AN ABSTRACT OF THE PAPER OF

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in Forest Engineering presented on May 4, 1981

Title: The Effect of Swinging and Sorting with a Skidder on Yarding and Loading Efficiency in Small Diameter Douglas-fir.

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This study evaluated the impact of using a rubber-tired skidder to keep the landing clear by sorting and decking the logs along the road prior to loading by a self-loading truck. The evaluation was accomplished through detailed time studies conducted on a Koller K-300 yarder, a Crown Super 3000 self-loader, and a John Deere 440 choker skidder, in a selective thinning of a Coast Range Douglas-fir stand with an average diameter range of eight to twelve inches.

Production increases on the yarding cycle were observed when the skidder was used to keep the landing clear. A major factor for higher production rates was reduced landing delays. Comparisons of the loading operation from decks built by the yarder and by the skidder showed a significant time savings when loading from skidder decks. The portions of the loading cycle most affected were the sort and swing loaded elements. The analysis indicated that sorted decks oriented at small angles to the road and decked as high as possible required the shortest loading time. The skidding cycle was evaluated from a mechanical engineering approach and compared to regression analysis results. The results

showed that the skidder was capable of production rates in excess of 10 cunits per hour. The hooking and decking elements consumed the largest portion of the skidding cycle. An alternate method of hooking or investigation of a grapple attachment is suggested.

Important factors influencing the harvesting of a unit were identified and a model was developed to aid in planning. The influence of landing geometry as related to log holding capabilities of a landing, log diameter, and stems removed per acre are explored.

Despite an improvement in overall production, the skidder did not prove cost effective for the study when its full cost was charged to yarding production. There were indications, however, that the skidder or a loader may be a necessity for longer yarding distances, flat decking slopes, high stem removals, or larger diameter trees. The skidder cost benefit ratio may also be improved if the skidder or operator remain active in the overall harvest operation when not needed for swinging and sorting.

The Effect of Swinging and Sorting with a Skidder on Yarding and Loading Efficiency in Small Diameter Douglas-fir

by

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A PAPER

submitted to

Forest Engineering Department
Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Forestry

Completed May 4, 1981

Commencement June 1981

APPROVED:

Professor of Forest Engineering in charge of Major

Head of Department of Forest Engineering

Dean of Graduate School

Date Paper is presented MAY 4, 1981

Typed by Lori L. McIntire for John C. McIntire

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THE EFFECT OF SWINGING AND SORTING WITH A SKIDDER ON YARDING AND LOADING EFFICIENCY IN SMALL DIAMETER DOUGLAS-FIR

INTRODUCTION

Current industrial stand management prescriptions in the Pacific Northwest require shorter rotation ages and thinning regimes which make it more difficult for the logger to maintain a profit due to lower volumes and higher numbers of pieces handled. The Forest Engineering Department at Oregon State University began research on this and other problems of harvesting smallwood in this region in 1972. One of the results has been a detailed evaluation of the yarding system for several small cable yarders (Kellogg, 1980). Loading has also been briefly studied (Clark, 1978, Schneider, 1978). Few attempts have been made to research the integration of these two systems.

Problems have surfaced while harvesting with small yarders due to limited tower height and lack of log repositioning (swing) capabilities. Self-loading log trucks are well adapted to handling small logs and are very mobile between deck locations but have difficulty in repositioning at a log deck. The connection and major source of problems between the yarding and loading systems is the stockpile of logs at the landing. The decking component of yarding and subsequent loading from a deck built by the yarder is an area that normally receives the attention of the logger only after a problem arises. Little is known about the operational effects of the remedies employed other than that they allowed the logging to continue. No published research was found on this subject.

This paper discusses the results of a field study conducted in the Oregon Coast Range during the summer of 1980, to test the effect, on yarding and loading efficiency, of sorting and swinging logs away from the landing with a rubber-tired choker skidder. The three systems examined are yarding, loading and skidding. Background and review of previous research in each of these areas will accompany the discussion.

STUDY OBJECTIVES

The objectives of the study were to:

1. Determine how yarding production is affected by the decking element.
2. Determine the effect of log deck characteristics on loading efficiency.
3. Determine production rates for the skidder swing-sort operation.
4. Determine the important variables and conditions necessary for the skidder to be cost effective in the harvesting system.

SCOPE

The study was part of a larger project aimed at improving productivity in smallwood cable thinning in the Pacific Northwest. Thirty-eight skyline corridors, a number of which were important in this study, were yarded in a second-growth Douglas-fir forest northwest of Corvallis, Oregon. Yarding was performed by a private contractor using a Schield-Bantam T350 yarder with a Cristy carriage and a Koller K-300 tower with a one ton capacity Koller carriage. A John Deere 440-C choker skidder was used to swing and sort logs away from the yarding area. Loading evaluations were performed on self-loading log trucks with Crown Super 3000 self-loaders. The study was conducted from July through September 1980.

Detailed time studies were made on each operation. This paper evaluated yarding production in sixteen skyline settings yarded by the Koller tower in both single and multispan configurations and with and without skidder swinging and sorting. Four additional settings are compared to determine the effect on the Bantam production, which has swing capabilities.

The skidding cycle, its productivity and possible alternate uses of the skidder are discussed. A comparison of production rates using regression analysis and mechanical (machine capacity) approach is made to extend the range over which estimates can be made with some degree of accuracy.

The loading system is evaluated in detail. The differences between loading from a skidder deck and a yarder deck are examined and decking characteristics as related to loading efficiency are examined.

An attempt is made to show the importance of the increased need for proper planning when smallwood machinery is involved. This is done by a cost and production comparison of various settings showing the important variables affecting the operation. A small computer model is developed and utilized to extend the use of regression equations. Felling, bucking, and hauling are not considered in the scope of this analysis.

SITE DESCRIPTION AND UNIT LAYOUT

The study area is located on a 65 acre tract of the Paul Dunn Forest (owned and operated by Oregon State University), in the NE-¼ of Section 16, T1OS, R5W, Willamette Meridian, Benton County, Oregon (Figure 1). The site consists of mixed stands of 20 to 40 year old Douglas-fir (Pseudotsuga menziesii), grand fir (Abies grandis), bigleaf maple (Acer macrophyllum) and Pacific madrone (Arbutus menziesii). The average volume over the entire unit is approximately 5000 cubic feet per acre with about 80 percent fir and 20 percent hardwoods by volume. Mean diameter (dbh) for the fir is 11 inches with about 245 stems per acre (Figure 3).

Thirty-six skyline corridors were layed out ranging from 300 to 800 feet in length and with approximately 200 feet spacing between corridors (Figure 2). Ground slopes were gentle, ranging from about ten to twenty percent. Yarding prescriptions were assigned in accordance with the study objectives for each yarder. When possible the trees were felled to a 45 degree lead to the skyline corridor and bucked to log lengths (16-42 ft). Initially felling included complete hardwood removal and thinning the fir. There was approximately 36 percent stem removal resulting in 160 residual stems per acre. Time constraints and harvesting logistics realized during the project changed this strategy to only falling the fir. The variations in brush content on the forest floor was, therefore, different for some of the corridors. For this reason several of the corridor data sets were dropped from the analysis. No extra space was cleared for landings although some turnouts were used later for skidder decking.

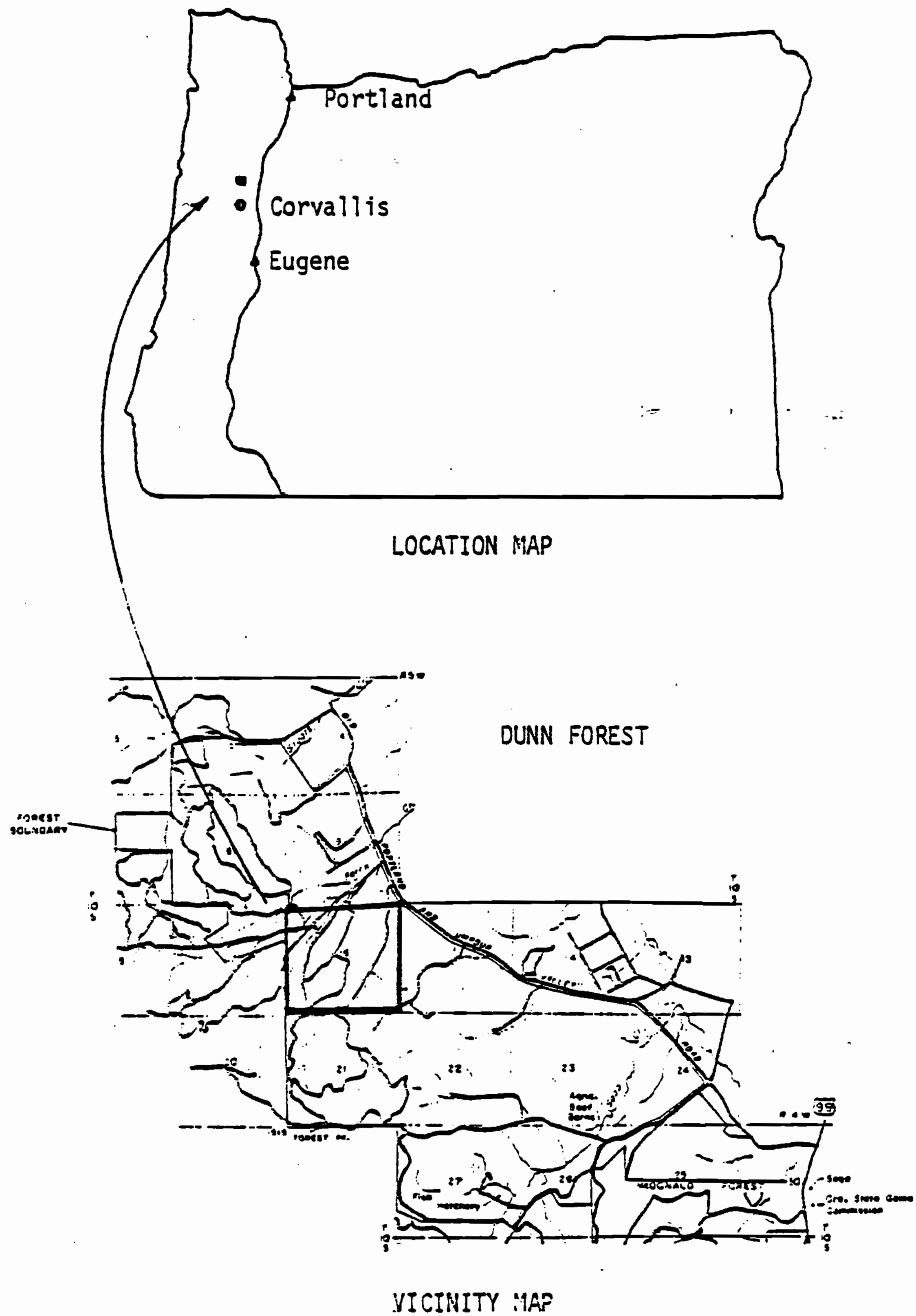

Figure 1. Study location maps.

Paul Dunn Forest, Benton Co. Oregon
NE ¼, Sec. 16, T. 10 S., R. 7 W., W. M.
Area: 65 Acres

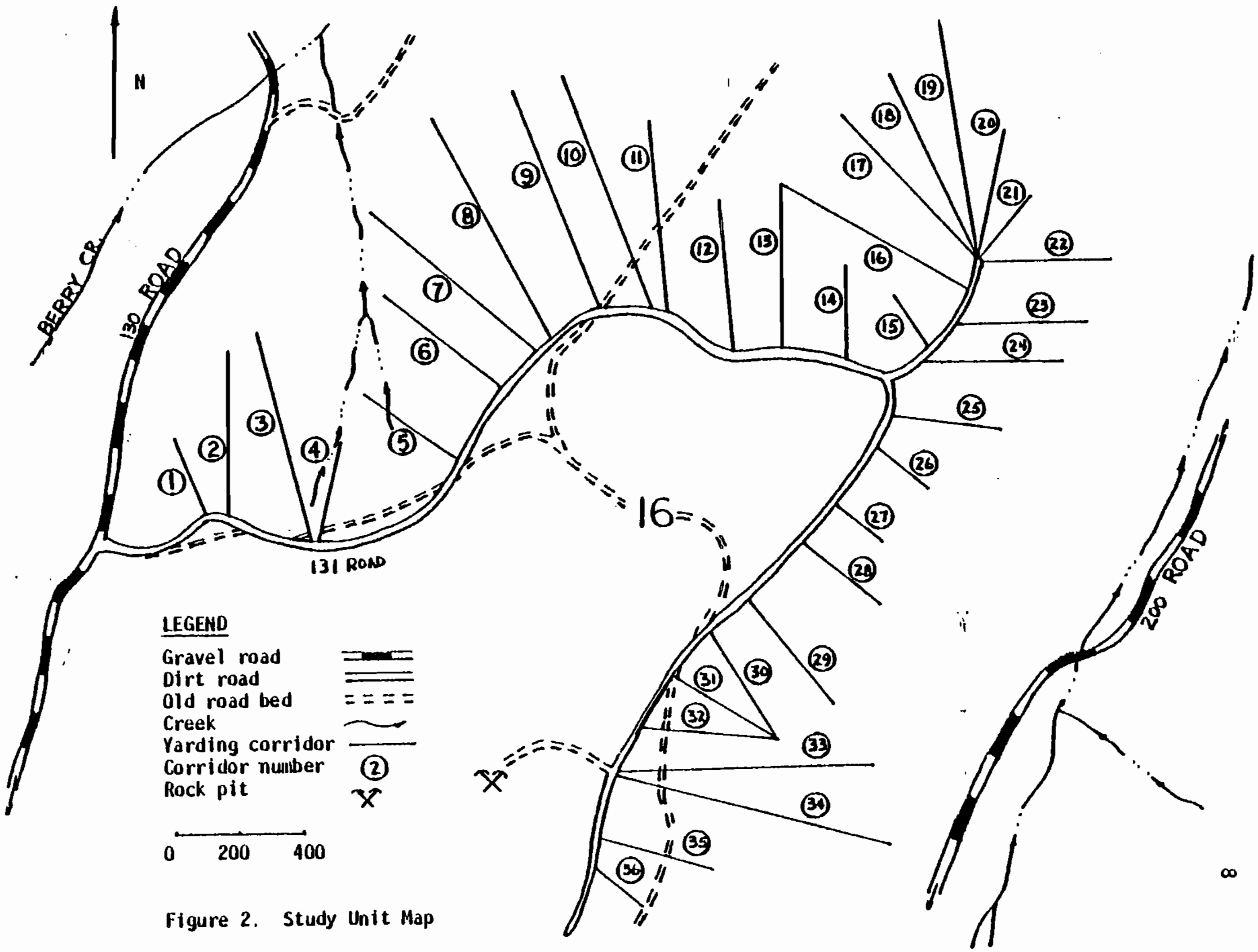

Figure 2. Study Unit Map

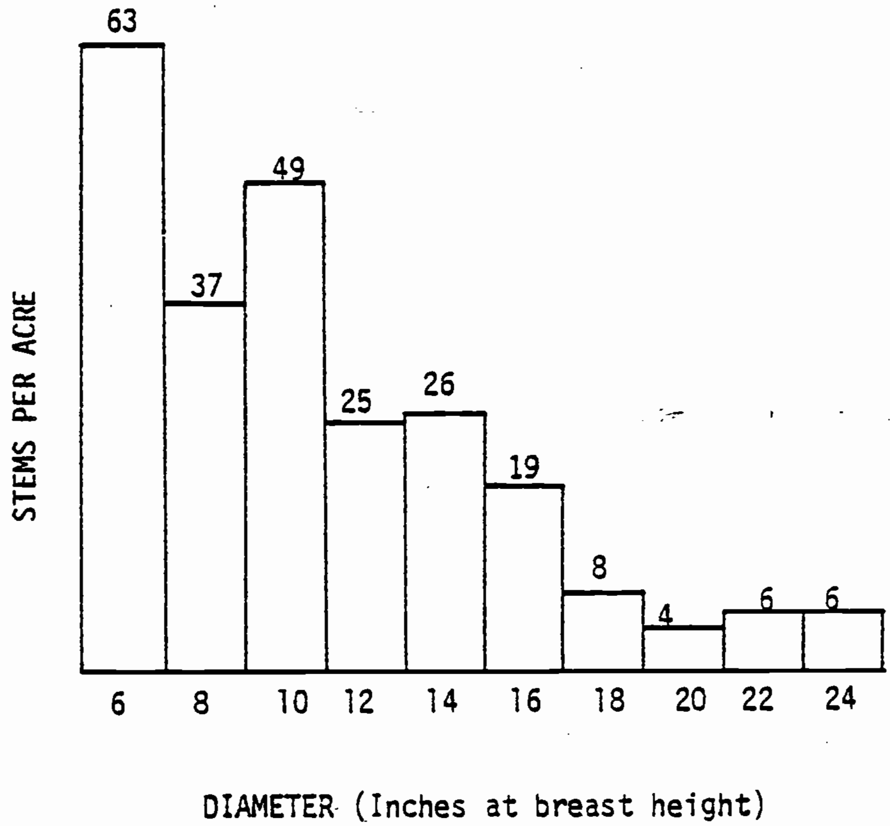

Figure 3. Diameter distribution of the Douglas-fir and grand fir before thinning.

THE YARDING STUDY

Background

The use of small yarders has benefits in harvesting cost reduction in aspects other than low initial investment and fixed cost. The size permits yarding from existing roads without expensive landing preparation. The light weight enables easy transport, with no adjustments for curve negotiation or disassembly for bridge or road weight limitations. The rigging requirements are less and minimal crew size is needed to operate a side.

Previous research with small yarders has identified several problems related primarily to deck interference. Fisher and Gibson (1977), in their report on the "Ecologger" yarder, noted:

> "A factor which dampened production efficiency was the absence of a skidder (and frequently loader) on the landing to remove logs from the deck in front of the yarder. Piling of logs by the yarder caused difficulties when the piles would become too large"

Gabrielli (1980) observed problems with decking and loading when thinning an eight inch diameter Douglas-fir stand. He noted that even with the Skagit SJ-2 yarder, which has swing capabilities, the landing became choked. In addition, the loader had difficulties reaching and sorting through the deck. Kramer (1978) pointed out other factors which increased turn time while yarding small diameter Douglas-fir with an Igland Jones Trailer Alp. He noted that when deck height reached eye level the yarder operator had difficulty placing logs on the deck. Climbing the deck to unhook and readjusting the logs with a peavy increased cycle time.

It is recognized that loggers have used various methods, including a skidder, to alleviate these problems when working with both large and small timber and yarders. When large volumes are yarded, however, the added costs are not as critical as in smallwood shows.

YARDING STUDY DESIGN AND DATA COLLECTION

The experiment was designed such that production rates for each yarder with and without decking interference could be found and differences tested. Due to other projects going on simultaneously, crew sizes were varied on the Koller yarder making several comparisons necessary to evaluate differences (Table 1.).

Table 1. Experimental treatments for the Koller tower

		Corridor Number	
Crew	Size	Without Skidder	With Skidder
2	3[1]	9m[2], 17, 27	19m, 20, 21
3	4	8m, 14, 28	33m, 13, 18
4	5	10m, 22, 25	34m

[1] Crew sizes in this column include the addition of the skidder operator when the skidder was used.

[2] Corridor numbers followed by an "m" denote multispans.

Crew assignments for the yarding crews on the Koller system were as follows:

Crew size = 2	Crew size = 3	Crew size = 4
1 yarder operator	1 yarder operator	1 yarder operator
1 choker setter	2 choker setters	1 chaser
		2 choker setters

On the Bantam yarder the crew was held constant at four people and consisted of a yarder operator, chaser, and two choker setters, Because of various site and experimental conditions for the other projects, a comparison is made for conventional yarding only to test for the skidder benefits on production rates. It was initially thought that if the yarder was swinging turns from prebunched decks, larger numbers of logs would build up faster at the landing and cause problems. This was not found to be true. An explanation given by the choker setters is that smaller turns were hooked to reduce the amount of stand damage so full payloads were not achieved. Because of the repositioning (swing) capabilities of the Bantam, it was expected that decking would not be a problem and analysis would not show an improvement with skidder aid. The treatment corridors are given below:

Table 2. Experimental treatments for the Bantam yarder

		Corridor Number	
Crew size		Without Skidder	With Skidder
4	5	2, 23	12, 30, 31

In order to determine how much effect the skidder has on cycle times and why, a detailed time study was conducted. The cycle elemental times were recorded to the nearest 1/100th of a minute with a stopwatch using the "snap back" method of continuous timing. All elements of the yarding cycle time were recorded but only a subset is needed to evaluate the skidder effect. The time elements of interest are described below:

INHAUL - the time to move a turn of logs from the carriage location to the landing. The activity begins when the carriage unclamps from the skyline and ends when forward movement of the turn stops at the landing.

REPOSITION - the time required to relocate logs on the deck. This activity does not occur during every cycle although it is common with a yarder having swing capabilities. The activity starts at the end of inhaul and finishes when the logs are in place on the deck.

UNHOOK - the time required to remove the chokers from the turn. The activity begins when the logs are positioned on the deck and the line slacks, and ends when the carriage leaves the landing.

The other elements in the cycle--outhaul, lateral outhaul, hook and lateral inhaul-- were recorded but detailed analysis is not important to this evaluation.

The following independent variables were recorded in an attempt to explain time variation for each activity:

SLOPE DISTANCE - the distance, in feet, from the yarder to the carriage position for each turn.

LOGS PER TURN - the number of logs hooked during each yarding cycle.

TURN VOLUME - the total cubic foot volume of all the logs yarded in a turn, calculated and summed using the Smailian Rule.

DECK HEIGHT - the height, in feet, of the deck measured from the ground to the highest log at the front of the deck after each turn.

Two other variables -- lateral distance and lead angle -- were measured but are not considered important in explaining skidder affected time.

YARDING DATA ANALYSIS

Multiple linear regression analysis was used to model cycle time. As mentioned earlier, crew size variations would not permit direct comparisons of total turn times between many of the corridors. To eliminate this "crew effect" only the portion of the cycle directly affected by the skidder was compared. Some multispan corridors were excluded from this comparison because of stand and felling conditions being different from the other corridors. The remaining comparisons are shown below:

			Corridor Number	
Comparison	Crew	size	Without Skidder	With Skidder
	2	3	17, 27	20, 21
1	3	4	14, 28	13, 18
2	4	5	34m	10m, 22, 25

The dependent element of time was established as the total of the inhaul, reposition, and unhook segments of the yarding cycle. By examining this portion of the cycle the first two crew assignments can be combined since landing personnel remained constant. A second comparison can be made with the 4/5 crew assignment which includes a chaser on the landing.

Preliminary elemental analysis found that slope distance, logs per turn, turn volume, and deck height were strong predictors of inhaul, reposition, and unhook times. Because of a strong correlation between deck height and slope distance, regressions including both terms do not produce valid results. For this reason deck height was dropped, although its influence is partially masked by slope distance.

The resulting equations for the comparison are shown in Table 3.

Table 3. Koller and Bantam yarder regression coefficients and statistics for skidder affected times (total of inhaul, reposition, and unhock)

Yarder		TREATMENT with skidder	TREATMENT without skidder
		Crew 3/4	Crew 2/3
KOLLER K-300	constant	.40567	.099953
	slope dist.	.001905	.003644
	log/turn	.034441	.202943
	volume/turn	.0060700	.0139628
	MEAN VALUE	1.19 minutes*	1.92 minutes
	n	240	341
	R^2	.4603	.4701
		Crew 5	Crew 4
KOLLER K-300	constant	.312956	.243484
	slope dist.	.002045	.002866
	logs/turn	.069985	.078365
	volume/turn	.003568	.0081357
	MEAN VALUE	1.15 minutes	1.45 minutes
	n	162	308
	R^2	.7775	.5542
SCHIELD-BANTAM T350	constant	.216419	.233079
	slope dist.	.003932	.004429
	logs/turn	.120735	.124143
	volume/turn	.001443	.009133
	MEAN VALUE	1.67 minutes	2.02 minutes
	n	120	219
	R^2	.6524	.3948

Note; All independent variables are significant at the .05 probability level.

* Times are based on slope dist. = 300 ft., logs/turn =2, volume/turn=23.

After obtaining regression equations and analysis of variance (ANOVA) tables for each treatment the data were pooled and a combined equation and ANOVA table was obtained. This information allowed a statistical comparison of the two treatment regression lines (Neter and Wasserman, 1974). The hypotheses tested were:

Ho: The two lines are the same
Ha: The two lines are different

The procedure is illustrated by example for the initial comparison and is used for the other crew sizes and the Bantam yarder (Figure 4). The results for all comparisons show that the skidder benefits the operations although for the Bantam analysis the difference is smaller. The test values for each comparison is show below:

Comparison		F	F critical ($p < 0.0001$)
Koller	2/3 and 3/4	52.41	4.62
Koller	4/5	19.33	4.62
Bantam		11.71	4.62

Since the skidder affected time equations do not include delays the difference in regression coefficients (Table 3) is probably related to decking. There are a number of explanations for the increased time when not using the skidder. Unhook time is increased due to climbing the deck and more obstructions (logs) when releasing the chokers. Inhaul is slowed as the turn approaches the end of the deck. In some cases the leading end of the turn catches on the end of the deck. Continuing inhaul would endanger the yarder operator. Barring this occurrence, once the height is above eye level the yarder operator may

Figure 4. F-test for comparing two regression lines for Koller yarder, crew 2/3 and 3/4.

NON-SKIDDER

Source		SS	df
Regression	SSR_1	=122.45	3
Residual	SSE_1	=138.04	337
Total	$SSTO_1$	=260.49	340

SKIDDER

Source	SS	df
Regression	SSR_2=19.47	3
Residual	SSE_2=22.83	236
Total	$SSTO_2$ =42.30	239

COMBINED

Source	SS	df
Regression	SSR(R)=101.31	3
Residual	SSE(R)=219.73	577
Total	SSTO(R)=321.04	580

SSE (full model) - $SSE_1 + SSE_2$ = 160.87

SSE (reduced model) = 219.73

$$F^* = \frac{SSE(R) - SSE(F)}{(n_1 + n_2 - (g + 1)) - (N_1 + n_2 - 2(g + 1))} \div \frac{SSE(F)}{n_1 + n_2 - 2(g+1)}$$

where: n = number of observations of respective data set
g = number of independent variables (regression parameters)

If F* F(.999,4,573) conclude the lines are different

$$F^* = \frac{219.73 - 160.87}{4} \div \frac{160.87}{573}$$

F* = 52.41 F(.999,4,573) = 4.62

THEREFORE, THE LINES ARE DIFFERENT

become apprehensive about maintaining line speed if he cannot see the turn approach. Production rates may also decrease if the rigging crew hooks lighter payloads to avoid the deck hang-up problem. Repositioning logs occurs more frequently when logs are on the landing. The turn must be set down in a stable position before unhooking and in such a way that placement of the next turn is not a problem. The time differences are depicted graphically in Figure 5, which illustrates the regression lines generated by varying slope distance while holding logs per turn and volume constant.

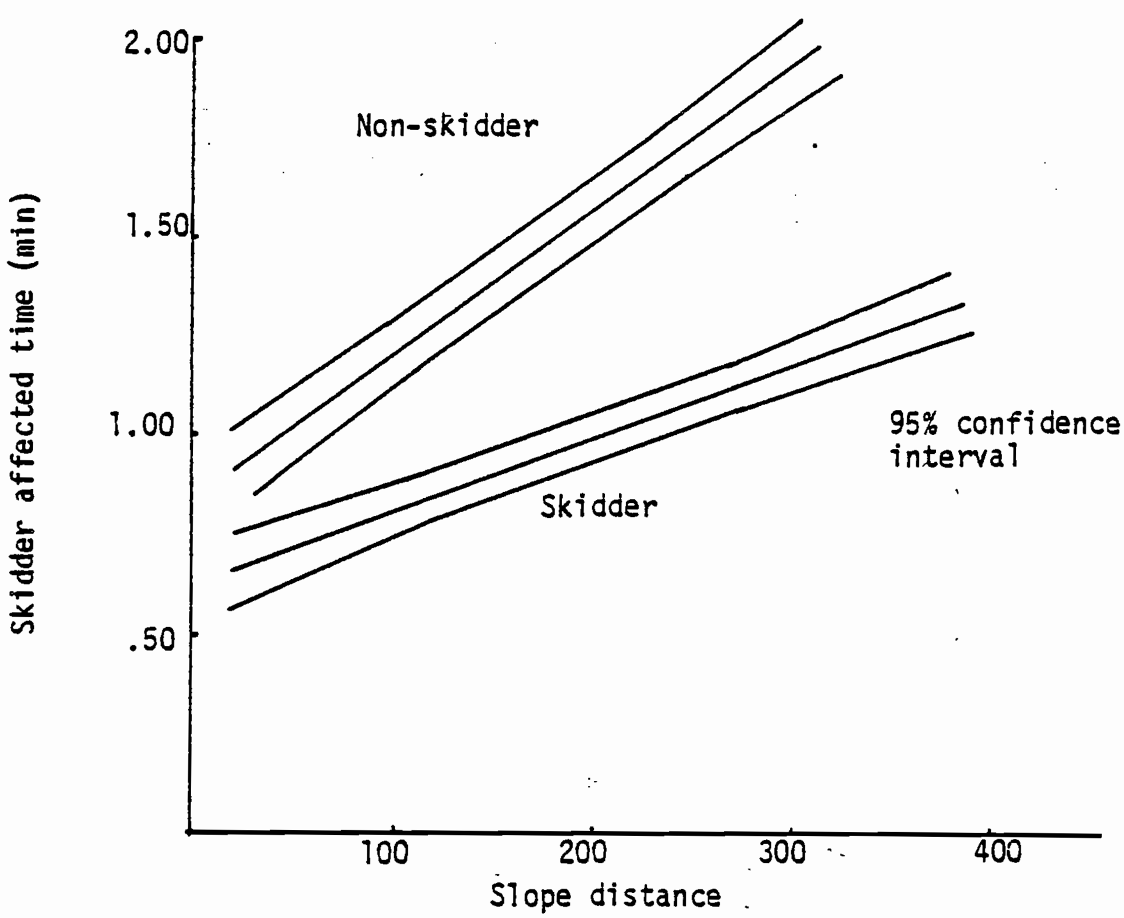

Figure 5. Skidder affected time comparison for Koller yarding with and without skidder present. (crew 2 & 3)

Complete delay-free cycle time equations for each crew size, with and without the skidder present, were calculated and are listed in Appendix C. For these equations separate regressions were made for two portions of the cycle and added together. This allowed the deck height and slope distance variables to enter the equations without interacting. The effect of deck height will be shown and discussed later by extending the use of the regression equations in a small computer model.

DELAYS

The differences between cycle times for each treatment is exaggerated further when delays are considered. Approximately 31 percent of all operating delay time was landing delay. This is further emphasized by the fact that 21 percent of all delay time was in landing delays. The presence of the skidder swinging reduced landing delays, as a percentage of delay-free turn time, from 23.8 percent to 2.8 percent. Practically all of these delays were a function of the presence of the log deck.

Four delays account for this time, identified as sideblocking, choker caught, turn jammed, and deck maintenance. Sideblocking is the process of pulling the turn off to the side of the deck to allow for more turns to be landed. This is not a problem with a yarder such as the Bantam with swing capabilities.

Choker caught usually occurs when the deck is within a choker length of the skyline and the choker bell catches in the deck stopping outhaul. The yarder operator must set the brake and remount the deck, clear the choker, and release the brake before outhaul can begin.

Turn jammed in deck occurs when clearance between the leading end of the turn is lower than the height of the deck. This problem can sometimes be eliminated by hanging an intermediate support at the end of the deck to gain needed clearance.

Deck maintenance usually consists of the removal of slash or the manipulation of the logs with a peavy to flatten the deck or rearrange jackstrawed logs.

The delays resulting when the skidder was present occurred mostly when the yarder was placed at the end of a spur road. Skidder interference resulted when the logs were pulled past the yarder operator so he had to move. This was not a problem under normal circumstances.

THE LOADING STUDY

Background

In the past, loading logs for transport to the mill has been a small portion of total harvesting costs. Relatively few logs were needed to make a truck load, so handling times were short. With smallwood, the number of logs needed to fill a truck to capacity is greatly increased. Clark (1978) has shown the inverse relationship between log diameter and pieces loaded per truck (Figure 6). Conway (1976) indicates that loading time increases in direct proportion to the number of logs loaded.

The self-loading log truck is well suited to conditions where high mobility and low initial costs are needed. The cost of a self-loader unit in early 1981, is about thirty thousand dollars less than an independent loader. Removing stumps, setting poles, hauling culverts, and removing debris from roads list some of its applications beyond log loading. Loading is done by the truck driver directly from the roadbed reducing landing space. An operator may be able to save waiting time at the mill by unloading himself which may mean one extra load in a day. The self-loader has the disadvantages of lower lifting capacity and a shorter reach than most independent loaders although these factors do not appear to be limiting in smallwood conditions. The loss in net payload due to the added weight of the self-loader could make conventional truck hauling more attractive for long distances.

A number of factors affect loading efficiency. Konnie (1976) encountered problems with obstructions limiting loading, small deck volumes necessitating moves, and deck arrangement. Sorting may also slow loading

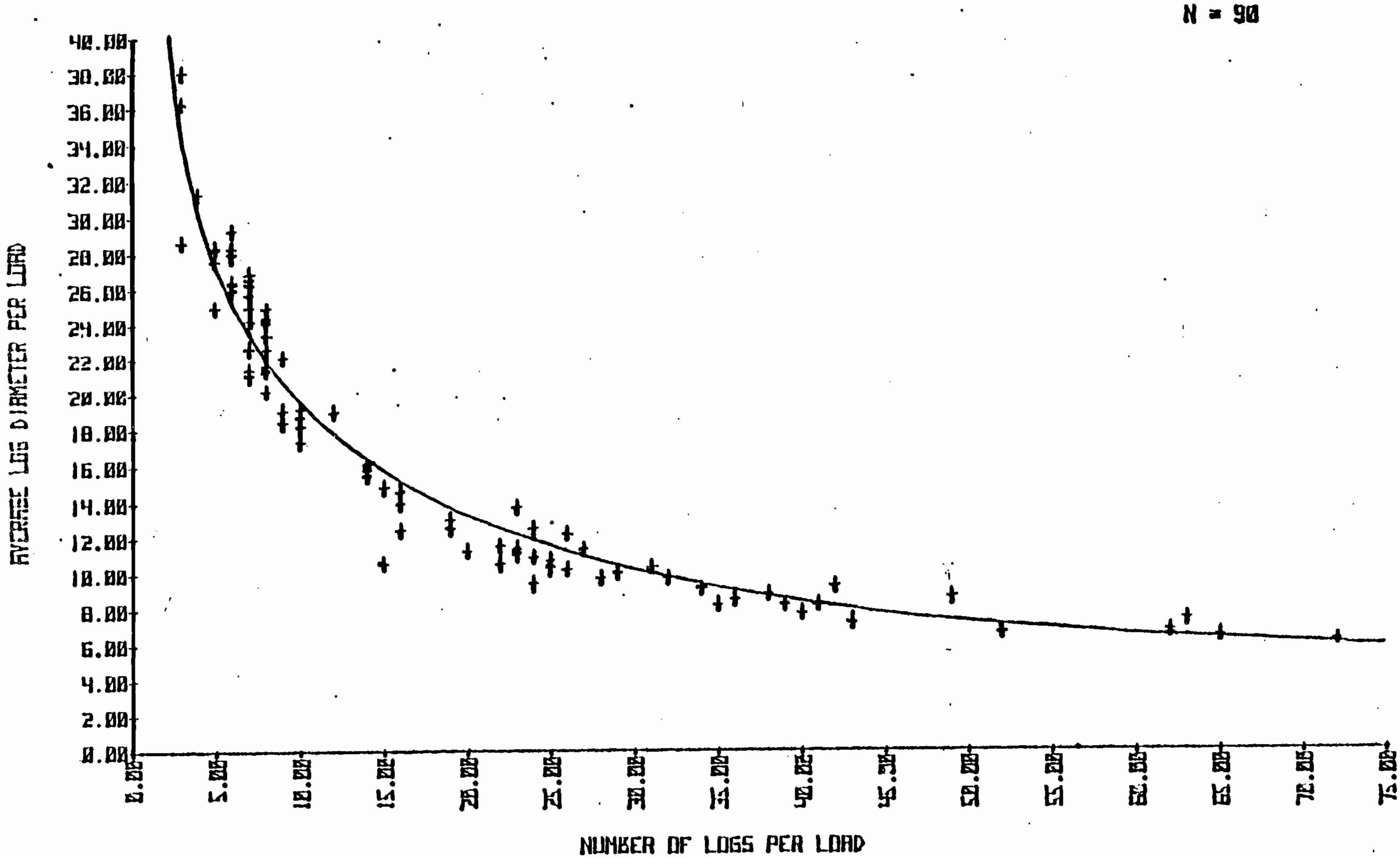

Figure 6 . Number of logs per load expressed as a function of the average log diameter (inches) per load for the total data base.
(after Clark 1978)

time in mixed stands. The possibility of eliminating these types of loading difficulties was tested by utilizing a skidder to swing the logs from the yarding deck to a sorted loading deck. The general approach used in this study was similar to that used by Clark (1978).

LOADING STUDY DESIGN AND DATA COLLECTION

To determine how loading efficiency is affected by log deck characteristics, the loading times for two types of decking configurations were recorded. The first deck type (yarder deck) is the most common loading configuration and will be considered the control. The second type is built by the skidder. With this configuration, an attempt is made to create a log deck that is ideally suited to loading. The decks were located at roadside at orientations between 0 and 45 degrees (identified by Clark (1978) as optimum) and free from obstructions (Figure 7). Logs were sorted by size and species so no extra sorting by the loader was necessary and deck volumes were sufficient to eliminate intermediate moves. The deck was to have the butt end of the logs evenly aligned such that extended reaches or truck repositioning was unnecessary. Although these conditions were desired, in practice, less than optimal results were achieved due to skidder operator abilities. Detailed information for four loads from yarder decks and seven loads from skidder decks were collected.

The method of continuous timing, as with yarding, was done for the loading cycle. This type of information aided in evaluation of the loading process so that places for possible improvement could be identified. Descriptions of the time elements that were identified for each cycle are as follows:

SWING UNLOADED - the time for the grapple to move from the trailer to

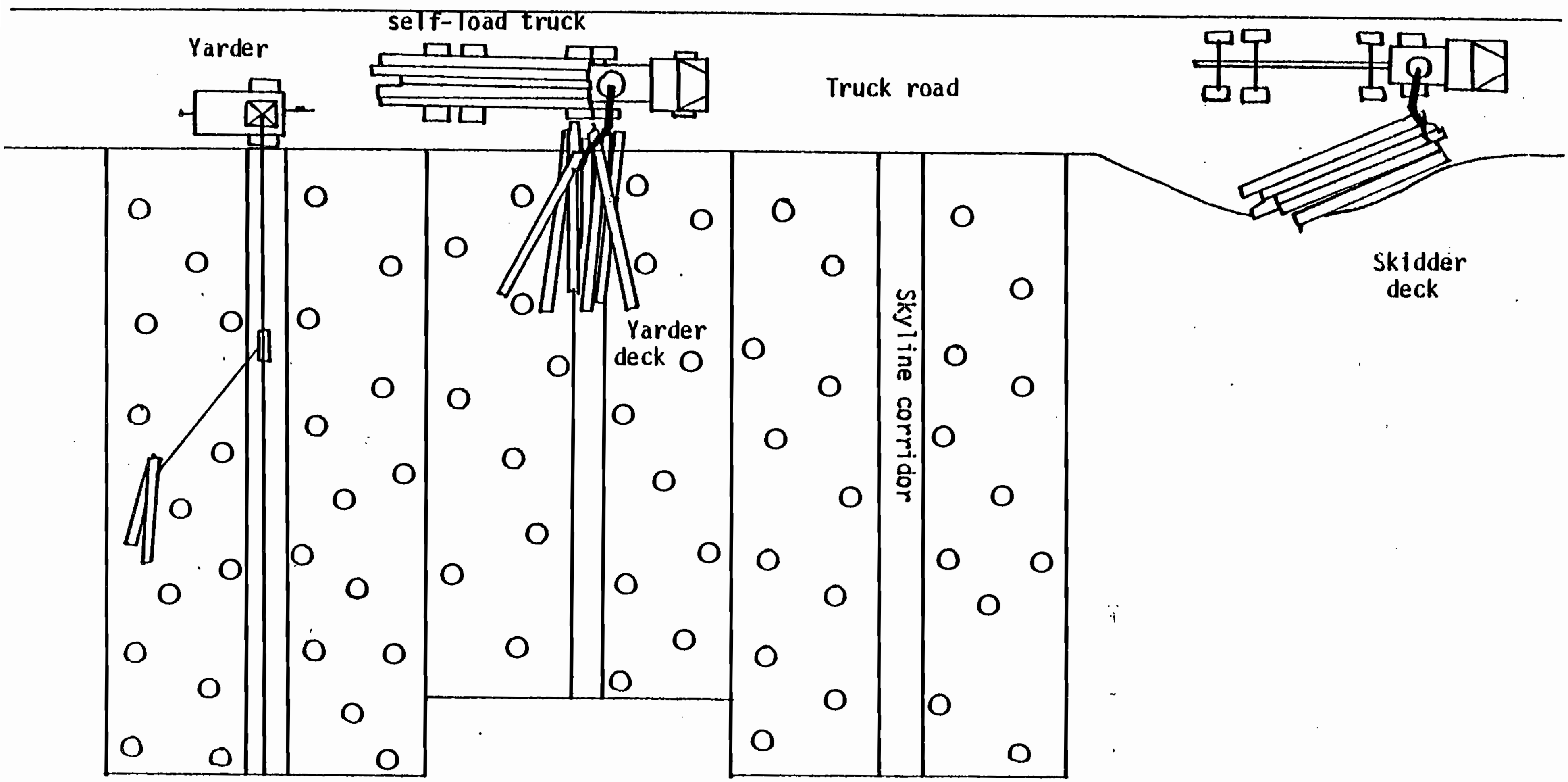

Figure 7. Harvest setting and decking configurations.

the log deck. The activity begins when the grapple releases the log after loading and ends when the next log in the deck is touched.

SORT - the time required to rummage through the deck and pick up a log. This may involve separating culls, other species, or just finding a log of suitable length. Time begins when the grapple touches the deck and ends when the log is lifted clear of the deck.

SWING LOADED - the time required to move the log from the deck position to the bunk. The activity begins when "sort" ends and terminates when the log is set on the truck.

ADJUST - the time used to move or relocate the log to its final position on the truck.

The sum of these four elements is considered one loading cycle or turn.

The following independent variables were thought to influence loading times and aid in explaining variations.

NUMBER HANDLED - the number of logs moved by the grapple before loading.

NUMBER LOADED - the number of logs actually placed on the truck.

HEIGHT - the position of the log to be loaded above the road surface.

AVERAGE DIAMETER - the average of the large and small end diameters of each log which is then averaged for the turn.

AVERAGE VOLUME/LOG PER CYCLE - the mean cubic foot volume per log in one loading cycle.

TOTAL VOLUME PER CYCLE - the sum of the log volumes for a loading cycle.

LENGTH - the average length of the log in one cycle.

DECK CONDITION - the general deck arrangement, such as uneven ends, amount of slash, or criss-crossed logs, was noted as a subjective aid in explaining differences.

Tree length, whole

Other productive activities were recorded to complete the assessment of the total time for the loading operation.

UNLOAD AND POSITION TRAILER - the process of releasing the trailer, stretching out the reach and positioning the trailer at the deck. The activity starts when the operator releases the trailer constraint cable and ends when he sets the idle speed on the power-takeoff.

SET-UP LOADER - the process of removing the grapple from storage and setting the outriggers for stabilization. The activity begins when the operator mounts the loader and ends when movement starts towards the deck.

STORE LOADER - returning the grapple to its storage position, releasing the outriggers and reducing idle speed.

BINDERS - the time required to secure the load with cables and fasteners, and remove the bunk pins.

BRAND - the time used to brand the logs with the distinguishing property mark before transporting.

LOADING ANALYSIS

Descriptive statistics were calculated for time elements and independent variables for each load and deck category (Table 4). It should be noted that there were very small differences between loads in the same category.

A Student-t test was used to determine whether or not delay-free times for the skidder decked loads were significantly less than yarder decked loads (Figure 8). The test procedure indicates that loading time per cycle is significantly less when loading from a skidder built deck. The observed difference in mean cycle times is 13.8 seconds or about 14 minutes per load.

Table 4. Summary statistics of elemental loading times (minutes) and independent variables when loading from skidder decks and yarder decks.

Element		Skidder decks	Yarder decks	Variable		Skidder decks	Yarder decks
SWING UNLOADED	Max	.31	.27	NUMBER HANDLED	Max	8	7
	Min	.05	.06		Min	1	1
	Mean	.12	.14		Mean	1.60	2.18
SORT	Max	1.50	1.85	NUMBER LOADED	Max	3	5
	Min	.03	.05		Min	1	1
	Mean	.21	.35		Mean	1.20	1.40
SWING LOADED	Max	.68	1.00	HEIGHT	Max	7	9
	Min	.05	.10		Min	0	0
	Mean	.18	.24		Mean	1.91	5.25
ADJUST	Max	1.05	.85	AVERAGE DIAMETER	Max	15.00	12.80
	Min	0	0		Min	4.10	5.00
	Mean	.09	.10		Mean	7.89	7.48
DELAY-FREE TIME PER CYCLE	Max	1.93	2.69	AVERAGE VOLUME PER LOG	Max	45.00	34.20
	Min	.18	.23		Min	1.70	2.40
	Mean	.599	.829		Mean	12.30	10.76
N		436	228	TOTAL VOLUME PER CYCLE	Max	45.00	44.00
					Min	1.70	2.40
					Mean	13.84	13.56
AVERAGE CYCLES PER LOAD		62	57	AVG. LOG LENGTH PER CYCLE	Max	54	50
					Min	13	15
					Mean	30.88	30.61
AVERAGE LOGS PER LOAD		75	80				

Figure 8. t-test for differences in loading time per cycle between deck types.

Hypotheses Tested:

Ho: $\mu_s = \mu_y$ Cycle times are the same

Ha: $\mu_s < \mu_y$ Cycle times from skidder decks are less than from yarder decks.

	Skidder decks		Yarder decks
Mean cycle time (minutes)	.599		.829
variance	.065		.170
degrees of freedom	435		227
pooled variance		.101	
t-calculated		8.839	
t-critical (.01,662)		2.326	

Reject Ho if 8.839 > 2.326

Conclude: Loading time per cycle is less from skidder decks than from yarder decks.

Examination of the magnitude of each elemental time with respect to its effect on total cycle time indicate that the combination of the sort and swing loaded elements consumed 66 and 71 percent of the cycle for skidder and yarder decks respectively.

Regression analysis gave poor results when working with each deck category individually. The narrow range of conditions in the study make the equation of little use in terms of applications to other operations, although the relationships are valuable in understanding how and what variables influence loading times.

To generate a significant equation it was necessary to use loading time per log as the dependent variable; the equation follows:

$$\begin{aligned}\text{Time/log (minutes)} = \; & .598236 \\ & +.112290^{*}(\text{handled}) \\ & -.326223\ (\text{loaded}) \\ & -.013553\ (\text{height}) \\ & +.004509\ (\text{vol/log}) \\ & +.004227\ (\text{length}) \\ & +.182270\ (\text{Y-S})\end{aligned}$$

$n = 661$

$R^2 = .4032$

where: Y-S = indicator variable
1 if loading from a yarder deck
0 if loading from a skidder deck

The variable of strongest influence on time per log is the number loaded per cycle. When several logs are loaded at one time, the time decreases per log. Additional data for another operator was compared in a general manner to check for differences in total time per cycle. The first operator typically loaded more logs per cycle but this was offset by extra time spent adjusting.

The indicator variable for deck type was second most important in explaining time per log. This shows that time increases when loading from yarder decks. Clark (1978) showed smaller deck angles to the road reduce time per load. Angles did not vary significantly between decks of the same type but differed between types. The yarder decks ranged from 75 to 90 degrees and skidder decks from 0 to 30 degrees. The deck condition was another influence probably expressed in this variable. The skidder decks usually had more even ends, less slash, parallel logs, and less obstructions, making loading easier.

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* All independent variables are significant at the .01 probability level.

Examination of the data and regression of the sorting element indicate that higher numbers of logs handled increases loading time. More logs were handled when loading from yarder decks, but this may largely be the extra sorting that the skidder would handle. Comparing ratios of the number handled to the number loaded, 1.6 and 1.3, for yarder and skidder decks respectively, shows that the skidder reduces this extra motion.

The negative regression coefficient for deck height shows the higher decks reducing loading time. In this study the skidder operator was not able to build high decks but this may not be the case in other operations.

Higher average log length and volume per log each increase loading time. This may be due to increased weight or operator care, but observations of other operators beyond this study suggests several other possibilities. Except for very long logs, the time to load short logs is generally high because of maneuvering and positioning difficulty. Average times for the other productive activities necessary to complete a truck load are listed in Table 5.

Table 5. Productive time per load other than the loading cycle for 32 truck loads

Category	Time (minutes) Mean	Standard deviation
Set-up and position	4.44	1.40
Set-up loader	.99	.60
Store loader	1.13	.40
Binders and pins	7.23	1.60
Brand	2.52	1.10
TOTAL/LOAD	16.31 minutes	

DELAYS

Delays were grouped into three categories based on what caused the delay. Group one are those caused by the deck or logs. Within this group, SLASH is a delay for time spent removing slash from the deck or the load. OBSTRUCTION is a delay because of standing trees too close for a normal swing. LIMBING is when the operator uses the grapple to clear the limbs from a log. This also included time lost from breaking a log when lifting from the small end.

The second group are those caused by the truck. DROP LOG is the reloading time lost due to a log rolling off the truck or from a bad grip on the log. This occurs most often when the bunks are full but the operator attempts to add more logs to get up to weight capacity. RELOAD is when a log is taken off the truck and loaded after adjustments to the load. LOADER REPAIR is time lost to breakdowns, such as broken hoses or loose fittings.

The third group are delays caused by the operator. SCALE is time lost when the operator leaves his loading perch to check the load weight. REPOSITION TRUCK occurs when reaching logs becomes difficult because of poor parking or because of deck arrangement. EXAMINE DECK is a pause between loading cycles to look for logs or some other reason known only to the operator. DISCUSSION is any operator interruption for personal reasons or discussion with the logging crew.

Delays accounted for a small portion of time to load a truck (Table 6). Because of the small number of loads evaluated in detail, the individual observed delays may not be representative of allocations for general loading conditions, although the total time per load is relatively consistent. The "drop log" delay accounted for a significant portion of the delays. This occurred because of the large number of logs needed to carry a weight capacity load. To minimize this delay, it is recommended that extensions be added to increase the height of the side stakes. Loading time per log also increased when logs were added after the bunks were full because of the difficulty in stable placement. Two delay types, obstructions and limbing, may be reduced by having the skidder redeck the logs.

Table 6. Detailed loading delays for 11 truck loads.

Delay Type	Mean time (min) per load: Skidder deck	Mean time (min) per load: Yarder deck
Slash	.127	.025
Obstruction	----	.300
Limbing	----	.375
Drop log	1.367	1.490
Reload	.043	----
Loader repair	7.950	----
Scale	.426	.135
Reposition truck	.421	.175
Discussion	.100	.230
Examine deck	.596	.158
Miscellaneous	----	.443
Total/Load	3.08*	3.33

* without loader repairs

Total time to load a truck may be estimated by multiplying loading time per log by the number of logs per load and adding productive activity and delay time. An example of loading time for one load follows:

Loading Time from a Skidder deck

Time per log (from regression) (using mean values from Table 4)		.56 min/log
Number of logs per load (Figure 6, or Table 4)	X	75.00 logs/load
Loading time per load		41.8 minutes
Other productive activities (Table 5)		16.1 min/load
Delays (Table 6)		3.1 min/load
TOTAL LOADING TIME		61.0 minutes

THE SKIDDING STUDY

Background

Using a skidder for swinging and sorting to aid the yarding operations is not new. Pease (1972) reported that tree length stems on several operations were cleared away from the yarder by a grapple skidder and placed in a hydraulic bunk. This eliminated a loader but required a substantial landing area for sorting and loading. Although this appears to be an efficient system, such new designs for the bunks are not widely used because of the high investment required (O'Leary, 1981). No existing literature quantifies the time and cost of this type of operation, i.e., the productive capacity, amount of idle time, or cost benefit to the operation.

The nature of the swing and sort process makes a mechanical engineering analysis applicable to a large range of conditions for production potential.

SKIDDING STUDY DESIGN AND DATA COLLECTION

The skidder swing and sort operation used a small (70 horsepower) choker skidder, a John Deere 440C. Detailed timing of the skidding cycle provided inputs for the non-mechanical elements and allowed for a comparison with regression analysis. At four different corridors, the skidder was timed while operating simultaneously with yarding.

The skidding cycle was broken into six elements as follows:

POSITION - the process of moving the skidder into position in preparation to hook a turn of logs. The activity starts when the skidder begins turning around to back up to the deck and ends when the machine stops moving.

HOOK - the operation of choking the logs. Time begins when the position element ends and ends when the skidder moves forward. This may also include rehooking.

TRAVEL LOADED - the act of moving with one or more logs for payload. The start and finish is triggered by forward movement and halting of movement.

UNHOOK - releasing logs from the choker. The activity begins at termination of travel loaded and ends when the skidder moves.

TRAVEL UNLOADED - forward or backward movement with no load.

DECK - the process of adjusting logs into a suitable pile or pushing the logs to a given orientation, usually involving the front end blade. The activity begins when any part of the skidder touches the log and ends when movement begins toward a deck.

The sum of these elements constitutes one skidding cycle. If an element occurs more than once within the cycle this time was also included. Other recorded information to help explain times were percent slope of the road, travel distance, number of logs hooked, volume (weight) hooked, number of decks, decking characteristics, and any delays or times not part of the cycle described above.

SKIDDING ANALYSIS

A mechanical (machine capability) approach for determining production capacity is an attractive alternative to regression analysis because the functional relationships that affect production do not have the problems of the terrain and brush variability and estimates are not limited by the range of data. Also in the situation studied the skidder was restricted to the supply rate of the yarder. Because of this limitation it is not known if the productive elements such as hooking and decking times are representative of conditions where the supply of logs arrived at a faster rate.

The procedure used for estimating production rates was developed by Fiske and Fridley (1975) and relies on soil-vehicle interaction formulated by Wismer and Luth (1972). The basic relationship in this analysis is a term called Tractor Potential (E) and is defined as follows:

$$\underset{(\text{lb-ft/min})}{E} = \frac{Ws \cdot D}{Tw + Tr} = \frac{Ws}{\frac{1}{VL} + \frac{1}{VE}}$$

where: Ws = turn weight - lbs
D = skidding distance - ft
Tw = travel loaded time - min
Tr = travel empty time - min
VL = velocity loaded - ft/min
VE = velocity empty - ft/min

Tractor Potential is the maximum rate at which the skidder could complete a turn, excluding the hooking and decking elements and assuming operation at full speed in the optimal gear. E, therefore, can be considered as the machine capability. Actual productivity depends on the preparation time, soil-vehicle relationships, operator efficiency and machine availability. The maximum production rate, WH, assuming 100 percent machine availability and operator efficiency is given by:

$$\underset{(\text{lb/min})}{WH} = \frac{1}{\frac{D}{E} + \frac{Ts}{Ws}}$$

In order to find the skid preparation time, Ts, a regression was calculated which includes hooking, unhooking and decking time as a function of the number of logs hooked and the number of decks or sorts:

$$Ts\ (\text{minutes}) = 1.394931 + .692235\ (\#\ \text{of sort decks}) + .4466512\ (\#\ \text{of logs})$$

A computer program was written for the Hewlett Packard 9830 desk-top computer to apply these relationships to wheeled skidders for various distances, turnsizes, slopes, or number of sorts. The differences in calculated production and actual production isolates the operator efficiency if delays are deducted. The results under the controlled conditions of a firm gravel road allow the model to be applied with relatively good confidence with the assumptions in the formulation (Appendix A).

The conditions observed during skidding are show in Table 7. Multiple regression analysis for the narrow range of conditions observed, yielded the following equation for delay-free skidding time when swinging:

$$\begin{aligned} \text{SKIDDING TIME} = {} & 1.24944 \\ & + .588229 \text{ (number of sort decks)} \\ & + .005063 \text{ (distance, ft.)} \\ & + .464303 \text{ (number of logs)} \end{aligned}$$

$$n = 95$$
$$R^2 = .2631$$

With the average conditions of the study, delay-free skidder production rates calculated by regression are 7.3 cunits per hour. Using calculated machine capability (E) coupled with the average skid preparation time observed, approximately 10.4 cunits per hour are possible if the operator works the skidder at its maximum speed. These calculations indicate that even higher rates are possible if the skidder is loaded with a practical limit of eight to ten logs (Appendix A). The regression estimate approaches the theoretical estimate when higher numbers of logs are hooked. This suggests that the operator generally ran the skidder at the same speeds no matter what the load. At average study conditions the ratio of the calculated production rates using both methods shows operator efficiency at 71 percent; with eight logs per turn - 76 percent; with ten logs per turn - 79 percent. The differences in production rates are reasonable given

Table 7. Summary of skidding elemental times and independent variables.

Element		Time (min)
Position	Max	.48
	Min	0
	Mean	.29
Hook	Max	4.40
	Min	.15
	Mean	1.69
Travel Loaded	Max	1.58
	Min	.35
	Mean	.77
Unhook	Max	2.41
	Min	.25
	Mean	1.04

Element		Time (min)
Deck	Max	5.00
	Min	0
	Mean	1.14
Travel Unloaded	Max	.80
	Min	.15
	Mean	.36
Delay-free time	Max	11.80
	Min	1.70
	Mean	5.16
Number of Observations		108

Independent Variable		
Number of Decks	Max	2
	Min	1
	Mean	1.15
Distance (feet)	Max	350
	Min	140
	Mean	222.73
Logs/turn (pieces)	Max	8
	Min	1
	Mean	4.51
Volume/turn (cubic feet)	Max	173.35
	Min	11.01
	Mean	62.73

this operator's skills.

The hooking and unhooking times were a substantial portion of the skidding cycle. The method used was to unhook from the yarder and rehook with the skidder's chokers. Alternate hooking methods, such as choker transfers or a grapple arrangement would reduce this time. A grapple machine with a winch addition would increase the efficiency of the swing and sort operation and still allow for roadside yarding.

Even at the actual production rates observed, the skidder has the capacity for an additional five cunits per hour above yarding production rates. This suggests that the skidder could be used elsewhere about 70 percent of the time. During the study the skidder operator made his own decisions as to how time was allocated to various tasks. A large portion of his time was spent chasing for the yarder, and limbing or bucking logs at the landing; other tasks included skidding turns close to the road, helping with yarding lines, clearing landing areas, and moving or repositioning the yarder.

Olsen's (1981) method of optimal crew size determination indicates that the addition of the skidder to the yarding system may not be the optimal choice in terms of yarding cost per cunit. This determination assumes all the logs on the unit can be yarded without interruption and prerigging, landing changes, and corridor layout is not charged to the operation. The benefit of adding a skidder and operator is probably not from increasing actual yarding production but rater by allowing a smoother overall operation. As mentioned, the setting conditions, i.e., area, stem removal, log diameters, and decking conditions may make a skidder or loader necessary or beneficial.

THE YARDING MODEL - an extension of regression

Numerous problems were observed at the log deck during the study. The short, stationary tower and several setting attributes were identified as being largely responsible for these problems which, in several cases, severely slowed or stopped production. A small computer model was developed to find out how these variables affected the yarding of the setting (Appendix B). The model uses the setting and rigging geometry to determine the number of logs that the landing can handle before becoming "jammed". It uses stand characteristics in conjunction with a regression equation to calculate production rates. It must be recognized that this is only a planning aid that will give estimates for the manager who is not experienced in dealing with the small machinery and logs. Since the model deals with averages (regression inputs) it cannot give precise answers.

The methodology for the calculations in the model is as follows:

1. Calculate available decking space.

This calculation requires the landing and rigging geometry, including the tower height to the skyline sheave, chordslope, landing chute slope, log diameter, and choker length (Figure 9). An assumption is made that the distance the skyline deflects with the load is negligible because of the load's proximity to the landing. In actual conditions the sag at this point will vary with the payload, its position, the span length and the tightness of the skyline. Observed deflections close to the landing during the study were not significant with the payloads encountered.

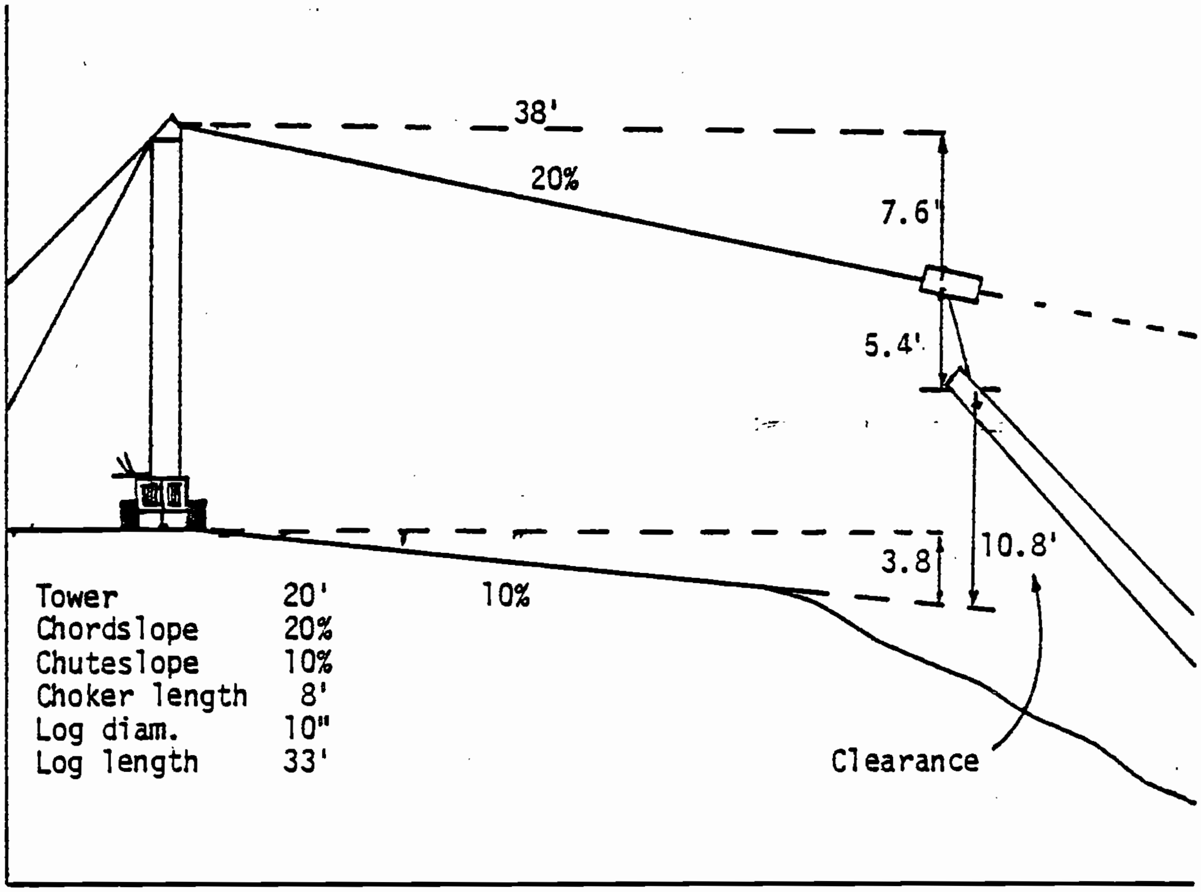


Figure 9. Landing geometry for decking calculations.

The relationship of the chordslope relative to the landing slope can be the cause of decking congestion. When the chute slope is similar to the chordslope there are fewer problems. If, however, the slope is greater than 20 percent the Oregon Safety Code (1980) does not permit decking in the chute "if a chaser is required to unhook the rigging from the logs or if workers are working below the landing chute and are exposed to rolling or sliding logs". If the chute is level the end of the turn will catch on the end of the deck.

Three adjustments are made from the tower height: 1) reduction because of chordslope, 2) reduction from choker length, and 3) addition or subtraction due to chute slope. The limiting distance between the ground and the leading end of a turn is the clearance. After clearance is determined the number of logs that the landing will hold is calculated. The stationary tower builds decks having triangular end areas. The availability of a chaser to peavy the logs to the side will allow for a few more turns. This information along with the clearance and available deck width allows the model to build the deck one row at a time reducing each row by the number of logs necessary to have the peak log at the calculated clearance.

2. Yard the setting turn by turn.

Yarding the setting is accomplished using the regression inputs of average lateral distance, logs per turn, and cubic foot volume per turn. The number of logs on the setting and corridor length allow slope yarding distances for each turn to be calculated and the deck height is increased, providing the remaining information to the regression equation for turn time calculations. Production estimates are then calculated and adjusted for yarding efficiency - this is a blanket reduction in the productive time for delays or crew efficiency.

Comparisons of the calculated yarding with actual field results with the Koller tower are shown in Table 8. An example run is shown in Appendix B. In three cases the model predicted when blockages would occur at the landing. Examination of the output shows several factors to be important in determining whether or not the unit can be logged without some sort

Table 8. Model comparison with field results.

Corridor No.	Actual Slope dist.	Calc. Slope dist.	Actual logs Yarded	Calc. log Yarded
8	773	394	415*	212
9	719	710	370	365
10	770	737	276	264
14	289	269	110	103
17	679	678	240	240
22	400	371	162**	150
25	340	339	175	174
27	201	172	166**	142
28	280	284	84	85

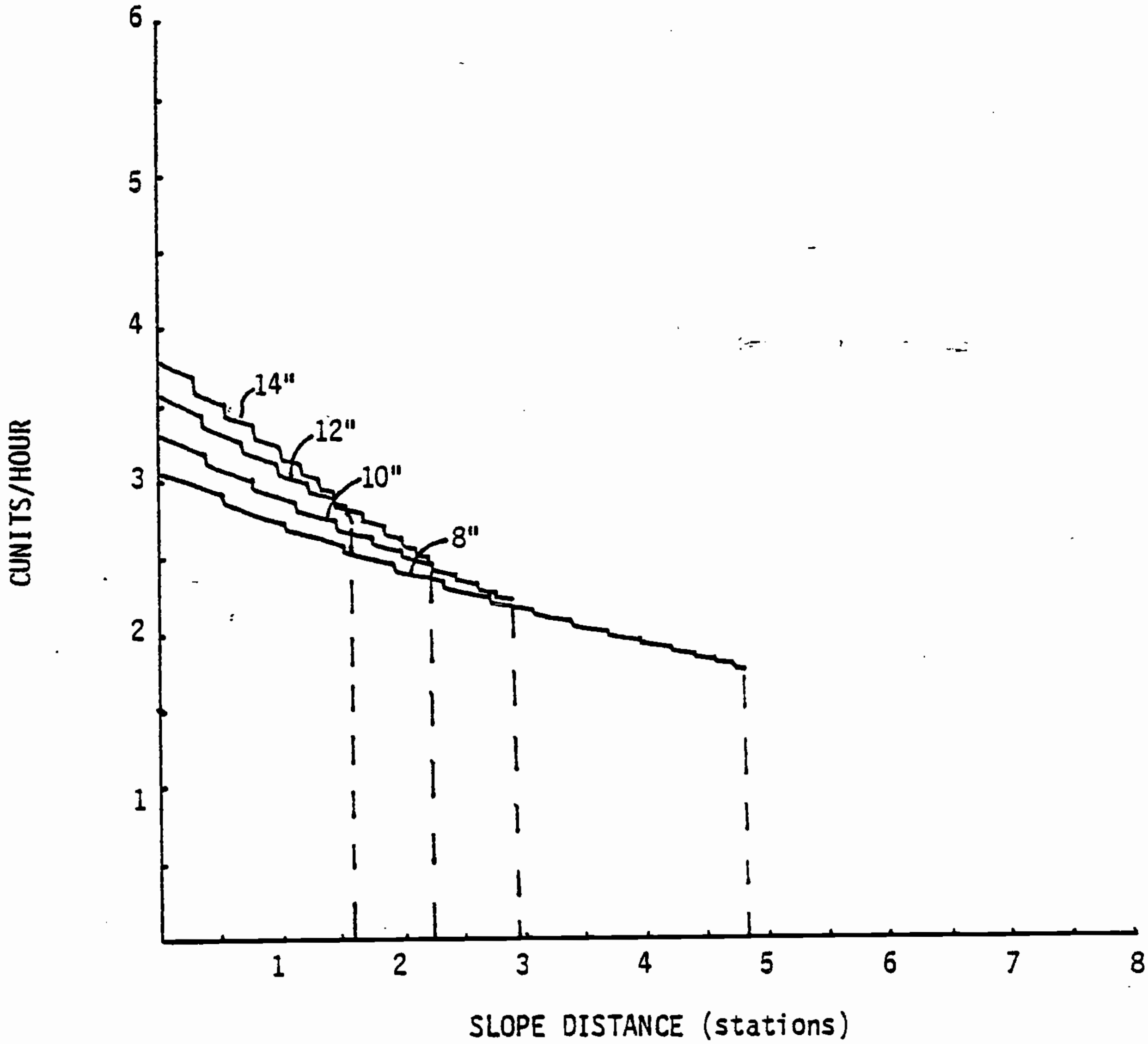
* On this unit yarding was stopped and logs removed and an intermediate support was rigged to give move clearance.

**Extensive sideblocking and use of the peavy was necessary to complete yarding.

of delay. The controlling factor is decking space. If clearance is small the number of logs will be reduced. Higher log diameters reduce the number that will fit in the same decking area. A large factor is the number of stems per acre removed; higher removal densities cause the deck to build up at shorter slope distances. The effects of these factors on yarding production at various slope distances are shown graphically along with the impact of deck height in Figures 10, 11, and 12.

The model should produce reasonable results for yarders with short fixed towers such as the Koller. Because of the deck building function and the small deflection assumption, results would have large errors if used with larger swing-boom yarders.

Figure 10. The effect of log diameter on yarding production.



Production begins at the highest rate for large diameters but is reduced much faster than smaller diameters because of deck space.

Figure 11. The efect of stem removal/acre on yarding production.

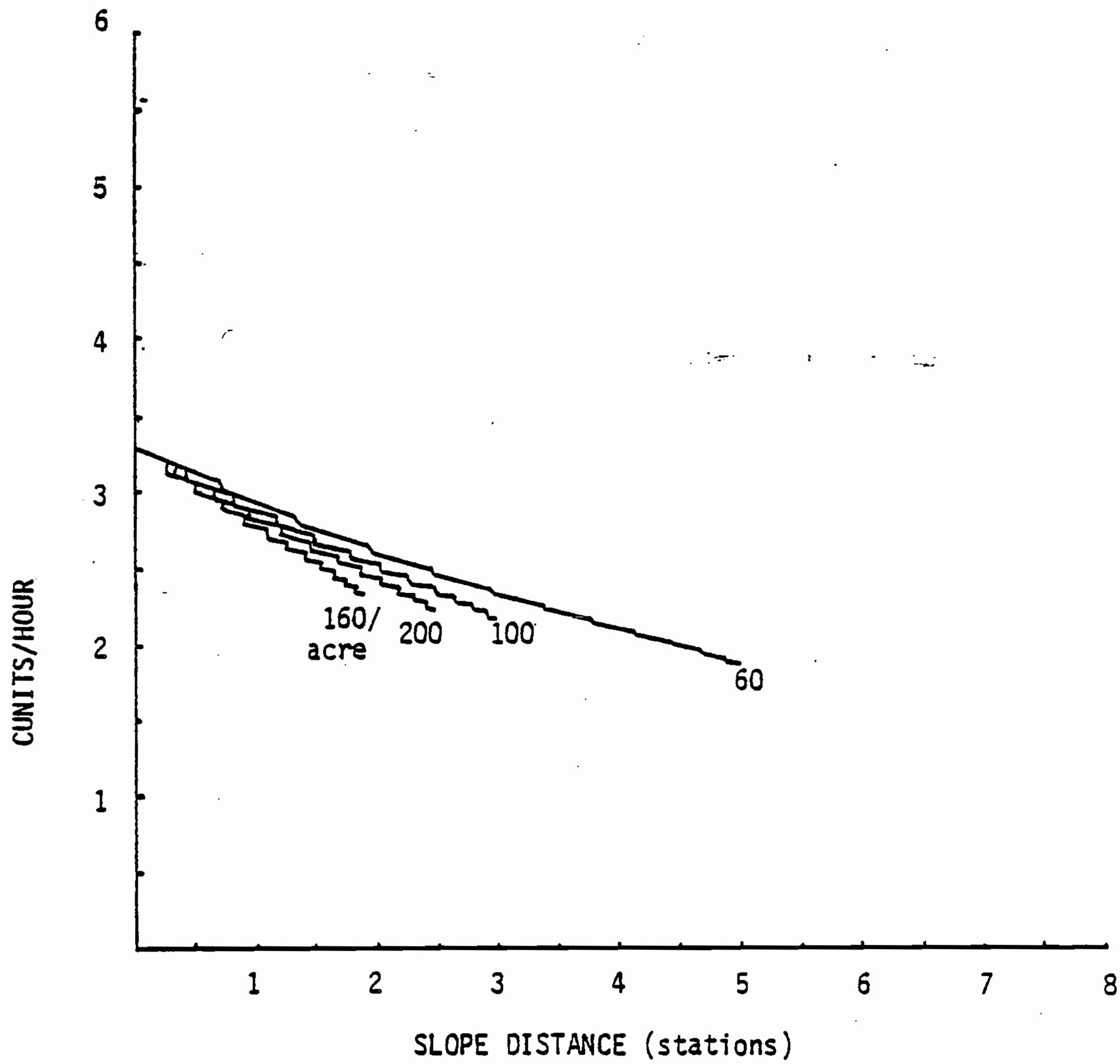
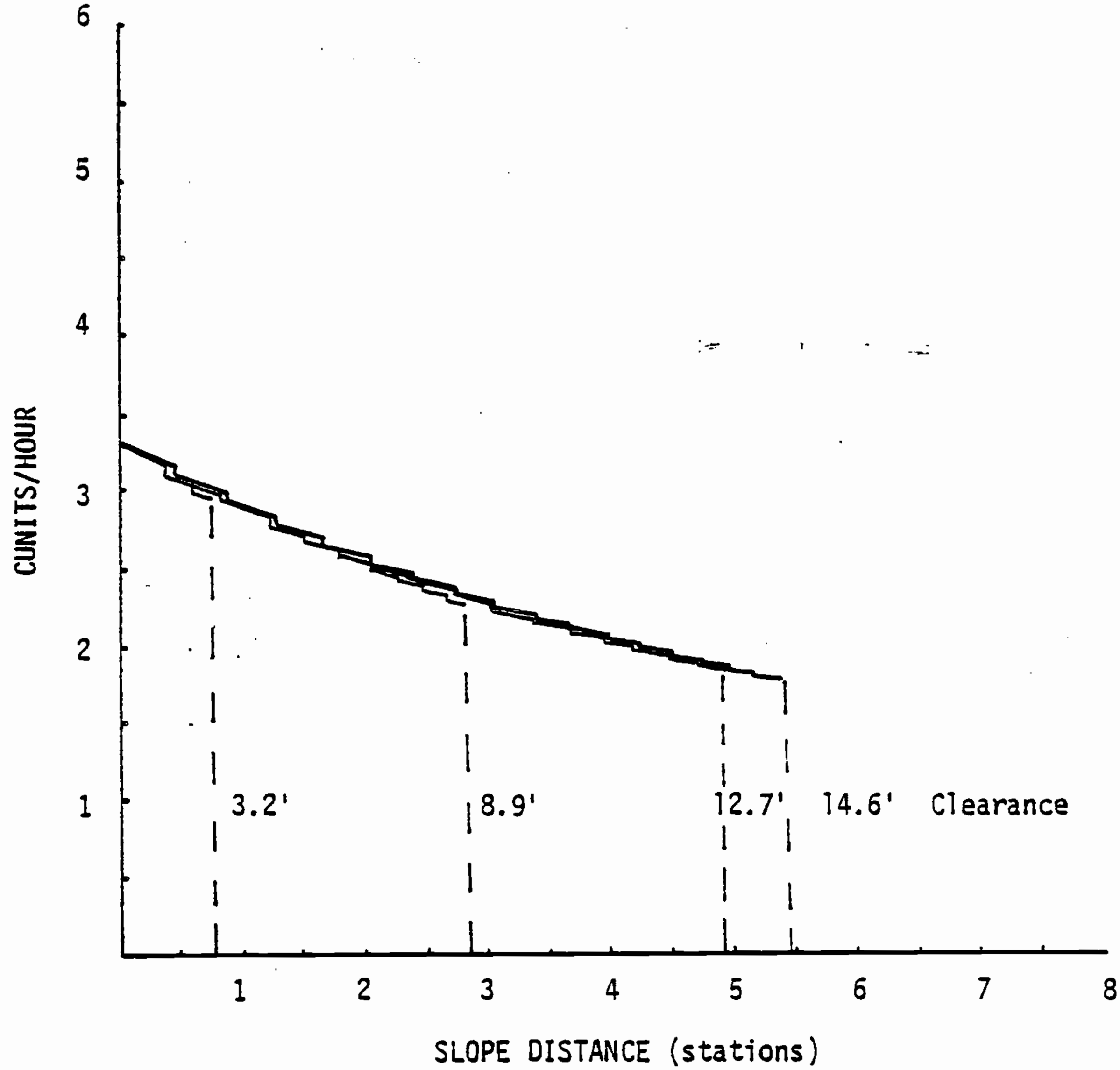


Figure 12. The effect of decking clearance on yarding production.



COST EFFICIENCY OF THE SKIDDER

An examination of actual hourly production rates for the Koller show the feasibility of cost effectiveness.

Skyline *Configuration	Crew Size	No Skidder (ft^3)	Skidder (ft^3)
Single-span	2	152.77	192.94
	3	174.39	225.37
Multispan	2,3,4	168.29	197.92

* After Olsen (1981) - Production is for a 300' average yarding distance.

A comparison of cost per cunit (ct) for various crew and machine combinations shows that the skidder can be a cost effective alternative if working for the yarder only a portion of the time. Both yarding and loading costs are affected by the use of the skidder. Individual equipment costs are in Appendix D.

The 14 minute reduction in loading time per load when loading from skidder built decks for the study conditions may be considered actual savings to the system. This reduces loading cost per cunit as follows:

$$\frac{.23 \text{ hours}}{\text{load}} \times \frac{\$40.30}{\text{hr}} \times \frac{\text{load}}{8.9 \text{ ct}} = \$1.05/\text{cunit saved}$$

The extra cost of the skidder added to the yarding system must be offset by the increased production. Using costs and production rates for the two crews and skidder combinations, costs per cunit can be compared. If the full cost of the skidder is charged to yarding, the unit cost is not competitive to the system without a skidder:

Crew 2/3

1) Yarder and crew
2) Yarder and skidder and crew

1) $\frac{\$41.92/hr}{1.53 \text{ ct}/hr} = \$27.40/ct$

2) $\frac{\$71.04/hr}{1.93 \text{ ct}/hr} = \$36.81/\text{ct} - \$1.05/\text{ct} = \$35.76/\text{ct}$

The difference between the two systems is $8.36 per cunit higher when the full cost of the skidder is included. For the 3/4, crew combination the increased cost is $4.69 per cunit. As mentioned in the skidder analysis section, the high productive capabilities of the skidder would allow the operator to work in other capacities much of the time which may significantly reduce the cost to yarding. When charging only a portion of the skidder and operator cost to the system the lower unit cost makes the swing and sort operation an attractive alternative. Table 9 shows the cost per cunit with varying skidder time charged to the yarding operation.

Yarding crew With Skidder	% skidder time charged to system 20	30	40	50	60
			($/ct)		
3	23.69	25.20	26.71	28.21	29.72
4	26.10	27.39	28.69	29.98	31.28

Table 9. The cost per cunit with varying skidder time charged to the yarding operation.

If the skidder is used only 30 percent of the time, the choices become more competitive:

Yarding crew 2 and skidder and operator	- $26.25
Yarding crew 2	- 27.40
Yarding crew 3 and skidder and operator	- 28.44
Yarding crew 3	- 31.76

The comparisons above are specific to this study. Important factors influencing these costs must be considered when deciding which system to use in other situations. The possibility of scheduling self-loading trucks before or after the yarding shift may be a feasible alternative.

Delay-free cycle times between the two systems shows a very slow convergence between cost lines, but several factors cause costs for the yarder only side to increase at a much faster rate. For example, reducing the clearance space increases the effect of deck height on turn time thus increasing the slope of the cost curve at a much faster rate. Larger diameters and higher percentages of stem removals cause the same type of reaction. The other factor that determines which system has lower unit cost is the efficiency level (Figure 13). A higher percentage of delays in the operation reduces the effective yarding time raising the cost curve; in this comparison, it brings the costs closer together. A combination of these factors is shown in Figure 14. The smooth upper line represents increasing yarding costs

Figure 13. The effect of yarding efficiency on production rates.

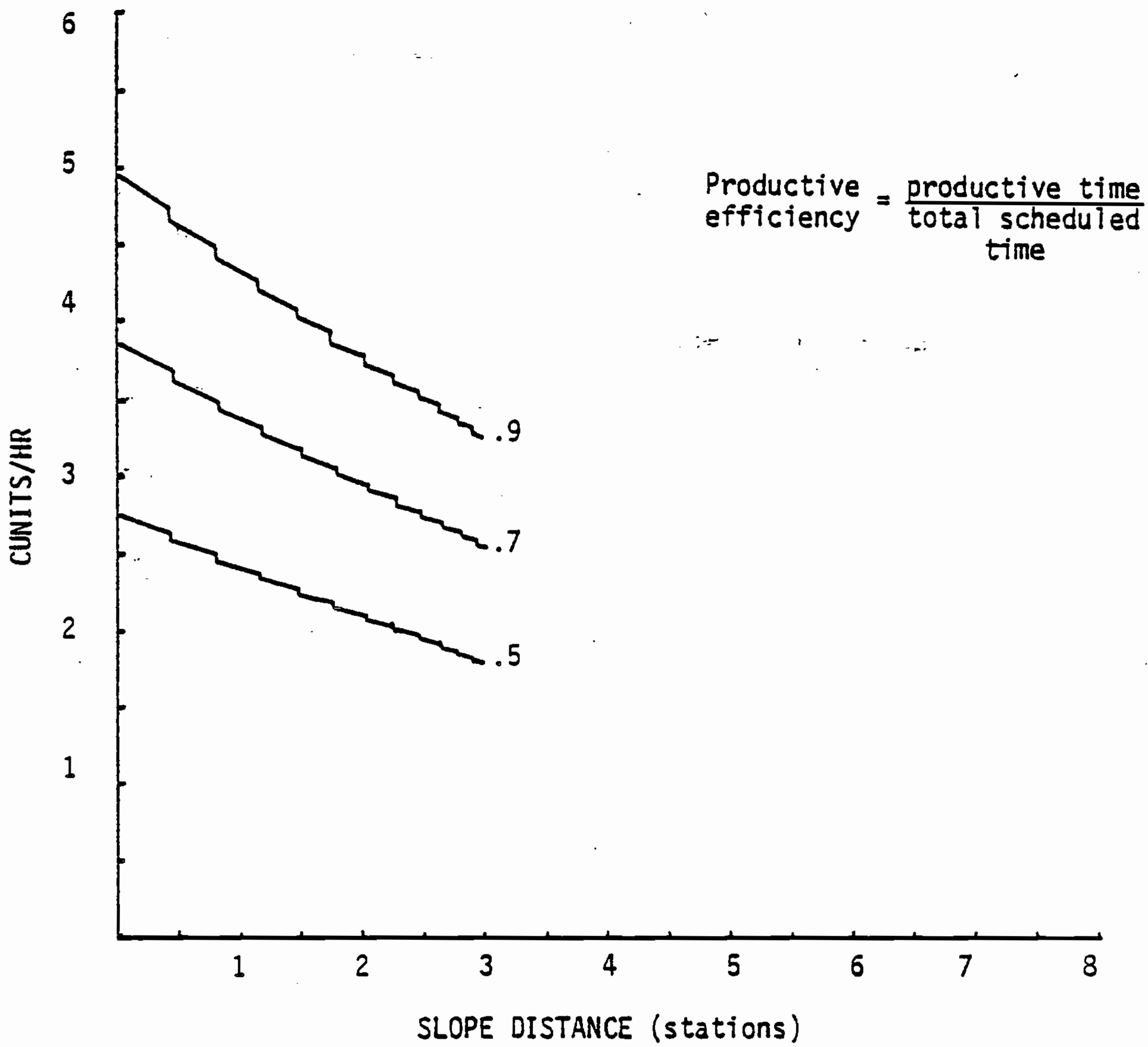
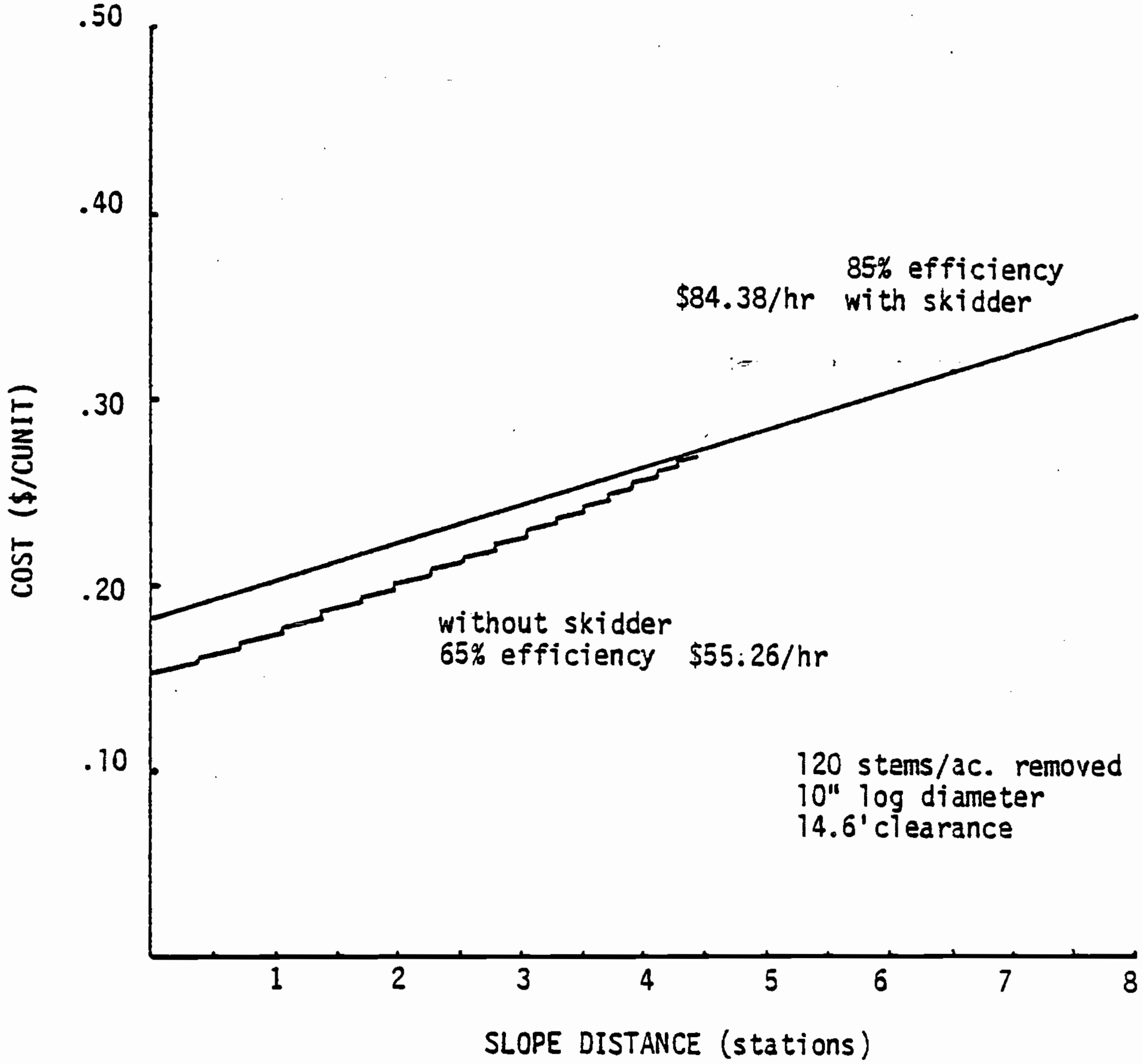


Figure 14. Cost comparison between the skidder plus yarder system and the yarder only system.



for the skidder aided side with 85 percent operating efficiency and an hourly cost of $84.38 per hour. The rough lower line is yarding cost for the yarder only side at 65 percent efficiency at an hourly cost of $55.26 per hour. This situation shows the single machine to be the best choice up to about 450 feet slope distance. The important factor is that the setting is 800 feet long and there are still 300 logs on the unit with no space on the landing. Since the efficiency levels vary between operations and removal rates, diameters, and landing geometry vary for each logging chance each comparison must be made individually.

SUMMARY AND CONCLUSIONS

This study tested the effect of a rubber-tired choker skidder on yarding and loading efficiency of small diameter Douglas-fir. The yarding, loading, and skidding systems were evaluated in detail with respect to swing and sort operations.

The portion of the yarding cycle that was affect by the swing and sort process was evaluated to see if yarding times were improved. The results showed that as yarding progressed on the unit the difference in time increased between the two systems. The skidder and operator provided a definite advantage to the inhaul, reposition, and unhook portion of the yarding cycle by keeping the deck clear. Landing delays as a percentage of delay-free yarding time were reduced from 24 percent to three percent with the availability of the skidder.

A detailed evaluation of the loading cycle was done on eleven truckloads from two decking configurations. The skidder was used to deck logs at roadside after sorting to reduce the amount of obstructions and sorting time. The control decks were built by the yarder during the normal course of yarding. A comparison of delay-free loading time per cycle indicated that 14 seconds per cycle or 14 minutes per load could be saved with the skidder. The portions of the cycle most affected were the sort and swing loaded elements. This implied that the deck orientation and pre-sorting by the skidder aided the operation. Regression analysis suggested that higher decks would also reduce loading time. Delays were relatively insignificant in proportion to the total loading time, but due to the high number of logs loaded per truck, extensions for the side stakes on the trailer would reduce delays from logs rolling off and possibly reduce loading time for the last portion of the load.

The swing and sort operation using a John Deere 440 choker skidder was studied to determine the important factors influencing cycle time and to quantify production rates. A mechanical engineering approach was used in conjunction with skid preparation times and compared with regression analysis results. The results showed that the skidder could handle between seven and eleven cunits per hour, leaving substantial time available for other tasks such as yarding, corridor layout, or pre-rigging. The engineering analysis showed that the skidder operator ran the skidder at 70 percent efficiency most of the time. This type of analysis could be useful in matching equipment (skidder and yarder) to other situations.

A yarding model was developed to show the influence of landing geometry and setting characteristics on yarding production. The effect of deck height appears to be a controlling factor where no swing machine is available. The most important variables of influence are landing slope relative to chordslope, log diameter, and stem removal per acre. The model can be used to determine if a setting can be logged without the need for a skidder or loader. Cost comparisons indicate that the skidder can be a cost effective solution to handling the log deck for small yarders if other activities are available or the decking geometry and setting conditions dictate its use.

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APPENDICES

APPENDIX A

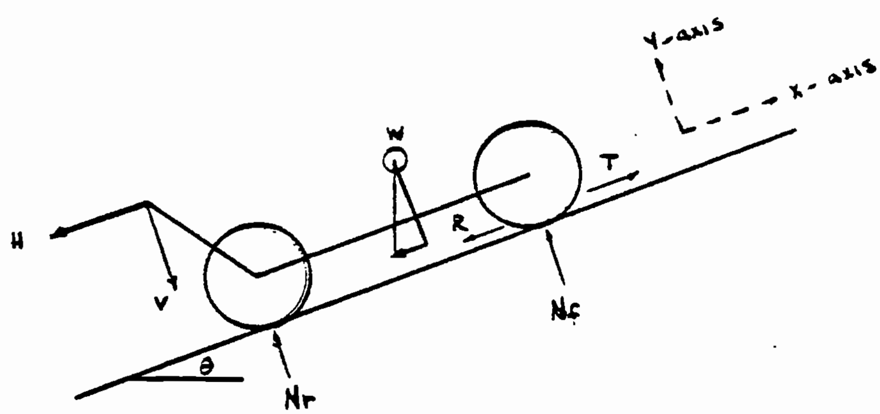
SKIDDING PRODUCTION FORMULATION

The following assumptions are made for the application of the Tractor Potential and Productive Capacity formulations by Fiske and Fridely (1975).

1. Constant output horsepower
2. Constant mechanical efficiency set = .80
3. Zero percent slip (Theoretical Velocity = Actual Velocity)
4. Arch skidding
5. Acceleration and deceleration are incorporated into maximum speed estimates. max V_L = 6 mph

   max V_E = 8 mph

Calculation of loaded velocities is best described by examination of the free-body diagram below:



where: W = Total skidder weight
R = Rolling resistance for all wheels, in pounds
N_f = Normal force on the front tires, in pounds
N_r = Normal force on the rear tires, in pounds
T = Thrust
H = Pull parallel to the ground, a component of the force exerted by the log.
V = Pull perpendicular to the ground, a component of the force exerted by the log.
θ = Ground slope

Summing forces in the x-direction for the loaded condition:

$$T = H + R + W(\sin\theta) \qquad (1)$$

Using Fiske and Fridely, the log drag forces are described as:

$$V = n\,Ws(\cos\theta) \qquad (2)$$

$$H = (1 - n)\,Cr\,Ws\,(\cos\theta) + Ws(\sin\theta) \qquad (3)$$

Where: n = a soil parameter
Ws = weight of the turn
Cr = coefficient of resistance to skidding

$Cr = 1.2 + 0.667 \tan\theta$ For arch skidding
$n = 0.5$

$$R = .04 \times (W\cos\theta + V) \text{ for an infinitely strong soil} \qquad (4)$$

Since mechanical efficiency M

$$M = \frac{(T)\ (V_L)}{(Hp)}$$

Rearranging we have

$$V_L = \frac{(Hp)\ (M)}{(T)} \qquad (5)$$

where: V_L = loaded velocity
Hp = Input horsepower

First substitute equation (2) into (4); then equations (3) and (4) into (1). Finally substitute (1) into (5) and the loaded velocity can be calculated.

$$V_L = \frac{(Hp)\ (M)}{(1 - n)\,Cr\,Ws(\cos\theta) + Ws(\sin\theta) + .04(W\cos\theta + nWs\cos\theta) + W\sin\theta}$$

Using the same conventions as before with θ empty = $-\theta$ loaded

Ws = 0 and drop out.

$$T = R + W\sin(-\theta)$$

$$T = .04\,(W(\cos(-\theta)) + W(\sin(-\theta)))$$

$$V_E = \frac{(Hp)\,(M)}{W\,(.04\cos(-\theta) + \sin(-\theta))}$$

Tractor Potential $E = \dfrac{Ws}{\dfrac{1}{V_L} + \dfrac{1}{V_E}}$

and

Productive capacity $WH = \dfrac{1}{\dfrac{D}{E} + \dfrac{Ts}{Ws}}$

where: D = skidding distance

Ts = Skid preparation time, i.e., hook, unhook, position, and decking.

Computer program for calculating skidder productivity.

```
10 DEG
20 DISP "W,H,M,N,V3,N1,D";
30 INPUT W,H,M,N,V3,N1,D
40 PRINT "SKIDDING PRODUCTION PROGRAM "
50 PRINT
60 PRINT "W="W,"H="H,"M="M
70 PRINT "N="N,"V3="V3,"N1="N1,"D="D
80 PRINT
90 PRINT "   %SLOPE      VELOCITY  VELOCITY  TURN       #LOGS      E          PROD."
100 PRINT "                  LOADED     EMPTY    WT                                CUFT/HR"
110 PRINT
120 FOR S=0 TO 15 STEP 3
130 K=0
140 FOR W1=4 TO 10 STEP 1
150 W2=W1*V3*33
160 K=K+1
170 T3=1.105131+0.692235*(N1)+0.446512*(K)+0.2398
180 T=ATN(S/100)
190 C=1.2+2/3*TAN(T)
200 P1=(1-N)*C*W2*COS(T)+W2*SIN(T)
210 P2=N*W2*COS(T)
220 R=0.04*(W*COS(T)+P2)
230 T1=P1+R+W*SIN(T)
240 T2=W*(0.04*COS(-T)+SIN(-T))
250 IF T1<0 THEN 280
260 V1=H*33000*M/T1
270 IF V1<528 THEN 290
280 V1=528
290 IF T2<0 THEN 320
300 V2=H*33000*M/T2
310 IF V2<704 THEN 330
320 V2=704
330 E=W2/(1/V1+1/V2)
340 V1=V1/88
350 V2=V2/88
360 W3=1/(D/E+T3/W2)*60/33
370 WRITE (15,380)S,V1,V2,W2,W1,E,W3
380 FORMAT 7F10.2
390 NEXT W1
400 NEXT S
410 END
```

Example calculation of Productive capacity using formula for

$$WH = \frac{1}{\frac{D}{E} + \frac{Ts}{Ws}}$$

SKIDDING PRODUCTION PROGRAM

W= 12400 H= 70 M= 0.3
N= 0.5 V3= 14 N1= 1.15 D= 222

%SLOPE	VELOCITY LOADED	VELOCITY EMPTY	TURN WT	#LOGS	E	PROD. CUFT/HR
0.00	6.00	8.00	2128.00	4.00	642048.00	996.05
0.00	6.00	8.00	2660.00	5.00	802560.00	1099.53
0.00	6.00	8.00	3192.00	6.00	963072.00	1181.34
0.00	6.00	8.00	3724.00	7.00	1.12E+06	1247.65
0.00	6.00	8.00	4256.00	8.00	1.28E+06	1302.49
0.00	6.00	8.00	4788.00	9.00	1.44E+06	1348.59
0.00	5.53	8.00	5320.00	10.00	1.53E+06	1379.32
3.00	6.00	8.00	2128.00	4.00	642048.00	996.05
3.00	6.00	8.00	2660.00	5.00	802560.00	1099.53
3.00	6.00	8.00	3192.00	6.00	963072.00	1181.34
3.00	6.00	8.00	3724.00	7.00	1.12E+06	1247.65
3.00	5.71	8.00	4256.00	8.00	1.25E+06	1297.19
3.00	5.22	8.00	4788.00	9.00	1.33E+06	1333.55
3.00	4.80	8.00	5320.00	10.00	1.40E+06	1364.13
6.00	6.00	8.00	2128.00	4.00	642048.00	996.05
6.00	6.00	8.00	2660.00	5.00	802560.00	1099.53
6.00	6.00	8.00	3192.00	6.00	963072.00	1181.34
6.00	5.47	8.00	3724.00	7.00	1.06E+06	1236.94
6.00	4.99	8.00	4256.00	8.00	1.15E+06	1281.26
6.00	4.58	8.00	4788.00	9.00	1.23E+06	1317.99
6.00	4.24	8.00	5320.00	10.00	1.30E+06	1348.93
9.00	6.00	8.00	2128.00	4.00	642048.00	996.05
9.00	5.89	8.00	2660.00	5.00	794005.38	1097.25
9.00	5.31	8.00	3192.00	6.00	896056.38	1166.30
9.00	4.83	8.00	3724.00	7.00	986634.70	1221.19
9.00	4.43	8.00	4256.00	8.00	1.07E+06	1265.87
9.00	4.09	8.00	4788.00	9.00	1.14E+06	1302.95
9.00	3.80	8.00	5320.00	10.00	1.21E+06	1334.22
12.00	5.80	8.00	2128.00	4.00	629924.21	991.39
12.00	5.21	8.00	2660.00	5.00	733657.00	1081.51
12.00	4.73	8.00	3192.00	6.00	834711.42	1150.32
12.00	4.33	8.00	3724.00	7.00	920132.77	1206.03
12.00	3.99	8.00	4256.00	8.00	996723.76	1251.05
12.00	3.70	8.00	4788.00	9.00	1.07E+06	1288.45
12.00	3.45	8.00	5320.00	10.00	1.13E+06	1320.03
15.00	5.18	8.00	2128.00	4.00	588652.34	976.73
15.00	4.68	8.00	2660.00	5.00	691130.91	1066.43
15.00	4.27	8.00	3192.00	6.00	781982.10	1135.97
15.00	3.93	8.00	3724.00	7.00	862959.17	1191.47
15.00	3.63	8.00	4256.00	8.00	935624.65	1236.79
15.00	3.38	8.00	4788.00	9.00	1.00E+06	1274.50
15.00	3.16	8.00	5320.00	10.00	1.06E+06	1306.36

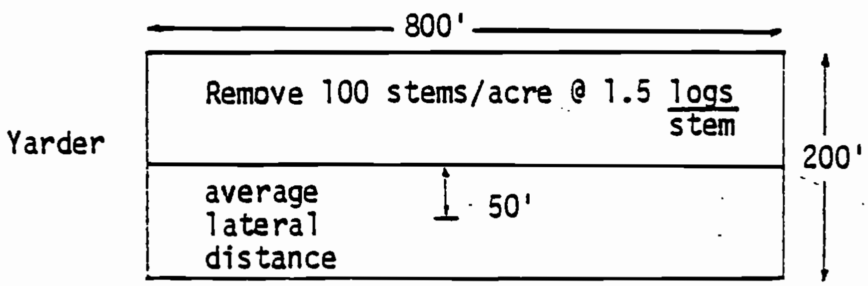
V3 = Volume/log
N1 = Number of sort decks
Other variables as defined previously

APPENDIX B

DECKING INFLUENCE ON YARDING PRODUCTION

The program will calculate deck height at any point in time, slope distance, turn time, cubic foot production per hour, number of logs decked, and cost per cunit. The program uses a regression equation that must match the operation to be evaluated. Equations developed during this study for various crew sizes (without skidder aid) are listed in Appendix C. A plot of cunits per hour vs. slope yarding distance is also available although graph limits may need to be changed.

Required Inputs:	Example
U = Unit number	1
Y = Yarding efficiency	.7
N = number of logs on the setting	550'
Y1 = corridor length	800'
D = log diameter	10"
L2 = log length	33'
T1 = tower height	20'
C1 = chordslope	.20
C2 = landing chute clope	.10
C3 = choker length	.8'
W = available deck width	25'
L = logs/turn	2
L1 = lateral distance	50'
V = Volume/turn	24
P = minimum acceptable production rate	0
C4 = hourly equipment and crew cost	54.83



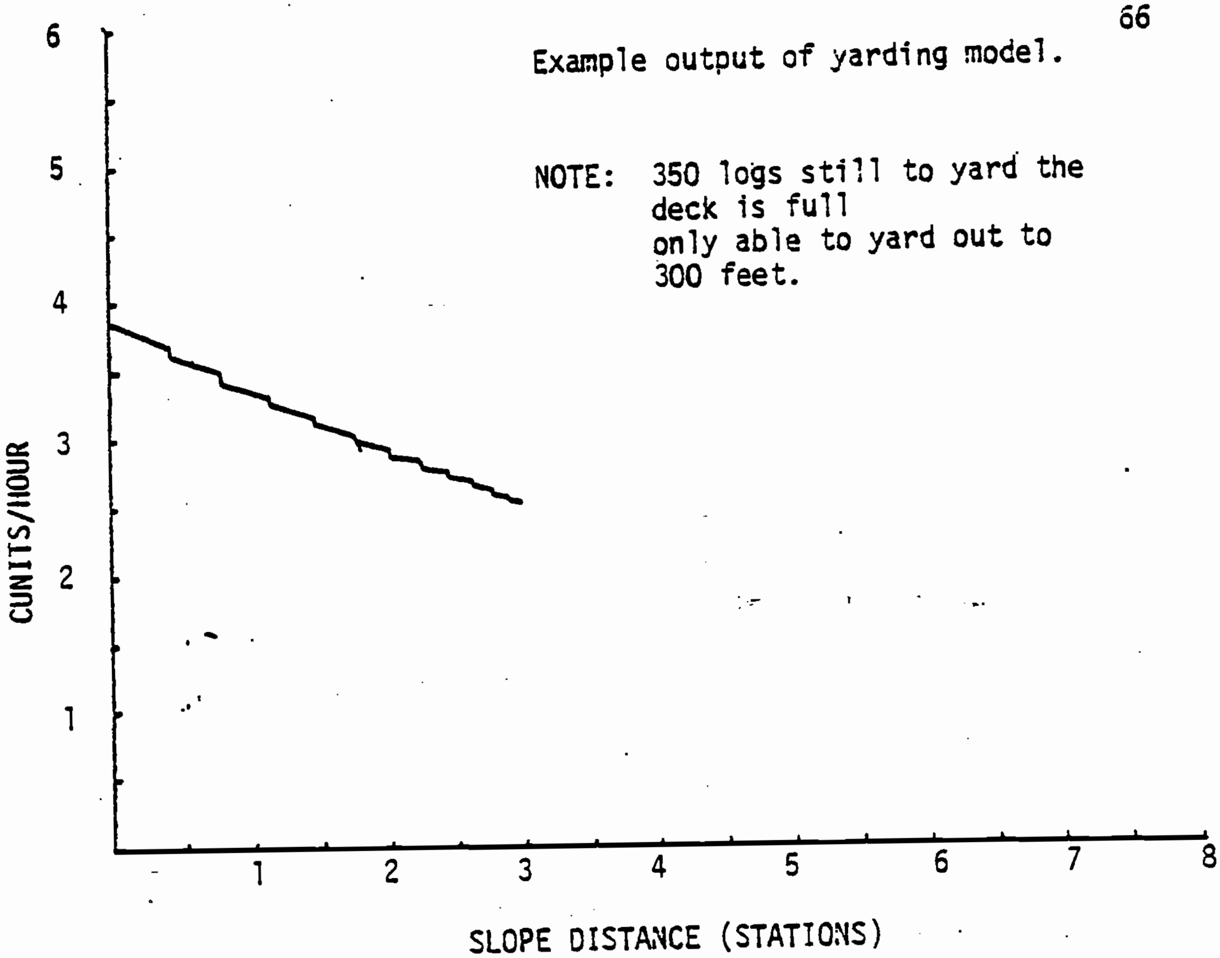
3.67 acres

∴ 550 logs on the setting

THE SMALLWOOD YARDING MODEL

```
10 REM PROGRAM SKID (PLOT,PROD-SYD)
20 DISP "UNIT NUMBER(U)";
30 INPUT U
40 DISP "Y,N,Y1,D,L2";
50 INPUT Y,N,Y1,D,L2
60 DISP "T1,C1,C2,C3,W";
70 INPUT T1,C1,C2,C3,W
80 DISP "L,L1,V,P,C4";
90 INPUT L,L1,V,P,C4
100 PRINT "SMALLWOOD YARDING PLANNING MODEL"
110 PRINT
120 PRINT "UNIT NO.="U
130 PRINT
140 PRINT "Y="Y;"N="N;"Y1="Y1;"D="D;"L2="L2
150 PRINT "T1="T1;"C1="C1;"C2="C2;"C3="C3;"W="W
160 PRINT "L="L;"L1="L1;"V="V;"P="P;"C4="C4
170 PRINT
180 SCALE 0,800,0,600
190 XAXIS 0,50,0,800
200 YAXIS 0,50,0,600
210 L3=0
220 D1=D/12
230 L2=L2+5
240 H1=T1-L2*C1+L2*C2-(C3-D1*PI)
250 H2=T1-(C3-D1*PI)
260 IF H1>H2 THEN 290
270 PRINT "CLEARANCE="H1
280 GOTO 300
290 PRINT "CLEARANCE="H2
300 PRINT
310 PRINT " DECK'     SLOPE    TURN   CU.FT.   LOGS      COST"
320 PRINT "HEIGHT  DISTANCE  TIME   PER HR  DECKED    CUNIT"
330 PRINT
340 N1=W/D1
350 N2=H1/D1
360 N3=N1/N2
370 N3=INT(N3)
380 K=0
390 K=K+1
400 IF K>N2 THEN 590
410 N1=N1-N3
420 N4=N1
430 H=K*D1
440 X=N4-L
450 N4=X
460 L3=L3+L
```

```
470 S=Y1*L3/N
480 T=0.450291+0.00736944*V+0.0176626*L1+0.529121*L
485 T=T+0.00282149*S+0.0564319*H
490 T=T/Y
500 P1=60/T*V
505 C5=C4/P1*100
510 PLOT S,P1
520 IF P>P1 THEN 630
530 IF L3>N+2 THEN 600
540 IF X <= 0 THEN 570
550 IF H>H1 THEN 600
560 GOTO 440
570 WRITE (15,650)H,S,T,P1,L3,C5
580 GOTO 390
590 PRINT
600 WRITE (15,650)H,S,T,P1,L3,C5
610 PEN
620 STOP
630 PRINT "SKID OR LOAD"
640 PEN
650 FORMAT F5.1,F11.2,F7.2,F8.2,F7.0,F8.2
660 END
```



SMALLWOOD YARDING PLANNING MODEL

UNIT NO.= 1

Y= 0.7   N= 550   Y1= 800   D= 10   L2= 33
T1= 20   C1= 0.2   C2= 0.1   C3= 8   W= 25
L= 2   L1= 50   V= 24   P= 0   C4= 55.26

CLEARANCE= 10.81799388

DECK HEIGHT	SLOPE DISTANCE	TURN TIME	CU.FT. PER HR	LOGS DECKED	COST CUNIT
0.8	40.73	3.90	369.17	28	14.97
1.7	78.55	4.12	349.49	54	15.81
2.5	113.45	4.33	332.70	78	16.61
3.3	145.45	4.52	318.28	100	17.36
4.2	174.55	4.71	305.81	120	18.07
5.0	200.73	4.88	294.99	138	18.73
5.8	224.00	5.04	285.57	154	19.35
6.7	244.36	5.19	277.36	168	19.92
7.5	261.82	5.33	270.21	180	20.45
8.3	276.36	5.46	263.97	190	20.93
9.2	288.00	5.57	258.57	198	21.37
10.0	296.73	5.67	253.90	204	21.76
10.0	296.73	5.67	253.90	204	21.76

APPENDIX C

REGRESSION EQUATIONS FOR KOLLER

WITHOUT SKIDDER

CREW 4 (10,22,25)

Time = .037302
+ .0027979 (SLPDIST)
+ .0182247 (LATDIST)
+ .509236 (LGSTURN)
+ .0911757 (DECKHT)
+ .00796932 (TURNVOL)
R^2 = .5212

CREW 3 (8,14,28)

Time = .4502091
+ .00282149 (SLPDIST)
+ .0176626 (LATDIST)
+ .529121 (LGSTURN)
+ .0564319 (DECKHT)
+ .00736944 (TURNVOL) **
R^2 = .4476

CREW 2 (9,17,27)

Time = .584083
+ .0034641 (SLPDIST)
+ .0152292 (LATDIST)
+ .427251 (LGSTURN)
+ .0665714 (DECKHT)
+ .0178205 (TURNVOL)
R^2 = .4284

WITH SKIDDER

CREW 5 (34s)

Time = .0741916
.00466162 (SLPDIST)
.0245706 (LATDIST)
.293742 (LGSTURN)
.00759683 (TURNVOL) *
R^2 = .6675

CREW 4 (33s,13s,18s)

Time = .612107
.00296974 (SLPDIST)
.0173265 (LATDIST)
.499394 (LGSTURN)
.00788264 (TURNVOL) **
R^2 = .4526

CREW 3 (19s,20s,21s)

Time = .922269
.00275107 (SLPDIST)
.0117850 (LATDIST)
.449032 (LGSTURN)
.0256433 (TURNVOL)
R^2 = .4697

* significant at the .20 probability level
** significant at the .10 probability level

COMBINED EQUATION FOR PREDICTING TURN TIME FOR THE KOLLER YARDER.

Delay-free turn time = 1.3969
(minutes)

Coefficient	Variable	MAX	MIN	MEAN
.00391347	(SLPDIST)	790	0	314.26
.0178717	(LATDIST)	200	0	36.63
.429317	(LGSTRN)	5	0	1.87
.0151707	(TURNVOL)	77.9	1.7	23.22
-.381483	(NHOOKERS)	1 or 2		Choker setters
-.0941052	(LDGCREW)	1 or 2		Landing crew
-.307468	(DMYSKID)	0 or 1		Skidder = 1 No skidder = 0

R^2 = .5369

MSE = 1.04

N = 1485

APPENDIX D

Hourly Yarding Costs - Koller Tower and Radio Set

Koller		
New Cost (CN) with carriage, and rigging	43,000	
Salvage Value (SV) (4 yrs, 20%)	8,600	
Net Cost	34,400	
Radio		
New Cost	4,000	
Salvage Value (4 yrs, 10%)	400	9,000
Net Cost	3,600	38,000
Average Investment (AI) = $\frac{CN + DEP + SV}{2}$		32,750
Fixed Cost		
Yarder Depreciation (4 yrs)	8,600	
Radio Depreciation (4 yrs)	900	9,500
Interest 15% of AI	4,912	
Insurance 3% of AI	983	
Taxes 3% of AI	983	6,878
		16,378
Variable Cost		
Maintenance and Repair (50% of DEP)	4,750	
Fuel (1.6 gal/hr x 1600 hs)	2,560	
Lubricants, filters, grease (10% of Fuel)	256	
Miscellaneous rigging	450	8,016
		$8,016
TOTAL ANNUAL COST		$24,394
Hourly cost (1600 hrs/yr)		$15.24
Labor (one crew member)		
Wage + 40% benefit		$13.34

Hourly Cost for John Deere 440 skidder

New Cost	50,000
Less: Tire cost	5,000
Net Cost (NC)	45,000
Salvage Value (SV) (5 years, 20%)	4,500
Average Investment (AI) $\frac{(NC) + (DEP) + (SV)}{2}$	29,250
Fixed Cost	
Depreciation (net cost over 5 years)	9,000
Interest (15% of AI)	4,387.5
Insurance (3% of AI)	877.5
Taxes (3% of AI)	877.5
	$15,142.5
Operating Costs	
Maintenance and Repair (50% of Dep)	4,500
Fuel (1.5 gph x $1.00 x 8hr x 200 days)	2,400
Filters, grease, lubricants (50% of fuel)	1,200
Tires: 1 @ $1250.00	1,250
Cable: 150' of 3/4" @ 1.04	156
Miscellaneous rigging	600
	$10,106
TOTAL ANNUAL COST	$25,248.5
Hourly Operating Cost (1600 Hrs/Yr)	$15.78

Hourly Loading and Hauling Costs

Truck with Self-Loader and Trailer

New Cost (CN)	$100,300
Salvage Value (SV) (10 yrs, 20%)	20,060
Net Cost	80,240
Average Investment (AI) $\frac{(CN) + (DEP) + (SV)}{2}$	64,192
Fixed Cost	
Depreciation	8,024
Interest (15% of AI)	9,629
Insurance (3% of AI)	1,926
Taxes (3% of AI)	1,926
	21,505
Variable Cost	
Maintenance and Repair (100% of Dep)	8,024
Fuel (8gph x 2600 hrs x $1.00)	20,800
Lubricants, hydraulics, filters, grease (20% of fuel)	4,160
Tires 1 set @ $10,500	10,500
	43,484
TOTAL ANNUAL COST	$64,989.
Hourly Cost (2600 hrs/yr)	$25.00
Labor (operator) Wage + 40% benefit	$15.80 /hr
Total Hourly Owning and Operating Cost	$40.80 /hr