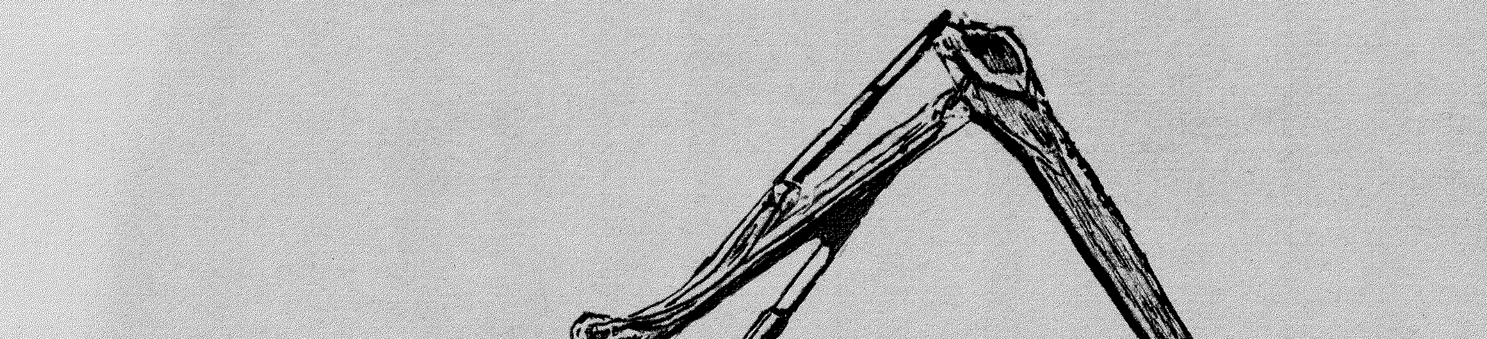
FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

Technical Report No. 1
December 1975

Evaluation of FMC 200 BG Grapple Skidder

R. Legault and L. H. Powell



245 HYMUS BLVD. POINTE CLAIRE, P.Q., CANADA H9R 1G6
300 — 2045 WEST BROADWAY, VANCOUVER, B.C., CANADA V6J 1Z5

ISSN 0318-7063

Evaluation of FMC 200 BG Grapple Skidder

R. Legault and L. H. Powell

Technical Report No. 1

FERIC

FOREST ENGINEERING
RESEARCH INSTITUTE
OF CANADA

INSTITUT CANADIEN
DE RECHERCHES
EN GÉNIE FORESTIER

December 1975

Foreword

This report on the FMC 200 BG Grapple Skidder, the first to be published by the Forest Engineering Research Institute of Canada, forms part of the Institute's project: "Evaluation of New Logging Machines" and continues the series previously published by the Logging Research Division of the Pulp and Paper Research Institute of Canada.

The objectives of this project are the description of new logging machines and their evaluation as to technical characteristics, potential productivity under measured conditions, and expected costs. The project reports are designed to assist future users in appraising the current status and prospective value of specific logging machines, thus facilitating the choice among available alternatives.

The short duration and restricted scope of the individual studies do not permit the drawing of meaningful conclusions relative to the effects of all environmental and operating factors. The results refer to "cases" only and are therefore of limited applicability.

Details of the study procedures and analyses have been omitted from this report in order to keep it brief. If needed, further details of the study can, however, be supplied on request.

All quantitative data throughout the report are given in Imperial units. The SI (Système International d'Unités) equivalents are appended within parentheses.

Grateful appreciation is extended to company personnel of Domtar Woodlands Limited, Lebel-sur-Quévillon, Quebec, and to FMC Corporation, Advanced Products Division, Mt. St-Hilaire, Quebec, for their cooperation and help during the study described in the report.

Table of Contents

Summary

If you were to consider an $85,000 self-loading tracked skidder for your operation, what criteria of productivity and cost would such a machine have to meet in order to qualify? The findings of this study may provide some of the answers.

Interest in the FMC 200 BG Grapple Skidder stems from its reported higher travel speed, better performance on slopes and greater mobility in wet areas as compared to wheeled skidders. The travel speed of the machine was not impaired by the maximum slopes observed (24%), and its high flotation and ease of travelling over wet areas were a promising indication of its potential mobility.

A recent FERIC study, on Domtar's limits at Lebel-sur-Quévillon, showed that the average productivity, based on average total time per turn of 19.3 minutes and average load size of 1.8 ct (5 m^3) was 5.6 ct (15.8 m^3) per productive machine hour (PMH) over an average distance of 1,033 ft (315 m). Total time per turn consisted of travel time empty and loaded (37%), loading time (45%), unloading and piling time (13%), and delay times (5%). The only controllable time element that appeared to affect productivity, was piling. Less time spent on piling at roadside would reduce the total time per turn and therefore increase the productivity.

Operating costs were based on a purchase price of $85,000 and on both favourable and unfavourable estimates of other cost factors. This approach has resulted in a considerable but still reasonable range of expected costs; $4.53 to $12.85 per cunit ($1.60 to $4.50/m^3) for skidding tree-lengths to roadside.

Assuming that the optimum road spacing is found by equating skidding cost to road-construction cost [4], it can be shown that the optimum road spacing for this machine is about 3,600 ft (1,100 m) resulting in a maximum skidding distance of 1,800 ft (550 m) and an average skidding distance 900 ft (275 m), provided skidding is carried out from both sides of the road.

The FMC skidder is a fast machine, whose travel speed empty was 308 ft/min (94 m/min). With loads up to 2.5 cunits (7 m^3), the FMC travelled in second gear, at speed averaging 276 ft/min (84 m/min) as compared to the BM Volvo SM 868 Grapple Skidder [5] which travelled at only 176 ft/min (53 m/min). The latter is a self-loading wheeled

skidder of lighter weight. Travel speed loaded of the FMC was not affected by the load volumes observed which suggests the desirability of increasing the bunk grapple capacity of the skidder.

The study was carried out on Domtar's limit at Lebel-sur-Quévillon, Quebec. Thirty-nine turns were timed and analyzed for measured stand and site conditions. The site was a clay soil with 8-10 in (20-25 cm) of humus under undulating topography. The stand was composed of two major species, black spruce (*Picea mariana* (Mill.) B.S.P.) 85%, and jack pine (*Pinus divaricata* Lamb.) 15%.

None of the site factors affected the speed of the machine. They included slopes up to 24%, ground wetness classes 2 and 3 (hard and soft ground) and obstacles (i.e., stumps and slash) up to 1 ft (0.3 m) in height.

The low volume per stem on the site of the study (average 4.8 ft^3 (0.14 m^3)) affected the productivity of the machine and could be a factor which would lower the economic profitability of a grapple skidder of this type when operating in stands of small timber.

A study of the ergonomic aspects of the work done by the operator revealed that the most important problems were high cab temperatures and noise levels. Temperatures in the Laurin cab reached 98°F (37°C) while the outside temperatures were around 72°F (22°C).

The average noise levels were recorded on the machine equipped with protective roll-over bars and front window; the measurements gave 89 dBA when the machine was idling and 101 dBA with the machine running full throttle. Measurements were also taken with the Laurin cab and the results were the same as above. There was an improvement when the machine is equipped with the Sims cab, in which the levels were 83 dBA idling and 94 dBA running at full throttle. With all three types of cab, the noise levels exceeded the current permissible limits of the U.S. Department of Labor [1].

Soil disturbance observations were also made and revealed that the effect of the skidder on the soil was negligible; approximately 10% of mineral soil exposed and almost no compaction.

Further studies will be conducted under West Coast conditions to evaluate the FMC 200 BG Grapple Skidder on steeper slopes and in larger timber.

Sommaire

Quels critères de productivité et de coût devrait rencontrer un semi-porteur à grappin, sur chenilles et d'un prix d'achat de \$85,000, afin de satisfaire vos exigences. Le but de ce rapport est de fournir les réponses.

Les principales caractéristiques du semi-porteur à grappin FMC 200 BG sont: sa plus grande vitesse de déplacement, ses performances supérieures sur les pentes et sa capacité de marche dans les terrains marécageux, comparativement aux débusqueuses sur roues. Les pentes maximales observées (24%) n'ont pas affecté la vitesse de la machine et sa flottabilité ainsi que sa facilité de déplacement dans les terrains marécageux sont des indicateurs de sa mobilité.

Une étude entreprise par FERIC sur les opérations de la Société Forestière Domtar, à Lebel-sur-Quévillon, Québec, a démontré que la production moyenne, calculée à partir de la durée moyenne par cycle de travail (19.3 min), du volume moyen par charge (1.8 ct (5.0 m^3)) et de la distance moyenne de débusquage (1,033 pi (315 m)) était de 5.6 ct (15.8 m^3) par heure effective de production. La durée moyenne par cycle se subdivisait en temps de déplacement à vide et en charge (37%), temps de chargement (45%), temps de déchargement et d'empilement (13%) et temps improductifs (5%). L'empilement était le seul élément de travail qui semblait affecter la production. Moins de temps écoulé à empiler les tiges réduirait la durée totale du cycle et par conséquent augmenterait la production.

Basés sur un prix d'achat de \$85,000 et sur des estimés favorables et défavorables pour d'autres éléments nécessaires aux calculs, les coûts d'opération suivant ont été obtenus: \$4.53 à \$12.85 du cunit (\$1.60 à \$4.50/m^3). Cet écart, considérable mais raisonnable, devrait être anticipé.

En supposant que l'espacement des routes est optimum lorsque leurs coûts de construction sont égaux aux coûts de débusquage, ont peut démontrer que l'espacement optimum devrait être approximativement 3,600 pi (1,100 m) résultant ainsi en une distance maximale de débusquage de 1,800 pi (550 m) et une distance moyenne de 900 pi (275 m), pourvu que le débusquage soit fait des deux cotés de la route.

La vitesse de déplacement à vide du semi-porteur FMC était de 308 pi/min (93 m/min). Avec une charge de 2.5 ct (7.0 m^3), le FMC, en deuxième vitesse, se déplaçait à 275 pi/min (84 m/min) comparativement à 175 pi/min (53 m/min) pour le BM Volvo SM 868 [5]. La vitesse du FMC n'était pas affectée par les charges observées, ce qui suggère la possibilité d'augmenter la capacité de sa benne.

Trente-neuf cycles de travail ont été chronométrés afin de déterminer l'influence possible des conditions de terrain (sol glaiseux recouvert d'environ 8 à 10 po (20 à 25 cm) d'humus) et de peuplement sur la machine. L'épinette noire (*Picea mariana* (Mill.) B.S.P.) 85% et le pin gris (*Pinus divaricata* Lamb.) 15% colonisaient le sol.

Les conditions de terrain, incluant les pentes jusqu'à 24%, l'humidité du sol caractérisée par les classes 2 et 3 (sols durs et mous) et les obstacles (i.e. souches et débris de coupe) d'une hauteur atteignant 1 pi (0.3 m) n'ont pas affecté la vitesse de déplacement de la machine.

Le faible volume par tige du peuplement en question (en moyenne 4.8 pi^3 (0.14 m^3)) a réduit le rendement de la machine et pourrait diminuer la rentabilité économique d'un semi-porteur de ce genre.

Du côté ergonomie, les principaux problèmes furent les hautes températures à l'intérieur de la cabine et l'intensité du bruit. La température à l'intérieur de la cabine Laurin atteignait 98°F (37°C) lorsque la température extérieure était de 72°F (22°C).

Sur une machine équipée d'un toit de protection et d'un pare-brise, l'intensité moyenne du bruit fut enregistrée à 89 dBA lorsque le moteur tournait au ralenti et à 101 dBA lorsqu'il tournait à pleine révolution. Les niveaux enregistrés sous la cabine Laurin étaient identiques aux précédents alors que sous la cabine Sims, ils étaient de 83 dBA (au ralenti) et de 94 dBA (pleine révolution). Même avec cette amélioration, l'intensité du bruit dépasse les limites permises par le département américain de la main-d'oeuvre [1].

Un examen du parterre de coupe après débusquage, a révélé que les dommages causés par le FMC étaient négligeables: approximativement 10% du sol minéral était découvert et le compactage minime.

Des études seront entreprises prochainement dans l'ouest canadien afin de déterminer la performance du semi-porteur à grappin FMC 200 BG dans des conditions différentes de terrain et de peuplement.

General Comments

The FMC 200 BG Grapple Skidder can be used to skid either tree-lengths or full trees. In this study the machine was skidding tree-lengths previously cut and bunched by a Beloit harvester and a Timmins "Fel-Del" harvester mounted on a Liebherr carrier. Neither the size, nor the spacing of the bunches was found to affect the productivity of the skidder. The only measured factor that affected the total time per turn was the skidding distance.

It is possible to compare the productivity of the machine with other skidders under similar operating conditions. The BM Volvo SM 868 Grapple Skidder, also studied in the same region [5], had a productivity of 6.8 ct (19.9 m^3) per PMH compared to the FMC's productivity of 5.6 ct (15.8 m^3) per PMH over a similar skidding distance of 1,033 ft (315 m) (see Figure 1). Since the travelling

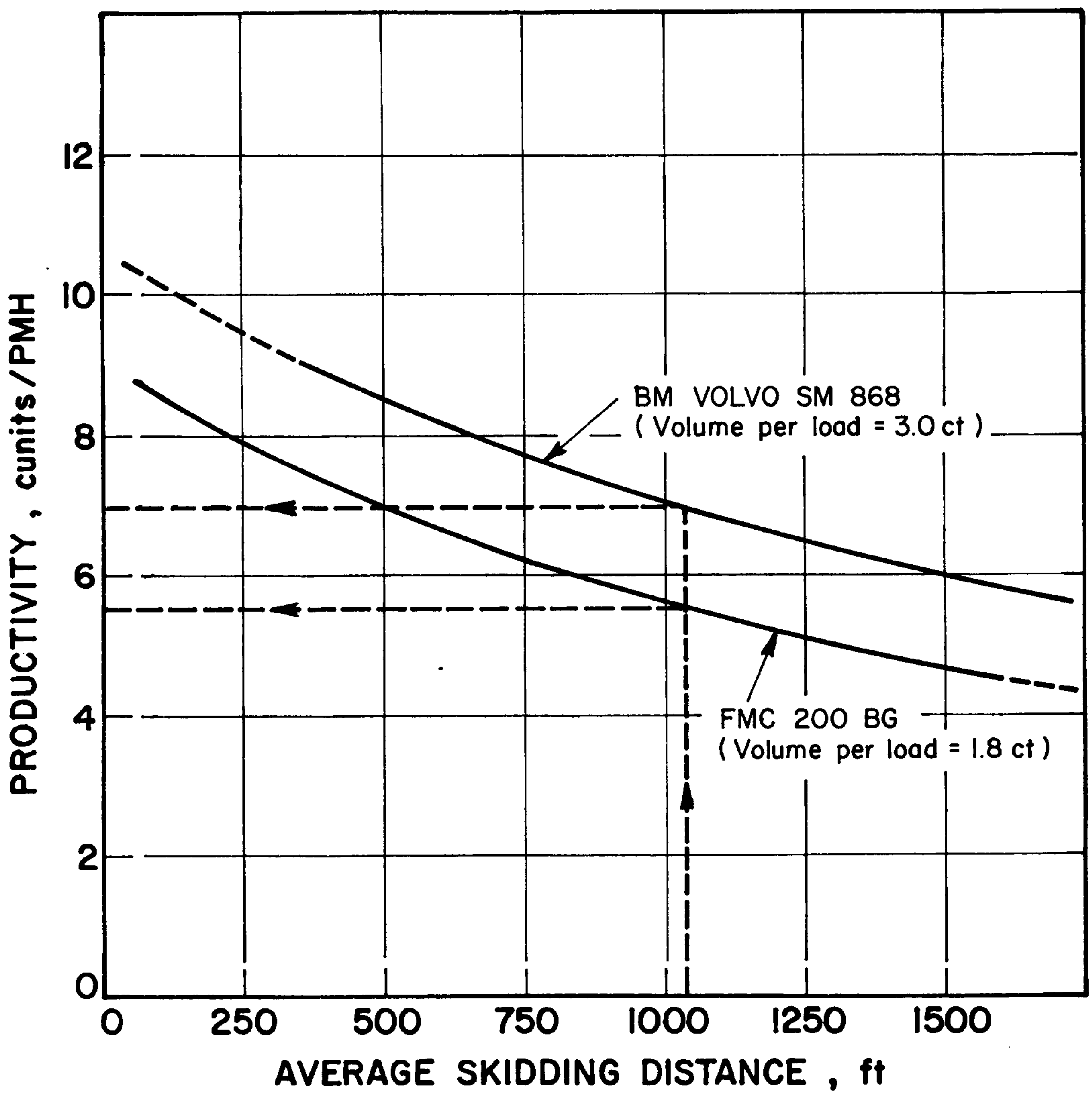


Fig. 1. Productivity of the FMC 200 BG based on total time per turn (see Table II) compared to BM Volvo's productivity [5].

speed of the FMC was greater than that of the Volvo, load volume is a factor affecting productivity.

An increase in the capacity of the bunk grapple would increase the productivity of the machine. Since it is equipped with a powerful engine, an increase in the load size should not affect its travelling speed, and the manufacturer is now testing the possibility of increasing the bunk capacity from 14.4 to 18.4 ft^2 (1.34 to 1.71 m^2) (area enclosed by grapple, tip to tip). The resulting larger volume per load would improve the productivity per PMH and therefore lower the unit cost.

A self-loading skidder like the FMC has an advantage over the regular wheeled choker skidder because the operator does not have to alight from the machine to build his load. The work is therefore much easier on the operator, especially in rough terrain.

The FMC skidder has a definite place where soft terrain would limit the use of regular wheeled skidders. The manoeuverability and pulling power through mud makes the skidding operation easier over wet areas.

An ordinary grapple skidder has a short round trip time but the low volume per load limits the skidding distance. On the other hand, the FMC Skidder can build bigger loads and skid them a greater distance, thus reducing the road-construction costs.

In a good operational layout, the harvesters work at right angles to the road. The skidding follows the same pattern, using the same trail as the harvester. At the loading point, the skidder manoeuvers into position facing the road, so that the travel loaded is done in a straight line (see Figure 2).

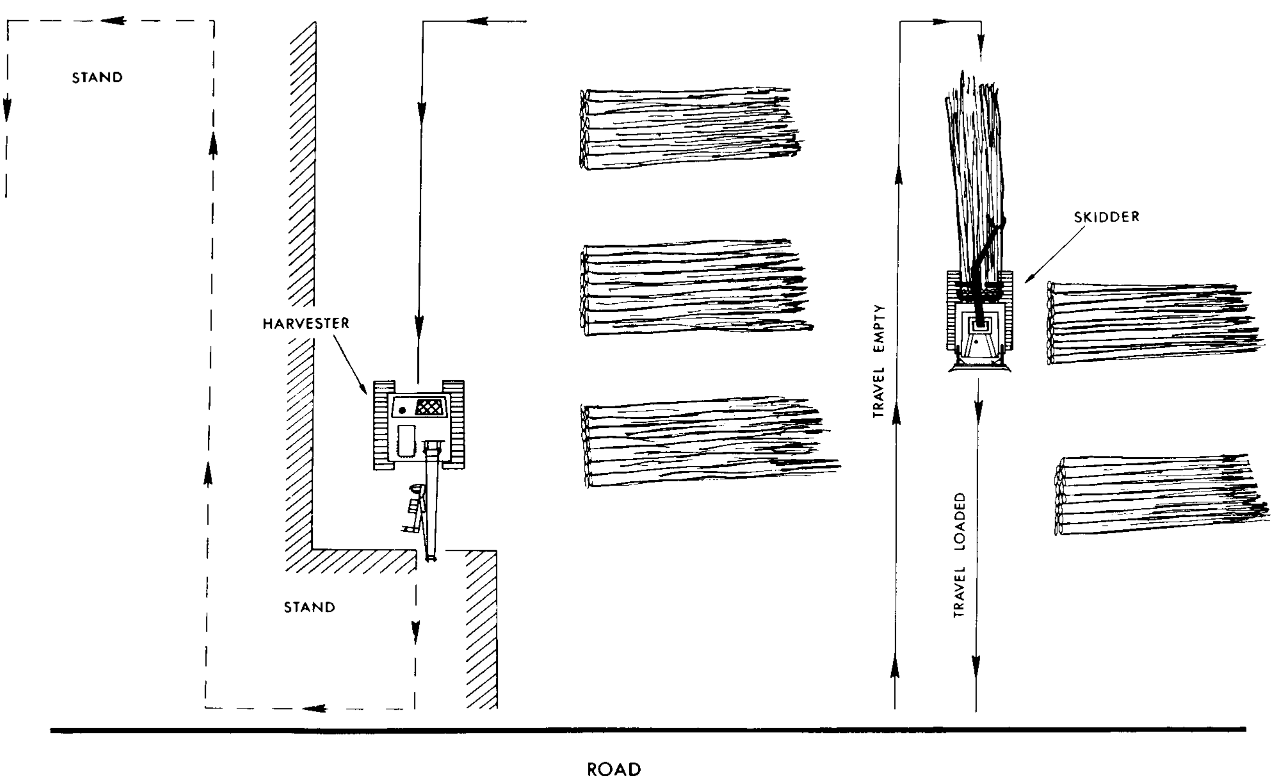


Fig. 2. Operational Layout

Machine Components

The FMC 200 BG Skidder is a tracked machine designed for forwarding of either tree-lengths or full trees.

It is equipped with a hydraulic loader and a rear built grapple enclosing 14.4 ft^2 (1.34 m^2) (area within grapple tip to tip).

The main components consist of:
1. 197 hp (147 Kw) Detroit Diesel Engine
2. Optional cab
3. Sprung suspension
4. Omark Prentice loader model 50
5. 22 inches (559mm) forged steel tracks

The low ground pressure 5.83 psi (2.82 kPa) at shipping weight gives the machine mobility over marginal terrain and the low center of gravity gives it stability on slopes.

The main components are shown in Figure 3. More detailed manufacturer's specifications are listed in Appendix A.

Operating Sequence

The operating sequence of the FMC 200 BG Grapple Skidder is similar to other regular skidders (5). The elements of the turns are illustrated in Figure 4 and details of each sequence are given in Appendix B.

The operating sequence of the Grapple Skidder consists of the following elements (see Figure 4):

Travel empty
Manoeuvering
Loading
Moving during loading
Travel loaded
Unloading
Piling

Fig. 3. The FMC Grapple Skidder

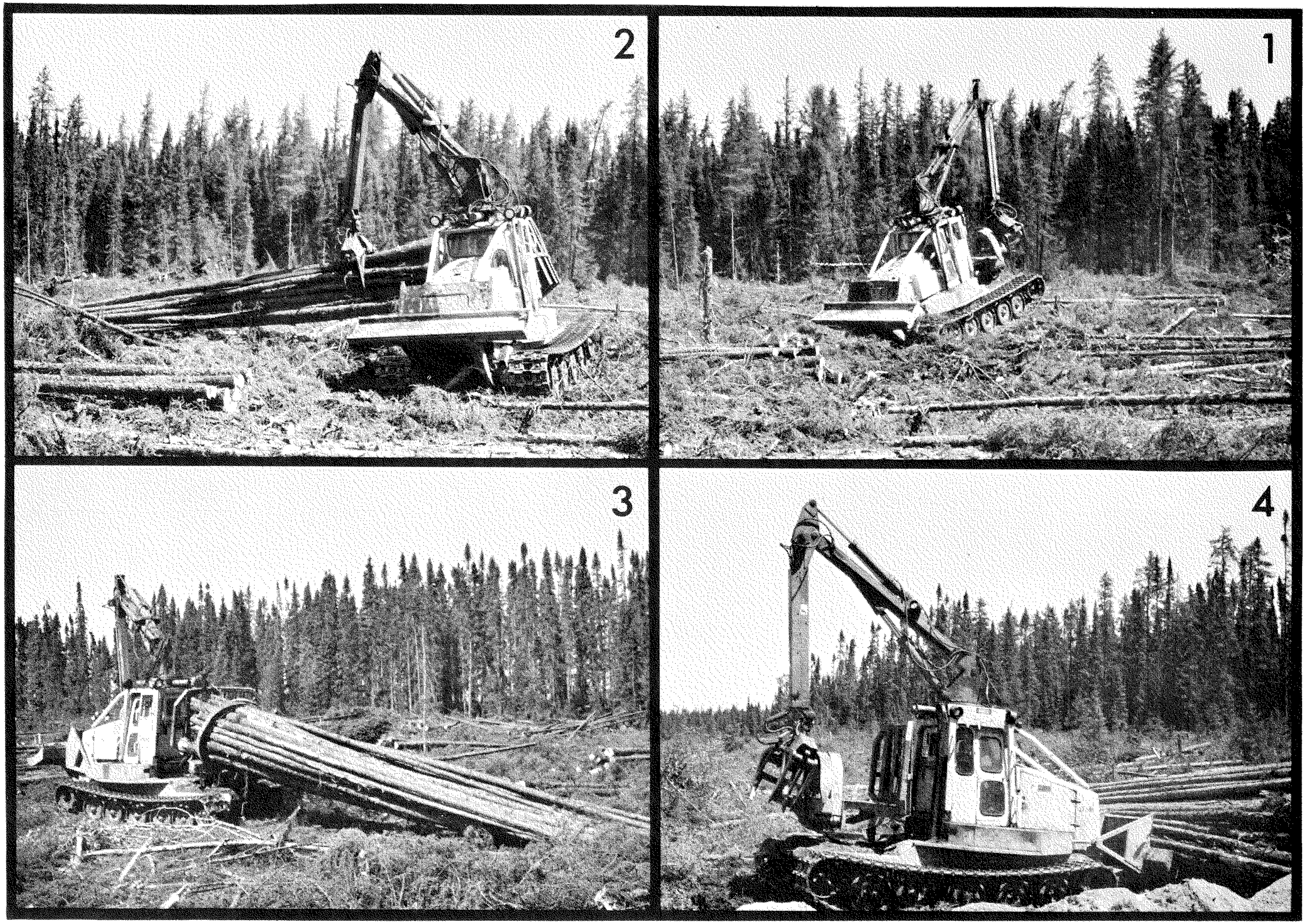


Fig. 4. Turn elements (1) travel empty (note the position of the loading grapple), (2) loading, (3) travel loaded (the loading grapple is attached to the front blade), and (4) piling.

Field Study

In June 1975, a FERIC field crew conducted a 1-week study on the FMC 200 BG Grapple Skidder on the limits of Domtar Woodlands Ltd., Lebel-sur-Quévillon, Quebec.

The machine was skidding tree-lengths, cut by Beloit and Timmins harvesters, from stump to roadside where the trees were loaded on trucks and transported to the mill.

The timing was done on one skidder with an operator who had approximately 4 months experience on the machine. A total of 39 turns were observed and the times of each element of the turns were recorded. Delays were recorded according to their duration as follows:

0-5 cmin:	included in the elements of the operating sequence
5 cmin-10 min:	recorded as delays
> 10 min:	not considered as part of productive time and therefore excluded.

The ground conditions such as slopes up to 24% did not affect the travelling speed of the machine. The skid trail wetness ranged from class 2 (hard) to class 3 (soft); wetness and such obstacles as stumps, slash and rocks did not affect the productivity of the skidder. The manoeuverability of the machine permitted the operator to avoid the major obstacles within the skidding trail.

Factors expected to affect the productivity of the machine were measured and are presented in Table I.

Table I: Operating Factors

	Imperial Units			SI Units		
Factors	Mean	S.D.	Range	Mean	S.D.	Range
Travel distance empty, ft (m)	1092	400	148-1574	333	122	45-480
Travel distance loaded, ft (m)	1000	417	10-1673	305	127	3-510
Skid trail slope, maximum, %	12.5	8.5	0-24	12.5	8.5	0-24
Trees per load	37	6	26-54	37	6	26-54
Volume per tree, ft^3 (m^3)	4.9	1.1	0.8-28.4	0.14	0.03	0.02-0.8
Volume per load, ft^3 (m^3)	176	30	112-246	5.0	0.85	3.18-6.97
No. of merchantable trees per acre (hectare)	502	258	189-1100	1242	637	467-2720
Merchantable volume per acre ct/acre (m^3/hect.)	28	22	9.7-50.6	196	157	66.8-356

Productivity of the FMC 200 Skidder

The average total time per turn was 19.3 minutes over an average distance of 1,033 ft (315 m) giving an average production of 5.6 ct (15.8 m^3) per PMH with an average volume per load of 1.8 ct (5 m^3). The travelling time is significantly influenced by the travel distance but time spent loading and unloading at sites plus delays are considered as constants since they were not significantly affected by any of the variables measured during the study.

Table II presents the characteristics of each time element.

These results are also presented in the form of a nomogram* based on the equation of Table II. The nomogram (see Figure 5) will indicate expected production per shift of length ranging from 6 to 10 productive hours. The dashed line represents the mean values of the results obtained from the study.

A productivity table based on average skidding distances ranging from 100 to 1,500 ft and load volumes ranging from 1.3 to 2.1 ct, is presented in Table III. The conversion from Imperial units to SI units is presented in Table IV.

*The reader is reminded that the nomogram represents specific conditions, and that any prediction under conditions outside the range of those found on the study will be subject to a considerable degree of uncertainty.

Table II: Summary of times per turn

Time Elements	% of Total Time		Mean, cmin	S.D.	Range	Equations
Travel empty	18.2	36.7	351	141	61-764	TEL = −42+0.73 DIA
Speed empty, ft/min			308	49	207-470	
Travel loaded	18.5		357	159	10-672	r^2 = 0.93
Speed loaded, ft/min			275	46	98-371	
Manoeuvering	1.9	45.2	37	17	18-107	Means used in nomogram
Loading	40.7		787	175	472-1173	
Moving during loading	2.6		50	32	10-140	
Unloading	3.2	18.1	61	13	29-89	Means used in nomogram
Piling	9.5		183	146	0-583	
Delay	5.4		104	195	0-717	
Total time per turn	100%		1930	415	1100-2760	TT = 1191 + 0.72 DIA r^2 = 0.49

TEL = Travel empty and loaded, cmin per turn
DIA = Average travel distance, ft
S.D. = Standard deviation
TT = Total time per turn
r^2 = Coefficient of determination

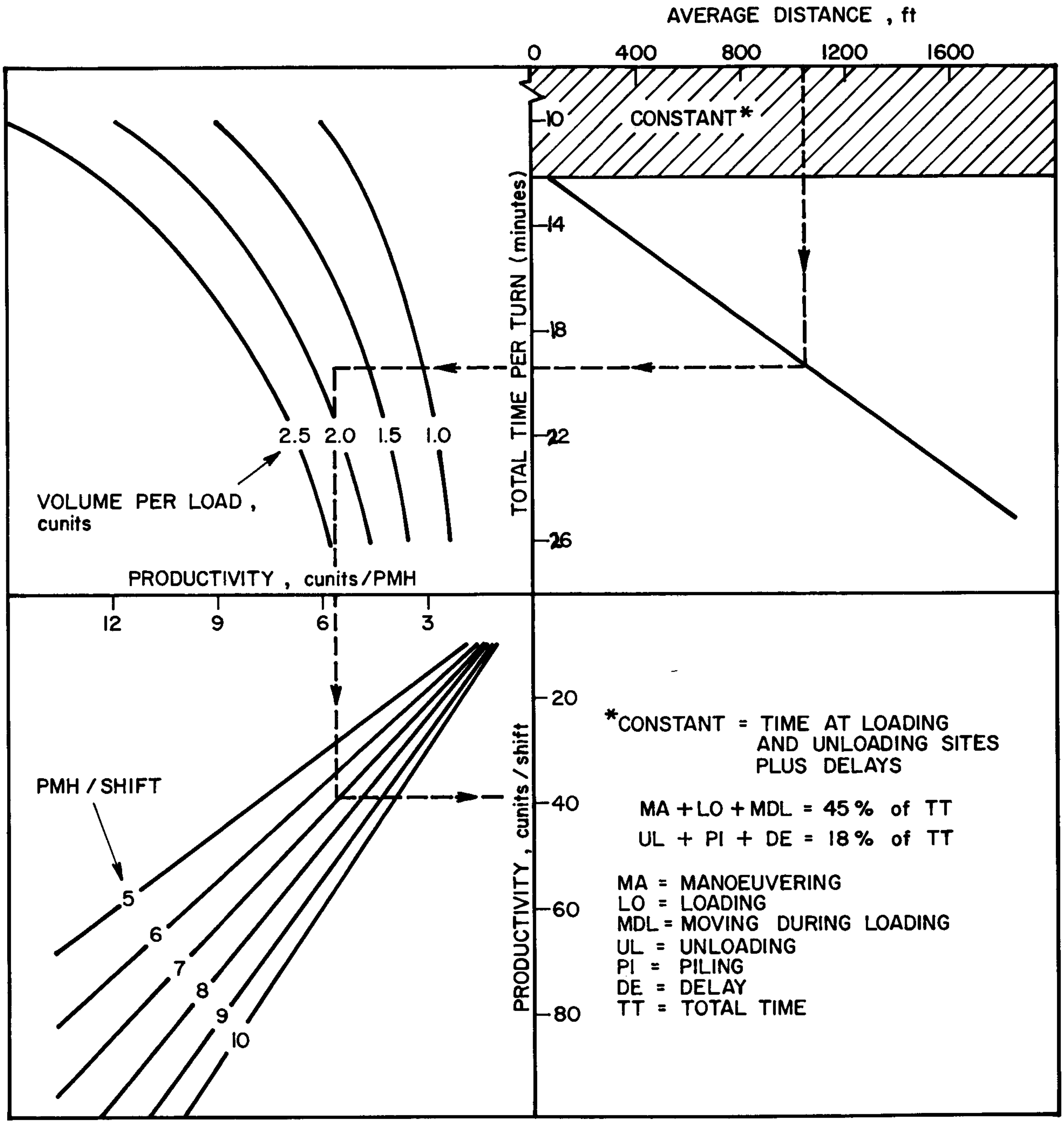


Fig. 5 Production Nomogram

On the operation studied, piling time appeared to be above average due to operator preferences. An improvement in the total time per turn could be made if piling at roadside were reduced to a minimum or omitted altogether. Omission of piling by improved operator practice and/or increased landing space could reduce the total time per turn by as much as 1.84 min, giving a potential average productivity of 6.2 ct ($17.5\ m^3$) per PMH with an average volume per load of 1.8 ct ($5\ m^3$). The total time per turn when piling is omitted is represented by the following equation:

$$PT = 1051 + 0.67\ DIA \qquad r^2 = 0.46$$

PT = Potential time, cmin
DIA = Average skidding distance, ft
r^2 = Coefficient of determination

Table III: Productivity Table (ct/PMH)

	Volume per Load (cunits)								
DIA*	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1
100	6.2	6.7	7.1	7.7	8.1	8.6	9.0	9.5	9.9
200	5.9	6.3	6.8	7.2	7.7	8.1	8.6	9.0	9.5
300	5.5	5.9	6.4	6.8	7.2	7.6	8.1	8.5	8.9
400	5.3	5.7	6.1	6.5	6.9	7.3	7.7	8.1	8.5
500	5.0	5.4	5.8	6.2	6.6	7.0	7.4	7.7	8.1
600	4.8	5.2	5.5	5.9	6.3	6.7	7.0	7.4	7.8
700	4.6	5.0	5.3	5.7	6.0	6.4	6.7	7.1	7.5
800	4.4	4.8	5.1	5.5	5.8	6.1	6.5	6.8	7.2
900	4.2	4.6	4.9	5.2	5.5	5.9	6.2	6.5	6.8
1000	4.1	4.4	4.7	5.0	5.3	5.6	6.0	6.3	6.6
1100	3.9	4.2	4.5	4.8	5.1	5.4	5.8	6.1	6.4
1200	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.1
1300	3.7	4.0	4.2	4.5	4.8	5.1	5.4	5.7	5.9
1400	3.6	3.8	4.1	4.4	4.7	4.9	5.2	5.5	5.7
1500	3.4	3.7	4.0	4.2	4.5	4.7	5.0	5.3	5.5

* DIA = Average Skidding Distance, feet.

Table IV: PRODUCTIVITY TABLE (m^3/PMH)

	Volume per load (m^3)								
DIA *	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
50	13.8	16.2	18.5	20.2	23.1	25.4	27.7	30.0	32.3
100	12.6	14.7	16.8	18.9	21.0	23.1	25.2	27.3	29.4
150	11.7	13.6	15.6	17.5	19.5	21.4	23.4	25.3	27.3
200	10.8	12.6	14.4	16.2	18.0	19.8	21.7	23.5	25.3
250	10.1	11.8	13.5	15.2	16.8	18.5	20.2	21.9	23.6
300	9.5	11.1	12.7	14.3	15.8	17.4	19.0	20.6	22.2
350	8.9	10.4	11.9	13.4	14.9	16.4	17.9	19.4	20.9
400	8.5	9.9	11.3	12.7	14.1	15.5	16.9	18.3	19.7
450	8.0	9.3	10.7	12.0	13.3	14.7	16.0	17.3	18.7
500	7.6	8.8	10.1	11.4	12.6	13.9	15.2	16.4	17.7

* DIA = Average Skidding Distance, metres.

Expected Costs under Eastern Conditions

The machine costs presented below have been calculated to provide a reasonable range of expected costs in view of the uncertainties entering into some of the estimated values.

Table V: Expected Costs

Known values

Purchase price $85,000 (f.o.b. St-Jérôme, Quebec.)
Fuel: Approximately $4.50 per PMH
Operator's wages $6.00 per SMH (including fringe benefits)
Depreciation period: 4 years
Interest and insurance factor 0.12

Estimated Values	Favourable	Unfavourable
Economic life of machine (SMH)	14,000	10,000
Utilization percent	80	70
Maintenance cost (100% and 200% of fixed cost) $/SMH	$7.90	$22.10

The skidding cost ($/ct) may be calculated from the following equation.

$$\$/ct = \left[\left[\frac{I}{L}\left(1+\frac{i(N+1)}{2}\right)+M+W\right]\frac{100}{U}+F\right]\frac{1}{P}$$

where I = Purchase price, $
L = Life of machine in scheduled machine hours (SMH)
i = Interest and insurance factor (0.12)
N = Depreciation period, years
M = Maintenance cost (repair parts and labour, service, tire wear, etc.) $/SMH
W = Crew wages, $/SMH
U = Machine utilization, %
F = Fuel, lubricant and hydraulic fluid costs, $/PMH
P = Productivity, ct/PMH (x 2.83 = m^3/PMH)

The favourable and unfavourable costs have been calculated from the information in Table V and the following productivity factors.

Productivity (from Table II)

	Favourable	Unfavourable
Average distance, ft (x 0.30=m)	500	1,500
Volume per load, ct (x 2.83 = m^3)	1.8	1.8
Total cost $/PMH	31.73	60.42
Productivity ct/PMH (x 2.83 = m^3/PMH)	7.0	4.7
Total costs, $/ct (x 0.35 = $/$m^3$)	4.53	12.85

The above equation is presented in the form of a nomogram in Figure 6. The two dashed lines represent the favourable and unfavourable extremes. Details of the construction of the nomogram are given in Appendix D.

The two examples show the considerable range of expected costs (from $4.53 to $12.85 per cunit) based on the two sets of assumptions used in the calculations. The cost differences indicate the importance of high utilization and effective maintenance. The nomogram (see Figure 6) is also presented in the form of tables in Appendix D.

The reader is again reminded that these examples are based on assumptions not necessarily having any connection with the operation studied. Anyone wishing to project hourly or unit costs for equipment of this type must make his own best assumptions and then use them in a similar manner to that presented here.

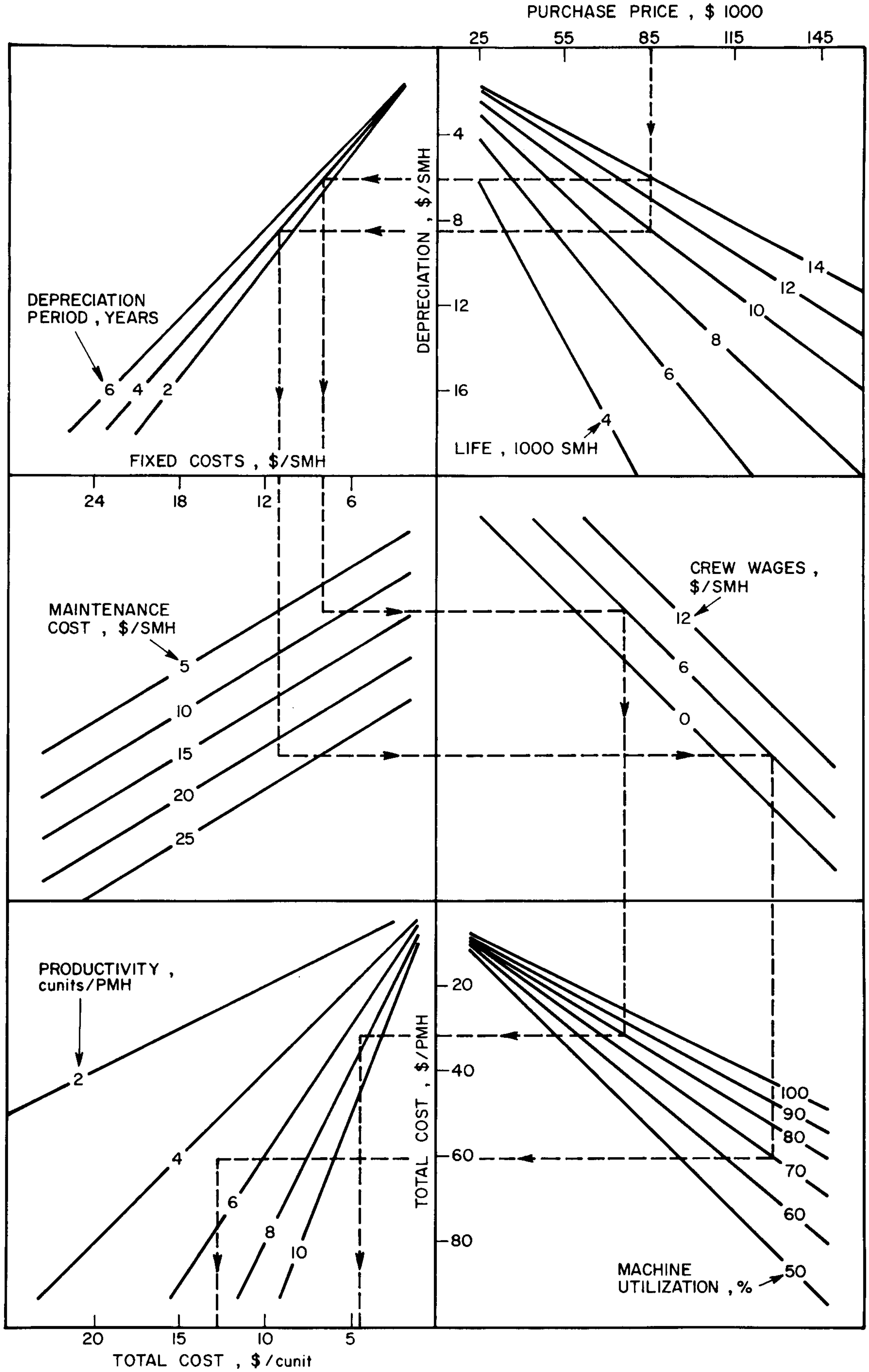


Fig. 6. Cost Nomogram

Road Spacing

The optimum road spacing when skidding from both sides of the road with the FMC 200 BG Grapple Skidder is found by equating the skidding cost to the road-construction cost [4]. Thus: $C\frac{S}{4} = \frac{R/12.1}{V\,S}$

C = Variable cost of skidding per ct per 100 feet	$0.22	
R = Road construction cost per mi (km)	$25,000	($15,625)
V = Volume per acre, ct (m^3/ha)	28	(196)
S = Road spacing, 100 feet		

The value of C given above is the favourable cost as calculated in the cost section of this report. The volume per acre (hectare) is the average value for the study area and the road construction cost is a representative cost of construction for the Lebel-sur-Quévillon area. The coefficient 12.1 is obtained by assuming that 1 mile (1.6 km) of road spaced at every 100 ft (30 m) serves 12.1 acres (4.9 ha).

Solving the equation for S gives an optimal spacing of about 3,600 ft (1,100 m), thus holding maximum skidding distance to 1,800 ft (550 m) and average skidding distance to 900 ft (275m). Skidding and road construction costs are calculated separately for different road spacings, from the formulas given in the heading of Table VI.

These costs are plotted in Figure 7 which illustrates how skidding costs and road costs change as the road spacing varies. The optimum road spacing, namely that spacing which results in minimum total cost per cunit, is obtained at the intersection of the two cost curves. Any spacing between 3,000 ft (915 m) and 4,500 ft (1,372m) will result in satisfactory costs.

A smaller load volume will increase the variable skidding cost and therefore reduce the most economical road spacing. For example, the favourable skidding cost, when calculated with a volume per load of 1.0 ct (2.83 m^3) gives an optimum road spacing of 2,700 ft (820 m) as compared to 3,600 ft (1,100 m) when the load volume is 1.8 ct (5.0 m^3). Curves for the unfavourable cost of skidding have also been plotted, giving a spacing of 2,200 ft (670m) to 3,000 ft (915 m).

Table VI: Skidding Cost and Road-Construction Cost for Different Road Spacings

Road Spacing S (100 ft)	Variable Skidding Cost \$/ct $C\frac{S}{4}$	Road Cost \$/ct $\frac{R/12.1}{V\,S}$	Total Cost \$/ct $C\frac{S}{4}+\frac{R/12.1}{V\,S}$
5	0.27	14.75	15.02
10	0.55	7.38	7.93
15	0.82	4.92	5.74
20	1.10	3.69	4.79
25	1.37	2.95	4.32
30	1.65	2.46	4.11
35	1.92	2.11	4.03
40	2.20	1.84	4.04
45	2.47	1.64	4.11
50	2.75	1.47	4.22
55	3.02	1.34	4.36
60	3.30	1.23	4.53

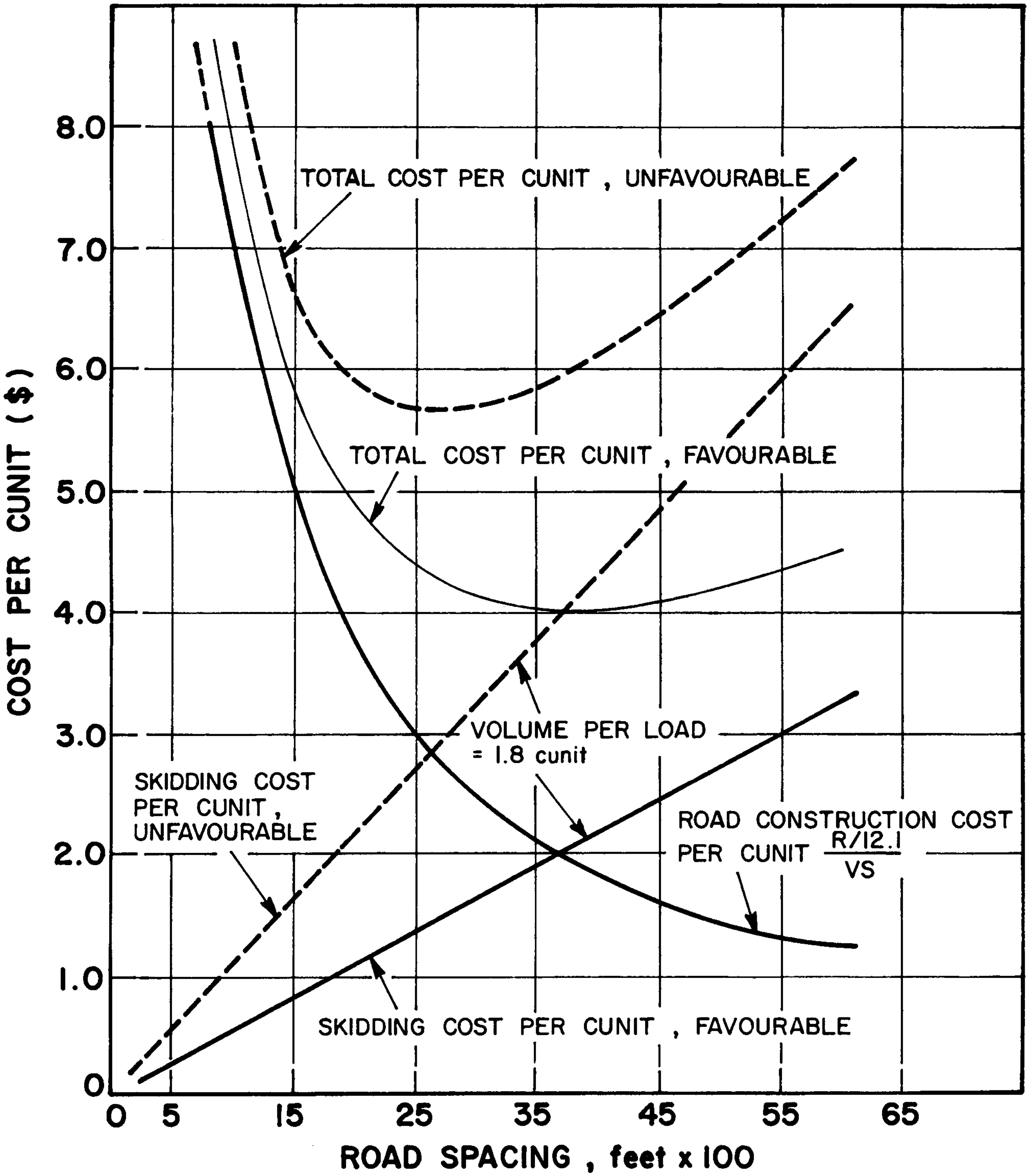


Fig. 7. Skidding Costs and Road Construction Costs

Surface Soil Disturbance

Visual observations of soil disturbance were taken in six 100 ft sections within two skidding trails.

Figure 8 represents the relative position of the sections, the skid trails and the strip and shows the location of the sections used during the study.

Observations were made in all six sections in and between tracks using British Columbia's classification [6]. Detailed assessments used in the classification are shown in Appendix C.

Figure 9 shows different classes of disturbance as recorded during the study.

The skidding trail was estimated to cover 32% of the whole area (average for both skid trails). The disturbance measured was 6.2% in litter disturbance, 4.3% in mineral soil exposed < 1 in (2 cm) deep, and 6.6% in mineral soil exposed ⩾ 1 in (2 cm) deep. There was no disturbance in the rest of the area studied. Figure 10 illustrates the result in percent of the whole area.

It was quite evident that disturbance of the ground to the extent of exposing mineral soil was practically negligible, the maximum for all areas being approximately 10%. For certain types of terrain or stands, such as black spruce, scarification might be needed for the establishment of future crops, but on sensitive sites logging with the FMC skidder minimizes damage to the soil and causes less compaction and disturbance along the skidding trail.

Observations on winter trails showed neither disturbance nor compaction of the soil.

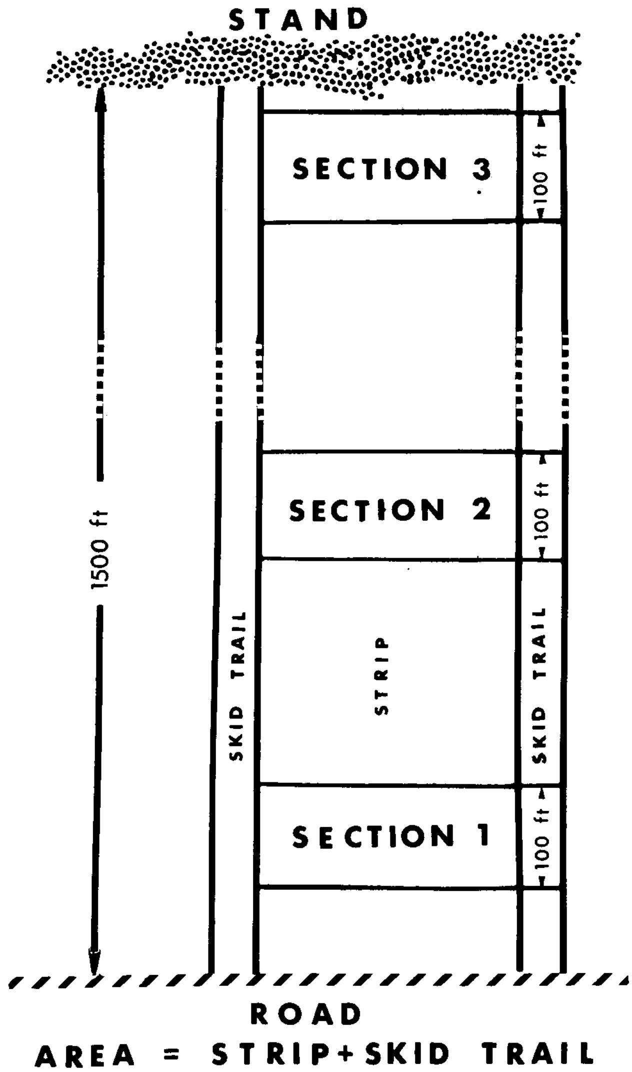


Fig. 8. Surface Soil Disturbance: Location of the Sections

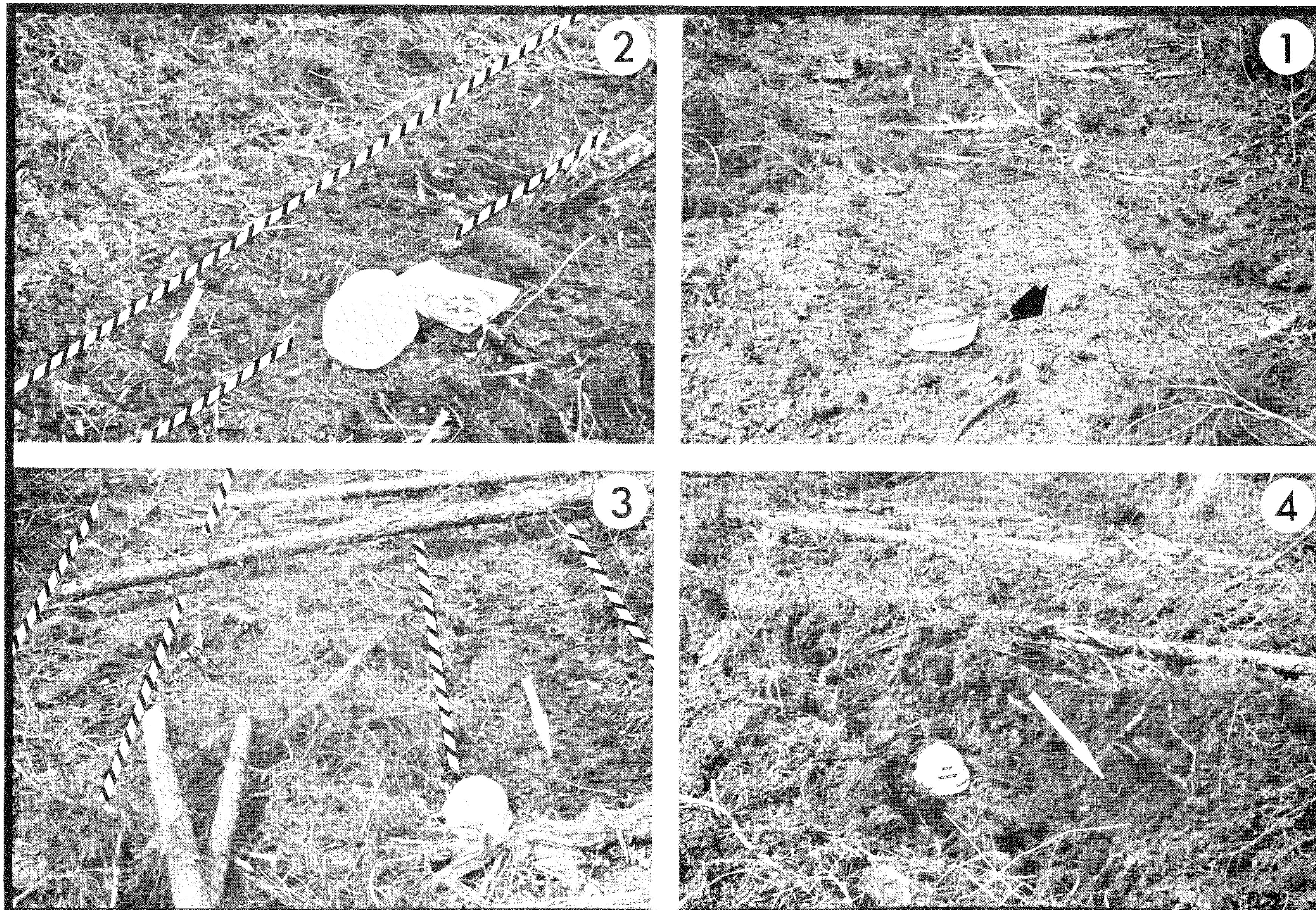


Fig. 9. Four Different Classes of Surface Soil Disturbance. (1) Humus scraped. (2) Tracks on disturbed humus. (3) Mineral soil exposed < 2 cm deep (1 in). (4) Deep disturbance, mineral soil exposed ≥ 2 cm deep (1 in).

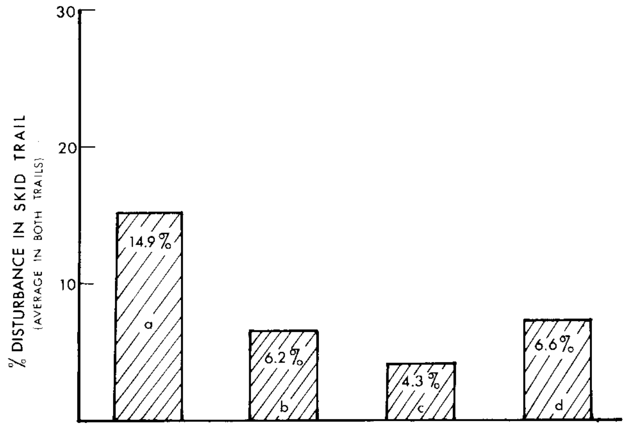


Fig. 10. Skid Trail Disturbance in Percent of Total Area

a. = No disturbance
b. = Litter disturbance
c. = Mineral soil exposed <1 in (2cm)
d. = Mineral soil exposed ≥1 in (2cm)

Ergonomic Aspects

An ergonomic checklist [2] was completed, based on the operator's comments on different aspects of the machine design. It consisted of assessment of the following:

- Mounting and alighting
- Working posture and operator's seat
- Instruments and controls
- Visibility and lighting
- Working climate and exhaust emission
- Noise

Mounting and alighting under normal conditions are convenient but can be dangerous when hydraulic oil drips off the loader, which is located over the operator's cab. Bailing out quickly is difficult because the cab doors are very narrow.

Working posture and operator's seat are good. The sitting posture is comfortable, the pedals and controls are conveniently located, while leg and kneeroom are both adequate. The major inconvenience occurs during loading. Since the loading controls are located at the operator's right, he has to turn sideways on a non-rotating seat.

Instruments and controls. The instruments provide all necessary checks; they are well located and of suitable types. The controls can be classified as very good; they are well located, of the right size and shape, and the force required to handle them does not fatigue the operator.

Visibility and lighting. The operator has a good view upward but the forward view of the ground is blocked by the engine cover. According to the operator, the visibility sideways is excellent but is blocked at the rear by the bunk grapple. The light intensity was modified by the owner company; five lights were added on the cab of the machine.

Vibration and shaking of the machine are severe enough to cause the operator discomfort and could lower his productivity. According to the operator, the machine is as much subject to vibration as other skidders he has operated.

Working climate and exhaust emission: temperatures were recorded inside and outside the Laurin cab at different times of the day as follows:

Time	Inside Cab	Outside Cab
13.30 hr	85°F (29°C)	74°F (23°C)
15.30 hr	98°F (37°C)	72°F (22°C)

Odour of exhaust fumes was also noticed in the cab, but no measurements were made.

Noise. Measurements of level and frequency of noise were made inside two different models of cab that can be adapted to the machine. Measurements were also taken on a machine without a cab. The machine was stationary at roadside and the measurements were taken with the engine idling and also running full throttle (2,500 rpm).

Table VIII: Average and Maximum Sound Pressure Levels (dBA)

Different Options	Idling		Full Throttle	
	Ave.	Max.	Ave.	Max.
No cab	89	91	101	103
Laurin cab	89	90	101	101
Sims cab	83	94	94	97

Figure 11 shows the observed dBA values plotted over an estimated exposure time during a shift. The duration of skidding is calculated from data recorded during the study assuming a utilization of 70%. Also plotted on Figure 11 is the permissible exposure curve adopted in 1969 by the U.S. Department of Labor [1]. This curve assumes a continuous period of noise of specified length. The noise of the FMC 200 BG Grapple Skidder is somewhat variable during the skidding, which is an advantage over continuous noise.

Observed sound pressure levels within octave bands, are illustrated in Figure 12. The dashed line indicates the maximum levels and the hatched area shows the range of average levels which were obtained with machine running at full throttle and idling.

The noise levels measured in the FMC 200 BG Grapple Skidder study exceeded the current permissible limits of the U.S. Department of Labor based on dBA and octave band criteria. Since the cab was lined with sound absorbing material, the use of ear

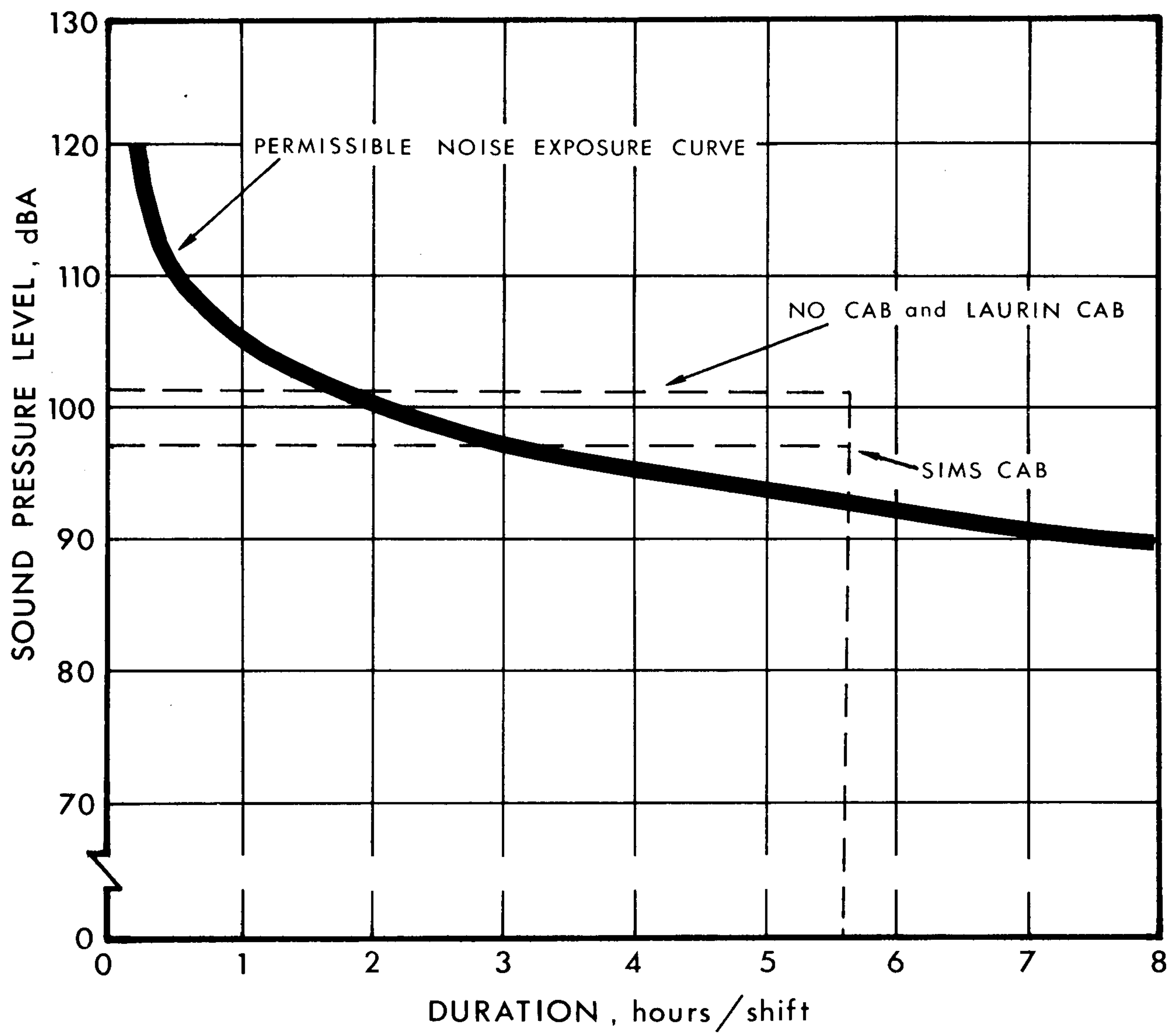


Fig. 11. Observed average noise levels (dBA) inside cab, full throttle, plotted over estimated exposure time, compared to the current permissible exposure curve of U.S. Department of Labor [1].

muffs by the operator would alleviate the problem associated with the high noise levels. However, noise reduction at source is the best cure, but is not always feasible either from an economical or a technical standpoint.

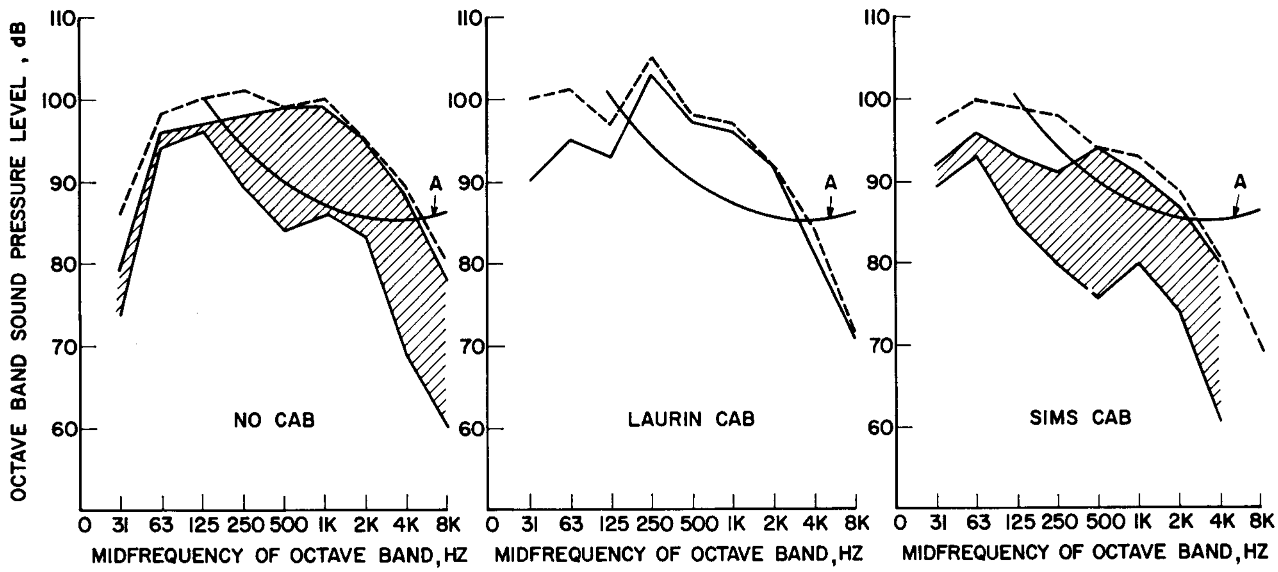


Fig. 12. Observed noise levels by octave bands. The dashed line shows the maximum levels and the hatched area shows the range of average levels (idling and full throttle) for three different options. Curve A shows the damage risk curve for one exposure per day of duration less than 6 hours to 1-octave band of noise. This curve is interpolated from Kryter, et al. [3].

APPENDIX A

Manufacturer's Specifications

The FMC 200 BG Grapple Skidder is manufactured by the FMC Corporation, Advance Products Division, San Jose, California.

General

Shipping weight	29,000 lb	(13,154 kg)
Maximum overall length with blade	250 in	(6,350 mm)
Overall height	156 in	(3,962 mm)
Overall width	103 in	(2,616 mm)
Ground clearance	19 in	(483 mm)
Blade height	27 in	(686 mm)
Blade width	102 in	(2,591 mm)

Engine

Model	6V53N — GM Detroit Diesel	
Number of cylinders	6	
Horsepower	197 hp	(147 Kw)
Displacement	318 cu.in	(5.2 l)
Governed RPM	2,600	
Torque (maximum at 1,500 RPM)	455 lb/ft	(61.5 kg/m)

Loader

Model	Omark — Prentice series 50	
Swing arc	270°	
Grapple rotation	360°	
Maximum overall height	318 in	(8,077 mm)
Maximum loading reach	189 in	(4,801 mm)
Rated lifting capacity	2,100 lb	(952.6 kg)
Maximum opening, tip to tip	42 in	(1,067 mm)
Minimum closure	7 in	(178 mm) diameter log

Bunk Grapple

Area enclosed by grapple open	24 ft^2	(2.33 m^2)
Area enclosed by grapple tips closed	2 ft^2	(0.19 m^2)
Bunk rotation	270°	
Maximum opening	57 in	(1,448 mm)

Suspension/Tracks

Type of suspension	Roadwheels, Torsion bar sprung	
Type of tracks	Forged steel grousers rubber bushed hinge pins	
Track shoe width	22 in	(559 mm)
Gauge	81 in	(2,057 mm)
Length of track on ground	113 in	(2,870 mm)
Ground pressure at shipping weight	5.83 psi	(40.19 kPa)

Hydraulic System

Pump capacity	2 each @ 34 GPM	(128.7 l/min)
Hydraulic system capacity	40 U.S. gal	(151.4 l)
System relief valve setting	1,800 psi	(12,410.6 kPa)

Power Train

Transmission	Clark H R 28420 — 2 Powershift 4 speeds forward, 4 speeds reverse
Torque converter	Integral with transmission
Differential	Controlled
Final drive	Planetary
Brakes, service	Hydraulic transmission mounted
Brakes, parking	Manual, transmission mounted
Brakes, steering	Controlled differential

Travel Speeds

	First		Second		Third		Fourth	
	mph	km/h	mph	km/h	mph	km/h	mph	km/h
Forward and Reverse	3.0	4.8	5.0	8.0	9.0	14.5	24.1	15.0

Standard Equipment

Air cleaner (dry type with preclean), brakes, bunk grapple, differential oil cooler, ROPS canopy, fan (reversible), loader with grapple, muffler (with spark arresters), seat, seat belts, transmission oil cooler.

Optional Equipment

The Sims cab is the only fully enclosed all-weather cab approved for security by the FMC Corporation, even though the Laurin cab can be adapted to the machine.

The machine is provided with the roll-over protective canopy, front glass window, and grilles on side and rear windows.

APPENDIX B

Operating Sequence

Travel Empty
The machine travels empty from the piles at roadside to the stump area.

Manoeuvering
The machine moves into a position from which it can load tree-lengths; it then places itself at right angles to the trees and facing roadside.

Loading
The knuckle boom loader is used to load tree-lengths, several at a time, onto the grapple at the rear of the machine. Loading is usually performed from one side of the machine.

Moving during Loading
When all the trees that can be reached from one point are loaded, the machine moves to the next loading point. The loading and moving during loading are repeated until the rear grapple is full.

Travel Loaded
The machine travels with a full load from the stump area to the roadside.

Unloading
At the roadside the machine deposits its load by opening the main grapple and driving out from under the load.

Piling
The machine moves to the side of the pile and, using the front blade, aligns the tree-lengths. Piling can be omitted depending on the operating conditions.

APPENDIX C

Assessment for Soil Classification

BRITISH COLUMBIA'S CLASSIFICATION

1. **No disturbance:** no visual alteration of the surface litter layer of soil, two miscellaneous non-soil features noted separately are stumps and rocks.
2. **Material removal:** the removal of any part of the soil is considered in this category. This does not include points where redeposition occurs after removal of material. There were three classes of material removal observed:
   a) **Litter disturbance** where removal is confined to organic litter layer (litter-humus).
   b) **Mineral soil exposed** ($<$ 1 in (2 cm) deep) where litter has been completely removed and mineral soil exposed.
   c) **Mineral soil exposed** ($\geqslant$ 1 in (2 cm) deep) where disturbance has removed mineral soil to expose the "B" horizon or deeper. This may be caused by butt gouging, stump upturning and severe skinning or scruffing.
3. **Material deposition:** the deposition of loose litter and mineral soil material which has been transported by dragging logs.
   a) **Litter deposition** where loose needles and fine twigs and parts of L-H layers are deposited.
   b) **Mineral deposition** ($<$ 1 in (2 cm)): this contains a mixture of litter and mineral soil spread shallowly over the site.
   c) **Mineral deposition** ($\geqslant$ 1 in (2 cm)): deep deposits of litter and mineral soil material over the surface.

APPENDIX D

D. 1. Nomogram

The dashed lines lead through all six sections starting on the axis marked "purchase price" in the upper right-hand section.

The first section gives depreciation cost in dollars per scheduled machine hour (SMH) calculated from the purchase price and the economic life in hours, assuming no scrap or other residual value. In the second section, interest (10%) and insurance (2%) on the average investment are added and the sum is called "fixed cost", $/SMH.

Maintenance cost, expressed in dollars per SMH, is added in the third section. The principal problem is still the difficulty of accurately predicting the future maintenance costs of prototypes. The fourth section adds an amount for crew wages (in this instance, a one-man crew is normal) in dollars per SMH.

The fifth section converts cost per SMH to cost per PMH by multiplying the cost per SMH by 100 and dividing by the machine utilization (percentage of scheduled operating time that is productive time) and then adds estimated hourly fuel, lubricant and hydraulic fluid costs (in this example, $4.50/PMH).

The cost per ct is calculated in the sixth section by dividing total cost per PMH by the expected productivity.

D. 2. Cost Tables

Tables D. 1.1. D. 1.2. and D. 1.3. give the total fixed costs, $/SMH in terms of different purchase prices, depreciation periods and lives of the machine.

Table D. 2. gives total variable costs in $/SMH in terms of maintenance costs ranging from $4.00 to $24.00 per SMH and a crew up to two men.

Table D. 3. adds total fixed costs in $/SMH (D.1.) and total variable costs in $/SMH (D.2.) and transforms the result to $ per PMH in terms of two different fuel costs and utilization percentages ranging from 50 to 100%.

Table D. 4. transforms total costs per PMH to a cost per cunit (cubic metre).

TABLE D. 1. Fixed Costs $/SMH

Table D. 1.1.
Purchase Price=$80,000.

Depreciation years / life/SMH	2	4	6
4,000	23.60	26.00	28.40
6,000	15.73	17.33	18.93
8,000	11.80	13.00	14.20
10,000	9.44	10.40	11.36
12,000	7.86	8.66	9.47
14,000	6.74	7.43	8.11

Table D. 1.2.
Purchase Price=$85,000.

Depreciation years / life/SMH	2	4	6
4,000	25.07	27.62	30.17
6,000	16.72	18.42	20.12
8,000	12.54	13.81	15.09
10,000	10.03	11.05	12.07
12,000	8.35	9.20	10.05
14,000	7.16	7.89	8.62

Table D. 1.3.
Purchase Price=$90,000.

Depreciation years / life/SMH	2	4	6
4,000	26.55	29.25	31.95
6,000	17.70	19.50	21.30
8,000	13.27	14.62	15.97
10,000	10.62	11.70	12.78
12,000	8.85	9.75	10.65
14,000	7.58	8.36	9.12

Interest+Insurance Factor=12%

TABLE D. 2. Variable Costs $/SMH

crew $/SMH \ maintenance $/SMH	4	6	8	10	12	14	16	18	20	22	24
0	4	6	8	10	12	14	16	18	20	22	24
6	10	12	14	16	18	20	22	24	26	28	30
12	16	18	20	22	24	26	28	30	32	34	36

Table D. 3. Total Cost, $/PMH

total cost $/SMH \ Utilization %	50		60		70		80		90		100	
	F+L+H $4.00	F+L+H $6.00	F+L+H $4.00	F+L+H $6.00	F+L+H $4.00	F+L+H $6.00	F+L+H $4.00	F+L+H $6.00	F+L+H $4.00	F+L+H $6.00	F+L+H $4.00	F+L+H $6.00
5.00	14.00	16.00	12.33	14.33	11.14	13.14	10.25	12.25	9.55	11.55	9.00	11.00
10.00	24.00	26.00	20.66	22.66	18.28	20.28	16.50	18.50	15.10	17.10	14.00	16.00
15.00	34.00	36.00	29.00	31.00	25.43	27.43	22.75	24.75	20.66	22.66	19.00	21.00
20.00	44.00	46.00	37.33	39.33	32.57	34.57	29.00	31.00	26.22	28.22	24.00	26.00
25.00	54.00	56.00	45.66	47.66	39.71	41.71	35.25	37.25	31.78	33.78	29.00	31.00
30.00	64.00	66.00	54.00	56.00	46.86	48.86	41.50	43.50	37.33	39.33	34.00	36.00
35.00	74.00	76.00	62.33	64.33	54.00	56.00	47.75	49.75	42.89	44.89	39.00	41.00
40.00	84.00	86.00	70.66	72.66	61.14	63.14	54.00	56.00	48.44	50.44	44.00	46.00
45.00	94.00	96.00	79.00	81.00	68.28	70.28	60.25	62.25	54.00	56.00	49.00	51.00
50.00	104.00	106.00	87.33	89.33	75.43	77.43	66.50	68.50	59.55	61.55	54.00	56.00
55.00	114.00	116.00	95.66	97.66	82.57	84.57	72.75	74.75	65.11	67.11	59.00	61.00
60.00	124.00	126.00	104.00	106.00	89.71	91.71	79.00	81.00	70.67	72.67	64.00	66.00
65.00	134.00	136.00	112.33	114.33	96.86	98.86	85.25	87.25	76.22	78.22	69.00	71.00
70.00	144.00	146.00	120.66	122.66	104.00	106.00	91.50	93.50	81.78	83.78	74.00	76.00

N.B. F+L+H=Fuel+Lubricant+Hydraulic fluid

Table D. 4. Total Cost $/Cunit ($/M³)

Total Cost $/PMH \ Productivity ct/PMH	3 (8.5)	5 (14.1)	7 (20)	9 (25.5)	11 (31.1)
20.00	6.67 (2.35)	4.00 (1.42)	2.86 (1.00)	2.22 (0.78)	1.82 (0.64)
25.00	8.33 (2.94)	5.00 (1.77)	3.57 (1.25)	2.78 (0.98)	2.27 (0.80)
30.00	10.00 (3.53)	6.00 (2.13)	4.29 (1.50)	3.33 (1.18)	2.73 (0.96)
35.00	11.67 (4.12)	7.00 (2.48)	5.00 (1.75)	3.89 (1.37)	3.18 (1.13)
40.00	13.33 (4.71)	8.00 (2.84)	5.71 (2.00)	4.44 (1.57)	3.64 (1.29)
45.00	15.00 (5.29)	9.00 (3.19)	6.43 (2.25)	5.00 (1.76)	4.09 (1.45)
50.00	16.67 (5.88)	10.00 (3.55)	7.14 (2.50)	5.56 (1.96)	4.55 (1.61)
55.00	18.33 (6.47)	11.00 (3.90)	7.86 (2.75)	6.11 (2.16)	5.00 (1.77)
60.00	20.00 (7.06)	12.00 (4.26)	8.57 (3.00)	6.67 (2.35)	5.45 (1.93)
65.00	21.67 (7.65)	13.00 (4.61)	9.29 (3.25)	7.22 (2.55)	5.91 (2.09)
70.00	23.33 (8.23)	14.00 (4.96)	10.00 (3.50)	7.78 (2.75)	6.36 (2.25)
75.00	25.00 (8.82)	15.00 (5.32)	10.71 (3.75)	8.33 (2.94)	6.82 (2.41)
80.00	26.67 (9.41)	16.00 (5.67)	11.43 (4.00)	8.89 (3.14)	7.27 (2.57)
85.00	28.33 (10.00)	17.00 (6.03)	12.14 (4.25)	9.44 (3.33)	7.73 (2.73)
90.00	30.00 (10.59)	18.00 (6.38)	12.86 (4.50)	10.00 (3.53)	8.18 (2.89)

N.B. These tables provide a reasonable range of expected costs.

References

1. BERANEK, L. L. Industrial noise control chem. Eng. 77 (9): 277-230, 1970.
2. HANSSON, J. E. and PETTERSON, B. Ergonomic checklist for transport and materials handling machinery, Skogsarbeten, Stockholm, 1969, pp 20.
3. KRYTER, K. D., WARD, W. D., MILLER, J. D., and ELDREDGE, D. H. Hazardous exposure to intermittent and steady-state noise. Jour. Acoust. Soc. Amer. 39: 451-464. 1966.
4. MATTHEWS, D. M. Cost control in the logging industry, McGraw-Hill Book Co., 1st Ed., 1942 (119-124).
5. POWELL, L. H. Evaluation of new logging machine prototypes: BM Volvo SM 868 Grapple Skidder. Logging Res. Rep. Pulp Pap. Res. Inst. Can. No. 45, 1971. pp 19, 9 fig., 3 tbl., 7 ref., 3 app.
6. WATT, W. J. Soil surface condition after cable logging in south eastern British Columbia. (Draft report in press).