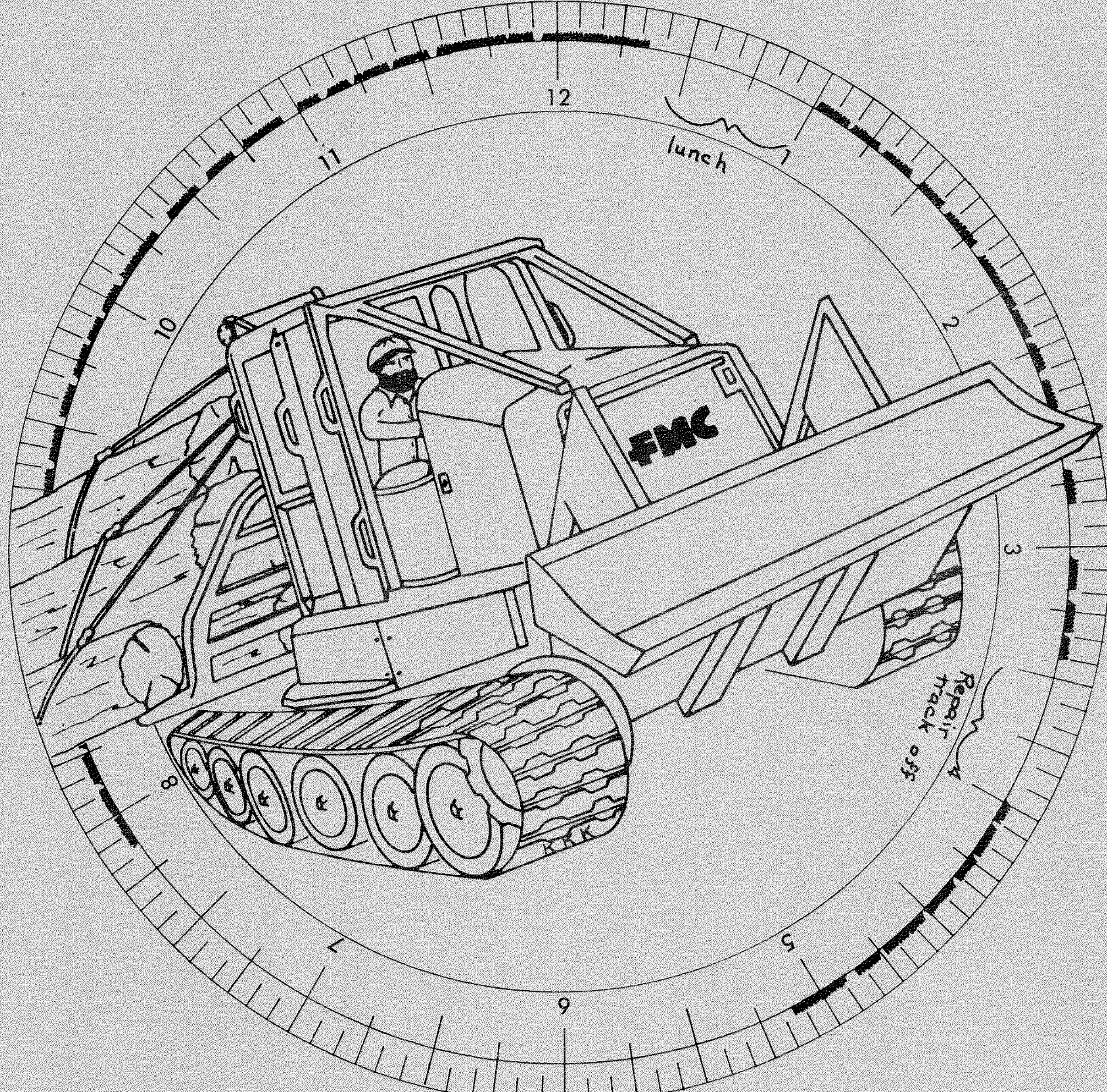
FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

PRODUCTION AND PERFORMANCE STUDIES OF FMC 200 SERIES SKIDDERS

L.H. Powell

Technical Report No. TR-29
December 1978



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FOREWORD

This report presents the results of production and performance studies of FMC 200 series skidders operating in British Columbia and Ontario. The work was prompted by the need for factual information on the performance of FMC skidders because concern for the environmental impact of ground skidding is leading to restrictions on traditional logging methods in mountainous terrain. The study results also complement the initial evaluation of the FMC 200BG Grapple Skidder reported in FERIC Technical Report No. TR-1 by R. Legault and L. H. Powell.

Initially, the project was directed toward FMC 200 series skidders operating in British Columbia. At the same time FERIC's Eastern Division was collecting similar information on longer term performance on two machines in Ontario, and this information was included with the data from B. C. The study was strongly encouraged by industry members of the "Steep Slope Committee" of the Nelson Forest District in Southeastern B. C.

The author particularly thanks the many individuals associated with the following companies who cooperated in the study:

Crestbrook Forest Industries, Ltd.
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Mallette Lumber Co., (1969), Inc.
Marling Logging
Northwood Pulp & Timber Ltd.
Tahsis Co., Ltd.
FMC Corporation, Woodlands Equipment Division

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B. D. Johnston (field work)
A. Larsson (field work)
B. A. McMorland (field work)
P. P. Tse (field work, programming and computer analysis)

NOTE

Readers interested in the complete case study for individual machines should write for the Supplement to TR-29, "FMC 200 Series Skidder Study: Details of Individual Machine Case-Studies," available from:

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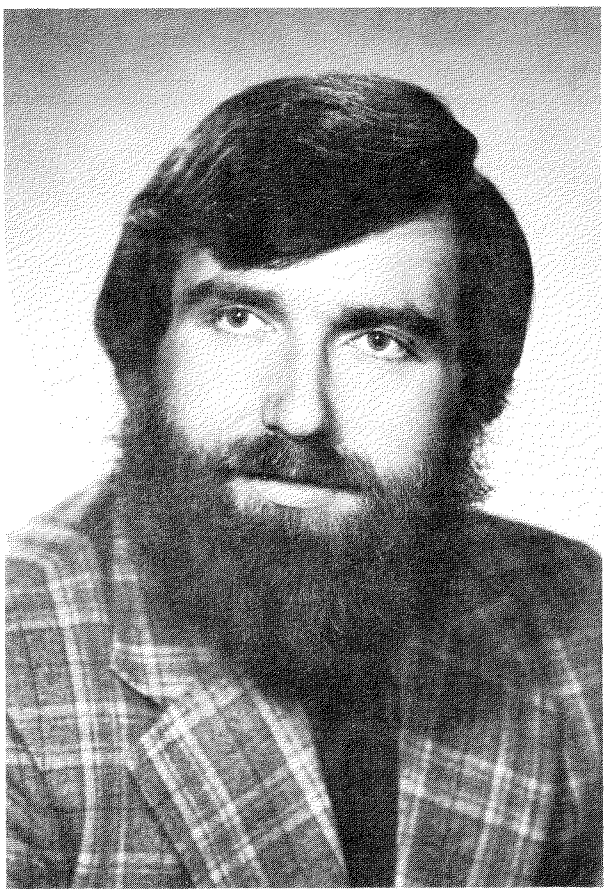

L.H. Powell received his B.Sc. Forestry from the University of Wales in 1968. He joined the Woodlands Research Division of the Pulp and Paper Research Institute of Canada in 1970 to work on logging machine evaluations and related projects. He moved over to FERIC when that organization was formed in 1975, and transferred to the Vancouver office in late 1975. He is a member of the Association of B.C. Professional Foresters, the Canadian Institute of Forestry and the Woodlands Section, Canadian Pulp and Paper Association.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This report enables potential users of the FMC skidder to compare machine performance under various terrain and operating conditions. It provides performance data on time, productivity, and cost from current FMC operations and assesses the environmental impact of skidding in areas with steep slopes and sensitive soils. Eight FMC machines (three model 200BG and five model 200CA) were studied during 1,253 shifts of skidding activities from December 1975 through May 1977. All were modified by FMC and its dealers over a four-month period between September and December 1976. (Details of these modifications are given in the following report.) Data collected for the six machine studies in B.C. cover a period before and after modification. For the two machines studied in Ontario, data were collected after modification. The studies define and measure the productive time elements of the work cycle and show that FMC skidders will allow the range of ground skidding to extend to slopes from 30 to 50 percent and still meet production and environmental requirements. The cost of purchasing and operating these machines is high, however, and they should not be used where less expensive machines give satisfactory performance.

RÉSUMÉ

Ce rapport permet aux utilisateurs éventuels de la débusqueuse FMC de comparer la performance de l'engin en fonction d'une variété de conditions de terrain et de facteurs du milieu de travail. Il fournit des données sur le temps, la productivité et les coûts provenant d'exploitations où l'on utilise couramment la FMC et il évalue l'impact, sur le milieu, du transport primaire dans des régions aux pentes escarpées et aux sols fragiles. L'étude a porté sur huit engins FMC (trois modèles 200BG et cinq modèles 200CA) travaillant durant 1253 postes de débusquage, de décembre 1975 jusqu'à mai 1977. Au cours de la période de quatre mois s'écoulant de septembre à décembre 1976, tous ces engins subirent des modifications effectuées par FMC et ses distributeurs. (On trouvera dans le rapport qui suit les détails relatifs à ces modifications.) Les données recueillies sur les six engins étudiés en Colombie-Britannique couvrent une période qui s'étend avant et après les modifications, alors que pour les deux engins étudiés en Ontario, les données ne furent recueillies qu'après modification.

Les études définissent et mesurent les éléments de temps productif du cycle de travail et démontrent que les débusqueuses FMC permettront d'étendre le transport primaire à des pentes allant jusqu'à 30 à 50%, tout en rencontrant les exigences de production et de protection de l'environnement. Cependant, le coût d'achat et de fonctionnement de ces engins est élevé, et on ne devrait pas les utiliser là où des machines moins coûteuses donnent un rendement satisfaisant.

INTRODUCTION

This report gives the results of a two-year study evaluating FMC skidder performance under various terrain and operating conditions. The study was carried out in cooperation with user companies in B. C. to provide performance data on time, productivity and cost, and to assess the environmental impact of skidding on areas with steep slopes and sensitive soils. Some Ontario data are included for comparison.

Because these were new machines there was no previous performance information. FERIC's study in Eastern Canada (Legault and Powell, 1975) gave production estimates for the 200BG model but gave no indication of long-term performance. The conditions of that study were not considered typical of skidding in Western Canada.

The most common logging method in the Interior of B. C. is ground skidding with wheeled machines and tractors. Wheeled skidders are generally suitable for skidding on areas with slopes up to 30 percent, while crawler tractors can skid on slopes up to 70 percent with an extensive network of skid roads. As logging operations advance onto steeper slopes, however, more stringent guidelines for soil and site protection are imposed and fewer roads can be built. Road-related soil disturbance (on slopes over 25 to 30 percent) on clearcuts ground-skidded in summer often exceeds recommended limits (Smith, 1976). Ground skidding in winter does not result in such extensive or severe soil disturbance. Use of cable-logging systems has increased on these steep sites, but there is a reluctance to use these more costly systems for marginal sites (30 to 50 percent slopes).

Logging managers wish to extend ground skidding to these marginal sites using machines like the FMC, but they need information on performance and reliability as well as assessment of soil disturbance and site damage.

Although the FMC is a tracked machine, methods used for wheeled skidder production studies by Bennett, et al., 1965; Cottell & Winer, 1969; McCraw & Hallett, 1970; Cottell, et al., 1971, formed a background for this study. Work by Axelsson (1972) was the basis for that part of the study concerned with repair-downtime data collection.

The FMC case studies define and measure the productive time elements of the work cycles for each machine. Delays were separated and analyzed and areas were visited for assessment of soil disturbance caused by skidding. Variables such as log volume, turn volume, skidding distance and slope were measured. Then relationships were studied (through multiple regression) between skidding time elements and the measured variables. Total time-per-turn relationships were also studied. Necessary delays were included in total time estimates. The results give a basis for comparison between the two models of the skidder in different skidding operations and for an estimation of cost.

This approach has inherent weaknesses which must be recognized. The relationships calculated between element times and measured conditions of the operation are weak and often leave large amounts of variation unexplained. Field work is expensive for such studies, and was usually performed over a relatively short period of time--several days to a week for each operation. It is difficult to know if the observed period is typical of the general operation, particularly in the occurrence of various types of delays. Not only that, but the presence of observers may influence the operator and lead to an improved performance for the period under observation.

The field work involved two levels of data collection: shift reports summarizing productive time,[1] delay time and causes, and total production; and detailed measurement of time elements[2] for each turn, along with such operating conditions as log volume, turn volume and distance.

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[1]Time definitions based on CPPA standards (Bérard, et al., 1968).

[2]Definitions of time element end points are given in Appendix I.

During visits to the operations to collect the detailed time data, visual assessments of soil disturbance were made on areas logged. Types of disturbance were classified by the methods described by Watt (1976) and Weetman (1973).

Eight skidders were studied during the period from December 1975 through May 1977--six in B. C. and two in Ontario. All machines were modified by FMC and its dealers over a four-month period between September and December 1976. Data collected from the six machines in B. C. cover a period before and after modification. For the two machines studied in Ontario, data were collected after modification.

The modifications were valued between $20,000 and $25,000. They were designed to improve the undercarriage and track assembly, chassis and frame, and they upgraded the 200-series to the newer, improved 210-series. Details of these modifications are given in Appendix II.

RESULTS AND COMPARISONS

The following section summarizes the results for each machine. Definitions of machine time elements, calculations of in-shift time, total machine time characteristics and skidding turn-time categories for detailed timing are fully explained in Appendix I. There is a supplement to this technical report describing the individual machine results in more detail, and this is available upon request from FERIC, Western Division.

Table 1 summarizes the operations for the eight FMC skidders in the study.

Table 1. Summary of FMC Skidders Studied

Machine & Model	Approximate Location	System Configuration (Types of Skidding)	Study Period	Average Skidding Distances ft	m	Range of Skid Trail Slope, %
1 200BG	East side Purcell Mtns.	Skidding clearcuts and rights-of-way, feller-buncher cut wood	Dec 1975 to Mar 1977	200 to 2,200	60 to 670	0 to 10
2 200CA	West side Selkirk Mtns.	Skidding clearcuts, with some cleanups, manually-felled wood	Aug 1976 to Mar 1977	100 to 2,500	30 to 760	0 to 50
3 200CA	Shuswap Lakes area	Skidding clearcuts and blow-down areas, manually-felled wood	Jul 1976 to Feb 1977	300 to 2,640	90 to 800	0 to 30
4 200CA	Shuswap Lakes area		Jul 1976 to Feb 1977	600 to 2,000	180 to 610	0 to 30
5 200CA	Vancouver Island	Skidding clearcuts, blow-down, and cleanup, manually-felled wood	May 1976 to May 1977	200 to 1,700	60 to 520	0 to 40
6 200CA	West side of Rocky Mtns.—Fraser Valley	Skidding clearcuts and cleanup, manually-felled wood	Jun 1976 to Mar 1977	200 to 2,000	60 to 610	0 to 35
7 200BG	Northeastern Ontario	Skidding clearcuts, feller-buncher cut wood	Oct 1976 to Apr 1977	500 to 1,800	150 to 550	0 to 10
8 200BG	Northeastern Ontario			500 to 1,800	150 to 550	0 to 10

Figures A and B show the two models of the FMC skidder. Figures C and D illustrate two interesting modifications to CA models which were made by users to facilitate handling of the chokers on the winch mainline.

A primary objective in carrying out the study was to enable potential users of the FMC skidder to compare the performance of the machines under different operating conditions. Since conditions and use of the skidder varied, it is necessary to keep in mind the major characteristics of each operation when interpreting the following tabulations of time, productivity and cost.

TIME

Table 2 summarizes shift-level time distributions for each machine studied. It comprises 401 shifts before modifications and 852 shifts afterward for a total of 1,253 shifts. The number of reported shifts for each machine varied because of date of entry into the study, shutdowns for weather, market conditions, and the scheduling of the modifications. Data collection for most machines ended with the shutdown for spring breakup in 1977 and this date varied with the location.

Machine availability of the skidder before modification was generally acceptable and ranged from 75 to 85%. Machine 1 was the exception with only 62.9%, (resulting from long repair times in early 1976 involving considerable wait-for-parts delays for two major repairs). After modification, availability increased for all machines and ranged from 82 to 95%. It seems reasonable for companies to aim for and achieve figures of 90% or greater. It is necessary for the manufacturer and the user company to provide sufficient maintenance support to keep machine availability at a high level. Availability can be maintained at this level if repairs and service can be done outside scheduled shift hours whenever possible. This allows for maximum use of the machine during shift hours but means staggered scheduling of maintenance crew time. An operator may be able to anticipate or prevent mechanical problems and improve availability as his experience (and perhaps motivation) increase.

Machine utilization is a measure of the organization's effectiveness in using scheduled time for productive work. Utilization varied from 58 to 81% before modification and from 76 to 92% afterward. The figures are strongly

Figure A. FMC 200BG Bunk Grapple Skidder

Figure B. FMC 200CA Choker Arch Skidder

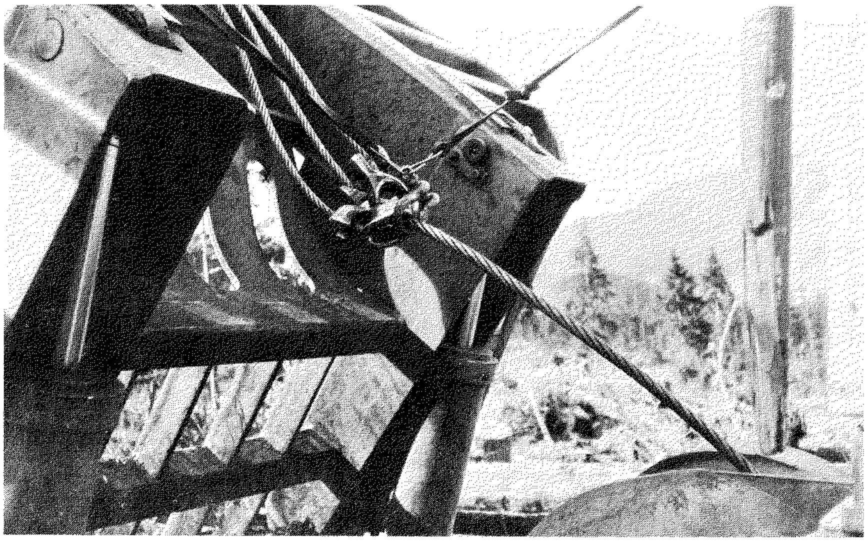

Figure C. Owner modification to CA model. A shackle suspended by two shock-cords prevents the chokers from being pulled into the winch drum.

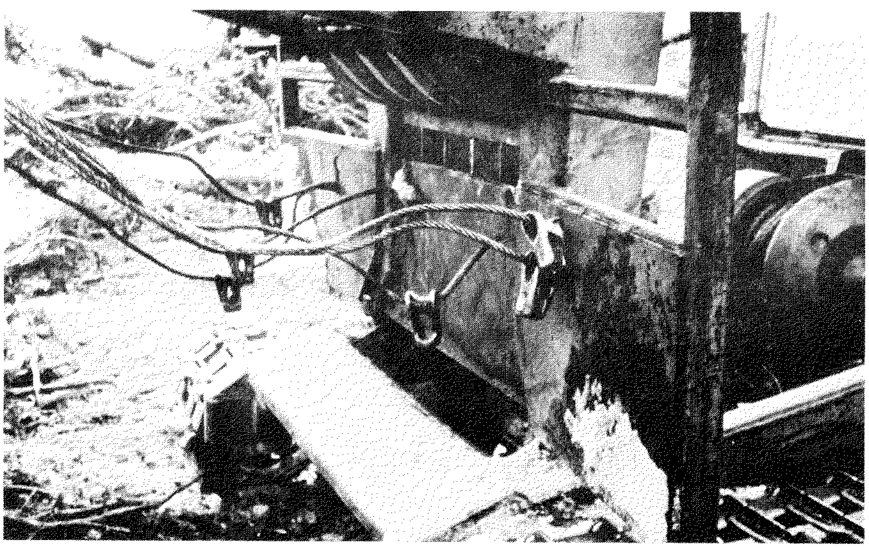

Figure D. Owner modification to choker arch. Steel plate with slots has been mounted on arch. Operator uses slots to arrange chokers in correct order for easy handling during hookup.

Table 2. Summary of Machine Time, Availability and Utilization from Shift Reports

Pre-Modification

Machine	Model	No. of Shifts	Time: Hours per Shift					Machine Avail. %	Machine Util. %	MNA
			Total	Productive	Delays					
			SMH	PMH	REP	SER	NMD			
1	200BG	155	8.0	4.7	2.7	0.3	0.4	62.9	58.1	64.4
2	200CA	20	8.0	5.9	1.8	0.2	0.1	75.2	73.9	33.6
3	200CA	45	8.0	5.0	1.7	0.2	1.2	77.2	62.3	36.5
4	200CA	49	8.0	6.2	0.8	0.3	0.6	86.1	78.1	17.8
5	200CA	83	8.0	6.3	1.3	0.04	0.3	83.0	78.8	26.4
6	200CA	49	9.2	7.5	0.6	0.7	0.5	86.6	81.4	32.1
7	200BG	N/A								
8	200BG	N/A								
Average		66.8	8.1	5.6	1.7	0.3	0.5	75.2	69.2	39.7

Post-Modification

Machine	Model	No. of Shifts	Time: Hours per Shift					Machine Avail. %	Machine Util. %	MNA
			Total	Productive	Delays					
			SMH	PMH	REP	SER	NMD			
1	200BG	133	8.0	6.3	1.0	0.3	0.3	82.9	78.6	22.1
2	200CA	91	8.0	6.1	1.0	0.3	0.5	82.8	76.4	22.5
3	200CA	44	8.0	6.8	0.2	0.6	0.5	90.3	84.4	11.6
4	200CA	45	8.0	6.8	0.2	0.2	0.8	95.0	85.4	5.9
5	200CA	130	8.0	7.1	0.6	0.1	0.3	91.6	87.9	18.2
6	200CA	67	8.7	7.9	0.4	0.3	0.03	92.1	91.7	8.6
7	200BG	174	7.9	6.1	1.4	0.01*	0.4	82.6	76.9	36.5
8	200BG	168	7.9	6.3	0.8	0.01*	0.7	89.2	80.8	28.6
Average		106.5	8.0	6.5	0.9	0.2	0.4	87.2	81.7	22.7

*For Machines 7 and 8, service was done out-of-shift, with 1 hour of service scheduled after each shift.

influenced by operator experience and motivation. Utilization values are always less than machine availability values and the difference shows the amount of available time which is not used for productive work (in this case, skidding).

This unused time is shown as non-mechanical delays in Table 2, and ranged from less than 1 to 15% of scheduled time during the study. This included time lost owing to bad weather, time spent assisting other machines, moving between logging shows, office time for the contractor with Machine 5, and other personnel delays. Review of the recorded causes of these delays suggests that personnel and planning problems are often responsible. Close supervisory support and control are needed to provide adequate numbers of felled trees for the skidder, to keep landing space available through proper truck and loader scheduling, to build skid trails where necessary and to prepare a thorough layout plan (landings, roads and skid trails) in advance of logging.

Machine Availability can be made to show high values by scheduling repair and service out-of-shift, so it does not give a true picture of how much maintenance is required to keep a machine in operation. Mechanical Non-Availability (MNA), however, does give a realistic picture and shows the amount of repair and service time needed to achieve each 100 hours of productive time. Both in-shift and out-of-shift time is used in the calculation. In the pre-modification period, MNA varied from 18 to 64 hours per 100 Productive Machine Hour (PMH). After modification, the range varied from 6 to 36 hours per 100 PMH.

The high values for Machine 1 in the pre-modification period and for Machines 7 and 8 in the post-modification period include periods of time for "wait for parts" and "wait for mechanics" which are organizational and not machine-associated problems. The low values of MNA after modification should be treated with caution because some machines were refurbished at the same time they were modified. This would effectively upgrade an older machine to almost new condition and fewer repairs would be expected.

In normal practice MNA would exceed 7 hours per 100 PMH. This minimum value allows one-half hour service per shift and no repairs in a 100-PMH period (which would cover 12½ eight-hour shifts). The average MNA value for the post-modification period appeared reasonable at 22.7 hours. Thus, 22.7 hours of MNA would cover 7 hours of service and 15.7 hours of repair for each 100 hours of productive time.

Productivity

Table 3 summarizes reported production figures for each machine. These figures cover the whole study period and are not separated into pre- and post-modification categories, since it was assumed that the modifications would influence mechanical performance of the machines and not productivity while skidding. All scheduled shifts for each machine are included, except for a two-month period when Machine 1 was on cleanup work and no production figures were reported. The production figures cover all the different types of skidding (clearcut, right-of-way, blowdown and cleanup) that were reported and may be regarded as normal operations for the skidder. The number of logs produced per shift varied considerably within each operation, and this is characteristic of most skidding operations where a large number of disturbing influences occur. These include skidding distance, slopes on skid trails, felling patterns, ground conditions and differences between operators. Productivity was also influenced by the use of the skidders in many areas where other skidding machines could not operate and conditions could not be regarded as ideal.

The 200BG version of the FMC produced the higher average number of logs per shift since it usually skidded behind feller-bunchers on flatter terrain. The productivity in terms of cunits per shift, however, was limited by the average tree size and the maximum capacity of the feller-buncher. The two 200BG's working in Eastern Canada have the highest piece count per shift, and the smallest average piece size.

Average log size varied from a low of 7 ft^3 (0.20 m^3) for Machines 7 and 8, to a high of 85 ft^3 (2.41 m^3) for Machine 2. Surprisingly, Machine 5 (working in coastal conditions on Vancouver Island) did not have the largest average piece size.

Piece size is obviously a key factor in volume production for skidders. The number of pieces that can be handled by the skidder during each turn is limited by the bunk grapple capacity of the 200BG and the number of chokers carried on the 200CA model.

The last columns in Table 3 show average production (gross volume) per shift, per productive machine hour, and per

Table 3. Summary of Skidder Production[1] from Shift Reports (8-hour shift basis)[2]

Machine	Model	No. of Shifts Reported	Av. No. of Logs/ 8-hour Shift	Av. Log Volume		Av. Gross Vol/Shift[3]		Production per PMH		Production per SMH	
				ft^3	m^3	cunits	m^3	cunits	m^3	cunits	m^3
1	200BG	288	166	17	0.48	29	82	5.29	15.0	3.58	10.1
2	200CA	111	60	85	2.41	51	144	8.35	23.6	6.34	18.0
3	200CA	89	84	46	1.30	38	108	6.58	18.6	4.82	13.6
4	200CA	94	89	49	1.39	44	125	6.74	19.1	5.50	15.6
5	200CA	213	123	46	1.30	57	161	8.39	23.8	7.08	20.0
6	200CA	116	118	34	0.96	40	113	5.72	16.2	4.99	14.1
7	200BG	174	580	7	0.20	41	116	6.76	19.1	5.20	14.7
8	200BG	168	656	7	0.20	46	130	7.29	20.6	5.89	16.7

[1]Gross volumes would be reduced by the amount of defect to estimate net volume produced.

[2]All comparisons assume a standard 8-hour shift because shift length varied from one operation to another.

[3]Average gross volume per shift is calculated from total volume produced and total shifts reported in the study period. This includes all shifts, both when there was production (i.e., shifts worked) and when there was no production.

scheduled machine hour for each machine in the study. Most ranged from 30 to 45 cunits (85 to 127 m^3) per shift, for both BG and CA models, except for the 200CA on Vancouver Island. Machine 5 averaged 57 cunits (161 m^3) per 8-hour shift, and reported production of 100 cunits (283 m^3) or more for 13 shifts during the study period (i.e., 6% of shifts reported).

Production per Productive Machine Hour (PMH) ranged from about 5.3 cunits to nearly 8.5 cunits (15 m^3 to 24 m^3). The best production per PMH was achieved by Machine 5, the FMC 200CA working on Vancouver Island. The lowest production per PMH was recorded by Machine 1, an FMC 200BG. Production figures show that models 200BG and 200CA may be expected to achieve productivities of between 6 and 7 cunits (17 and 20 m^3) per PMH, with a potential goal for 200CA's of up to 9 cunits (25.5 m^3) per PMH.

The last column in Table 3 shows production per scheduled machine hour (SMH). These values follow a similar trend to cunits per PMH, except that machine utilization enters the scene, and values are correspondingly reduced. Values ranged from 3.5 cunits/SMH to just over 7 cunits/SMH (9.9 to 20 m^3/SMH), with an overlap in the spread for each model of skidder. Again, the best production in cunits per SMH was for Machine 5.

Productivity measures from the detailed timing of four machines show how the turn times differed, and can provide estimates of expected production based on turn time and volumes observed. Table 4 shows the breakdown of turn time into elemental times for the two models under different types of skidding. The figures are from the detailed timing, and are calculated for a skidding distance of 1,000 feet (305 m). Table 5 shows how these operations varied in number of logs per turn and volume per turn. Average number of logs per turn ranged from 3 to 14 for the 200CA model, and from 9 to 14 for the 200BG model. Despite the smaller log size for the 200BG machine, turn volume was the highest because of the higher number of logs skidded per turn. For the 200BG, turn volume averaged over 4 cunits (11 m^3) per turn. Average turn volume for the 200CA ranged from 1.6 cunits to 3.4 cunits (4.5 to 9.6 m^3) per turn. In general, these loads were comprised of fewer trees of larger average size. The average gross volumes exceeding 2 cunits (5.7 m^3) per turn indicate good skidding practices, with the operator putting the machine's capacity to good use. Naturally there are times--particularly during cleanup operations--when the turn volume is very low.

Table 4. Average Turn Time Results from Detailed Time Studies (based on skidding distance of 1,000 feet (305 m))

Time Element	200CA		200BG			
	Clearcut Skidding		Clearcut Skidding		Right-of-Way Skidding	
	minutes	%	minutes	%	minutes	%
Travel empty	2.74	14	3.69	30	5.14	21
Travel loaded	5.49	28	2.95	24	7.83	32
Maneuver	0.78	4			0.49	2
Loading	5.88	30	4.80	39	4.65	19
Move during loading	0.20	1			2.20	9
Unloading	1.76	9	0.37	3	0.49	2
Delays	2.74	14	0.49	4	3.67	15
Total Time per Turn	19.59	100	12.30	100	24.47	100

Table 5. Average Turn Size from Detailed Time Studies

Machine	Type of Skidding	Average No. of Logs per Turn	Average Gross Volume per Turn	
			ft^3	m^3
1	Clearcut	9	418	11.8
1	Right-of-way	14	462	13.1
3	Clearcut (steep)	4	264	7.5
3	Clearcut (flat)	6	162	4.6
4	Clearcut (steep)	5	338	9.6
4	Clearcut (flat)	7	162	4.6
5	Clearcut of blowdown area	3	220	6.2

Costs

Cost estimates for the different skidding operations were developed from shift-level information on time consumption and productivity, together with assumed hourly costs for machines and operators. To enable comparison among the different machines, cost of skidding logs from stump to roadside was calculated. The production (on an 8-hour shift basis) and estimated costs[1] for each machine are shown in Table 6. The following cost assumptions were used:

Purchase price: 1977 new price, in Canadian dollars.

Depreciation: straight line, 5-year life with a 10% residual value, and 250 operating days per year.

Interest: 12% on average investment.

Repairs and Maintenance: 100% of fixed cost over life of machine.

Labour: $96.00 per man/day including fringe benefits for Western Canada, and $80.00 per man/day for Eastern Canada.

[1]Cost figures are not recorded company costs and should be used for comparative purposes only; they are based on actual production and hypothetical machine costs with no allowance for engineering, roads, supervison, employee transportation, overhead or profit.

Table 6. Production and Cost Estimates for FMC Skidders (8-hour Shift Basis)

Machine	Model	Crew	Production Per 8-hour shift[1]					Machine Price 1977 $	Cost per 8-hour shift			Skidding Cost	
			Log Av. ft³	Log Av. m³	Pieces	Gross cunits	Gross m³		Owning $/shift	Operating $/shift	Total $/shift	$/cunit	$/m³
1	200BG	1	17	.48	166	29	82	115,000	118	290	408	14.07	4.96
2	200CA	1	85	2.41	60	51	144	115,000	118	272	390	7.65	2.71
3	200CA	1	46	1.30	84	38	108	115,000	118	277	395	10.39	3.66
4	200CA	1	49	1.39	89	44	125	115,000	118	264	382	8.68	3.06
5	200CA	1	46	1.30	123	57	161	115,000	118	260	378	6.63	2.35
6	200CA	1	34	.96	118	40	113	115,000	118	255	373	9.33	3.30
7	200BG	1	7	.20	580	41	116	115,000	118	255	373	9.10	3.22
8	200BG	1	7	.20	656	46	130	115,000	118	249	367	7.98	2.82

[1] Production data are taken from Table 3.

Capital costs are for 1977 machines, even though individual costs varied owing to the date of purchase, import duty, and company-bargaining with dealers. For example, machines purchased in 1975 had an initial purchase price of about $85,000 and machines purchased in 1977 cost around $115,000. Two of the machines in the study were leased, but were treated like the others for the purpose of cost calculation.

The cost range of $6.63 to $14.07 per cunit ($2.35 to $4.96 per m^3) compares favourably with actual costs reported by several of the companies cooperating in the study. Actual values are not reported to protect confidentiality. If the FMC skidders were consistently operated on easier ground and in stands of good timber, their production would probably be higher and costs would be more favourable. If the terrain is suitable for wheeled skidders, however, the FMC's special capabilities become unnecessary and it may become an expensive substitute for wheeled skidders.

Considering the variety of conditions and types of skidding observed, the cost range in Table 6 ($7.44 per cunit or $2.61 per m^3)is not unreasonable. This suggests that the companies have been successful in selecting the FMC for skidding under their conditions. The 200BG model had a cost range from $7.98 to $14.07 per cunit ($2.82 to $4.96 per m^3) and the 200CA a range from $6.63 to $10.39 per cunit ($2.35 to $3.66 per m^3). These costs reflect the abilities of the operators and effectiveness of supervision as much as they do the performance of the skidders.

Repair Downtime

Table 7 summarizes reported total repair times and number of repairs for each machine separated into the pre- and post-modification periods. From these values average repair time is calculated, and using productive machine hours the mean time between repairs is calculated. Except for Machine 2, all machines in B. C. showed improvement in average repair time after modification. For Machines 7 and 8, no data were available for the pre-modification period and no comparison was possible. While the number of repairs and total repair hours were greater for the post-modification period, it can be seen that there were more than twice the scheduled hours reported for that period. There was also a small improvement in the mean time between repairs following modification.

Table 7. Summary of Repair Downtime

Pre-Modification

Machine	Total SMH	No. of Repairs	Total Repair Hours	Av. Repair Time (hours)	Mean Time between Repair (PMH)
1	1,240	55	416.5	7.6	13.1
2	160	4	35.5	8.9	29.6
3	358	20	74.5	3.7	11.2
4	390	22	40.8	1.8	13.8
5	664.5	11	112.5	10.2	47.6
6	450	29	78.3	2.7	12.6
7	-	N/A			
8	-	N/A			
Total	3,262.5	141	758.1		
Average of all machines	543.8	23.5	126.4	5.4	16.0

Post-Modification

Machine	Total SMH	No. of Repairs	Total Repair Hours	Av. Repair Time (hours)	Mean Time between Repair (PMH)
1	1,064	79	137.8	1.7	10.6
2	726.5	10	93.5	9.4	55.5
3	352	8	9.0	1.1	37.1
4	360	9	9.0	1.0	34.1
5	1,043.1	43	116.8	2.7	21.3
6	580.5	12	27.5	2.3	44.4
7	1,369	55	236.0	4.3	19.1
8	1,319	69	143.0	2.1	15.4
Total	6,814.1	285	772.6		
Average of all machines	851.8	35.6	96.6	2.7	19.5

The improvement in average repair time should not be attributed entirely to the modifications which were made. Several companies used the modification time to have the machine overhauled, effectively introducing a new machine into the study when reporting resumed. Not all the machines were of equivalent age when they started reporting data for the study, and reporting did not continue for equal lengths of time for all the machines following modification. Total repair time before modification (including both in-shift and out-of-shift repairs) was equal to 23% of the scheduled machine hours reported. After modification, total repair time equalled 11% of scheduled time.

Tracks and Suspension

Table 8 summarizes the repair times for the track and suspension for each machine. The assembly was broken into four major areas:

- repairs to pads, pins and bushings
- repairs to road wheels
- repairs to torsion arms
- repairs of a general nature (e.g., track adjusters, replacing tracks)

Table 8 also shows a total for all machines and the percentage of total repair time reported.

Prior to the modifications, more than half the repair time was spent on the road wheels and torsion arms and accounted for 26% of the total repair time reported. After modification the time for these two components accounted for only 6% of the total repair time. Track-associated repairs were reduced from 335 hours in 401 shifts to 193 hours in 852 shifts after modification.

The road wheels on the early machines were of a composite type consisting of an aluminum center with a rubber tire and steel cover. The bonding between the metals and rubber often failed. The composite wheels were replaced by all-steel wheels, both before and as part of the modification. These survived rough treatment on all types of terrain. (Some users reported failures in the steel wheels due to cracking of the outer rim, but this occurred after data collection had terminated. Since then the manufacturer has increased the thickness of the steel wheel by 25%.)

Table 8. Summary of Repair Hours to Track and Suspension Assembly

Pre-Modification

Component	Machine Number								All Machines
	1	2	3	4	5	6	7	8	
Pads, pins & bushings	10.0	-	8.0	2.5	-	10.0			30.5
Road wheels	2.0	24.5	19.5	5.0	47.0	7.5			105.5
Torsion arms	7.0	-	6.0	-	43.0	39.0			95.0
General	85.0	6.0	1.5	-	4.5	7.0			104.0
Total hours	104.0	30.5	35.0	7.5	94.5	63.5	N/A	N/A	335.0
% of repair hours	25	86	47	18	84	81			44

Post-Modification

Component	Machine Number								All Machines
	1	2	3	4	5	6	7	8	
Pads, pins & bushings	9.0	-	-	2.5	-	-	2.0	23.5	37.0
Road wheels	4.0	-	-	-	-	-	5.5	3.0	12.5
Torsion arms	2.5	-	-	-	17.5	-	6.0	6.0	32.0
General	7.0	5.5	-	-	64.6	11.5	3.0	19.5	111.1
Total hours	22.5	5.5	-	2.5	82.1	11.5	16.5	52.0	192.6
% of repair hours	16	6	-	28	70	42	7	36	25

Torsion arm failures decreased following modifications, when stronger bars were used and road wheel vertical movement was decreased by the addition of stops. Machine 5 had more torsion arm breakage after modification than the other machines and this was attributed to a particularly rocky area which was being skidded.

Track life could not be assessed from the study data because no replacements were reported during the study period. The original track on Machine 1 had lasted 1,350 hours and a new track was fitted just after the study ended. Machine 5 also reported a track replacement just after the study ended, and the track had lasted 1,750 hours. Figures E and F illustrate the difference between a worn track and a new one.

The manufacturer has recently provided the necessary equipment for re-bushing track pads to recondition tracks which still have some usable life in the pads. Before this, replacement of the complete track was often the only solution. Figure G illustrates a track bushing failure.

Track costs are a major item in machine maintenance. Replacement cost for the tracks is approximately $16,000 to $17,000. Assuming a track life of 2,500 hours, this works out at approximately $6.75 per hour, or 13 to 15% of total hourly cost for track costs alone.

Soil Disturbance

From the visual assessments of areas skidded by five of the eight machines, soil disturbance was not considered to be a problem. There were a few examples where better planning and supervision could have minimized disturbance and avoided the damage which occurred. For a more realistic appraisal of the soil disturbance, FMC-skidded areas should be visited again after several years. This would allow more meaningful assessments of erosion and regeneration problems. On some areas where the FMC worked with other types of skidders, it was not always possible to isolate the disturbance related to the FMC. Figures H to K illustrate skidding areas for several machines and show some examples of soil disturbance.

Areas with steep slopes and sensitive soils should have careful planning and layout for skidding operations, even with FMC machines. Post-logging treatment of areas is also very important and must not be neglected. The handbook for

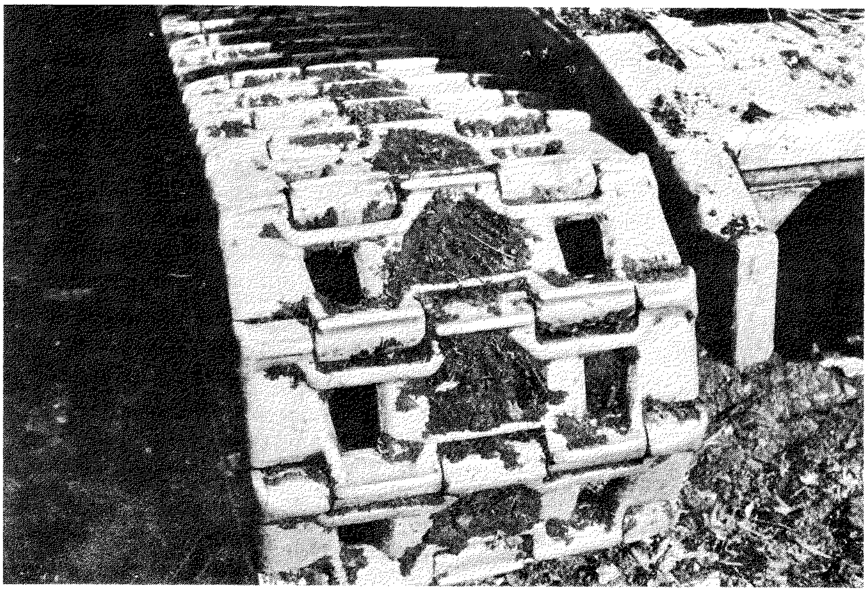

Figure E. Worn track with pads showing wear to grousers and edge of pads after skidding in rocky terrain. Compare with Figure F below.

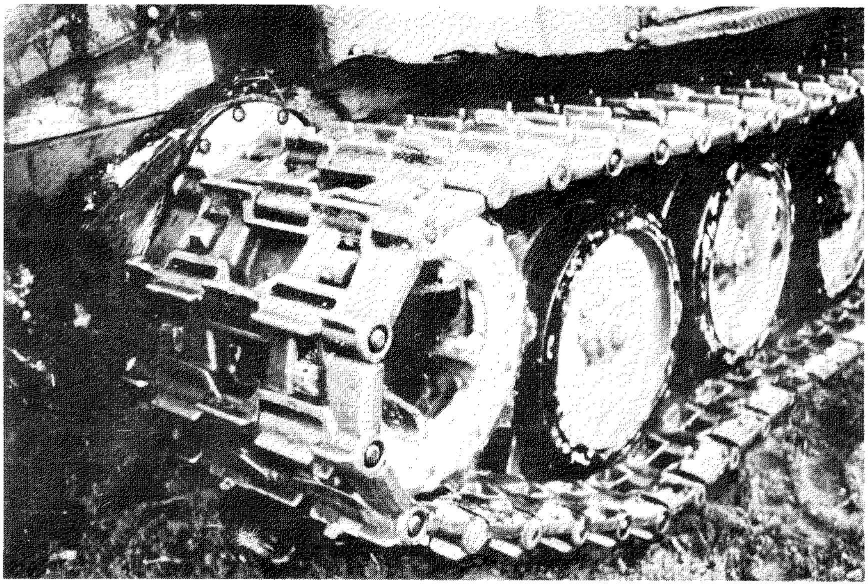

Figure F. New tracks

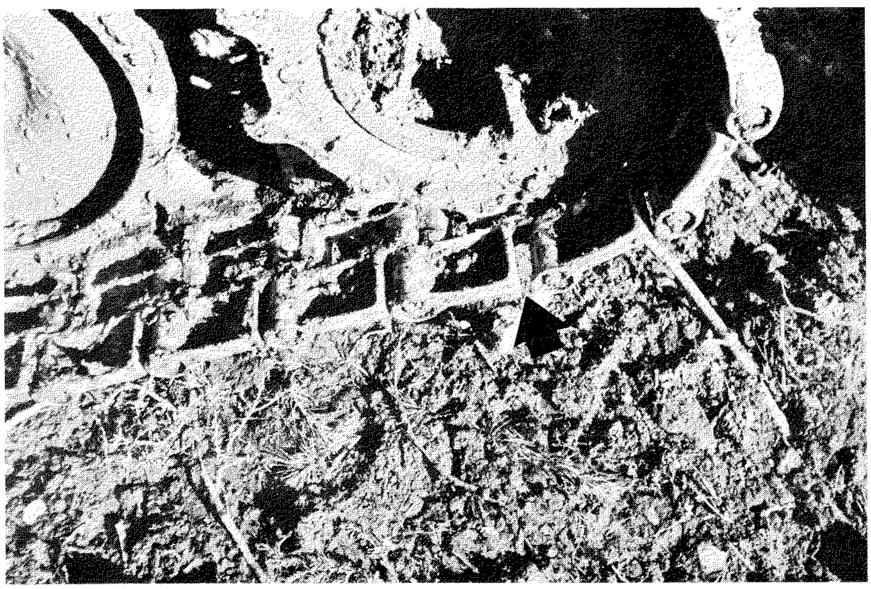

Figure G. Track bushing failure. Arrow indicates enlarged clearance between track pads due to bushing failure. Normal clearance can be seen between adjacent pads.

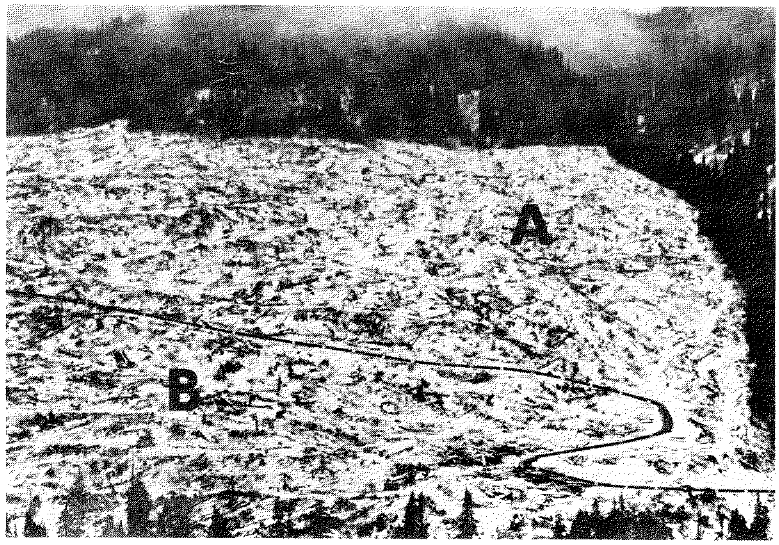

Figure H. Skid trail patterns for Machine 2 in clearcut area. A shows random pattern of FMC trails on steep area (30% to 40% slopes), and B shows horizontal Cat skid trails. The dashed line shows the truck road location.

Figure I. Plateau area skidded by Machines 3 and 4, with skid trail passing through small-sized timber.

Figure J. Machine 5 working on clearcut logging. Note the increased disturbance at the right where skid trail approaches landing and is more heavily used.

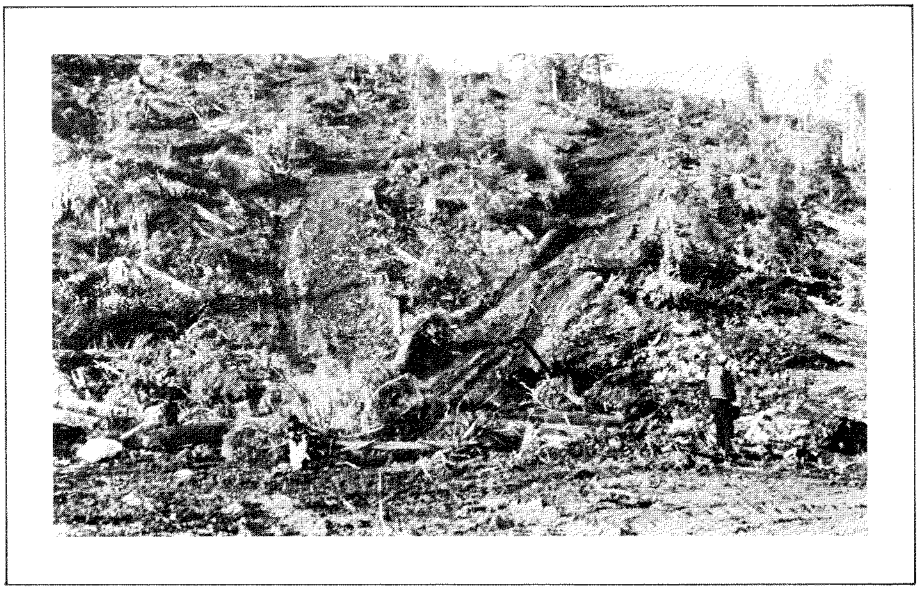

Figure K. Steep area skidded by Machine 6. These trails were prepared by a bulldozer for the FMC to skid the area. They are also heavily used in sections approaching the landing.

ground skidding prepared for the Kootenay area of B. C. by Murray et al. (1976) provides a comprehensive guide which is applicable to ground skidding operations generally, including FMC skidding.

CONCLUSION

Observations covering more than 1,200 shifts of skidding activities by 8 FMC machines, (200BG and 200CA), indicate that the machines have achieved acceptable levels of performance. Machine Availability improved following extensive modifications to the undercarriage in late 1976. Machine Utilization has also been at a high level in the post-modification period, averaging over 80%. Productivity averaged more than 5 cunits (14 m^3) per productive machine hour for all machines during the study, which covered different types of skidding from clearcut skidding to cleanup skidding. The number of FMC skidders in B. C. has increased from fewer than 10 in 1975 to about 30 in 1977, indicating the acceptance of this machine for log skidding.

In addition to the time and production results obtained from the data collected, the study has provided some specific lessons.

1. The 200BG model skidder is suited to operation in conjunction with a feller-buncher. Since few feller-bunchers are able to operate on slopes exceeding 15 to 20%, the full terrain capabilities of the 200BG are not utilized. Feller-buncher operators must produce large bunches of trees to reduce the loading time and to encourage the skidder operator to optimize the volume of each turn.

2. The 200CA model skidder was utilized in a variety of skidding jobs, from the easiest logging chance to the worst. At times the FMC was used to skid portions of cable-yarder settings not reached by the yarder, or to skid steep pitches beyond the capacity of wheeled skidders or crawler tractors. Costs were high in these cases, but the machine filled a role which could not have been filled satisfactorily by the other machines available. For this reason direct comparisons of cost and productivity are not feasible.

3. Acceptable use of scheduled time was achieved on the FMC operations studied. Some improvement could be achieved through better planning and daily supervision, (which would also provide for recognition of environmental concerns on sensitive sites). The selection, instruction and motivation of FMC operators is also important. The right operator can reduce the risk of machine abuse and prevent excessive repair downtime.

4. As recommended in the cable system study (Cottell, et al., 1976), year-round employment is essential to encourage skilled and interested workers and contractors who have skidding experience. A fair skidding rate based on the terrain and timber is a necessity for survival to the contractor who has invested the required capital outlay.

5. The results from detailed timing in some of the case studies show potential productivities ranging from 5 cunits to 24 cunits (14 m^3 to 68 m^3) per PMH, depending on skidding distance, terrain conditions, local volumes and operator differences. These results indicate productivity goals which can be achieved but are seldom maintained over long periods. This last point is illustrated by the difference between these potential values and the actual values calculated for the study. While the short-term studies indicate the relationships of some factors to productivity, they do not explain all the variation that is found in the day-to-day production figures.

6. The 200CA skidders operated effectively on slopes up to 45%. A test of the 200BG in winter also showed the machine could operate on slopes up to 45%, but snow conditions were not favourable for effective skidding production. Since the study ended, Machine 1 has operated effectively behind a Swedish feller-buncher on slopes up to 50%.

7. Repair downtime decreased following the modifications, particularly in the area of tracks and suspension. The improvements to the undercarriage were successful, but track life is still often not at an acceptable level. The high track replacement costs cause considerable concern to most users and this is the area where more attention is needed by the manufacturer.

The FMC skidders do not provide the solution to all ground skidding problems. They will allow the range of ground skidding to extend to the 30 to 50% slope range while still meeting production and environmental requirements. The machines in the study have achieved acceptable levels of performance and time utilization. These levels could be improved further with the necessary inputs of organization and planning. The cost of purchasing and operating these machines is high, however, and they should not be used where less expensive machines give satisfactory performance.

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APPENDIX I

Definitions

1. Definitions of Machine Time Elements

CPPA Standard Definitions for Machine Availability and Utilization, Woodlands Section Index 2428 (B-1), have been used as a basis. However, CPPA Machine Availability by definition is influenced not only by the manufactured quality of the machine, but also by operational factors, mainly the efficiency of the maintenance support organization, the number of shifts and hours scheduled per day, and the amount of repair and service performed out-of-shift. Other Total Machine Time characteristics have been used to present a more accurate measurement of machine manufacturing parameters, independent of operational factors. These are defined below:

Scheduled in-shift time (or Scheduled Machine Hours, SMH):
The time during which the machine is regularly scheduled to do productive work, e.g., 8 or 9 hours per shift, with one, two or three shifts per day. It should be noted that the scheduling refers to machine time, not operator time. For example, an operator's regular half-hour break for lunch is not to be included in SMH. The scheduled in-shift time is divided into:

- Productive machine-time
- Machine downtime due to maintenance (i.e., repair and service)
- Machine downtime due to non-mechanical delays.

Scheduled out-of-shift time: The time during which no production is regularly scheduled for the machine. Time for active repair and service only is to be recorded on the Daily Report form regarding out-of-shift time.

Productive machine-time (or Productive Machine Hours, PMH):
That part of scheduled in-shift time during which the machine is performing a function for which it was scheduled.

Repair: Repair is mending or replacement of part(s) due to failure or malfunction. It also includes modifications and improvements of the machine, <u>but in this study</u> the major improvement made by FMC dealers to update the

the machines was not included because the total time the machines were out of service varied, and the extent of work done also varied. The total downtime for reasons of repair is normally subdivided into three time elements: Active repair, Waiting for mechanic(s), and Waiting for part(s). Due to differences in reporting by the cooperating companies this breakdown was not always made and was therefore not used in the presentation of the results.

Service: Service is fuelling, etc., and preventive maintenance performed to retain the machine in satisfactory operational condition. It includes:

- Fuelling, lubricating, adding hydraulic oil, cleaning, etc.
- Routine inspection and checking
- All work specified in a preventive maintenance program (overhaul, replacement of oil filters and spark plugs, etc.).

If the machine is serviced while under repair, the time involved is to be classified as repair, not service.

Non-mechanical delay: That part of scheduled in-shift time during which the machine is not doing productive work for reasons other than maintenance. The various reasons for non-mechanical delay may be subdivided as follows:

- Operational lost time such as weather or terrain conditions (e.g., warm-up, machine stuck); waiting for other phase of an integrated operation, waiting for supervisor's instructions; aiding other machines; visitors; etc.
- Personnel (e.g., operator late, sick, etc.).
- In-shift moving (i.e., moving or transport of the machine between operating sites, or between site and camp, assuming the machine is not under repair or service).

2. Calculations of In-Shift Time and Total Machine Time Characteristics

Machine Utilization, %

$$= \text{CPPA Machine Utilization} = \frac{\text{PMH}}{\text{SMH}} \times 100$$

Machine Availability, %

$$= \text{CPPA Availability} = \frac{\text{SMH} - (\text{MAINT. IN SHIFT})}{\text{SMH}} \times 100$$

Mechanical Non-Availability

= Repair Time + Service Time
= Total maintenance, in Hr/100 PMH

Average Repair Time

$$= \frac{\text{Total Repair Hours}}{\text{Total Number of Repairs}}, \text{ in hours}$$

Average Time between Repairs

$$= \frac{\text{Total PMH}}{\text{Total Number of Repairs}}, \text{ in hours}$$

3. Definition of Skidding Turn Time Categories (for detailed studies)

Time Element	Begins	Ends
Travel empty	when the skidder starts to travel empty from the piles at the landing to the stump area	when forward motion stops so that "maneuver" or "loading" can begin
Maneuver	at the end of travel empty	when loading grapple activities start or manual setting of chokers starts
Loading	at the end of maneuver	when the skidder starts to move with a bunch in the grapple or a load on the choker arch
Move during loading (= move time between loading points)	at the end of loading	when forward motion stops and loading re-commences
Travel loaded	at end of loading when a full load has been accumulated	when skidder starts at landing
Unloading	at end of travel loaded	when skidder starts moving again so that travel empty may begin
Delays	when a production function is inter-rupted	when the production function re-commences

Delays were treated in different ways depending on their duration:

0 - .05 min, included in above elements;
.06 - 9.99 min, recorded as delays, with appropriate comments; and
10 minutes and greater, not considered as part of productive time and excluded.

APPENDIX II

Details of Modifications Supplied by FMC

FOR BOTH 200BG AND 200CA MODELS

"PART I

Area Involved	Specific Improvements
Wheels	Hi-strength all-steel wheels
Wheel hubs	All-steel larger wheel hubs with - Extra heavy Timken tapered roller bearings - New metal to metal face seals with protective flanges - Easy access oil filler plugs
Road arm assemblies	New improved road arm assemblies with - Weld-reinforced, interference fit larger spindles with extension for jack - Weld-reinforced, interference fit trunnions with steel-to-steel arm retainers
Final drive housings	Steel final drive housings to replace aluminum

"PART II

Track idler relief	Track tension relief valve for suspension protection
Torsion bars	New plastisol-coated steel torsion bars to replace taped bars
	Excursion limiting blocks to reduce torsion bar stress level
Cooling & exhaust system	Improved cooling with closure plates and perforated hood doors to redirect engine air flow
	Strengthen, modify exhaust pipes

Area Involved	Specific Improvements
Cab	Cab floor and firewall reinforcement
Frame	Frame riser support plates
	Trunnion tie plates
Tracks	Track wear plates

FOR 200BG MODELS ONLY

"PART I

Frame	Strengthen frame with - Idler frame tie plates - Corner braces - Closure plates
ROPS	Reinforce ROPS with - Front gussets - Rear diagonals - Radiator enclosure anchor plates

"PART II

Hydraulic system	Improve hydraulics with - Main boom pressure booster - Boom overload cushion valve - Bunk hold pressure gauge - Pressurized, closed system - Elevated pressure cap
Bunk area	Strengthen bunk with - Fence riser plates - Bunk corner plates

FOR 200CA MODELS ONLY

Arch area/rear deck	Strengthen rear frame arch support - Arch pivot clevis anchors - Arch pivot side plates - Log deck tie plates - Arch cylinder clevis anchors

Area Involved	Specific Improvements
	- Arch arm span plates - Transversal bed plate - Rear cross member plates - Box beam extension plates - Cross beam - Enclosure plates - Side frame stiffener."