JAAKKO PÖYRY
JAAKKO PÖYRY CONSULTING, INC.

Harvesting Systems

A Background Paper for a Generic Environmental Impact Statement on Timber Harvesting and Forest Management in Minnesota

Prepared for:

Minnesota Environmental Quality Board
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August 1992

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August 19, 1992

Dr. Michael Kilgore
GEIS Project Manager
Minnesota Planning Office
300 Centennial Office Building
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Dear Mike:

Pursuant to the State of Minnesota's GEIS contract with Jaakko Pöyry Consulting, Inc. as formally executed on May 15, 1991, the sixth task included preparation of background papers. One of these papers, Harvesting Systems, is attached for review and approval.

The material contained in the document is presented in accordance with the terms outlined in Attachment A (to the base contract), Section III, subsection F.

We look forward to your approval of this work product in due course.

Respectfully yours,

Doug G. Parsonson
GEIS Project Coordinator

DGP/cms
Attachment

cc: B. Dunn
J. A. McNutt
A. Veverka

SUMMARY

The objectives of this Background Paper are to document the harvesting systems currently used in Minnesota and those potentially available, and to provide an assessment of the competitive aspects and physical impacts of various harvesting systems by including a thorough discussion of:

- the harvesting systems and equipment currently used in Minnesota by covertype;
- the harvesting systems and equipment employed elsewhere in similar conditions;
- the transport systems currently used to move harvested wood from the forest to processing facilities;
- ground pressure indices for the different harvesting systems and equipment; and
- comparative productivity and cost data for the harvesting and transport systems used in Minnesota.

The Background Paper is intended to provide information about harvesting systems to guide the GEIS Study Groups. The information provides background and a common understanding among the groups to aid in the preparation of the technical papers.

Information was obtained from field trips to harvesting operations, discussions with people engaged in timber harvesting and forest management, and a questionnaire distributed to logging contractors operating in Minnesota. The logging survey was distributed to logging contractors through the Minnesota Timber Producers Association (TPA) and directly by mail to non-TPA members. Supplementary information was also obtained from information presented in the *Silvicultural Systems Background Paper* (Jaakko Pöyry Consulting, Inc. 1992).

A total of 70 contractors with 457 employees responded to the logging questionnaire. The total harvest volume reported by the survey respondents (636,439 cords) is approximately 19 percent of the estimated annual Minnesota industrial wood harvest reported during the period 1990-91. Of the volume reported, 30 percent was softwood pulpwood, 6 percent softwood logs, 57 percent hardwood pulpwood, and 7 percent hardwood logs. Slightly over half the volume harvested (53 percent) was forest company purchased or owned stumpage. However, in the central hardwood unit logging of stumpage purchased by the contractor (own stumpage purchases) was more prevalent (71 percent). When only the southeast is examined, 100 percent of the contractors logged their own stumpage purchases.

The most common silvicultural systems employed were clearcutting and clearcutting with residuals accounting for over 80 percent of the total volume

harvested. Most logging occurred during the winter (December-February, 43 percent), while the least occurred during the spring (March-May, 9 percent). Logging during the summer (June–August) accounted for 22.5 percent of the volume harvested, while 25.3 percent of the volume was harvested during the fall (September–November).

In the aspen-birch (81 percent) and northern pine (69 percent) units, the majority of the felling was by feller-buncher. In the central hardwood unit, all of the felling reported in the survey was by chain saw. For the state on average, 73 percent of the felling was by feller buncher, 27 percent by chain saw, and less that 0.5 percent by harvester.

Off-road transport of wood was mainly by grapple skidder (69 percent of the volume harvested). Off-road transport by cable skidders accounted for 30 percent and forwarders slightly less than 1 percent of the volume harvested. Grapple skidders were most widely used in the aspen-birch (77 percent) and northern pine (64 percent) units. Cable skidders were most used in the central hardwood unit (68 percent). Forwarders were also used to a small extent in the central hardwood unit (2 percent). The use of other off-road transport equipment or methods was not indicated in the questionnaire. The average age of logging equipment in Minnesota is high with the majority (64 percent) of all equipment being greater than six years old.

The majority of the delimbing was done manually using a chain saw (66 percent), while 33 percent was delimbed using mechanized equipment. In addition, 68 percent of the delimbing and topping was in the cutover, while less than 32 percent was at roadside. Less than 1 percent of the volume was full tree chipped. In general, chain saws are used to delimb hardwoods in the cutover, while mechanical delimbing is used more in softwoods and occurs mainly at roadside. There was also a minor amount of mechanical delimbing in the cutover.

As with felling and delimbing, the greatest mechanization in bucking is in the aspen-birch unit (81 percent), followed by the northern pine (61 percent) and central hardwood (27 percent) units. The majority of the bucking occurred at roadside (76 percent). Only 7 percent of the wood was bucked in the cutover. Almost 17 percent of the wood was not bucked and was transported to the mills as tree lengths. Less than 1 percent of the volume harvested was full tree chipped. The majority of the full tree chipping was of hardwood residuals destined for hog fuel.

Statewide, the average logging site area was 32 acres. The average logging site area in the aspen-birch unit was 40 acres, while in the northern pine and central hardwood units it was 28 and 25 acres, respectively. However, since logging operations commonly consist of several cutting units, individual cuts are probably smaller in size.

Transport of wood from roadside to the mills is by truck. Less than 1 percent of the volume transported was in chip form. Approximately 82 percent of the volume was transported in pulpwood or log lengths, while 17 percent was as tree lengths. Almost all wood was transported by tractor-semitrailer units, with an average load capacity of about 10 to 11 cords (80,000 lb GVW in summer and 88,000 lb GVW in winter). Tandem axle trucks with pup trailers are also used to some extent.

Productivity and costs of logging vary extensively. The main factors are tree size, off-road transport distance, merchantable volume per acre, total merchantable volume and whether the operation is clearfelling or thinning. On average, the relative unit costs for clearfelling are approximately 55 to 75 percent of equivalent costs for thinning operations.

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LIST OF PREPARERS

Dr. Reino Pulkki

ACKNOWLEDGEMENTS

The author wishes to acknowledge the considerable input from personnel in various forestry organizations in Minnesota. This input included data, background information, and helpful comment. The Minnesota Timber Producers Association (TPA) assisted by distributing copies of the logging questionnaire and by encouraging its members to respond. Considerable information was obtained from the numerous logging contractors who responded to the logging questionnaire. To illustrate the different types of logging equipment the Forest Engineering Research Institute of Canada (FERIC) allowed the use of harvesting equipment line drawings presented in Peterson (1989).

1 INTRODUCTION

The objectives of this Background Paper are to document the harvesting systems currently used in Minnesota and those potentially available, and to provide an assessment of the competitive aspects and physical impacts of various harvesting systems by including a thorough discussion of:

- the harvesting systems and equipment currently used in Minnesota by covertype;
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- the transport systems currently used to move harvested wood from the forest to processing facilities;
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Information was obtained from field trips to harvesting operations, discussions with people engaged in timber harvesting and forest management, and a questionnaire distributed to logging contractors operating in Minnesota. The logging survey was distributed to logging contractors through the Minnesota Timber Producers Association (TPA) and directly by mail to non-TPA members. Supplementary information was also obtained from information presented in the *Silvicultural Systems Background Paper* (Jaakko Pöyry Consulting, Inc., 1992).

This Background Paper is intended to provide information about harvesting systems to guide the GEIS Study Groups. The information provides background and a common understanding among the groups and to aid in the preparation of the technical papers.

2 HARVESTING DEFINITIONS

In this background paper the terms harvesting and logging are used synonymously. Figure 2.1 presents a chart of wood procurement flow and wood-quality characteristics influenced by and/or influencing wood harvesting. Appendix I presents a *Glossary of Harvesting Terminology*. However, since there is considerable misuse of the terminology related to harvesting methods and systems they are outlined in detail below.

Harvesting method.—The form in which wood is delivered to the logging access road. The form in which the wood is delivered depends on the

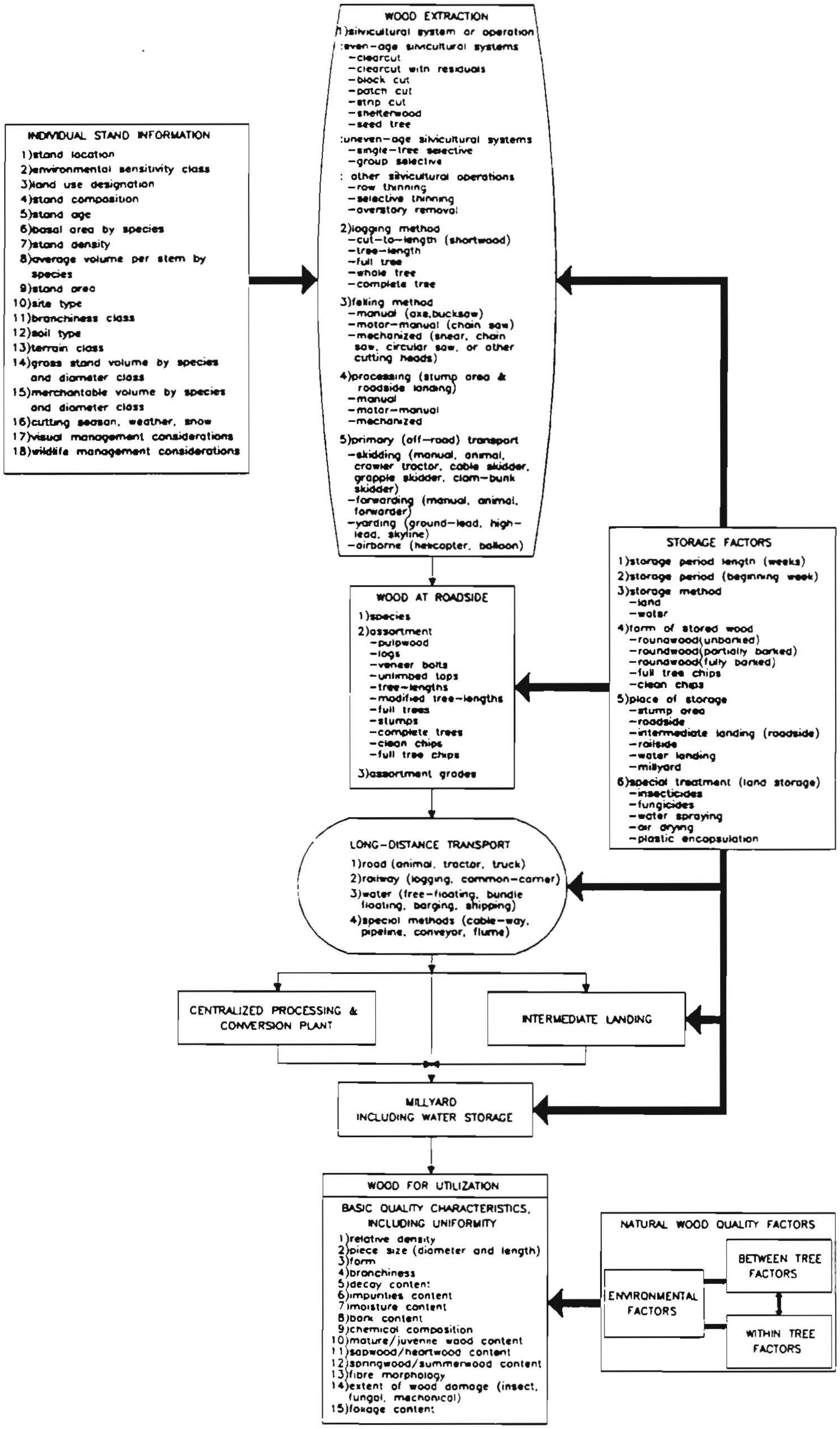


Figure 2.1. Wood flow, quality and logging options in wood procurement.

amount of processing (e.g., delimbing, bucking, barking, chipping) which occurs in the cutover. The different harvesting methods are:

Cut-to-length (shortwood).—Trees are felled (cut-off above the stump with stump height less than stem butt diameter), delimbed and bucked to various assortments (pulpwood, sawlog, veneer bolt, etc.) directly in the stump area. Trees can be topped down to a 2-inch top diameter and limbs and tops can be left in windrows or spread over the cutover. Logging can be fully mechanized or motor manual. Off-road transport is usually by forwarding (i.e., wood is carried off the ground), although in Minnesota skidders are most often used to transport hardwood logs in the southeast. The cut-to-length method can be utilized in all silvicultural systems (e.g., clearfelling, thinning, individual tree selective logging) (see Jaakko Pöyry Consulting, Inc. (1992) for definitions of silvicultural systems and terminology). Roadside landings are minimal since all processing is done in the cutover and high roadside piles can be made. The method also allows better sorting and storage of various wood assortments. The method can be used efficiently even when inwoods inventory levels are minimal (i.e., hot-logging is very applicable). Although the use of this method is re-establishing itself in the rest of North America due to its "softer" environmental impact (e.g., it now accounts for about 20 percent of the volume harvested east of Alberta in Canada), its use in Minnesota is very limited.

Tree length.—Trees are felled, delimbed and topped in the cutover. Delimbing and topping can occur in the stump area or at a point before roadside. In softwoods, trees can be topped down to a 2-inch top, however, generally topping occurs at a 3- to 4-inch top. In Minnesota trees are mainly skidded to roadside with cable or grapple skidders—use of crawler tractors or clam-bunk skidders was not indicated in the questionnaire. The tree lengths are bucked to pulpwood and logs at roadside, or can be left as tree lengths for tree length hauling to the mill. The tree length method is most applicable to clearfelling, and can be used in row thinning. Landing requirements at roadside are much greater than for the cut-to-length method. The tree-length method is the most widely used logging method in Minnesota.

Full tree.—Trees are felled and transported to roadside with branches and top intact. In Minnesota, skidding to roadside is mainly by cable or grapple skidders. The full trees are processed at roadside (there is no full tree hauling in Minnesota). Roadside processing of full trees can include:

- full tree chipping and hauling of full tree chips to the mill (more or less used only for hog fuel in Minnesota)
- delimbing and topping to produce tree lengths for hauling to the mill

- delimbing, topping and bucking to produce wood assortments for hauling as pulpwood to pulpmills or pulpwood using panel mills, and logs to sawmills or veneer mills
- chain flail-delimbing-debarking-chipping to produce clean chips for transport to pulp and paper, or panel mills

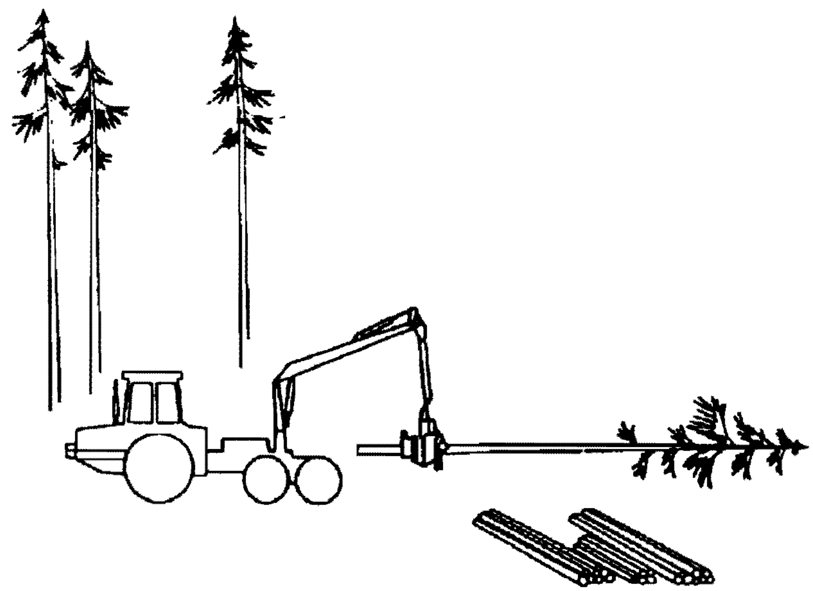
With the full tree method the limbs, tops and wood residue, and in the case of the chain flail-delimber-debarker-chippers also the bark, are left in piles at roadside and must be disposed of. The slash could be raked into piles and burned, or left as is for natural breakdown. Another alternative is to spread the slash or delimber-debarker mulch back into the cutover. The full tree method is most applicable to clearfelling operations, and in some cases to first commercial thinnings where the material is chipped directly in the stump area or transported to roadside by forwarder. The landing requirement is the highest with this method. The full tree method is the second most widely used method in Minnesota.

Whole tree.—Full trees including the stump are removed to roadside for processing and utilization. This method is not used in Minnesota.

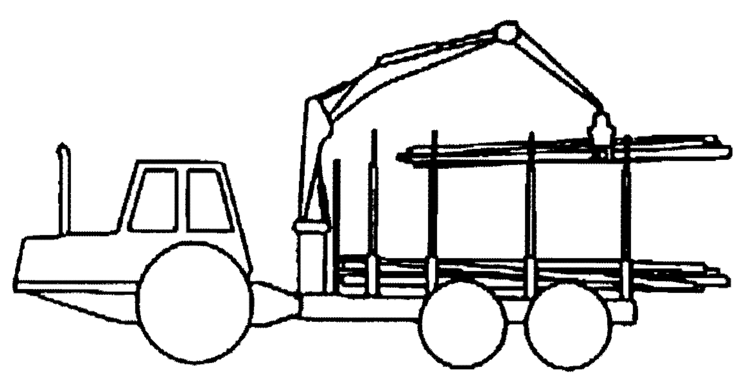
Complete tree.—Full trees, including stump and major roots are removed to roadside for processing and utilization. This method is not used in Minnesota.

Harvesting system.—The tools, equipment and machines used to harvest an area. The individual components of the system can be changed without changing the harvesting method (i.e., the form in which the wood is delivered to roadside). A typical cut-to-length logging system could employ a one-grip harvester which fells, delimbs and bucks the trees right in the stump area, and a forwarder to carry the pulpwood and logs to roadside (figure 2.2). With the tree length method a common system would include motor-manual (chain saw) felling, delimbing and topping, tree length skidding to roadside, and roadside slashing (figure 2.3). A typical harvesting system used in full tree harvesting would include a feller buncher, grapple skidder, stroke delimber and slasher (figure 2.4).

Tables 2.1 and 2.2 summarize the characteristics of the cut-to-length, tree length and full tree methods, and their applicability to the various silvicultural systems used in Minnesota (see *Silvicultural Systems Background Paper*, Jaakko Pöyry Consulting, Inc., 1992). Appendix II presents line drawings of the major types of logging equipment.

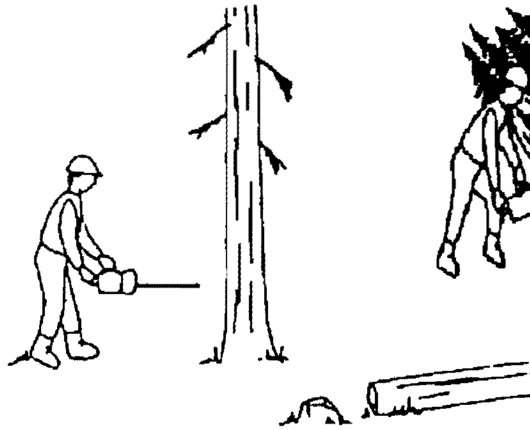


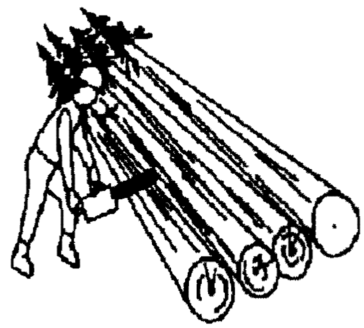
(1) One-grip harvester (fells, delimbs and bucks with same attachment).



(2) Forwarder.

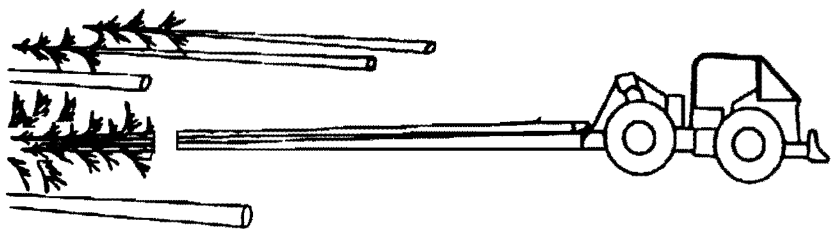
Figure 2.2. Cut-to-length logging using a (1) one-grip harvester and (2) forwarder system.



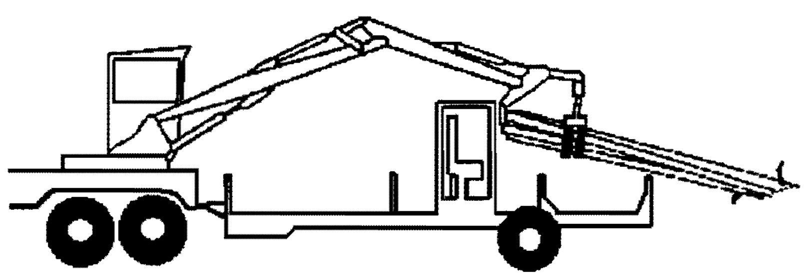


(1) Chain saw felling

(2) Chain saw delimbing and topping

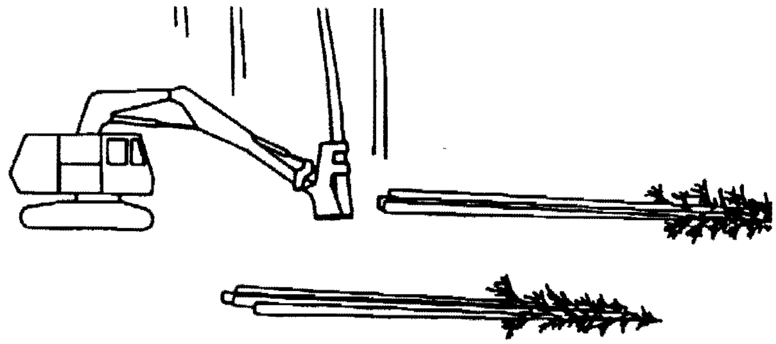


(3) Cable skidder

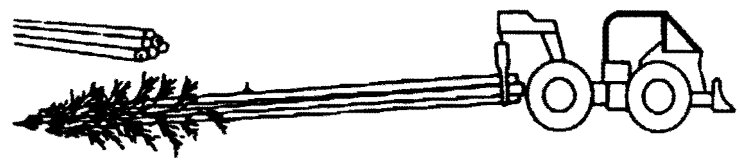


(4) Small-size towable slasher

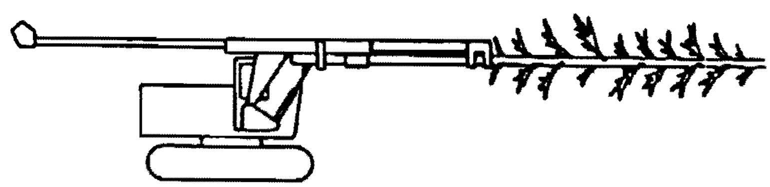
Figure 2.3. Tree length logging with (1) motor-manual (chain saw) felling, (2) delimbing and topping, (3) cable skidding of tree lengths, and (4) slashing with a portable slasher.



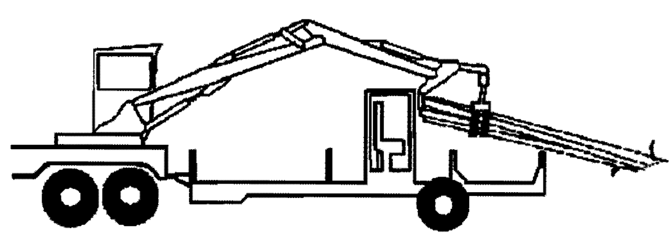
(1) Boom equipped feller-buncher



(2) Grapple skidder



(3) Stroke delimber



(4) Small-size towable slasher

Figure 2.4. Full tree logging system with (1) knuckle-boom feller buncher, (2) grapple skidder, (3) stroke delimber and (4) portable slasher.

Table 2.1. Characteristics of logging methods applicable to Minnesota.

CHARACTERISTIC	Cut-to-length	Tree-length	Full tree
Felling equipment	Chain saw	Chain saw	Chain saw
	One-grip harvester	Feller buncher	Feller buncher
	Two-grip harvester	One-grip harvester	
		Two-grip harvester	
Off-road transport equipment	Forwarder	Cable skidder	
	Cable skidder (limited use)	Grapple skidder	
		Clam-bunk skidder	
		Cable yarder	
Delimbing and topping location	Stump area	Stump area	Roadside
		Cut-over (concentrated within cutover)	Not delimbed
Bucking location	Stump area	Roadside	Roadside
		Centralized yard	Centralized yard
		Mill	Mill
		Not bucked	Not bucked
Slash distribution	Evenly spread	Evenly spread	Roadside piles
	Windrows	Small piles	No slash left
Roadside landing requirements & impact	Small	Large	Largest
Maximum effective off-road transport distance	2000 ft	Cable & grapple skidders - 1000 ft	
		Clam-bunk skidder - 2000 ft	
Access road requirement	27 ft/acre	Cable & grapple skidders - 40 ft/acre	
		Clam-bunk skidder - 27 ft/acre	
Area with vehicular traffic	Low	Cable & grapple skidders - heavy	
		Clam-bunk skidder - moderate	
Ground disturbance - dry	Low	Moderate	Heavy
Ground disturbance - frozen	Minimal	Low	Low
Ground disturbance - wet	Moderate	Heavy	Heavy
Protection of residual trees & regeneration	Good	Moderate	Poor

Table 2.2. Applicability of harvesting methods to silvicultural systems and operations.

Operation	Cut-to-length	Tree-length	Full tree
Even-age			
clearcutting	Good	Good	Good
clearcutting with standing snags and live trees	Good	Good	Good
patch cutting	Good	Good	Good
alternate strip cutting	Good	Good	Good
progressive strip cutting	Good	Good	Good
shelterwood cutting	Good	Moderate	Poor
seed tree cutting	Good	Good	Moderate
Uneven-age			
individual tree selective cutting	Good	Poor	Poor
group selective cutting	Good	Moderate	Poor
Other			
selective thinning	Good	Poor	Poor
row thinning	Good	Moderate	Poor
overstory removal (shelterwood and seed tree)	Good	Moderate	Poor

Forest access roads are formed roads intended for use by highway trucks. They are distinct from temporary skid trails used by off-road equipment. Forest access road densities required by the various logging systems vary from 27 to 40 feet per acre (i.e., the length of road required on average to access an area for logging). At a road density of 40 feet per acre, the maximum off-road transport distance will be 1,000 feet assuming the roads are evenly distributed throughout the area. Logging systems using grapple and cable skidders generally require a higher density of roading because these systems become more expensive to operate as road densities fall. In contrast, forwarders and large clam-bunk skidders can effectively operate to off-road transport distances in excess of 2,000 feet, which equates to a road density of 27 feet per acre.

In the Lake States, a general rule of thumb often used is to build an access road for every 40 acres. This is equivalent to 33 feet per acre (i.e., the midpoint of the road densities given above).

3
MINNESOTA LOGGING AND TRANSPORT METHODS AND SYSTEMS

Information on logging methods and systems used in Minnesota was obtained from field trips to harvesting operations, discussions with people engaged in timber harvesting and forest management, and a questionnaire distributed to logging contractors operating in Minnesota (appendix III). The logging survey was distributed to logging contractors through the TPA and directly by mail to non-TPA members. No questionnaires were distributed to the major forest industry companies since they contract out most of their logging work. Small sawmills with logging operations were included in the survey. However, many indicated they no longer had logging operations.

A total of 70 contractors with 457 employees responded to the logging survey. There was a wide distribution in the size of the contractors responding, however, most contractors (90 percent) had 10 or less employees (figure 3.1). Table 3.1 presents a summary of the logging questionnaire results for the aspen-birch, northern pine and central hardwood Forest Inventory and Analysis (FIA) survey units, as well as for all survey units combined. Table 3.2 presents a summary of the logging survey data for only the southeastern part of the state.

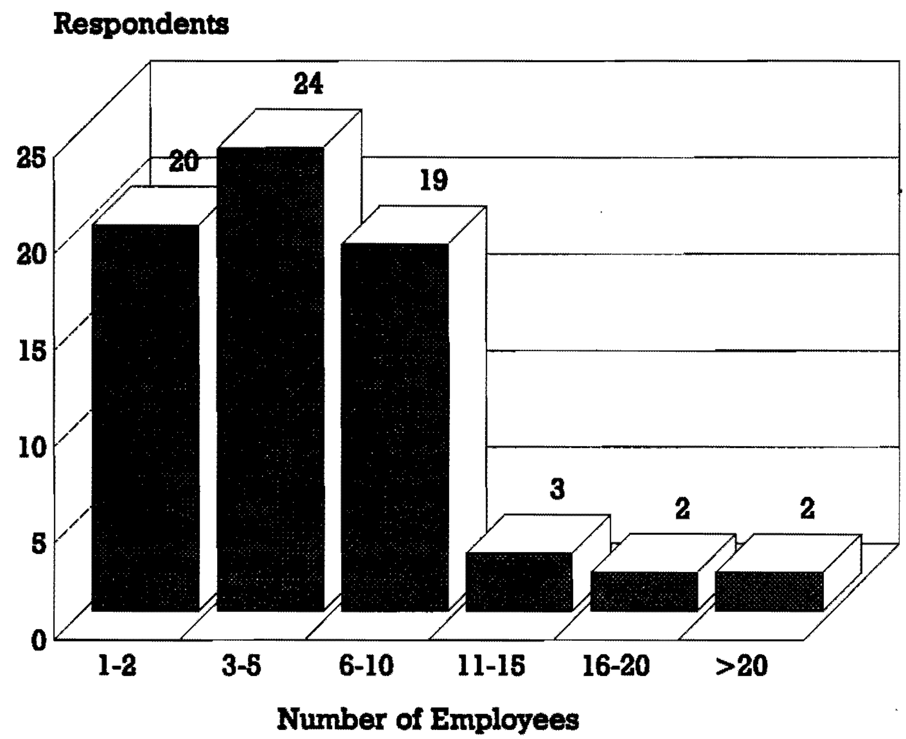


Figure 3.1. Logging contractor size based on number of employees.

The data presented reflects the situation over the period 1990–91. The total annual harvest volume reported by the survey respondents (636,439 cords) is approximately 19 percent of the estimated annual Minnesota industrial wood harvest in the period 1990-91 (3.3 million cords excluding firewood, Jaakko Pöyry Consulting, Inc. (1992)). Of the volume reported, 30 percent was softwood pulpwood, 6 percent softwood logs, 57 percent hardwood pulpwood, and 7 percent hardwood logs.

Table 3.1. Logging questionnaire results for northern and central Minnesota (1990-91 period). All percentages are of total volume harvested.

Forest Inventory and Analysis (FIA)	Aspen-Birch	Northern Pine	Central Hardwood	Total
NUMBER OF EMPLOYEES (including self)	214	210	33	457
STUMPAGE SOURCE, %				
a) log own stumpage purchases	48	45	71	47
b) log company purchased/owned stumpage	52	55	29	53
TOTAL VOLUME HARVESTED, cords				
Yearly softwood pulpwood volume harvested	82,130	105,441	500	188,071
Yearly softwood log volume harvested	6,720	29,273	575	36,568
Yearly hardwood pulpwood volume harvested	194,763	169,236	2,000	365,999
Yearly hardwood log volume harvested	2,950	32,026	10,825	45,801
TOTAL	286,563	335,976	13,900	636,439
SILVICULTURAL SYSTEMS USED, %				
a) clearcutting (area greater than 5 acres)	45	35	14	39
b) clearcut with standing snags and live trees	48	35	44	41
c) patch cutting (clearcut area 0.25-4.9 acres)	4	5	0	5
d) strip cutting	0	6	0	3
e) seed tree cutting	0	1	0	1
f) shelterwood cutting	0	2	0	1
g) selective cutting	1	7	36	5
h) thinning	1	7	6	4
SEASON OF HARVEST, %				
a) winter (December-February)	47	40	42	43
b) spring (March-May)	9	10	11	9
c) summer (June-August)	20	24	23	23
d) fall (September-November)	24	26	25	25
FELLING METHOD, %				
a) chain saw	19	30	100	27
b) feller buncher	81	69	0	73
c) harvester	0	1	0	0
OFF-ROAD TRANSPORT, %				
a) cable skidder	22	35	68	30
b) grapple skidder	77	64	29	69
c) forwarder	1	1	3	1

(continued on next page)

Table 3.1 (continued)

Forest Inventory and Analysis (FIA)	Aspen-Birch	Northern Pine	Central Hardwood	Total
OFF-ROAD TRANSPORT, %				
a) cable skidder	22	34	68	30
b) grapple skidder	77	64	29	69
c) forwarder	0	1	3	1
DELIMBING, %				
a) chain saw	57	73	97	66
b) mechanical	43	26	3	33
c) not delimbed	0	1	0	1
BUCKING/SLASHING, %				
a) chain saw	5	20	71	14
b) mechanical	81	61	27	69
c) not bucked	14	19	1	17
DELIMBING & TOPPING LOCATION, %				
a) cut-over	65	69	97	68
b) roadside landing	35	30	3	32
c) not delimbed	0	1	0	1
BUCKING LOCATION, %				
a) cut-over	4	8	40	7
b) roadside landing	82	72	58	76
c) not bucked	14	19	1	17
OTHER PROCESSING, %				
a) full tree chipping	0	1	0	1
b) chain flail - delimber-debarker-chipper	0	0	0	0
AVERAGE LOGGING SITE AREA, acres	40	28	25	33

Table 3.2. Minnesota GEIS logging questionnaire for southeastern Minnesota (1990-91 period). All percentages are of total volume harvested.

Item	Total
NUMBER OF EMPLOYEES (including self)	29
STUMPAGE SOURCE, %	
a) log own stumpage purchases	100
b) log company purchased/owned stumpage	0
TOTAL VOLUME HARVESTED, cords	
Yearly softwood pulpwood volume harvested	0
Yearly softwood log volume harvested	0
Yearly hardwood pulpwood volume harvested	0
Yearly hardwood log volume harvested	9,000
TOTAL	9,200
SILVICULTURAL SYSTEMS USED, %	
a) clearcutting (area greater than 5 acres)	0
b) clearcut with standing snags and live trees	45
c) patch cutting (clearcut area 0.25-4.9 acres)	0
d) strip cutting	0
e) seed tree cutting	0
f) shelterwood cutting	0
g) selective cutting	46
h) thinning	9
SEASON OF HARVEST, %	
a) winter (December-February)	40
b) spring (March-May)	14
c) summer (June-August)	21
d) fall (September-November)	24
FELLING METHOD, %	
a) chain saw	100
b) feller buncher	0
c) harvester	0
OFF-ROAD TRANSPORT, %	
a) cable skidder	96
b) grapple skidder	0
c) forwarder	4

(continued on next page)

Table 3.2 (continued)

Item	Total
DELIMBING, %	
a) chain saw	100
b) mechanical	0
c) not delimbed	0
BUCKING/SLASHING, %	
a) chain saw	100
b) mechanical	0
c) not bucked	0
DELIMBING & TOPPING LOCATION, %	
a) cut-over	100
b) roadside landing	0
c) not delimbed	0
BUCKING LOCATION, %	
a) cut-over	61
b) roadside landing	39
c) not bucked	0
OTHER PROCESSING, %	
a) full tree chipping	0
b) chain flail - delimber-debarker-chipper	0
AVERAGE LOGGING SITE AREA, acres	23

Of those loggers responding to the survey, slightly over half the volume harvested (53 percent) was forest company purchased or owned stumpage. However, in the central hardwood unit logging of stumpage purchased by the contractor (own stumpage purchases) was more prevalent (71 percent). When only the southeast is examined, 100 percent of the contractors logged their own stumpage purchases.

The most common silvicultural systems employed were clearcutting and clearcutting with residuals; accounting for over 80 percent of the total volume harvested (figure 3.2). However, in the central hardwood unit the percentage of total volume harvested from selective cutting was greater (35.5 percent), while the percentage of volume from clearcutting was much less. This was much more pronounced for southeastern Minnesota (table 3.2), where the logging practices differ considerably from the rest of the state. However, a major question in regard to selective logging is whether the selection is based on the removal of only merchantable trees and species (i.e., high-grading), rather than selection for improvement and perpetuation of the stand.

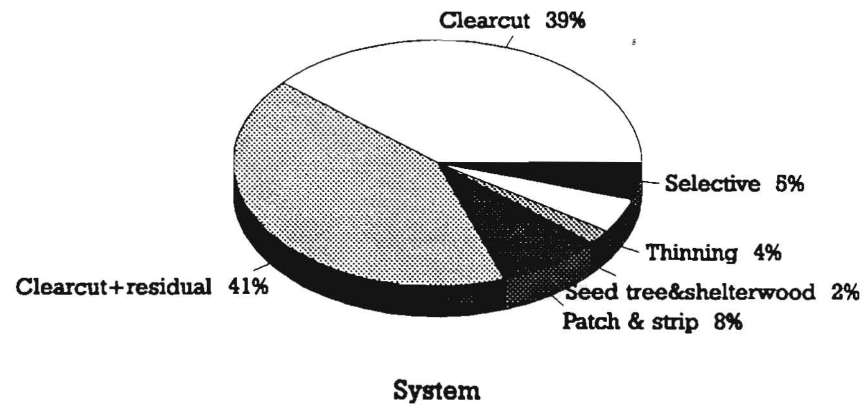


Figure 3.2. Percentages of volume harvested by silvicultural systems and thinning.

Most logging occurred during the winter (December-February, 43 percent), while the least occurred during the spring (March-May, 9 percent). Logging during the summer (June–August) accounted for 22.5 percent of the volume harvested, while 25.3 percent of the volume was harvested during the fall (September–November) (figure 3.3). This distribution is more or less the same throughout all units (table 3.1).

In the aspen-birch (81 percent) and northern pine (69 percent) units the majority of the felling was by feller-buncher. In the central hardwood unit all of the felling reported in the survey was by chain saw. For the state on average, 73 percent of the felling was by feller buncher, 27 percent by chain saw, and less that 0.5 percent by harvester (figure 3.4).

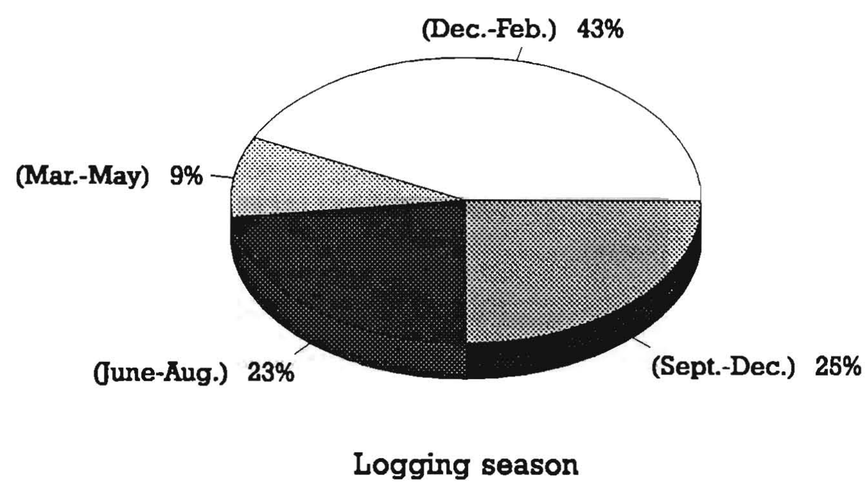


Figure 3.3. Percentages of volume logged by season.

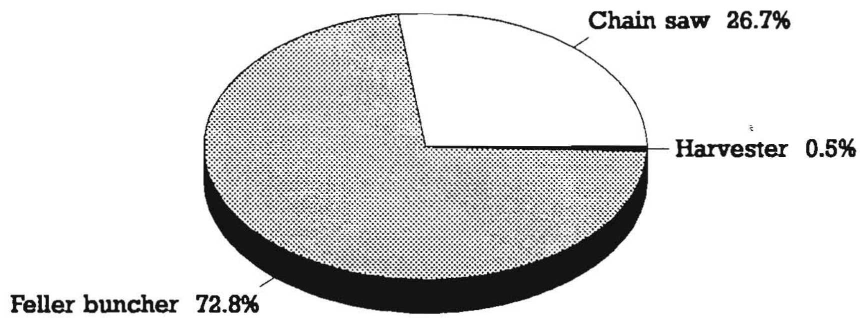


Figure 3.4. Percentages of volume logged by felling method.

Off-road transport of wood was mainly by grapple skidder (69 percent of the volume harvested). Off-road transport by cable skidders accounted for 30 percent and forwarders slightly less than 1 percent of the volume harvested (figure 3.5). Grapple skidders were most widely used in the aspen-birch (77 percent) and northern pine (64 percent) units. Cable skidders were most used in the central hardwood unit (68 percent). Forwarders were also used to a small extent in the central hardwood unit (2 percent). The use of no other off-road transport equipment or methods was indicated in the questionnaire.

The majority of the delimbing was by chain saw (66 percent), while 33 percent was mechanically delimbed. In addition, 68 percent of the delimbing and topping was in the cutover, while less than 32 percent was at roadside (figure 3.6). Less than 1 percent of the volume was full tree chipped. In general, chain saws are used to delimb hardwoods in the cutover, while mechanical delimbing is used more in softwoods and occurs mainly at roadside. There was also a minor amount of mechanical delimbing in the cutover.

As with felling and delimbing, the greatest mechanization in bucking is in the aspen-birch unit (81 percent), followed by the northern pine (61 percent) and central hardwood (27 percent) units. The majority of the bucking occurred at roadside (76 percent) (figure 3.7). Only 7 percent of the wood was bucked in the cutover. Almost 17 percent of the wood was not bucked and was transported to the mills as tree lengths. As mentioned earlier, less than 1 percent of the volume harvested was full tree chipped. The majority of the full tree chipping was of hardwood residuals destined for hog fuel.

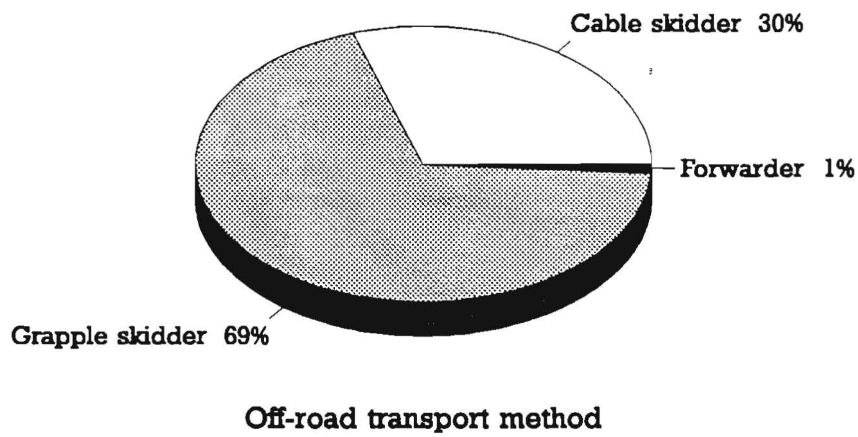


Figure 3.5. Percentages of volume logged by off-road transport method.

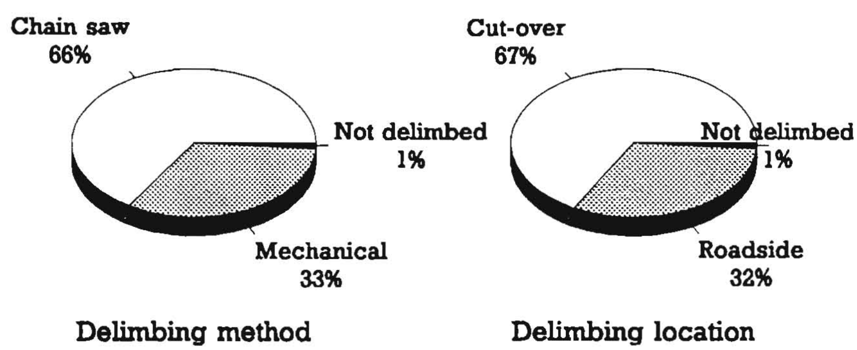


Figure 3.6. Percentages of volume logged by delimbing method and location.

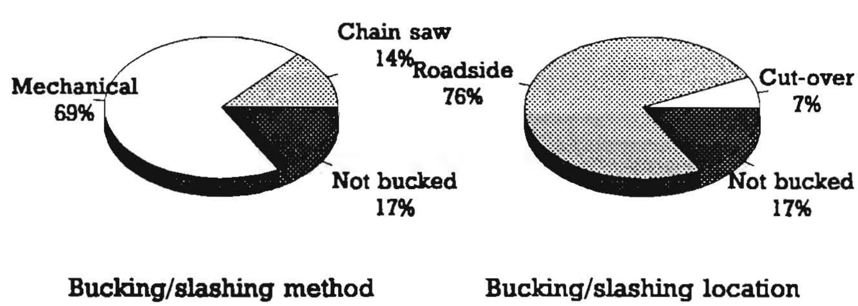


Figure 3.7. Distributions of volume logged by bucking methods and location.

The statewide logging mean size was 32 acres. However, as indicated by figure 3.8, the average (weighted by volume cut) varied considerably by geographic region. For example, the average logging area size in the aspen-birch unit was 40 acres, while in the northern pine and central hardwood units it was 28 and 25 acres, respectively. The average for the southeast (not included in figure 3.8) was 23 acres.

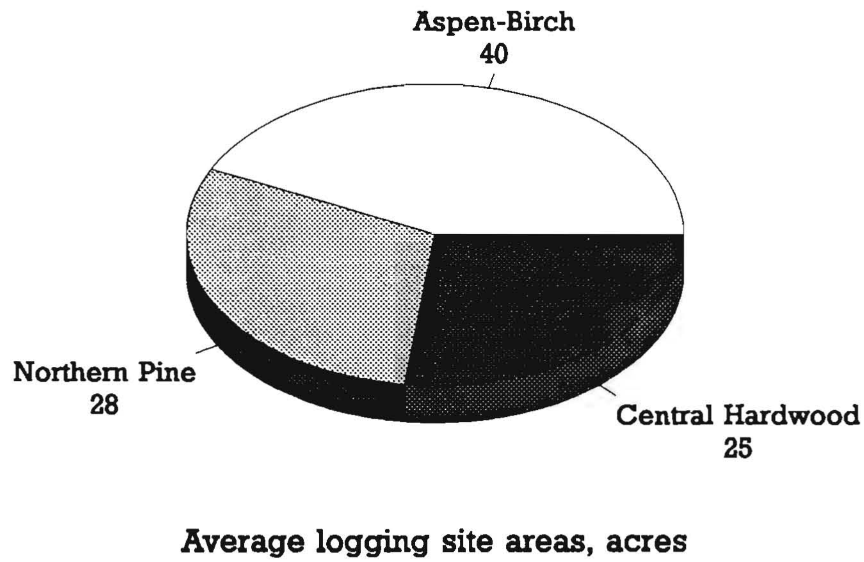


Figure 3.8. Logging area sizes for the northern and central FIA units (weighted by volume logged).

Transport of wood from roadside to the mills is by truck. Approximately 82 percent of the volume was transported in pulpwood or log lengths, while 17 percent was as tree lengths. Less than 1 percent of the volume transported was in chip form. Almost all wood was transported by tractor-semitrailer units, with an average load capacity of about 10 to 11 cords (80,000 lb GVW in summer and 88,000 lb GVW in winter). Tandem axle trucks with pup trailers are also used to some extent.

To indicate recent developments in logging mechanization and productivity, table 3.3 compares the results of the GEIS logging survey to a similar profile of Minnesota loggers conducted by Bolstad and Sinclair in 1980. As can be seen, there has been a major shift in the substitution from manual felling and processing to mechanized equipment. Two of the main reasons for mechanization have been: (1) to increase productivity, and (2) to control further increases in the excessively high workers' compensation cost which was 47 percent in 1991.

Table 3.3. Minnesota logging surveys comparison.

Item	1991 survey	1980 survey*
FELLING METHOD, %		
a) chain saw	27	66
b) feller buncher	73	34
c) harvester	0	0
OFF-ROAD TRANSPORT, %		
a) cable skidder	30	71
b) grapple skidder	69	20
c) forwarder	1	9
DELIMBING, %		
a) chain saw	66	91
b) mechanical	33	8
c) not delimbed	1	1
BUCKING/SLASHING, %		
a) chain saw	14	61
b) mechanical	69	27
c) not bucked	17	12
DELIMBING & TOPPING LOCATION, %		
a) cut-over	68	79
b) roadside landing	32	20
c) not delimbed	1	1
BUCKING LOCATION, %		
a) cut-over	7	9
b) roadside landing	76	80
c) not bucked	17	12
OTHER PROCESSING, %		
a) full tree chipping	1	1
Aver. production, cd/man/year	1,393	1,202

* 1980 survey - Bolstad and Sinclair (1980)

4 LOGGING EQUIPMENT USED IN MINNESOTA

The logging questionnaire also included a section on logging equipment used and the age of the equipment. Table 4.1 presents data on the average age of the main types of logging equipment, while figure 4.1 depicts the age distribution for each of the major types of logging machinery.

Table 4.1. Average ages of feller bunchers, skidders/forwarders, delimbers, slashers and full tree chippers reported in the logging questionnaire.

Machine type	Number with age reported	Average age, years	Standard deviation, +/-
Feller bunchers	57	8	6
Skidders/forwarders	149	10	6
Delimbers	37	7	6
Slashers	43	7	6
Full tree chippers	2	10	3

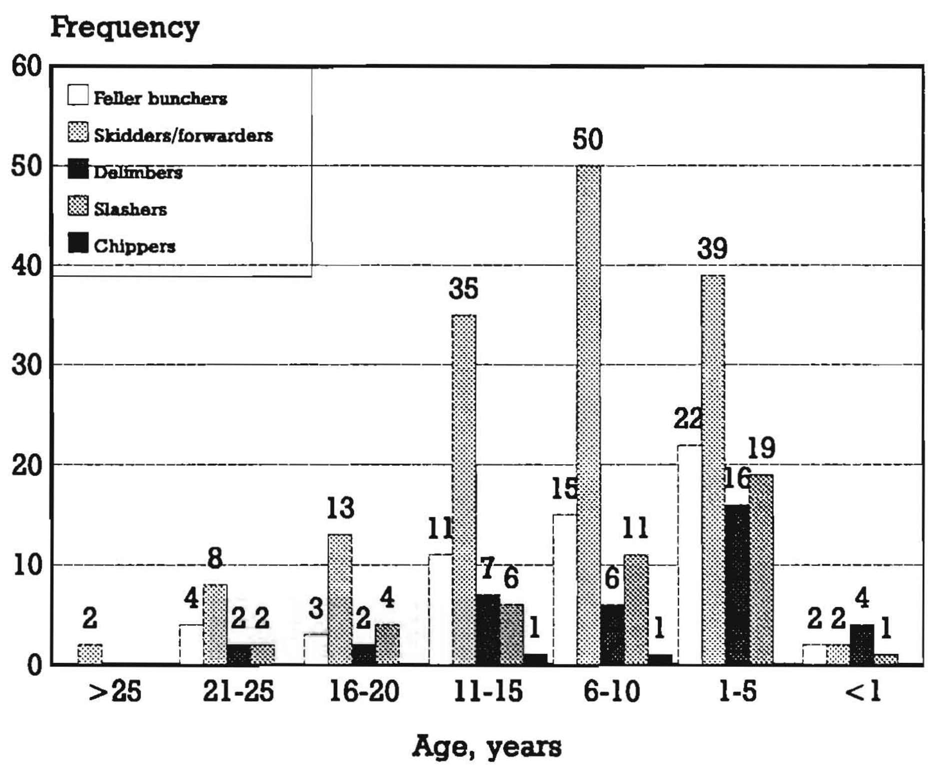


Figure 4.1. Logging equipment age distribution.

The average age of logging equipment in Minnesota is high. The majority (64 percent) of the machines are more than six years old. In most situations excessive maintenance requirements and breakdown costs on equipment older than 5 years (i.e., greater than 10,000 to 15,000 operating hours depending on the equipment) makes their use as the main equipment in a harvesting system uneconomical. Older machines also have more oil leaks and hydraulic hose failures than newer equipment, and thus represent a greater potential risk of environmental impact through soil and groundwater contamination. In addition, newer machines are designed better ergonomically and are quieter which improves operator amenity and also reduces offsite impacts due to noise. No information was obtained as to operating hours on the equipment. The high average age may thus also be a function of underutilization of the equipment.

Table 4.2 presents data on models of feller bunchers used, felling head mounting (fixed felling-head [drive to] or boom), machine weights, and published ground pressures (unloaded) for some of the equipment. Feller bunchers which have fixed felling-heads and which must drive to each tree

Table 4.2. Feller bunchers used in Minnesota as indicated in logging questionnaire.

MODEL	Machine weight, pounds			Standard tire	Ground psi	Type
	Total	Front	Rear			
FELLER-BUNCHERS (total number = 62)						
Barko 775	27,000			23.1-26		drive to
Bobcat				track		drive to
Bobcat 1075				track		drive to
Bobcat 1080 (track)	17,475			track		drive to
Case 880						drive to
Case 1187 (24" track)	51,050			track	8.13	boom
Can-Car Clipper				23.1-26		boom
Drott 40 (30" track)	49,280			track	6.36	boom
Franklin 170PSL						drive to
JD350 (crawler)	10,600			track		drive to
JD450 (crawler)	15,930			track		drive to
JD490				track		drive to
JD544 (rubber tire)	28,500			28.1-32		drive to
JD643	36,900			30.5-32	9	boom
Hydro Ax	25,680	24,680	11,000	23.1-26		drive to
Hydro Ax 311	19,200			18.4-26		drive to
Hydro Ax 411	22,800			23.1-26		drive to
Hydro Ax 511	30,550			28L-26		drive to
Hydro Ax 611	31,200			28L-26		drive to
International 515						drive to
Morbell/Morbark Wolverine	13,600	9,010	4,590	18.4-26		drive to
Terex front-end loader						drive to
Timbco 420 (23.6" pad)	43,500			track	7.7	boom

Total number of feller bunchers which must *drive to* each tree felled = 40.
Total number of boom equipped feller bunchers = 22.

to fell (number in survey = 40) will impact a larger percentage of the area than feller bunchers equipped with booms (number in survey = 22) which can reach off to the side and fell a number of trees from one position. Table 4.3 presents similar data for skidders and forwarders used. Table 4.4 lists the models of delimbers, slashers and full tree chippers used as indicated in the questionnaires. The data presented in tables 4.2, 4.3 and 4.4 only present the equipment indicated in the questionnaire responses and should not be interpreted to be all inclusive in regard to the models of logging equipment used in Minnesota.

Table 4.3. Skidders used in Minnesota as indicated in logging questionnaire.

SKIDDERS/FORWARDERS (total=161)	Machine weight, pounds			Standard tire	Ground psi
	Total	Front	Rear		
Caterpillar 508	18,730			23.1-26	
Caterpillar 518 (grapple)	27,525			23.1-26	
Clark 664(wt for cable)	15,890	9,950	7,250	18.4-34	8.4/6.2
Clark 665 (wt for grapple)	20,140	10,020	10,120	23.1-26	
Clark 666 (wt for cable)	18,450	10,620	7,830	23.1-26	7/5.2
Clark 667 (wt for grapple)	25,300	14,100	11,200	24.5-32	8.1/6.4
Franklin 100					
Franklin (170 cable)	19,930	12,955	6,976	24.5-32	
Interna. Harv. S8 (forwarder)					
Interna. Harv. skidder	14,000	8,400	5,600		
John Deere JD440 (cable)	14,300	8,300	6,000	18.4-26	7.5/5.4
JD540 (cable)	16,150	10,982	5,168	18.4-34	
JD548 (grapple)	18,040			23.1-26	
JD640 (cable)	20,180	13,521	6,659	24.5-32	
JD648 (grapple)	26,250	14,700	11,550	24.5-32	
Pettibone (master 12)					
Timberjack TJ208	12,300	7,995	4,305	16.9-30	
TJ215				16.9-30	
TJ215 (forwarder)	17,984	11,689	6,295	23.1-26	6.2/4.5
TJ225E	14,850	9,504	5,346	18.4-26	
TJ230	15,500	9,920	5,580	23.1-26	
TJ230 (forwarder)	19,532	11,966	7,566	24.5-32	
TJ240	17,160	10,639	6,521	23.1-26	
TJ350	19,995	12,015	7,980	23.1-26	
TJ380 (grapple)	24,500	12,260	12,240	28L-26	
TJ450 (grapple)	25,040	12,150	12,890	28L-26	
Tree Farmer TF C4	11,900	8,330	3,570	16.9-30	8.3/3.5
TF C5	13,440	8,870	4,570	18.4-26	8/4.2
TF C6	16,600	10,910	5,690	23.1-26	
CDT					

Table 4.4. Models of delimbers, slashers and chippers used in Minnesota as indicated in the logging questionnaire.

DELIMBERS (total = 41)
Can-Car Processor
Case
CTR
Denis combination
Hood
Hydro Ax chain flail
Hahn harvester
John Deere (693 & 743)
Siiro
North Shore Grapple
Other (homemade)
SLASHERS (total = 46)
Barko
CTR
Hawk
Hood
Husky
Lemco
Siiro
Other (homemade)
FULL TREE CHIPPERS (total = 2)
Morbark 20
Trelan D60

Ground pressures were not available for all machines and would vary considerably depending on the tire size or track width, and load size. However, most ground pressures indicated in the table are from 5 to 9 psi. Loaded ground pressures for skidders and forwarders would be slightly higher than the front axle ground pressure and would be approximately 9 to 10 psi. Most of the newer skidder models are equipped with wider flotation tires with cross-sectional widths of 23.1 to 24.5 inches.

5
LOGGING AND TRANSPORT COSTS (summer 1991)

From discussions with contractors and other forestry professionals involved in wood procurement, the following average harvesting costs were obtained (logging in clearfelling conditions):

- pulpwood logging cost to roadside (easy conditions) . = $10.00/cord
- pulpwood logging cost to roadside (difficult conditions) = $15.00/cord
- winter road . . . . = $1,000/mile
- absolute minimum access road (no gravel) . . . . = $3,000/mile
- company gravelled access road . . . . = $5,000/mile
- county/state gravelled access road . . . . = $8–10,000/mile
- main forest haul road . . . . = $25–34,000/mile

The average hauling cost for wood, as reported by forest industry personnel in the period 1990–91, was approximately $0.15/cd/mile hauled, with a fixed cost of $4.75 per cord. These costs include empty travel to the logging site. The hauling cost expressed as an equation is as follows:

- hauling cost ($/cord) = 4.75 + 0.15 * (miles hauled)

In the summer of 1991, the general cost for procuring aspen pulpwood was estimated to be as follows (does not include forest industry overheads):

- stumpage = $7.00/cord
- access roads and landings = $2-3.00/cord
- logging = $12–15.00/cord
- loading = $1-2.00/cord
- hauling (about 60 miles) = $13.00/cord
- contractor profit = $2-3.00/cord
- total cost = $37–43.00/cord

A large amount of research has been done on the effect logging chance factors have on logging costs. In general, the major factors are tree size, off-road transport distance, merchantable volume per acre, total merchantable volume for the logging chance, and whether the operation is clearfelling or thinning (also applicable to selective logging) (figures 5.1, 5.2, 5.3 and 5.4). The relative cost indices presented are more or less the same as found in other areas, however, the added benefit is that the effect of thinning is also given. The general relative costs trends presented were combined into a relative logging cost model for use in determining logging and transport costs for the low, medium and high harvest scenarios (i.e., Minnesota base logging costs were adjusted according to the stand conditions). The model allowed the adjustment of delivered wood costs under various management scenarios where average tree size, average volume per acre, cut block size and transport distance could vary, and for cases where thinning or selective logging was done. The relative logging cost model is presented in table 5.1.

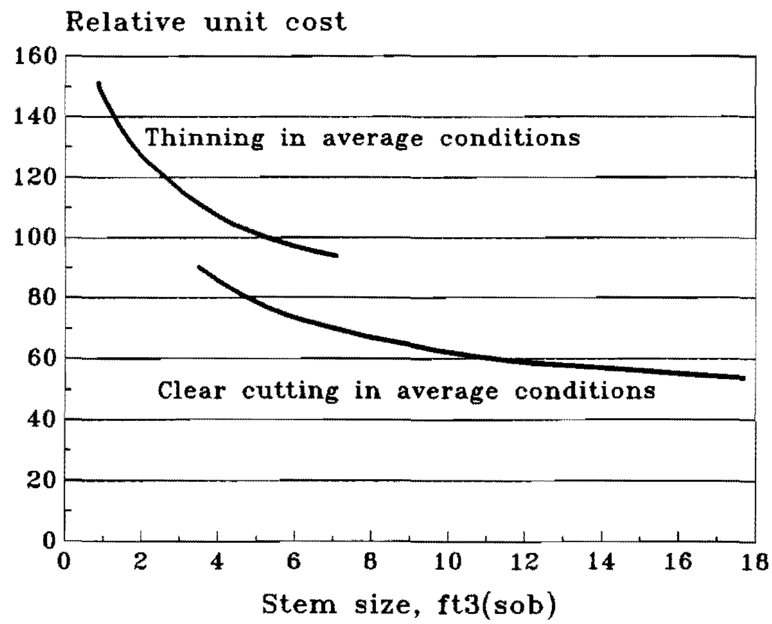


Figure 5.1. Effect of tree size on relative logging cost (includes all costs except roads) (Metsäteho 1983).

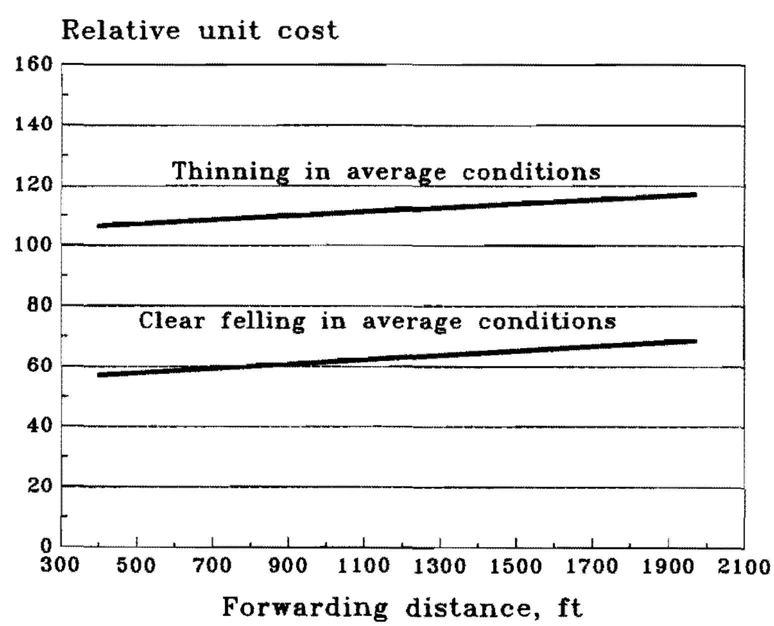


Figure 5.2. Effect of forwarding distance on relative logging cost in thinning and clearfelling (includes all costs expect roads) (Metsäteho 1983).

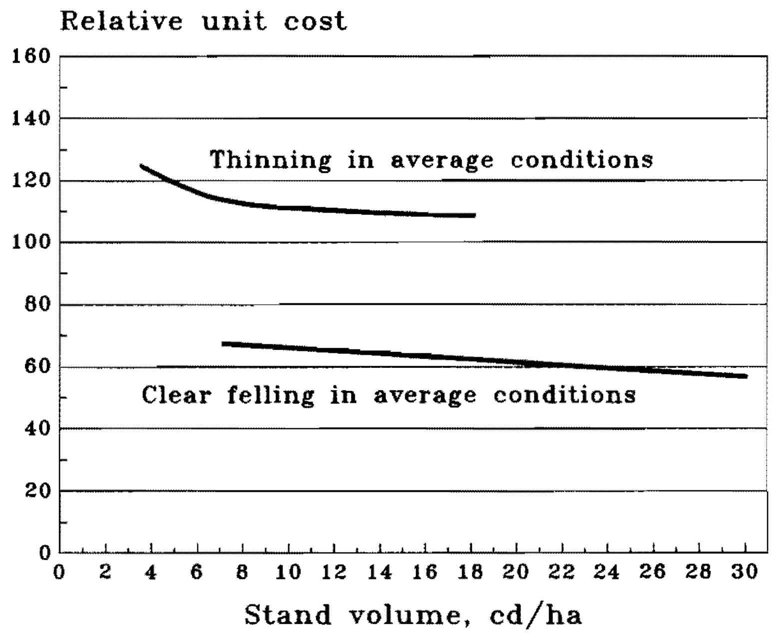


Figure 5.3. Effect of volume per acre on relative logging cost (includes all costs except roads) (Metsäteho 1983).

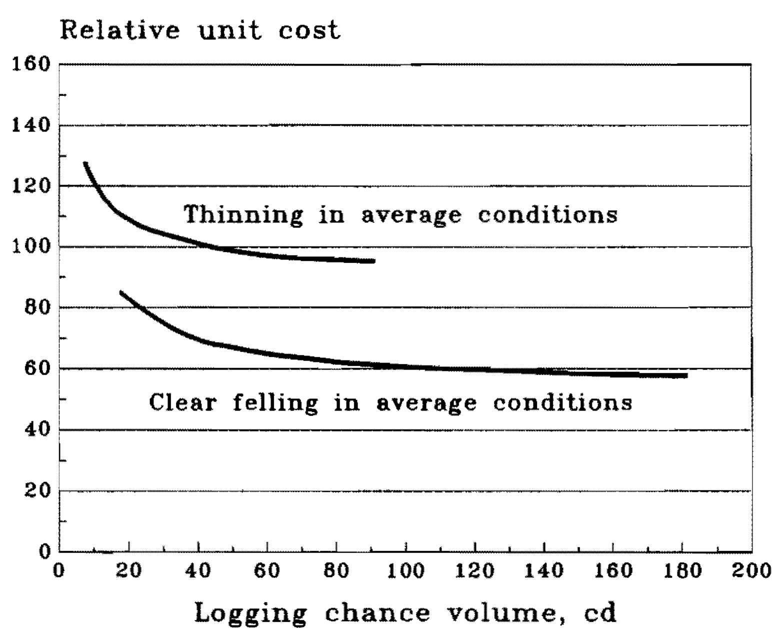


Figure 5.4. Effect of logging chance volume of relative logging cost (includes all costs except roads) (Metsäteho 1983).

Table 5.1. Harvesting cost model with some test data.

Variable	Variable Description	Test Values and Equations	Limitations
A	Thinning (0=no, 1= yes)	1	Either thinning or clearfelling, not both
B	Clearfelling (0=no, 1=yes)	0	
C	Average tree size (ft^3)	6	Range: 1-20 ft^3
D	Average off-road transport distance (feet)	400	Range: 0-2000 ft
E	Merchantable volume per acre removed (cords/acre)	10	Range: 4-40 cords/acre
F	Total logging chance volume (cords)	100	Range: 15-450 cords
G	Tree size effect	$=A \times (161.9 - 18.64 \times C + 1.525 \times C^2 - 0.0414 \times C^3) + B(123.7 - 12.42 \times C + 0.828 \times C^2 - 0.0198 \times C^3)$	
H	Off-road transport distance effect	$=A \times (104 + 0.007 \times D) + B \times (54.1 + 0.007 \times D)$	
I	Volume/acre effect	$=A \times (140.6 - 5.62 \times E + 0.3225 \times E^2 - 0.006 \times E^3) + B \times (74.1 - 0.5972 \times E)$	
J	Logging chance volume effect	$=A \times (134.6 - 0.4865 \times F + 0.0018 \times F^2 - 0.000002183 \times F^3) + B \times (98.1 - 0.375 \times F + 0.001228 \times F^2 - 0.0000013068 \times F^3)$	
K	Overall weighting factor	$= (G \times 2 + H + I + J) \div 5$	
L	Base wood cost	22	
	Factored wood cost ($/cord)	$=L \times (K \div 100)$	

The equations are only applicable for the ranges indicated in table 4.1. If a value is above the range then the upper range value should be used, while if it is less than the lower limit the lower range value should be used. Using the extreme values for tree size, off-road transport distance, volume per acre and total logging chance volume, the costs per cord for thinning would be between $16.22 and $29 and for clearfelling $11.35 and $20, assuming a base cost of $22/cord.

6 OTHER HARVESTING SYSTEM ALTERNATIVES

6.1 Cut-to-length Method

The cut-to-length method is the most widely used logging method in the Nordic countries (greater than 95 percent of volume harvested) and its use is being re-established in North America after almost disappearing in many areas during the 1980's. The method is very applicable for use in smaller logging chances (e.g., the average logging chance area in southern Finland is 5 acres) and it is an environmentally "soft" technology. The logging systems most often used in the cut-to-length method are:

- motor-manual (chain saw) felling-delimbing-bucking with forwarder
- two-grip harvester with forwarder
- one-grip harvester with forwarder

The most recent major development has been in the development of one-grip harvesters, which are small in size, can work in thinnings and clearfellings, and have minimal impact on the site since the machine can reach up to 27 feet off the side of the machine (i.e., swath width of 54 feet) (figure 6.1). The harvester can delimb and top the trees in front of it to form a brushmat on which it and the forwarder can travel and thus minimize soil compaction, rutting and puddling.

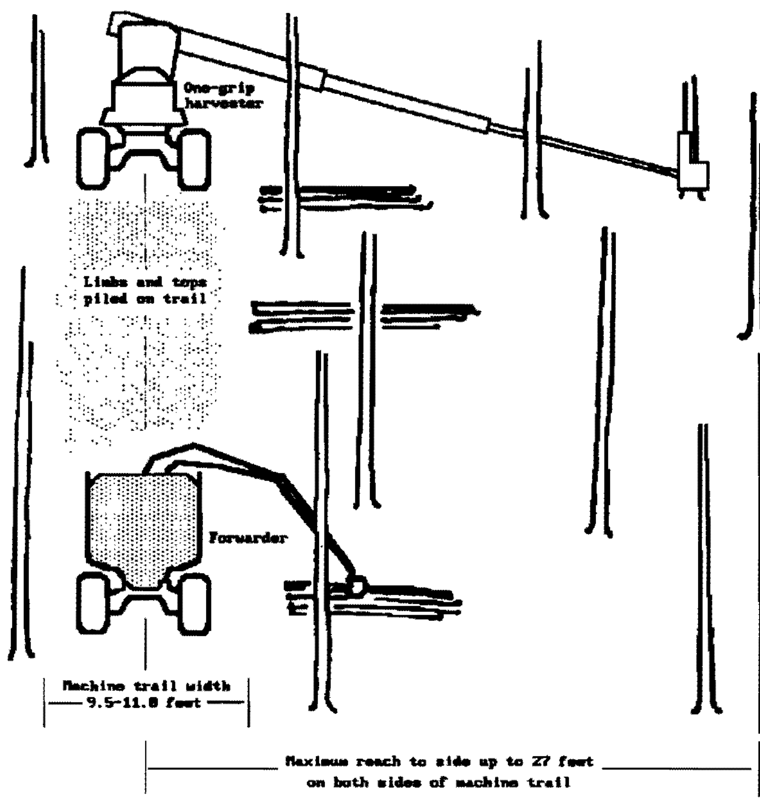


Figure 6.1. Long-reach one-grip harvester and forwarder system. (Note: processing can be done on machine trail so tops and limbs form a brush mat to minimize ground disturbance.) (Figure adapted from Metsäteho 1983.)

6.2
Multi-axle Low Ground Pressure Forwarders

To minimize the impact of forwarders on forest soils and to minimize damage to residual trees and their root systems during thinnings, small-size, multi-axle, low ground pressure forwarders have been developed (figures 6.2 and 6.3). The use of these types of forwarders, as well as good operator training, has resulted in less than 2 percent of residual trees being damaged during thinning (Sirén 1987). Loaded ground pressures for these machines can be less than 3 psi.

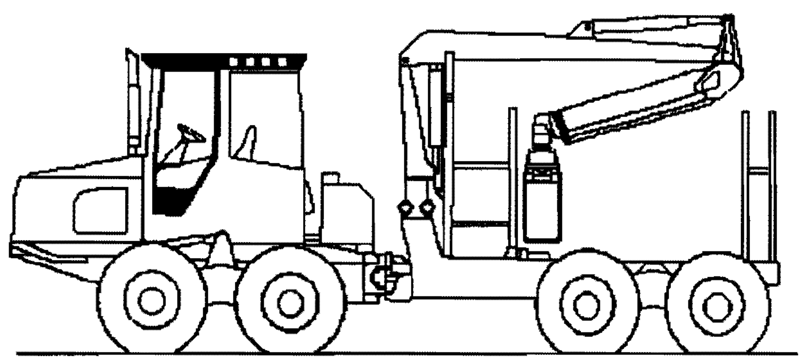


Figure 6.2. Large-size multi-axle low ground pressure forwarder.

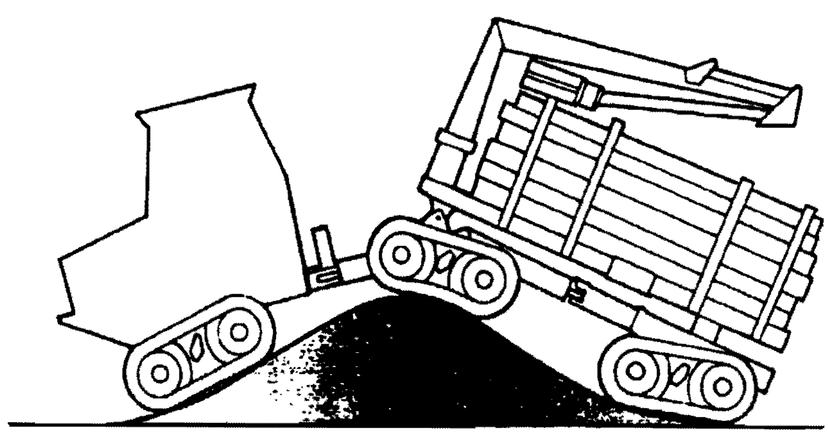


Figure 6.3. Small-size multi-axle low ground pressure forwarder.

6.3 High Flotation Tires

To minimize detrimental ground disturbance on low strength soils (bogs, and wet clays and silts) the easiest solution would be to harvest only during the winter when the ground is frozen. This is not always possible or feasible. Skidding wood from these areas with conventional logging tires (i.e., 18 to 24 inches in width) will most often result in unacceptable levels of ground disturbance, especially on the major skid trails and near the landings. To reduce the negative impact of skidding or forwarding special high flotation tires have been developed (figure 6.4). These tires range in width from 42 to 50 inches, although tires up to 68 inches in width are available. Ground pressures with the high flotation tires can range from 1.5 to 3.5 psi, depending on the tire width, and skidder or forwarder size.

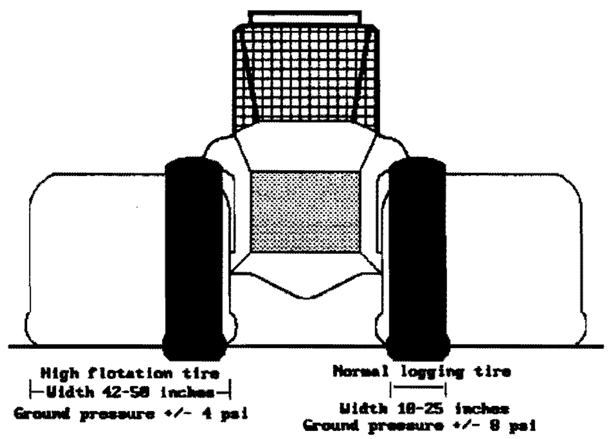


Figure 6.4. High flotation and conventional tires for a skidder.

High flotation tires have been shown to reduce site disturbance and damage to advanced regeneration. On slopes the wide tires increase stability and mobility, and the reduced site disturbance results in less erosion. However, the tires are expensive, cause increased stress on the equipment, are subject to puncture and sidewall wear, and severely limit the maneuverability and mobility of the equipment. Also, the increased width of the equipment limits their applicability to logging applications where narrow machine trails are required (e.g., thinning, selective logging, shelterwood logging).

6.4 Chain flail-delimber-debarker-chippers

A recent development in logging has been the chain flail-delimber-debarker-chippers which can process both tree lengths and full trees directly into debarked chips at roadside or forest landings. The benefit of this technology is that the bark is now left in the forest. Research is currently being done on how to most economically redistribute the limb/top/foliage/bark mulch evenly over the cutover. Once the mulch is redistributed over the cutover nutrient removal through logging would be minimized.

7 CONCLUSIONS

Harvesting is an integral part of silviculture and is the first step in the renewal or rejuvenation of a forest, while also making wood available for use by society. There are a considerable number of methods, systems and equipment available for harvesting in all silvicultural systems and conditions present in Minnesota. When choosing a harvesting system the following factors must be considered though:

- stand location;
- environmental sensitivity class;
- land use designation;
- species of trees cut;
- tree size (volume, diameter, length);
- volume per hectare/acre;
- branchiness;
- logging area size;
- average and maximum off-road transport distance;
- distance to point of utilization;
- brush/undergrowth conditions;
- ground conditions (soil type and strength);
- slope and position on slope;
- obstacles;
- snow depth;
- weather conditions (e.g. rain, wind, low temperature, high temperature);
- visual management considerations; and
- wildlife management considerations.

The above will influence logging costs, and impacts on the site and residual trees. Each logging system is best suited to specific conditions, with the full tree mechanized systems most suited to large concentrated harvesting operations, and small tree length or cut-to-length systems more suited to small widely dispersed logging operations. The choice of the logging method will also influence the amount of access roads required in the area. Harvesting mechanization has had a very positive impact on improving the working environment and safety for forest workers. Proper choice and use of the equipment will not result in increased site impacts when compared to the old manual logging systems. Many of the new machines available will in fact result in less impact on the site than the narrow-tired skidders used in the 1960s and 1970s. However, proper planning of logging operations and use of equipment, following Best Management Practices (BMPs) (Anon 1990), and good training of workers are required to minimize negative environmental impacts of harvesting operations, while still meeting economic objectives.

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APPENDIX I - GLOSSARY OF FOREST HARVESTING TERMINOLOGY

1. GENERAL

FOREST INDUSTRY
- industry which uses trees as raw material, including the marketing of its products
- (= wood industry)

WOOD
- wood biomass in any form, excluding bark

TIMBER
- a term referring to roundwood assortments and trees in general

WOOD PROCUREMENT
- technical and commercial operations involved in obtaining wood for the wood industry, including tree/stand marking, stumpage and wood purchases, and harvesting

WOOD SALE
- the sale of wood based on either the delivery or stumpage sale method, the method employed depending upon the contract

STUMPAGE SALE
- a wood sale where the seller agrees to make standing trees available for harvesting by the purchaser according to the conditions agreed upon in the contract

DELIVERY SALE
- based on a delivery contract, where the seller is responsible for wood cutting and primary transport, and in many cases for long distance transport in part or in whole, depending upon the conditions agreed upon in the contract

PAYMENT RATE
- a fixed basis agreed on by authorities, associations, unions, etc., for determining the fees payable for goods or services

PIECE RATE
- payment based on amount of work done (e.g., based on volume produced)

HOURLY RATE
- payment based on hours worked irrespective of amount produced

INCENTIVE BONUS
- additional payment in excess of hourly rate after a minimum amount of production

2. TREE AND ITS PARTS

TREE
- the entire tree biomass (i.e. roots and stump (root stock), bole, branches, bark and foliage)
- (= COMPLETE TREE)

WHOLE TREE
- the entire tree biomass, excluding the roots (i.e. stump, bole, branches, bark and foliage)

FULL TREE
- the tree biomass above the stump (i.e. bole, branches, bark and foliage)

TOPPED FULL TREE
- full tree without top (i.e. without tree top above a minimum top diameter but still containing branches on the lower section)

PART TREE
- modified full tree where the lower bole is delimbed and the upper bole cut off without delimbing

TREE-LENGTH
- full tree delimbed and topped

LONG-LENGTH
- tree-length bucked to unspecified long log lengths

LOG
- piece of tree-length which fulfils the dimension requirements set by e.g., sawmilling and veneer peeling
- typical log lengths are 8, 10, 12, 14, 16, 18, 20 feet, etc., plus trim allowance
- trim allowance is usually 4 inches for an 8 foot log and 6 inches for a 16 foot log, however, this varies depending on the log destination
- (= sawlog)

BOLT
- piece of tree-length which fulfils the dimension requirements set by pulp and paper mills and/or wood-based panel mills (excluding veneer mills), and generally smaller diameter than logs
- usually 100 inches in length (i.e., 8 feet plus 4 inches trim allowance)
- (= pulpwood)
- (= stick which generally refers to small-size bolt)

ROUNDWOOD
- wood in round form and can include bark

SPLITWOOD
- a bolt which is split lengthwise into two or more pieces

FIREWOOD
- short dimension splitwood prepared manually or mechanically and to be used as fuel

ENERGY WOOD
- any part of tree biomass in any form to be used for fuel
- (= fuelwood)

CHIPS
- a wood assortment prepared from complete trees or any part of complete trees by slicing, chopping or crushing. Chips can be classified according to the form of wood being chipped, where chipping occurs or the intended use: e.g.,
• logging residue chips
• full tree chips
• roundwood chips
• sawmill chips
• pulpmill chips (refiner or digester)
• fuelwood chips

WOOD RAW MATERIAL
- the biomass of a tree which is used as a raw material and can be in any form (e.g. whole tree, full tree, tree-length, logs, bolts, chips)

FOLIAGE
- leaves/needles of a tree

TECHNICAL FOLIAGE
- a special form of screened full tree or logging residue chips which contains a high percentage of foliage, and may also include wood, bark, buds, and small twigs. A special case of technical foliage is called "muka", which is a powder used for animal fodder

ROOT STOCK
- all the tree biomass left below the felling cut (i.e. stump and roots)

LOGGING RESIDUES
- all wood biomass separated from the desired wood assortments during harvesting and usually left in the forest, including branches, tops, stumps, and even the under-sized trees left standing or felled in clearfellings
- (= slash)

FOREST RESIDUES
- all wood biomass, in addition to wood assortments, which is left in the forest in connection with silvicultural or logging operations and includes trees felled in tending seedling stands and precommercial thinnings

KNOTTINESS
- the classification of the amount of knots in mechanically processed wood products

BRANCHINESS
- the classification of the amount of branches (limbs) on a tree

3. WOOD ASSORTMENTS

WOOD ASSORTMENT
- a part of a tree fulfilling the dimension and/or quality requirements set by wood utilization

STANDARD LENGTH LOGS/BOLTS
- logs/bolts bucked to specified lengths which are measured
- standard lengths are generally 8, 10, 12, 14, 16, 18, 20 feet, etc., plus a minimum 4 inch trim allowance

ESTIMATE LENGTH LOGS/BOLTS
- logs/bolts bucked to specified lengths by optically estimating their length

FREE LENGTH LOGS/BOLTS
- logs/bolts freely bucked to lengths within certain limits

SURFACED DELIMBED WOOD
- trees or tree parts with branches cut off flush with the bark or wood surface

ROUGHLY DELIMBED WOOD
- trees or tree parts with branch stubs existing over the entire length or over a part of it

HALF DELIMBED WOOD
- trees or tree parts with branches existing over a part of the stem, while branch stubs may exist over the remainder
- (= PARTIALLY DELIMBED WOOD)

UNBARKED WOOD
- trees or tree parts with all or nearly all bark intact

STRIP DEBARKED WOOD
- trees or tree parts with the bark removed from at least two sides over the entire length

ROUGHLY DEBARKED WOOD
- trees or tree parts with the outer bark totally removed and the inner bark partly removed

CLEANLY DEBARKED WOOD
- debarking where all the bark is removed, including the outermost annual growth ring

4. LOGGING METHODS

LOGGING
- technical operations involved in getting standing trees from the forest to the point of utilization
- (= harvesting)

DELIVERY LOGGING
- logging based on a delivery sale contract and performed by the seller

STUMPAGE LOGGING
- logging based on a stumpage sale contract and performed by the buyer

COMPLETE TREE METHOD
- logging method where the entire tree biomass, including the major roots, is extracted to roadside intact

WHOLE TREE METHOD
- logging method where the entire

tree biomass (excluding the roots) is extracted to roadside intact

FULL TREE METHOD
- logging method where the entire tree biomass above the felling cut (i.e. above the stump) is extracted to roadside intact

TOPPED FULL TREE METHOD
- logging method where full trees are topped in the stump area and extracted to roadside with the remaining branches intact

PART TREE METHOD
- a modified full tree method where the lower stem suitable for logs is delimbed and bucked, and the remainder of the stem is cut-off and no delimbing is done (i.e. delimbed logs and undelimbed top are delivered to roadside)

TREE-LENGTH METHOD
- logging method where delimbed and topped stems are extracted to at least roadside intact

LONG-LENGTH METHOD
- logging method where tree-lengths are cut into unspecified long lengths and extracted to roadside where wood assortments may be produced

CUT-TO-LENGTH METHOD
- logging method where felled trees are processed into wood assortments in the stump area and the processed wood assortments are then transported to roadside

SHORTWOOD METHOD
- similar to the cut-to-length method, except that the only wood assortment generally produced is pulpwood

5. CUTTING AREA

CUTTING AREA
- a forest area or stand delineated or marked for logging
- (= logging area, block)

MARKING
- marking of trees for felling. The marking can be referred to according to the method of marking, who is doing the marking or what is being marked: e.g.,
• colour (paint or ribbon) marking
• axe marking
• marking for thinnings
• marking by cutter
• marking of sawlogs, poles, etc.

LOGGING CHANCE
- a uniform forest area in logging and/or planning and usually includes several cutting strips
- often it refers to the cutting area description using the following factors which affect logging operations:
• stand location
• environmental sensitivity class
• land use designation
• species of trees cut
• tree size (volume, diameter, length)
• volume per hectare/acre
• branchiness
• logging area size
• average and maximum off-road transport distance
• distance to point of utilization
• brush/undergrowth conditions
• ground conditions (soil type and strength)
• slope and position on slope
• obstacles
• snow depth
• weather conditions (e.g. rain, wind, low temperature, high temperature)
- (= COUPE)

CUTTING STRIP
- an area delineated from the cutting area for a cutter, logging machine or work crew
- (= STRIP)

STRIP ROAD
- a planned primary transport route from which the trees and other obstacles hampering transport are removed and some levelling of the ground done if required

LOGGING TRAIL
- a planned primary transport route where the trees obstructing transport are removed
- (= MACHINE TRAIL)

TECHNICAL LOGGING TRAIL/STRIP ROAD WIDTH
- the actual width of the logging trail/strip road

LOGGING TRAIL/STRIP ROAD SPACING
- the average distance between the centre-lines of the logging trails/strip roads

LOGGING ROAD/STRIP ROAD DENSITY
- the length of logging trail/strip road in the cutting area calculated as an unit length per area (e.g. m/ha or feet/acre)

6. TREE CUTTING

TREE CUTTING
- felling of trees and their conversion to wood assortments in the stump area, as well as other operations relating to stump area work (e.g. marking of piles, bunching and piling in the stump area)
- (= TIMBER CUTTING)
- (= CUTTING)

FELLING
- separating trees at the stump from their growing site

DIRECTIONAL FELLING
- planned felling of trees where the felling direction makes latter stages easier, e.g., felling trees in the direction of the forwarder trail in the assortment method to decrease the distance bolts must be moved when bunching at trail-side

DELIMBING
- removing branches from trees, trees to be felled or tree parts
- (= LIMBING)

MEASURING
- determining the points at which the stem is to be bucked by considering the measured length, and quality and dimension requirements

BUCKING
- cutting trees or tree parts to predetermined lengths
- (= CROSS-CUTTING)

TOPPING
- separating the top part of a tree, which is smaller than the minimum merchantable diameter, from a tree

SLASHING
- mechanical cross-cutting of trees or tree parts at roadside or at a processing station
- generally capable of multiple-stem cross-cutting
- (= mechanical bucking)

SPLITTING
- splitting or cutting in direction of the wood fibers

DEBARKING
- removing the bark from trees or tree parts
- (= BARKING)

CHIPPING
- making of chips

FLAGGING LOGS/BOLTS
- marking of individual logs/bolts in the strip

FLAGGING PILES
- marking of piles in the strip or at roadside

BUNCHING
- collecting and arranging stems or stem parts into piles in the strip. According to where the wood is bunched in relation to the primary transport route, bunching can be further classified: e.g.,
• stump area bunching
• trail-side bunching
• zonal bunching

ALIGNING
- a bunching method where bolts prepared from directionally felled trees are moved beside logs according to the bunching instructions

SORTING
- moving or keeping similar wood assortments together

PILING
- arranging (stacking) wood assortments into piles

CROSS-PILING
- piling wood so that each layer is placed perpendicular to the preceding one

7. WOOD STORAGE

WOOD STORAGE
- storing wood raw material during the various phases of wood procurement. Ways to store are: e.g.,
• pile
• cross-pile
• bundle
• load (e.g., loaded trailer)
• heap (pell mell)
• scattered stock
• standing stock

SCATTERED STOCK
- a type of storage where the wood has not been moved after wood cutting (i.e., after preparation)

STANDING STOCK
- a cutting area awaiting logging

FOREST LANDING
- an area within a forest area where wood is piled and stored directly after primary (forest) transport

ROADSIDE LANDING
- a forest landing beside a road which can be driven on by a haul truck

INTERMEDIATE LANDING
- any landing alongside a long-distance transport route between the forest/roadside landing and millyard
- an intermediate landing can be beside a road, railway or water transport route

PILE
- a formation of stacked wood usually of even lengths, uniform direction of piling and of nearly even height, and often having vertical supports at the ends

CROSS-PILE
- a pile where each layer is piled perpendicular to the preceding one
- usually used to ease scaling or to enhance drying

BUNDLE
- a bound handling unit of trees, tree parts, logs, bolts, etc.

HEAP
- wood piled where there is no arrangement

8. WOOD TRANSPORT

TARE
- a deduction from the gross weight of a substance and its container in allowance for the weight of the container

PRIMARY TRANSPORT
- transport from the stump area to beside a long-distance transport route (generally to roadside)
- (= FOREST TRANSPORT - refers to area in which transport occurs)

- (= TERRAIN TRANSPORT - refers to transport along the ground in the cutting area)
- (= SKIDDING, FORWARDING, YARDING, etc., refers to the mode of primary transport)

SKIDDING
- transporting trees or tree parts by dragging them partly or fully in contact with the ground

FORWARDING
- transporting trees or tree parts entirely off the ground by a terrain transport vehicle

GROUND-LEAD SKIDDING
- skidding by a cable method to a bunching point with no vertical lift

YARDING
- skidding by a cable method to a bunching point in a way where the load is partly or entirely lifted off the ground by the cable (mainline)

EXTENDED PRIMARY TRANSPORT
- transport which starts in the stump area and is continued directly along a long-distance transport route by the same transport vehicle to the point of utilization or to any intermediate landing along the way: e.g., forwarding continued along a road to beside a water transport route or railway

TWO-WAY TRANSPORT
- a transport arrangement where the same vehicle is used to transport goods in both directions
- (= RETURN HAULING)

LONG-DISTANCE TRANSPORT
- transport following primary transport from the forest to the point of utilization and can be in one or more stages: e.g.,
• truck from roadside to millyard
• truck from roadside to railside and railway to millyard
• the transport of finished products to the market is also long-distance transport
• major methods are road (truck) transport, railway transport and water transport

LOADING
- lifting trees or tree parts from the ground, water or transport vehicle and moving them onto a transport vehicle

ON-VEHICLE BUNDLING
- binding trees or tree parts into bundles in the load space of a vehicle for subsequent transport (e.g. bundle floating) or handling purposes

9. EQUIPMENT AND TERMINOLOGY

FOREST MACHINE NOMENCLATURE
- depending on the work requirements a forest machine may be named according to the work phase(s) performed, the wood assortment the work is performed on, the construction of the machine and/or the place of its use. Some examples of forest machine names are:
• feller-buncher
• feller-forwarder
• delimber-bucker-buncher
• feller-delimber-bucker- buncher
• feller-chipper
• shortwood harvester
• chip forwarder
• full tree forwarder
• cable skidder
• grapple skidder
• clam-bunk skidder
• articulated-steering wheeled forwarder
• tracked harvester
• forest chipper
• mill chipper
• one-grip harvester
• two-grip harvester
• chain flail-delimber-debarker-chipper

WOOD TRANSPORT MACHINES
1 Land-borne transport machines
1.1 Tractors
• forest tractors may be divided
• according to construction
- wheeled tractors
- tracked tractors
• according to work method
- forwarder
- skidder
1.2 Other tractors (e.g. agricultural)
1.3 Trucks
1.4 Railways
1.4.1 Logging railway
1.4.2 Common-carrier railway
1.5 Cable systems
1.5.1 Ground lead
1.5.2 Yarding
1.5.2.1 High-lead
1.5.2.2 Sky-line
1.6 Other machines
2 Water-borne transport machines
3 Pipelines
4 Air-borne transport machines
4.1 Helicopter
4:2 Balloon

FELLER-BUNCHER
- a machine used to fell trees and move them into bunches or windrows

FELLING HEAD
- an apparatus attached to the end of boom for felling trees and may use one of the following methods for cutting: e.g.,
• shear(s)
• chain saw
• circular saw
• cone saw
• auger

PROCESSOR
- a self-propelled or portable machine generally used in the stump area or at roadside and performs at least two processing

functions (i.e., delimb, top or buck) and does not fell trees

PROCESSING HEAD
- a processing apparatus attached to the end of a knuckle-boom and may be moved in regard to trees or tree parts during the processing

MULTIPLE-TREE PROCESSING
- simultaneous processing of more than one tree or tree part: e.g.,
• multiple-tree delimbing (e.g. flail delimber)
• multiple-bolt debarking (e.g. drum debarker)

HARVESTER
- a self-propelled machine which fells trees and performs at least two processing functions
- one-grip and two-grip harvesters

ONE-GRIP HARVESTER
- a harvester which fells, delimbs, tops and usually bucks into assortments, with the same felling and processing unit (i.e. with one grab of the tree)

TWO-GRIP HARVESTER
- a harvester which fells the tree and transfers it to a separate processing unit on it for delimbing, topping and in most cases bucking into assortments

HARVESTER HEAD
- felling-processing apparatus attached to the end of a knuckle-boom and may be moved in regard to trees or tree parts during the processing
- is the felling-processing component of a single-grip harvester

FOREST TRACTOR
- self-propelled wheeled or tracked vehicle used in forestry primarily for carrying or dragging wood and if required, for other work purposes

FORWARDER
- a forest tractor, usually self-loading, which carries the wood entirely free of the ground

SKIDDER
- a forest tractor which carries the wood load partly on the machine and the rest is skidded along the ground

CABLE SKIDDER
- a skidder which employs a mainline and chokers to gather and fasten the load

GRAPPLE SKIDDER
- a skidder using a large suspended grapple (opening downward) for gathering (picking up) and fastening the load

CLAM-BUNK SKIDDER
- a skidder equipped with an integral loader for lifting trees or tree parts into an inverted clam which holds the load during transport

DELIMBER
- a self-propelled or portable machine used to remove branches from trees or tree parts. For further classification the principle operating method and/or machine construction may be used: e.g.,
• chain flail delimber (flail delimber)
• wrap-around knife delimber
• wrap-around chain delimber
• milling head delimber
• intermittent feed delimber
• continuous feed delimber
• pocket delimber
• drum delimber
• stroker delimber

SLASHER
- a self-propelled, portable or stationary machine used at roadside, intermediate landing or millyard to buck trees or tree parts to predetermined lengths

DEBARKER
- a machine for removing bark from trees or tree parts

CHIPPER
- a machine for chipping trees or tree parts. Further classification is according to the method used for chipping, place of chipping or chip type (dimension) produced: e.g.,
• drum chipper
• disk chipper
• cone-screw chipper
• shear chipper
• hammermill chipper (crusher)
• mill chipper
• forest chipper
• piece chipper

CHAIN FLAIL-DELIMBER-DEBARKER CHIPPER
- a machine which uses chains to delimb and debark full trees before feeding into a chipper which is mounted on it

LOADER
- a machine, including both integral loader and base machine, used to load or unload wood onto or from transport vehicles. When further classifying a loader its principle operating function and/or its construction may be used: e.g.,
• front-end loader
• knuckle-boom loader
• telescopic boom loader
• boom and cable loader
• log lift
• crane loader (crane)

YARDER
- self-propelled or portable machine consisting of a system of power-operated winches, used to skid trees or tree parts to a landing with the aid of machine mounted or separate tower to obtain cable lift

BUNDLING BARGE
- a barge of pontoon construction for transport forest machines and equipment over water and to serve

as a dumping ramp where bundles are made on the barge or directly on the forest tractor

INTEGRAL LOADER
- the actual lifting apparatus of a loader
- also often referred to as LOADER
- the parts of a knuckle-boom integral loader are:
• pillar (post)
• lifting arm
• loader jib
• extension arm
• grapple rotator
• heel boom
• grapple

GRAPPLE
- freely movable component of a boom or arch for grasping wood, usually from above

CLAM
- grasping component for loading, unloading and/or moving wood, where the wood is grasped as an entire handling unit (organized storage formation)
- grasping occurs by clamping the wood with movable jaws onto fixed arms or a bunk

HIGH FLOTATION TIRE
- special wide tires, ranging in width from 42-50 inches, with low ground pressure to minimize ground disturbance

SCHEDULED MACHINE HOURS (SMH)
- the hours a machine is scheduled to perform work

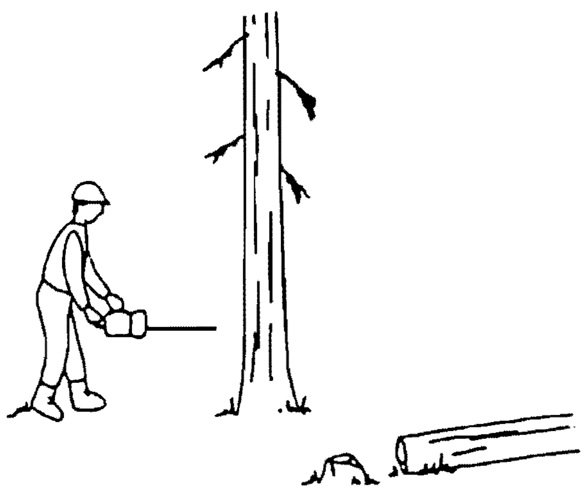
AVAILABLE MACHINE HOURS (AMH)
- the hours a machine is actually available to perform work (i.e. SMH - repair time - in shift service time)

PRODUCTIVE MACHINE HOURS (PMH)
- the hours a machine is actually performing productive work (i.e. AMH - delays - in shift moving)

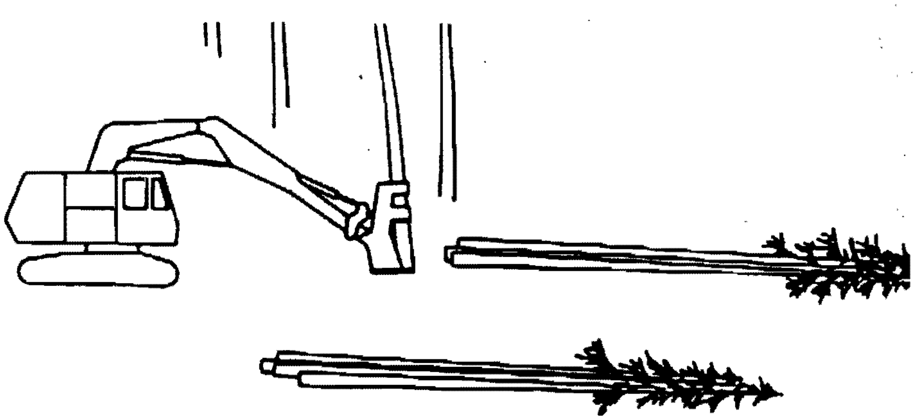
MACHINE AVAILABILITY
- the percentage of the SMH when a machine is available to perform work (i.e. AMH/SMH)

MACHINE UTILIZATION
- the percentage of the SMH when a machine is actually performing productive work (i.e. PMH/SMH)

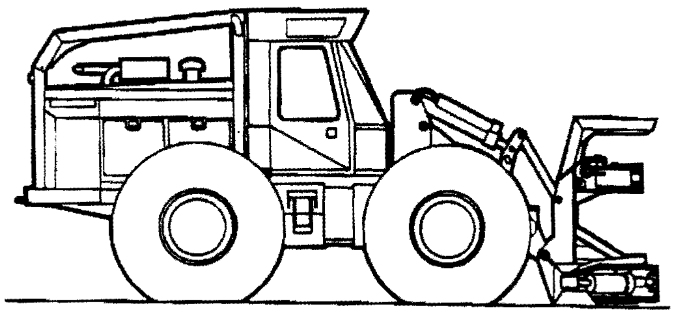
APPENDIX II - LINE DRAWINGS OF LOGGING EQUIPMENT
(Most drawings courtesy of the Forest Engineering Research Institute of Canada: Peterson (1989))



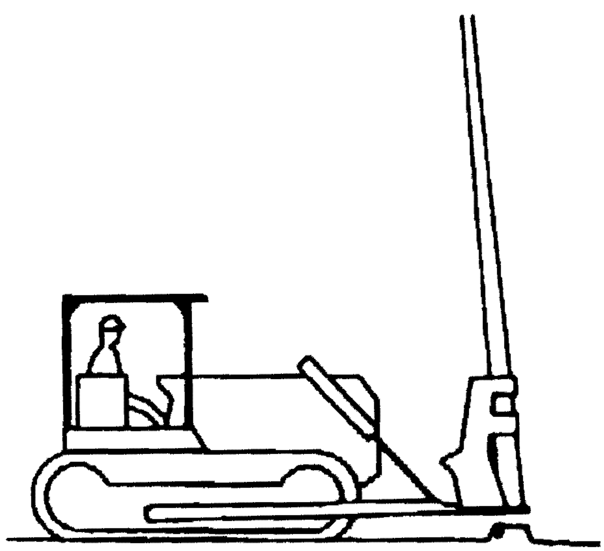
Chain saw felling



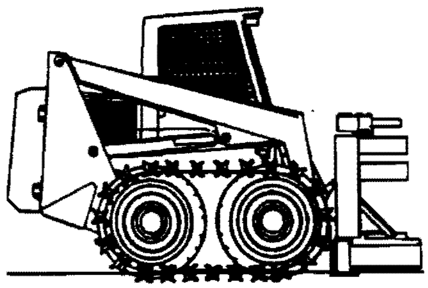
Boom equipped feller-buncher



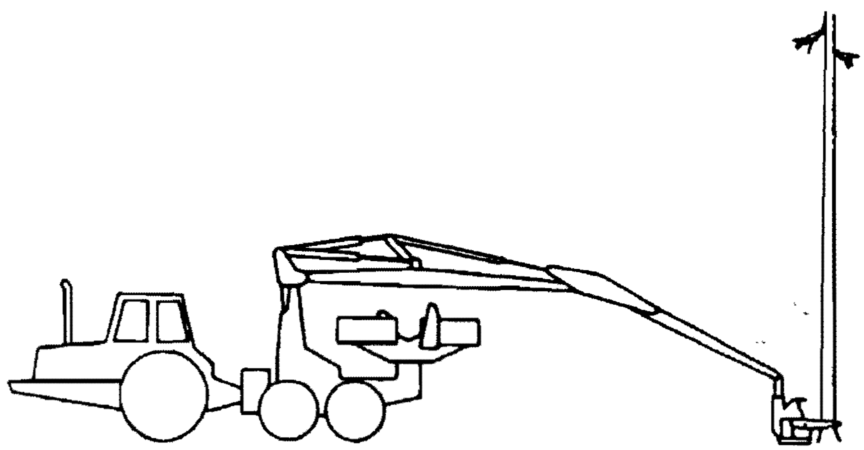
Rubber-tired feller buncher with solid mounted felling head (i.e., must drive to each tree).



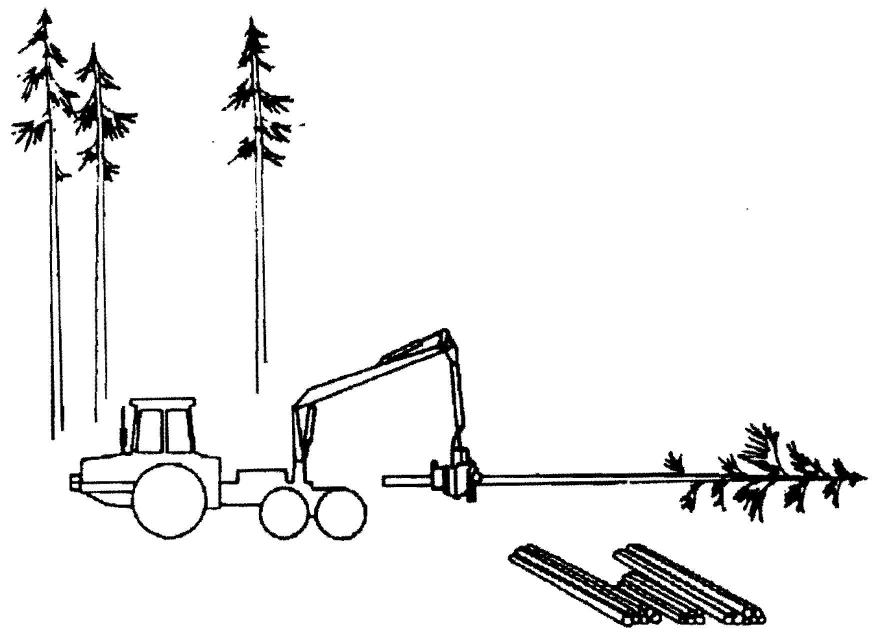
Solid-mounted felling head on crawler tractor (must drive to each tree to fell)



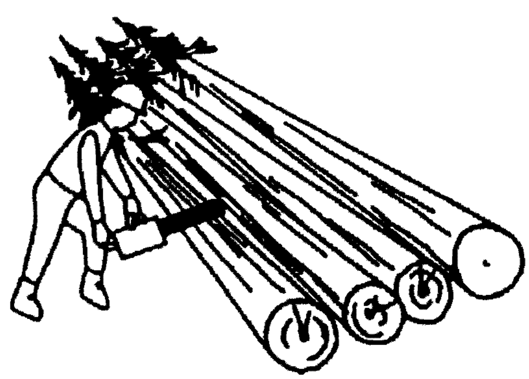
Mini feller-buncher with solid-mounted felling head (must drive to each tree to fell)



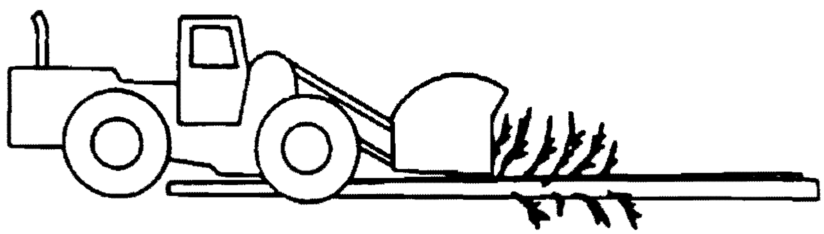
Two-grip harvester (fells with felling head, and delimbs and bucks with separate processing attachment)



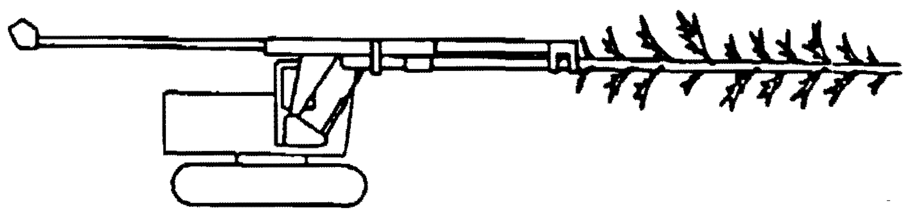
One-grip harvester (fells, delimbs and bucks with the same attachment)



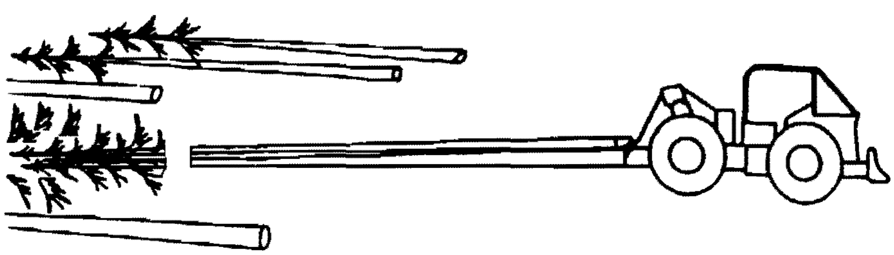
Motor-manual (chain saw) delimbing and topping



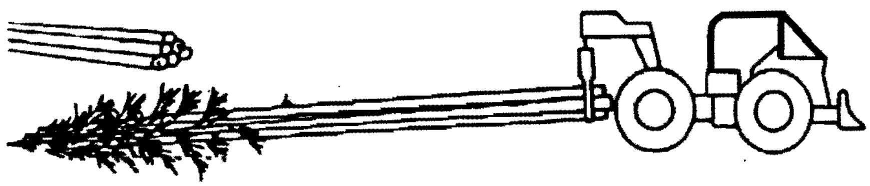
Chain flail delimber



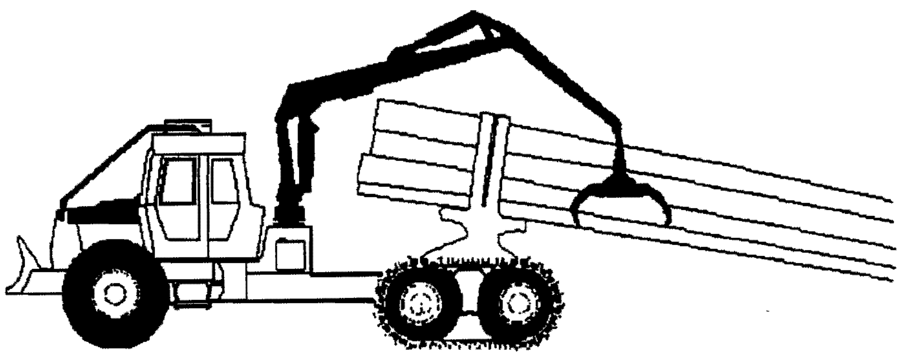
Stroke delimber



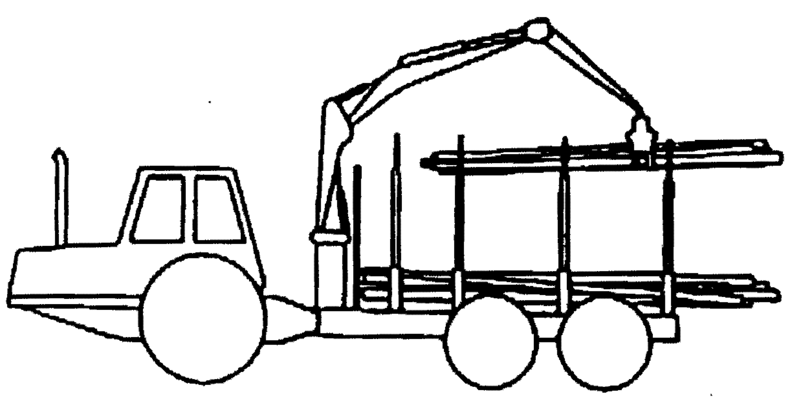
Cable skidder



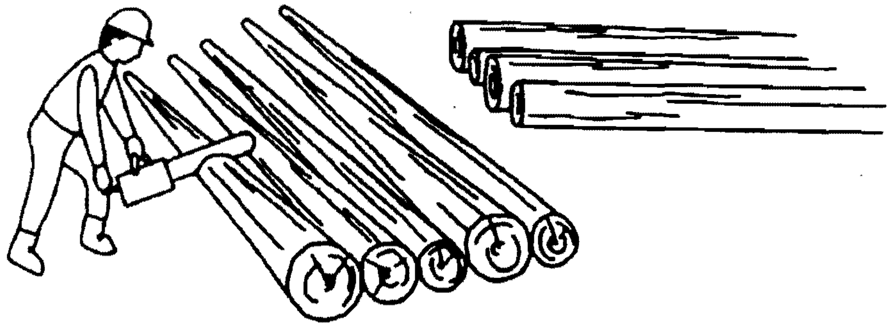
Grapple skidder



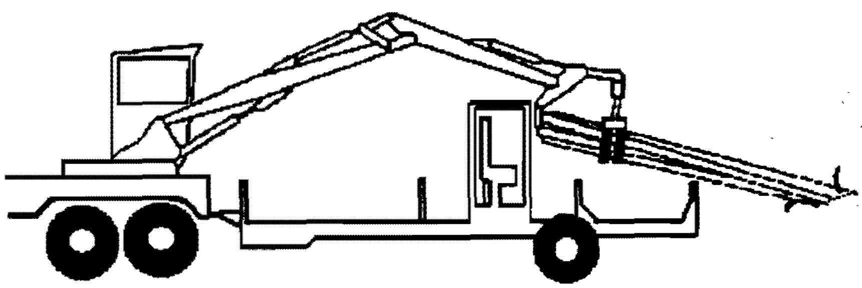
Clam-bunk skidder



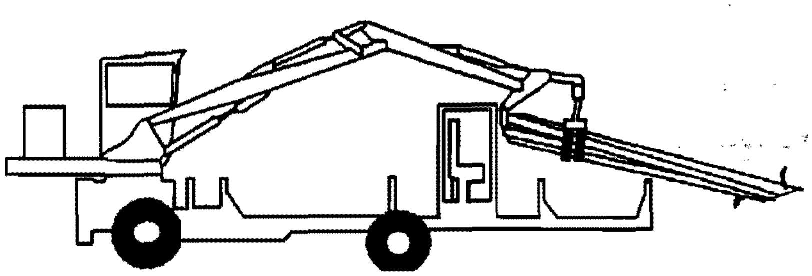
Forwarder



Motor-manual (chain saw) bucking



Small-size towable slasher



Self-propelled self-loading slasher

Jaakko Pöyry Consulting, Inc.

Dear Contractor/Logger:

Enclosed you will find a questionnaire being forwarded to you by the Minnesota Timber Producers Association. This questionnaire is vital in forming the background information for the Generic Environmental Impact Statement (GEIS) for Minnesota. The GEIS will surely have a major impact on future develoments in forest management and harvesting in Minnesota, and thus your future. For us to be able to accurately portray logging and the equipment used in Minnesota, we would like to ask you to take a few minutes to complete the questionnaire and return it in the stamped, self-return envelope. If you have any questions about the questionnaire, you could contact Bruce Barker, Minnesota Timber Producers Association (218-722-5013), or Doug Parsonson, Jaakko Pöyry Consulting, Inc. (612-224-5400, Suite 215).

A little explanation of the harvesting methods terminology is as follows:

- clearcutting (area >5ac) refers to any clearcut area greater than 5 acres in size
- clearcutting with standing residuals refers to any clearcut area where snags or other live trees are left standing, e.g., for wildlife reasons
- patch cutting refers to any clearcut area from 0.25 to 4.9 acres
- seed tree cutting refers to 10-20 dominant trees left per acre to provide seed to regenerate the area (mostly used in pine)
- shelterwood cutting refers to 20 or more dominant trees left per acre to encourage and shelter regeneration (used widely in oak regeneration)
- selective cutting would only refer to individual tree or group selection cutting in tolerant hardwoods.

Thank you

Doug Parsonson
GEIS Project Coordinator

Enclosures

APPENDIX III - LOGGING QUESTIONNAIRE SHEET

GEIS MINNESOTA LOGGING QUESTIONNAIRE - 1990 STATISTICS		
COUNTY:		name
NUMBER OF EMPLOYEES (including self)		number
STUMPAGE SOURCES (% OF TOTAL VOLUME HARVESTED)		
a) log own stumpage purchases		%
b) log stumpage purchased/owned by companies		%
TOTAL VOLUME HARVESTED PER YEAR		
Yearly softwood pulpwood volume harvested		cords
Yearly softwood log volume harvested		cords
Yearly hardwood pulpwood volume harvested		cords
Yearly hardwood log volume harvested		cords
HARVESTING METHODS USED (% OF TOTAL VOLUME HARVESTED)		
a) clearcutting (area greater than 5 acres)		%
b) clearcut with standing snags and live trees		%
c) patch cutting (clearcut area 0.25-4.9 acres)		%
d) strip cutting		%
e) seed tree cutting		%
f) shelterwood cutting		%
g) selective cutting		%
h) thinning		%
	100	%
SEASON OF HARVEST (% OF TOTAL VOLUME HARVESTED)		
a) winter (December-February)		%
b) spring (March-May)		%
c) summer (June-August)		%
f) fall (September-November)		%
	100	%
FELLING METHOD (% OF TOTAL VOLUME HARVESTED)		
a) chain saw		%
b) feller buncher		%
c) harvester		%
	100	%

GEIS MINNESOTA LOGGING QUESTIONNAIRE - 1990 STATISTICS		
OFF-ROAD TRANSPORT (% OF TOTAL VOLUME HARVESTED)		
a) cable skidder		%
b) grapple skidder		%
c) forwarder		%
d) other ( )		%
	100	%
DELIMBING (% OF TOTAL VOLUME HARVESTED)		
a) chain saw		%
b) mechanical		%
c) not delimbed		%
	100	%
BUCKING/SLASHING (% OF TOTAL VOLUME HARVESTED)		
a) chain saw		%
b) mechanical		%
c) not bucked		%
	100	%
DELIMBING & TOPPING LOCATION (% OF TOTAL VOLUME HARV.)		
a) cut-over		%
b) roadside landing		%
c) not delimbed		%
	100	%
BUCKING LOCATION (% OF TOTAL VOLUME HARVESTED)		
a) cut-over		%
b) roadside landing		%
c) not bucked		%
	100	%
OTHER PROCESSING (% OF TOTAL VOLUME HARVESTED)		
a) full tree chipping		%
b) chain flail - delimber-debarker-chipper		%
AVERAGE LOGGING SITE AREA		acres

GEIS MINNESOTA LOGGING QUESTIONNAIRE - 1990 STATISTICS		
EQUIPMENT:	Number	Age
a) Models of feller bunchers		
1 -		
2 -		
3 -		
b) Models of skidders		
1-		
2-		
3-		
c) Models of delimbers		
1-		
2-		
3-		
d) Models of slashers		
1-		
2-		
3-		
e) Models of chippers		
1-		
2-		
f) Models of trucks		
1-		
2-		
3-		
g) Models of trailers		
1-		
2-		
3-		