and to use planting machines.

It would be interesting to integrate both operations much more, and to consider both operations as a whole system. System analyses have been carried out till now concerning sub-systems, or even sub-subsystems. It gives a good comparison between the systems, but it does not say anything about the decision-making behind choosing the specific system if the preceding stage is not included.

System analysis of the whole system may lead to a better insight how the different operations are linked together and may lead to development of integrated machines which carry out logging and stand establishment at once. This, of course, lays in a far future and it will often not be possible because of climatic conditions in areas where the planting period is very short.

HARVESTING

The several operations, as felling, delimbing, debarking, croscutting, transport in the stand to the road, have still to be carried out, does not matter what kind of system and what kind of mechanization grade you choose.

Debarking is mainly mechanized. Mobile debarking machines are still in use, although more and more timber is debarked at the delivery

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[1] Paper presented at the conference COFE/IUFRO - 1984. Orono, Maine, USA/Fredericton, New Brunswick, Canada. 12-18 August.

[2] W. Heij, senior scientist, Department of Forest Technique and Forest Products, Agricultural University, Wageningen, The Netherlands.

point. This may be a central conversion site or the wood processing industry.

The full tree system, where the felling and the skidding are the only operations in the forest, is in Western Europe in use on a small scale. At the central conversion site you need the possibility to use the waste for energy or to get rid of it in an other way. Trials in the Netherlands to use the full tree system, to chip the trees totally and to produce green chips for the particle board industry were not very successful and the system has been abandoned.

The shortwood system and the tree length system - in the later case crosscutting can be carried out at the forest road or at a central conversion site - are in use mainly. On a small scale thinnings are harvested by means of processors, machines which are developed especially for this purpose. Smaller forwarders, more adapted to the circumstances, have been constructed. Forwarding of shortwood is often carried out by heavier farming tractors with crane in combination with a trailor; the investment for such a combination is far lower than for a specialized forwarder and the basic machine, the tractor, can be used for other purposes. For skidding tree lengths heavier farming tractors equiped with a graple are available.

The larger part of the felling and delimbing is still carried out with the power saw. Although the power saw has been improved over the years - less noise, less vibration, lighter weight - working with it is still heavy labour. Out of a viewpoint of ergonomics and safety, it remains a doubtfull tool. Although the in Scandinavia developed systems of felling and delimbing by means of the power-saw are ergonomically better working methods, workers have to learn to use the system and to adapt theirself to it. At the other side more untrained labour is moving in the forest, since employing own people is expensive and more timber is sold to a contractor.

The power-saw will not disappear very soon, since the more mechanized systems have their limitations, especially in a forestry you find in Western Europe. Because of the high population pressure on the forest one is looking for more "natural" harvesting systems, which results in smaller harvested areas and, if possible, in the use of natural regeneration.

The main objection against the use of machines in the forest is soil compaction and damage to the remaining trees. In this view and also in the view of wishing to propagate more "natural" systems, the use of horses for skidding is getting more popular. Sometimes you get the impression that the limitations for the use of a horse are forgotten. A horse can be very useful for concentrating trees, if the skidding distance is limited to an average of 25 m. Then, the bunches can be skidded to the forest road by adapted heavier farming tractors equiped with a graple. One has to keep in mind that horses, skidding tree lengths, also damage remaining trees. Moreover, horses, travelling along the same path several times, may cause a higher soil compaction than a tractor. In our department at the Agricultural University at the moment a study is carried out to get more insight in compaction of forest soils.

Western European forestry has always been more small-scale forestry than the forestry in Scandinavia and North-America. The in both areas developed forest machines are often of a size, which can not be used in Western Europe. Trials and careful introduction of these machines were not always successful. The progress of mechanization has been slower and is slowing down lately. At the other side, as from the middle of the seventies smaller forest machines and also equipment which can be used in combination with heavier farming tractors, have been developed, which are more adapted to local circumstances.

STAND ESTABLISHMENT

Stand establishment is executed mainly artificially, by planting or by seeding. Seeding can be used if seeds are available abundantly, which is not often the case, especially if you take provenance and quality of the mother stand into consideration. The by far larger part of the artificial regeneration is carried out by planting and in most cases bare-rooted plants are used. The planting stock at the nursery is selected and the larger, mainly twice transplanted plants are used for reforestation. Larger plants are used in combination with wider spacing. Larger plants will overgrow the weeds quicker and the crowns of the trees will come into closure earlier. The very wide spacing, especially of Pinus silvestris, which was applied in the Netherlands in the seventies, has been turned slightly backwards, since branching of the trees was very heavy.

If site preparation, i.e. manipulation of the site cover, can be omitted, depends on the amount of slash and undergrow and on the method of soil preparation and artificial regeneration which will be applied. The slash can be windrowed and eventually be burned. Reduction of slash and undergrow by means of mulching is often applied, especially in the Netherlands. An other applied method of reduction of slash is the use of a rolling chopper.

Soil preparation is mainly applied on spots, or on strips. In the Netherlands soil preparation is minimized. The carefully built up humus should not be disturbed by heavy soil preparation because of increased break-down of the humus and, consequently, loss of moisture and nutrients. This applies especially to the poorer sandy soils, where you can find most of the forests in the Netherlands. In Northern Germany, in more or less comparable circumstances, very often the stumps are removed from the area, windrowed together with the slash and the whole area is ploughed. It may be that the forest soils in Northern Germany are of a better quality than in the Netherlands, but there are also other objectives, as reduction of weed competition and late frost damage, and the use of cheaper one-year old plants.

Operational analysis of systems for artificial regeneration shows that systems without mechanization or partly mechanized systems prevail in Western Europe, although fully mechanized systems, as for example the forest-plough-planting machine, are cheaper. Use of the forest-plough-planting machine, also in combination with windrowing the logging slash, a reasonably cheap method; is in the Netherlands limited to private forest owners, while others use more expensive methods. The use of the mulching machine for site cover manipulation became very popular in the Netherlands in the seventies, but it is a costly method, especially if it is followed by mechanized spot-wise soil preparation and handplanting. Use of more expensive methods can only be explained, if the results on the long term will be better.

At the end of the seventies a Danish planting machine has been introduced, a machine, which is combining site preparation, soil preparation and planting in one machine. Prelimenary research showed that the costs of establishment by means of this machine are at a level of the costs of the cheapest methods. The machine can be used in easy and average circumstances.

In view of the more ecological methods natural regeneration is propagated. This can be done according to the selection felling system of single trees or of small groups. Of course, the quality and the provenance of the stand has to be such, that it is meaningful to make use of natural regeneration. It might be a cheap establishing method, but the costs of tending and thinning the stand will be higher than in the case of clearcutting larger areas followed by artificial establishment of a limited amount of plants. The possibility of using mechanized systems will be limited and it is an open question how much damage will be done to the remaining stand. It is often argued that natural regeneration will improve the stability of the stand. This will only be true if the stands are tended properly and if the trees get enough room for development. In Germany, and especially in Southern Germany the system is in use already a long time, although only 10% of the total reforested area in Western Germany is treated according this system.

IMPACTS

System analyses give a good comparison of costs of different systems, but it is often not clear why different systems are used in apparently similar circumstances. System analyses have been carried out on subsystems but never on the overall system of harvesting and stand establishment.

It is clear, there is an impact of harvesting on stand establishment. The way a logger leaves the logging area behind, may exclude special stand establishment methods or may include extra work to make a special method possible. Twenty years ago in the Netherlands final felling, especially of Pinus silvestris was executed harring-bone-wise; the branches could be windrowes easily by hand and a clean logging area was left. Nowadays parallel felling takes place and the logging waste is left scattered over the area. At one side this depends on the used logging machines, at the other side this depends on the fact, that more untrained labour is moving into the forest.

Apparently establishing methods are used, which are too expensive considering the circumstances (table 1). The reason may be the equipment for a cheaper method is not available and the available more expensive system is used. Or it may be possible one is equiped for the worst circumstances and the equipment is used in all circumstances.

I am pleading here for making a system analysis of the total chain of activities from the mature stand up to the growing young stand (fig. 1). This will give a better insight in the whole system and perhaps will lead to a better coordination of activities.

Forestry in Western Europe is tending to a

Site preparation	Soil preparation	Planting	% Afforested area		Relative costs per ha
			private	state	
windrowing, manual	-	manual	15	6	100
-	-	manual	7	11	108
mulching	-	manual	7	6	167
mulching	forest plough	manual	43	20	172
mulching	spotlike scarifier	manual	-	18	172
mulching	forest plough planting machine		17	8	176
mulching	plant hole grubber	manual	11	31	206
Total area (ha)			154	140	

Table 1. — Some of the used establishment systems and relative costs in the private and state sector of forestry in the Netherlands (1979)

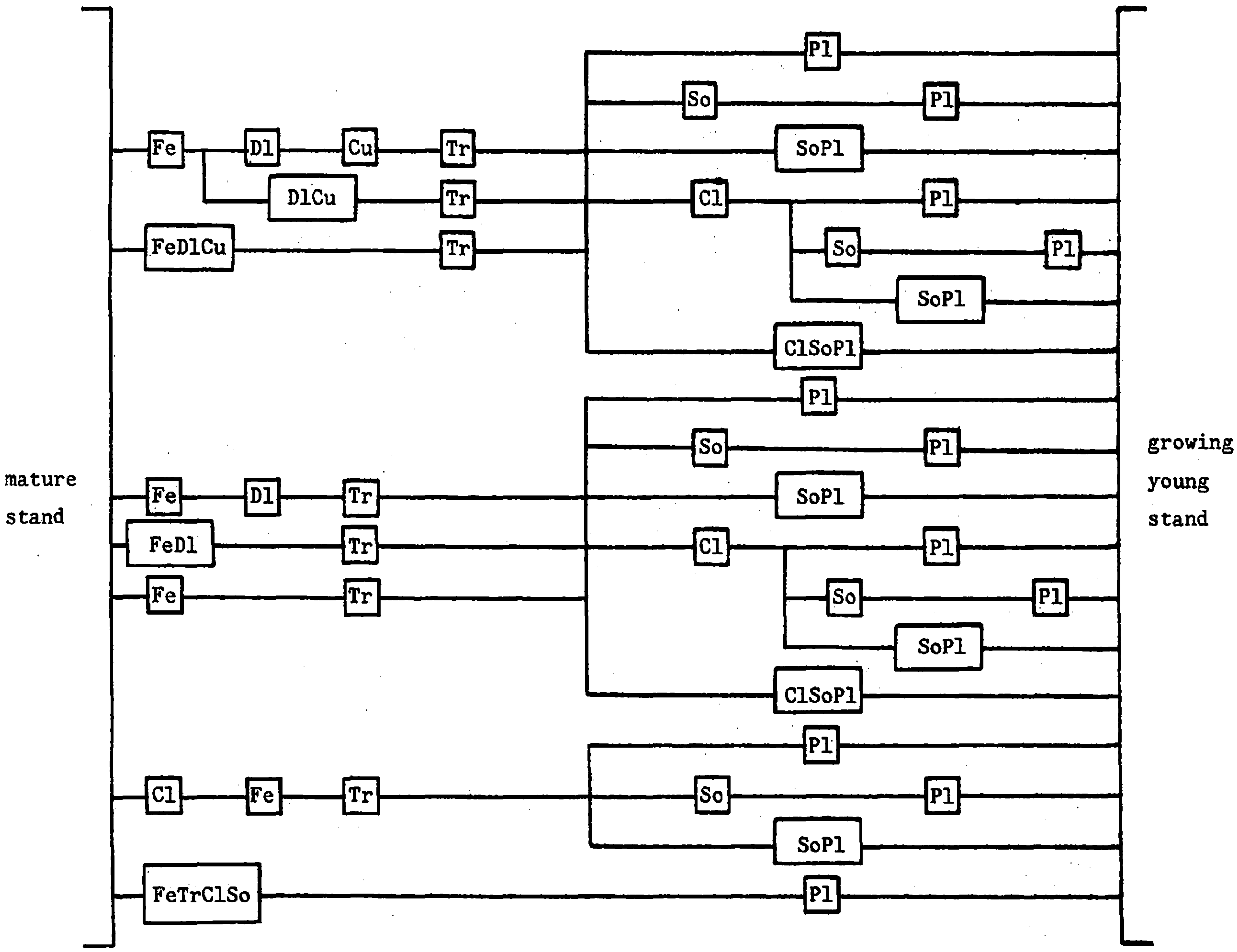

Figure 1. -- Possible systems in a whole system of harvesting and stand establishment in the Netherlands.

☐ = (sub)system; an integrated system, if more codes are brought together in one block.

Fe=felling
Dl=delimbing
Cu=crosscutting
Tr=terraintransport
Cl=clearing/site preparation
So=soil preparation
Pl=planting

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stronger application of ecological considerations. In the case of clear cut and artificial regeneration this means decrease of the size of the object area, for example < 1 ha. The final consequence may be the system of selection felling of single trees or very small groups of trees; in that case you might make use of natural regeneration. Contrary to this, an Eastern German study shows that biologically and technically the best results are reached, if the size of the object areas varies between 3 and 10 ha.

Decrease of the size of the object area implies increase of costs. Decrease of the size of the object area means moving people and machines more often. This will increase the amount of general times, decrease productivity and increase costs. Moreover the productivity of a machine at a smaller area will decrease, since more turns have to be made.

Use of the system of slection felling of groups or single trees will increase costs or decrease yields, since:

- harvesting without damage to the remaining stand has to be carried out more carefully. Costs of harvesting a shelter above a young stand, a silvicultural system, which is often applied in areas where late frosts are occuring, may be indicative.
- in many cases the use of natural regeneration will not be possible, because the quality of the stand is too low. Artificial regeneration will be necessary. The smaller the size of the object area, the higher the costs will be.
- economical and technical limitations necessitate more traditional forest labour. Activities can

not be executed by machines, but have to be carried out manually. Moreover, using traditional methods will have impacts on ergonomics and safety.
- supervision has to be intenser,
- if the same amount of timber will be harvested per ha per year, timber felling will take place more scattered over the forest area. Transport of the timber will be more expensive.

FINAL REMARKS AND RECOMMENDATIONS

Forestry in Western Europe has manifold objectives, as protection against wind and water erosion, satisfaction of the psycho-social needs of mankind and wood production. A high pressure of the population which considers the forests as public owned, has an influence on the way of managing the forests. Moreover, the forests are owned by many owners; the average size of the woodlot is small.

In general you can speak of small scale forestry. This means there are limitations concerning the possibility for mechanization and the level of mechanization. Mechanization is not an aim in itself; except of a higher productivity, one of the objectives is humanizing hard forest labour.

Anyhow, if wood production is still one of our objectives, the forests will be harvested and new stands have to be established. From the mature stand up to the growing young stand a chain of activities has to be carried out. These activities we want to carry out as efficient as possible. At the moment the motivations of decisions concerning the choice of methods for the different activities are sometimes very cloudy. Used subsystems vary in costs sometimes twice.

In view of this I would like to recommend the following:

- A system analysis should be made of the whole system of harvesting and stand establishment, not only as a comparison of costs, but also to get more insight in process of decision making concerning the different steps in the chain of activities.
- Further development of methods, tools and equipment which are adapted to small scale forestry and also of methods and tools for mechanical weed control in the first stage of the establishment, since the use of chemicals has been or will be limited because of public pressure.

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ROLL SPLITTING AS AN ALTERNATIVE TO CHIPPING FOR A WOODY BIOMASS FUELS PREPARATION[1]

Dennis T. Curtin[2]

Abstract--A prototype roll splitter, developed by K. C. Jones and Associates for Forest Engineering Research Institute of Canada (FERIC), is being cooperatively tested by FERIC and TVA. The objectives of the test are to document the energy required to fracture round bolts of a variety of hardwood species and determine the effects of the fracturing process on moisture content and drying characteristics of the fractured bolts.

Energy consumption, dewatering, and drying rates are presented.

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[1] Paper presented at the conference COFE/IUFRO - 1984. Orono, Maine, USA, 12-14 August.

[2] Dennis T. Curtin is Timber Harvesting Operations Project Manager in the Division of Land and Economic Resources, Tennessee Valley Authority (TVA), Norris, Tennessee, USA.

THE SPRUCE BUDWORM IN MAINE[1]

David E. Fosbroke, Douglas R. Gill, and Thomas J. Corcoran[2]

ABSTRACT

The current spruce budworm epidemic is the most widespread of this century, affecting more than half of Maine's 8 million acre spruce-fir forest. The economic importance of this timber resource, particularly for pulp and paper products, stirred early interest in the monitoring of spruce budworm population levels.

Forest stands containing high percentages of balsam fir are very susceptible to severe defoliation, which results in growth reductions and eventually mortality. During severe budworm infestations, widespread mortality occurs in mixedwood stands as well as spruce-fir stands. In addition to growth loss and mortality, spruce budworm defoliation can cause major problems; one problem involves how to best salvage potentially high volumes of timber before it deteriorates beyond usable limits. This problem is not easily solved because decay, windbreak, and blowdown of budworm damaged trees result in the waste of this usable resource if salvage operations are not completed within one to three years after tree mortality.

The most common and effective method of spruce budworm control is the aerial application of chemical and biological insecticides. Silvicultural control methods focus on the removal of balsam fir from susceptible stands as a means of reducing the risk of budworm predation. The combination of insecticide use, silvicultural practices, and insect monitoring, commonly referred to as integrated pest management, provides a comprehensive method of moderating future budworm population surges.

Regardless of the magnitude of insecticide use or silvicultural prescription, current budworm caused mortality will continue for some time, even after depleted food supplies have reduced budworm populations to endemic levels. However, with the development of sound economic strategies for planning optimal salvage schemes and control levels, we can reduce the magnitude of potential timber losses due to budworm devastation.

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[1] Poster presented at the conference COFE/ IUFRO - 1984. Orono, Maine, USA, 12-14 August.

[2] David E. Fosbroke and Douglas R. Gill are Research Assistants, College of Forest Resources, University of Maine, Orono, Maine, USA. Thomas J. Corcoran is Professor of Forest Engineering, College of Forest Resources, University of Maine, Orono, Maine, USA.

MECHANIZED SHORTWOOD THINNING SYSTEM[1]

ABSTRACT

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First commercial selective thinning in southern pine plantations is feasible when using small machines to produce shortwood. The primary advantage of selective thinning is that trees which will produce the most income in the future are left as opposed to row thinning which removes many of the high quality trees. Conversion of felled trees to shortwood before transporting out of the woods is an advantage in a selective thinning operation. The shortwood can be loaded on small forwarders and hauled out of the stand in narrow corridors which meander around quality trees normally removed for straight access routes needed for skidders.

A feasible operation consists of feller bunchers, chainsaws or mechanical processors for delimbing and bucking, and forwarders. Small, highly maneuverable rubber-tired feller bunchers are used to fell trees and bunch them at access corridors. The operators select which trees are to be removed. Narrow, winding corridors (3.5m) are opened about every 27m (90 ft). Trees are selectively cut between the corridors. In manual processing, bunches with approximately 15 trees each are laid parallel to the corridors. Chainsaw operators delimb and buck the trees in the bunches into shortwood. Because of the large bunches, no additional piling of the shortwood is required to optimize forwarder productivity.

An alternative to manual delimbing and bucking is mechanized processing. Processors are safer and require less labor. Trees are bunched perpendicular to the corridors by feller bunchers with 20-25 trees per bunch. The processor operates from the corridor with limbs and tops remaining to improve trafficability and reduce compaction. The processed shortwood is piled along the edge of the corridors.

Forwarders extract approximately 4 bunches per turn for the manual processing alternative or 2 piles per turn behind the mechanical processors. Forwarding distance averages 122m (400 ft) with maximum distances of about 275m (900 ft). With approximately 8 trees per cubic meter (28 trees per cord) the average volume per turn is $7.2m^3$ (2 cords). Wood is off-loaded onto set-out trailers at the landing.

For an average daily production of $21.5m^3$ (78 cords), the balanced systems would be as follows:

Machines	Chainsaw Processing	Mechanical Processing
	--- Number of Machines ---	
Feller bunchers	2	2
Chainsaws	5	-
Processors	-	2
Forwarders	3	3

This mechanized shortwood system with either chainsaw or mechanical processing has proven cost effective in thinning loblolly pine plantations between ages of 14-18 years old in southern USA. Current bolt length is 2.3m (7.5 ft). The result is an acceptable silvicultural treatment completely paid for by the value of the pulpwood removed.

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[1] Poster presented at the conference COFE/IUFRO-1984. Orono, Maine, USA, August 12-14.

ROAD AND BRIDGE CONSTRUCTION[1]

A. Allen Murphy[2]

ABSTRACT

Introduction

The material on this poster was a combination of materials on road construction, culvert locations, setting pools, and basins, filter strips, horizontal and vertical road shoulder slopes, road locations in the field. Other supplemental material included bridge terminology, bridge plans, road classifications, culvert installation, information on skidder trails and other road information.

Description of Data Base

The data base of this poster is from company plans of bridges, field data collected over a period of years, and pages of the company manual on road and bridge construction. This material was supplemented by photos of work in the field.

Conclusions

The data put together for this poster is a summary of field data put down on paper in a plain and simple way by using plans and sketches to show the proper road construction in the field, proper bridge design, and culvert installation.

The only literature used was the Seven Islands Land Company booklet entitled "Access Road, Water Crossings and Skidder Trail Layout" by Murphy.

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[1] Poster presented at the conference COFE/IUFRO - 1984. University of Maine, Orono, Maine, USA, 12-14 August, 1984.

[2] A. Allen Murphy is the Forest Engineer for Seven Islands Land Company, Bangor, Maine, 04401, USA.

A MAP-BASED INFORMATION SYSTEM FOR LOGGING ROAD MANAGEMENT[1]

Maarten A. Nieuwenhuis and Thomas J. Corcoran[2]

ABSTRACT

The use of computerized information systems in forest management is increasing rapidly. Most of these systems are developed primarily for stand management. An important section of forest management which is often not included is the transportation and road construction aspect.

In the last decade more emphasis has been directed towards this part of the overall managing process. Three reasons warrant inclusion of road construction, road maintenance and transportation scheduling in the information system: the increase in construction and fuel costs, the growth of the existing road networks, and the increase in road construction due to the salvage operations of spruce budworm damaged timber in the Northeast of the United States and Eastern Canada.

A computerized map-based information system, which combines the easy accessibility of maps with the data storage and retrieval capabilities of a computerized data-base, provides the management with a tool to deal with the large amounts of data involved. The output capabilities in the form of maps and/or reports make the system flexible enough to suit the needs of different users.

The road network management capabilities of the system are enormous: road and structure maintenance scheduling, selection of road segments and structures for upgrading procedures, traveltime estimations, shortest route determinations, and possibly the selection of an optimal manner, using soil; river, stream, lake; covertype; and elevation data from the total system.

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[1] Poster presented at the conference COFE/ IUFRO - 1984. Orono, Maine, USA, 12-14 August.

[2] Maarten A. Nieuwenhuis is a Research Assistant, College of Forest Resources, University of Maine, Orono, Maine, USA. Thomas J. Corcoran is Professor of Forest Engineering, College of Forest Resources, University of Maine, Orono, Maine, USA.

PENDULUM BALLOON LOGGING SYSTEM[1]

Eldon D. Olsen[2]

Abstract--We tested the concept of using a tethered balloon for load transport. Potential system applications are ship to shore transport, logging, and heavy construction in remote areas. System capabilities were predicted using computer models and small scale field experiments. The system is still in a developmental stage.

SYSTEM DESCRIPTION

The pendulum-swing system differs from conventional balloon systems with the load always suspended directly beneath. In this new system, lift for the load is provided by a stationary balloon and the load is swung to the landing in a pendulum-like movement.

An application of the pendulum-swing balloon system is illustrated in Figure 1. Components include a natural-shaped balloon with a capacity of 31,000 m^3, three or more guylines, and a conventional yarder.

The helium-filled balloon is held in a relatively fixed position 450 m above the ground by means of three or more guylines, at least one of which is attached to a winch capable of spooling the entire length of the guyline. This winch allows the balloon to be repositioned by changing guyline length. The remaining guylines are anchored near the perimeter of the harvesting unit.

RESULTS

Because the length of three separate lines (mainline, haulback, lift) are simultaneously changed the system will be computer controlled. Field tests of models have indicated that the system is relatively stable under normal operating conditions. Stability comes from the guylines restricting balloon movement and from operating lines controlling the load hook position.

The major restriction of this system is its vulnerability to high gusty winds. For winds in excess of 46 km/hr (25 knots) the system must be secured in a sheltered location. The initial cost of the system is about $2,688,000 (U.S.). Operating costs are about $900/hr based on an 184 working day season and an 8 person crew or 10% more than the hourly operating costs of conventional balloon systems. A typical load/unload cycle can be accomplished every 5-6 minutes. Predicted productivity comparisons indicate that the pendulum system is superior to conventional balloon logging (Yo-Yo system) only at yarding distances under 800 m (fig 2). The comparison is for Pacific Northwest U.S.A. conditions with 100 metric tons per hectare to be harvested.

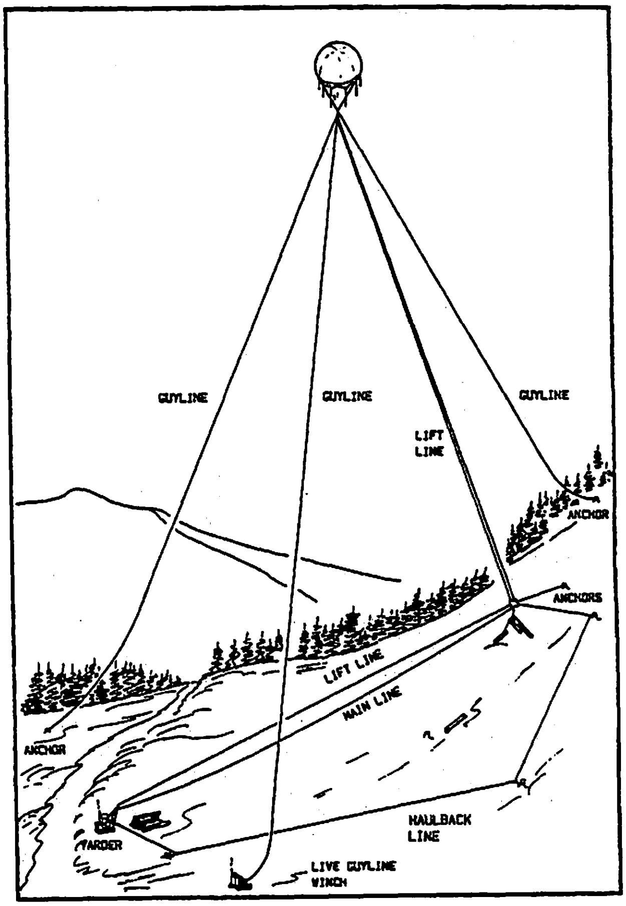

Figure 1.--Pendulum swing balloon logging systems.

Funding for the project was provided from a grant to the OSU Foundation by J.L. Bell who holds a 1974 U.S. Patent Number 3807577 on the pendulum swing concept.

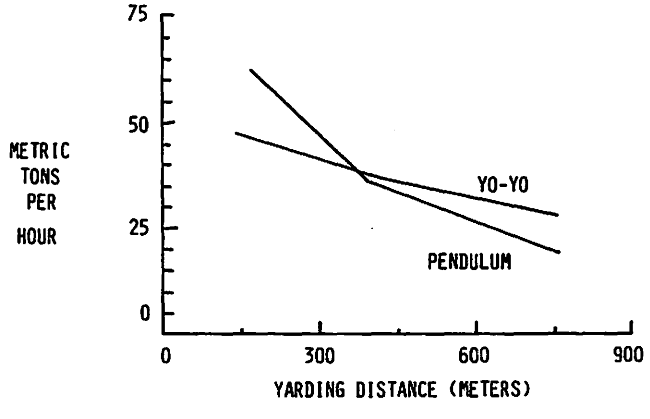

Figure 2.--Comparison of production.

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[1] Poster presented at the conference COFE/IUFRO 1984. Orono, Maine, USA, 12-14 August.

[2] Eldon D. Olsen is Associate Professor of Forest Engineering, Oregon State University, Corvallis, Oregon, USA.

MICROCOMPUTER-BASED FOREST OPERATION PLANNING DECISION SUPPORT SYSTEMS[1]

E.W. (Ted) Robak[2]

Abstract.- North American forest operations are generally highly mechanized and capital-intensive and are, therefore, highly sensitive to planning deficiencies. A study of contemporary operational planning methods has revealed that, although the basic analytical techniques employed are usually adequate, the process itself is not conducive to the application of sensitivity analysis. Managers have indicated that they are not being given the information, tools and/or time to formulate better operating plans or to change those plans in reaction to unforseen problems or opportunities. A decision support system (DSS) could reduce these shortcomings in the management decision-making process by combining effective data-base management, modeling and dialog capabilities to provide decision support for unstructured and semi-structured problems. Proper application of the DSS concept could greatly enhance the abilities of managers to plan and control forest exploitation activities.

The goals of a DSS for forest operational planning and control should be to improve a manager's ability to analyze the potential effects of future operating decisions and accurately estimate the efficiency of ongoing harvesting, transportation, stand establishment and support activities. Such a support system should be capable of retrieving information from forest resource, equipment and financial data-bases, it should be able to effectively interact with the strategic decision-making environment and yet must always be accessible to a manager in his workplace, no matter how remote that might be. One microcomputer-based DSS currently under development (OP-PLAN) will use the entire operating budget as the major objective decision criterion for sensitivity analysis, while relying on a manager's experience and intuition to ensure that physical, biological and organizational constraints are properly recognized. OP-PLAN would also be used as a managerial control tool during the operating year by facilitating the formulation of plan revisions and new budget estimates for comparison against the original budget. However, it should be recognized that although this DSS could help managers improve their operational planning and control, its utility will be greatly increased when it forms part of a network of specific DSSs that are integrated vertically and horizontally (connecting all levels and departments of an organization) and that effectively access the rich information environment in which they exist.

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[1] Poster presented at the conference COFE/IUFRO - 1984. Orono, Maine, U.S.A, 12-14 August.

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ABSTRACT

THE EFFECT OF HEAT STRESS ON FOREST HARVESTING PRODUCTIVITY[1]

Leo A. Smith, Michael R. Seay, and Donald L. Sirois[2]

INTRODUCTION

The effect of heat stress on the productivity of forest harvesting personnel has been considered by only a few investigators. Both Axelson (1974) and Smith (1984) present speculation on the topic, but actual forest harvesting data supporting the observations are not presented. The present poster summarizes the effects of heat stress on productivity revealed by analysis of production records of three harvesting crews working in southeastern Alabama.

DESCRIPTION OF THE DATA BASE

Daily production records from two years of operations of three six-man logging crews employed by a large harvesting company in southeastern Alabama were selected for study. During the study period each crew experienced no turnover in personnel, harvested similar stands utilizing similar equipment and methods, and operated under relatively stable market conditions. Crews 1 and 2 typically worked on dry, upland terrain and their data were combined for analysis. Crew 3 typically was assigned work in low lying areas. The harvesting system consisted of chainsaw felling, delimbing and topping, cable skidding, and loading of whole stems. Crew 3 differed in that track rather than tire mounted skidders were typically utilized. Natural stands of mature pine were harvested; some stands had been prelogged for pulpwood. Environmental data were readings recorded every three hours by the nearest (80 km) station of the U.S. National Weather Service. A total of 806 crew/days were included in the final data set after elimination of days involving atypical harvesting activity.

ANALYSIS AND RESULTS

A number of heat stress indexes have been proposed to reflect the composite effects of the different variables in the occupational thermal envoironment. The Oxford Index was used in this study. The Oxford Index (WD) is defined as (.85*wbt + .15*dbt) The WD was calculated using the average of the temperature readings from the 0900, 1200, and 1500 hours of the day.

The relationships between harvested weight per manhour and the following independent variables were evaluated: WD, week day, and tract rating. The tract rating was a numerical score assigned by the logging company reflecting the relative desirability of a tract. Analysis of variance indicated that production was significantly affected (.10 level) by tract rating and WD for crews 1 and 2. Only tract rating was significant for crew 3. Attempts to develop regression models of production per manhour as a function of tract rating and WD resulted in very low R-square values.

Based on the results of Duncan's multiple range test the crew 1 and 2 tract ratings were divided into a high and low group. Similarly, the WD values were divided into a high group (WD>25 degrees C) and a low group (WD <=25). The combination of high track rating and low WD resulted in 15.8% greater average productivity than the low track rating-high WD combination. There was no interaction between the grouped variables and the two middle groups differed by only 2.8%.

CONCLUSION

The analyzed data indicated a reduction in productivity under WD conditions greater than 25 degrees C. A model describing productivity reduction as a function of WD could not be developed most likely due to the inherent daily variability in harvesting data.

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RESIDUAL HARVESTING SYSTEMS FOR THE SOUTH[1]

ABSTRACT

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More importance is being placed on the utilization of small diameter, unmerchantable trees as well as residuals remaining after harvest. This is partly due to the increasing uses for forest biomass and the increasing costs of fossil fuels. Another important reason is to offset the high cost involved in regeneration with intensive mechanical site preparation.

New techniques and machines are being developed to harvest more of the woody biomass for energy. Methods range from conventional harvesting systems with portable chippers to specialized machines and innovative concepts. Some research emphasis has been directed toward the development of multi-functional harvesting machines that fell the unmerchantable trees and/or pick up the residual slash for chipping and primary transport. Other concepts include baling and hogging the residuals behind conventional harvesting operations.

Recovering energy wood economically is a major problem due to the high cost of collecting, handling, and transporting the low volume trees and components. One solution is chipping the wood at the site and transporting to the mill boiler in vans. There are four separate concepts being developed for this purpose:

Portable Chippers - Chippers in this category are usually mounted on a trailer and are towed to the site and operated at the landing. They are an integral part of a conventional system that includes feller bunchers and skidders. Products may be only energy wood or a mixture of energy wood and merchantable roundwood using a loader. The nature of the system demands the harvest of whole trees to certain diameter limits. Recovery of the downed slash is infeasible. Therefore the energy wood is pre-harvested or simultaneously harvested with the other products from the stand.

Such a system offers the potential for increased utilization at competitive costs for certain stands. Current equipment can be used. Disadvantages include high costs associated with low volumes of biomass and non-recovery of logging slash.

Mobile Chipper Harvester - The concept is a chipper mounted on a carrier with felling capability for small trees and brush in a continuous swath. Chips are discharged onto a second vehicle for forwarding to the landing or other unloading point. With this process, the trees in otherwise unmerchantable stands can be utilized for energy wood. The system can be applied in post-harvesting operations to recover the remaining standing trees and logging slash on the site. The advantage is the utilization of biomass that would otherwise be wasted. Use of this system could result in more cut-over acres being reconverted into merchantable stands. The product will be cleaner because the material is not skidded. This is a specialized system with only one product capacity.

Mobile Chipper Harvester-Forwarder - This machine concept includes the addition of an onboard provision for collecting the chips and forwarding to the landing. Instead of having several machines, the system consists of one machine which performs all the functions of felling, chipping, and forwarding.

There are advantages in having less machines in the system. Disadvantages include restrictions to certain stands and productivity loss because of the forwarding function. Little or no downed biomass can be collected with this system.

Mobile Chipper-Forwarder - The concept is based on a self-loading chipper mounted on a carrier. Working behind a feller buncher, trees from piles are chipped in the stand and discharged into an onboard container. The chips are forwarded to the landing by the machine for dumping into an open-top van. Because feller buncher are a part of the system, tree diameter is very critical for economical recovery. The potential for recovering slash may be limited.

Since the skidding function is removed, then the system has the potential of producing cleaner chips. The separation of the felling function improves system utilization when one machine is down. There is a productivity loss because of forwarding with the same machine that does the chipping.

In summary, a practical approach to better utilization of the woody biomass for energy wood is to use conventional equipment for harvesting the small diameter trees to economical limits. For recovery of the residual slash, more specialized machines are being developed. They offer the potential of better utilization at an economical cost and a reduction in the site preparation needed for regeneration.

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