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TB25: The Effect of Stand Factors on the Productivity of Wheeled Skidders in Eastern Maine

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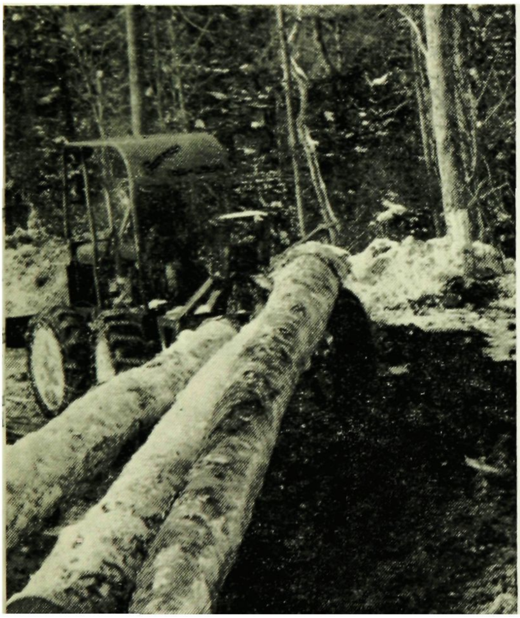

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CONTENTS

THE EFFECT OF STAND FACTORS ON THE PRODUCTIVITY OF WHEELED SKIDDERS IN EASTERN MAINE

Ernest B. Harvey, III[1]
Thomas J. Corcoran[2]

INTRODUCTION

In Maine, pulp and paper manufacturing is a most important industry. It accounts for over 27% of the total value of all products manufactured in the state, and utilizes more wood than all other wood-using industries combined (Larson, 1962)[3]

The pulp and paper industry of Maine owes its foundation and subsistence to the state's forest resources. Forest acreage comprises 87% of the state's total land area (Larson, 1962), and supports an annual harvest of over 2,000,000 cords of pulpwood (Maine Forest Service, 1964)[4].

In recent years much attention has been paid to the harvest of Maine's pulpwood crop. If it were not for advances in effective and efficient methods of harvesting, the source of supply that Maine's forests represent to the pulp and paper industry could not have been fully realized. Without continual effort toward updating the methods of converting the forest resource to the initial inputs of the paper making process, the pulp and paper industry could hardly expect to maintain the vital and thriving position it enjoys today.

From its earliest beginning to the present, harvesting in Maine has been labor intensive. With the advent of the chainsaw and through improved methods of direct transportation, equipment has steadily relieved the need for manpower and hand labor per unit of pulpwood product. However, traditional methods of harvesting have tended to become somewhat obsolete since they have not proved to be completely effective in their response to the demands placed upon them by shortages of labor, increased emphasis on costs, and greater productivity requirements.

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[2] Associate Professor of Forestry

[3] Larson, E. vH. 1962. *The forest wealth of Maine.* Maine Forest Service and N.E.F.E.S., U.S. Forest Service, 29 pp.

[4] Maine Forest Service. 1964. *Maine timber cut summary for* 1964. M.F.S., Augusta, Maine. 4 pp.

Mechanization in harvesting was inevitable, for it is widely recognized that the efficiency of woodland operations has not kept pace with that of primary and secondary wood-products manufacturing. With the realization of the role that harvesting plays both in the inherent quality and monetary value of today's final-mill products, strong advances in this technology have occurred and will continue to occur.

The most striking application of mechanization to harvesting in Canada has been in the form of rubber-tired skidders (Seheult, 1964)[5] Wheeled skidders have reduced pulpwood costs, increased labor productivity, and have made year-round operations possible. Stenzel (1963)[6] noted that in the northeast the cost savings resulting from the use of the rubber-tired skidders have been as high as 20%.

Mechanization, be it wheeled skidders or any other form, usually represents a large capital investment to the firm. Therefore, it becomes increasingly essential that the machines be utilized properly to insure an adequate return on the investments. The optimum employment of the skidder, or any other equipment, is not only a function of a proficient operator but also depends upon a knowledge of the degree of effect that factors inherent in a forest stand have on production rates. With dependable information about the relationship between operating conditions and equipment productivity, sounder planning of harvesting operations should be possible. Such planning would create more efficient, lower cost operations, which in turn means a lower cost resource to the mill.

The objective of this study was, therefore, to determine what forest stand factors, as they constitute a set of operating conditions, affect skidder and skidder crew productivity and the degree of their effect.

STUDY METHODS

This study was conducted on the mechanized tree-length harvesting operations of the St. Croix Paper Company[7]; where these activities provide approximately 71% of total pulpwood requirements of the company's mill at Woodland, Maine. The tree-length harvesting system used by the company has been termed a "hot-wood" operation with pulpwood moving from the stump to the mill on a continual basis. Usually, wood was delivered to the mill the same day it had been cut.

The harvesting operations were conducted under various stand

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[5] Seheult, L. R. 1965. *Pulpwood harvesting developments in* 1964. Woodlands Review, Pulp and Paper Magazine of Canada. pp. 208-212.

[6] Stenzel, G. 1963. *Mechanization increases in logging.* Forest Products Journal, XIII(11): 463-474.

[7] St. Croix Paper Company a division of Georgia-Pacific Corp.

conditions, on various types of terrain, and during all seasons of the year. However, each of these operations was performed basically under a fixed system. This system could be characterized by the use of a wheeled skidder for tree-length yarding, palletized hauling of 4-foot pulpwood, and a 5-man pulpwood production crew (exclusive of the pallet-truck operator). For the purposes of this study, one skidder and a 5-man crew operating on a specific area constituted a single operation.

Description of the operations

The roads on the operating area can be classified under two general types, permanent gravel and temporary bulldozed. The permanent roads, leading from the public highways, generally ran through the middle of a large cutting area with a gravel surface 20 to 24 feet wide and a right of way of 60 to 70 feet in width. The temporary roads were not graveled except under extreme conditions. The surface of these roads was about 11 feet wide with a right of way width of 30 to 40 feet. The temporary roads were generally about one-half mile apart, depending on the terrain.

The landing areas, to which the tree-length logs are skidded, were located predominately on the temporary roads but were occasionally situated on the gravel roads when it was advantageous. The landing areas were normally one-half mile apart on the roads, which limited maximum skidding distance to about one quarter of a mile. The landing spacing varied however, depending on the terrain. Each landing was typically oblong in shape and ranged from 100 to 150 feet in length and 75 to 80 feet in width. The area encompassed by a landing was regulated by the type of pallet body utilized. For example, a larger landing was required for the 32-foot pallet than for the 20-foot pallet.

Located on each landing were two pallet bodies of the same size. One of the bodies was used to bundle, for haul, rough spruce (*Picea glauca* (Moench) Voss), (*Picea rubens,* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.), the other for peeled hemlock (*Tsuga canadensis,* (L.) Carr.). When the 20-foot pallets were used, a trench was constructed below ground level to accommodate the pallet. This greatly facilitated loading since these pallets had to be loaded fairly high to obtain an 8-cord payload. Weight limited the payload of the 32-foot pallets to about 10 cords.

At each landing, a 5-man crew cut, skidded, and bucked the tree-length wood and loaded the 4-foot lengths onto the pallets. Each crew was normally composed of two fellers, a skidder operator, and two bucker-loaders. Because of accidents or other occurrences, the crew

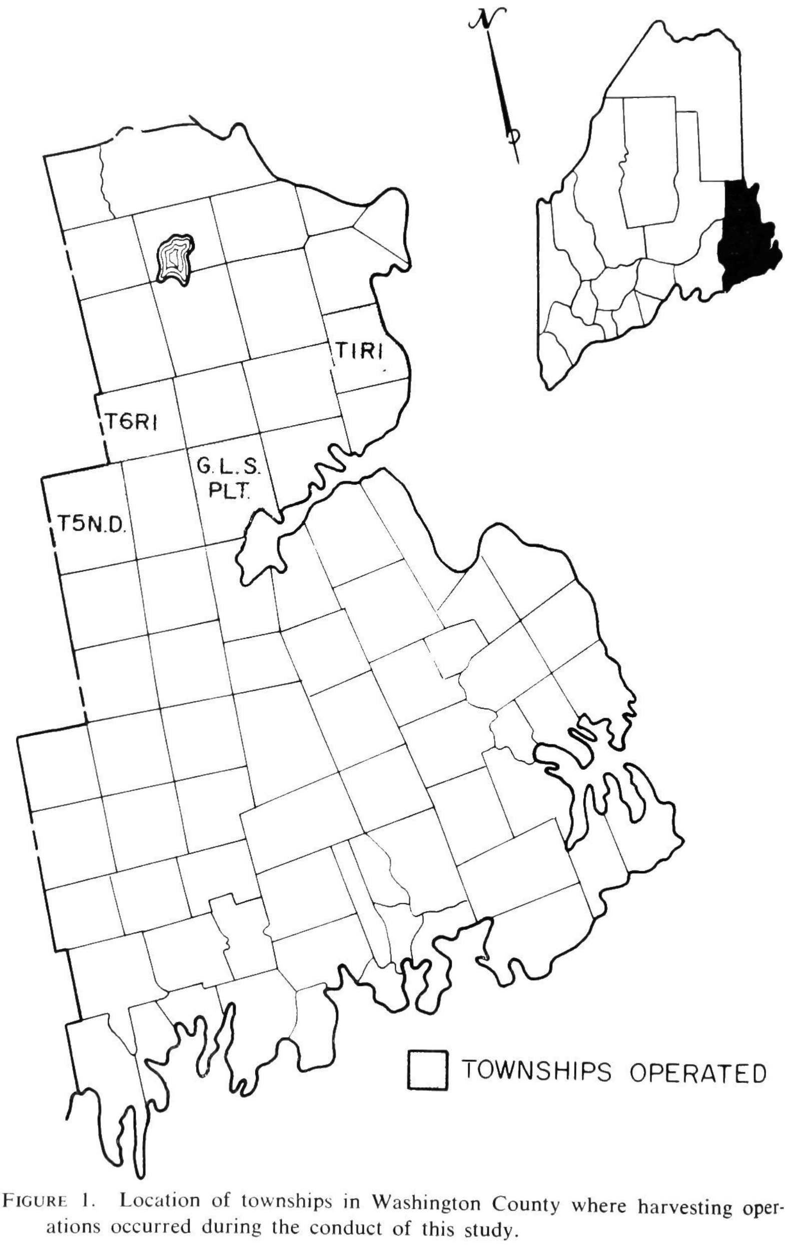

FIGURE 1. Location of townships in Washington County where harvesting operations occurred during the conduct of this study.

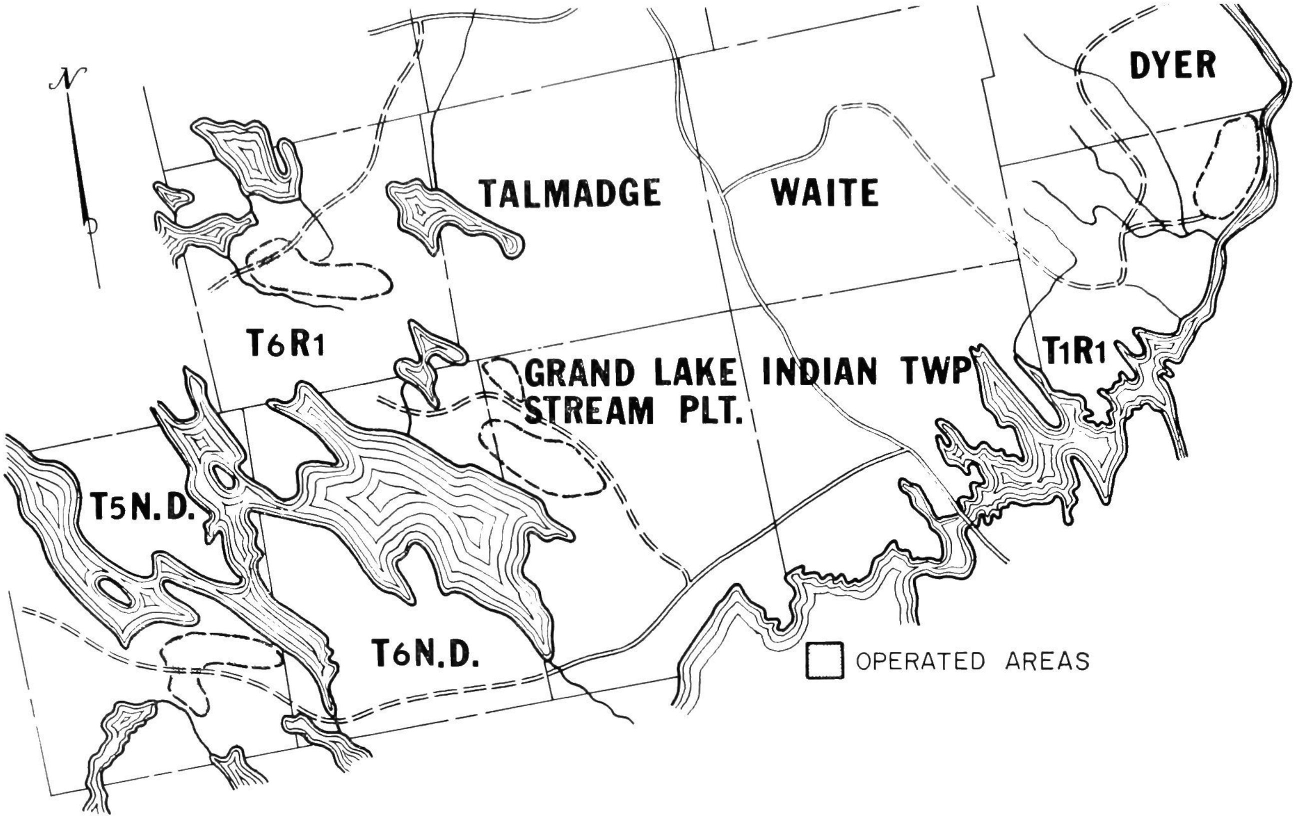

FIGURE 2. Location of operated areas from which data was collected.

size did occasionally vary from four to six men. These men were paid hourly wages, plus a bonus for production over specified weekly standards.

The wheeled skidder functioned as a transportation vehicle in moving the tree-length wood from the felled position at the stump to the landing. Each machine normally carried six choker chains, but its capacity in number of tree-length logs depended in most cases on how many trees the cutters had managed to fell during the skidder's absence. Choking was accomplished by the operator with the assistance of the fellers.

Description of operating areas

The harvesting operations investigated in this study were located in four townships of Washington County, Maine (figure 1). Detailed information as to location of the operations within townships is presented in figure 2. Species composition and other quantifying statistics for each township are presented in tables 1 and 2.

Township 1 Range 1. This area, located on the international boundary with Canada, was operated in the winter of 1965. The terrain in this area was on the whole level, with only a few small ridges; how-

Table 1. Stand composition by percentage of total volume per acre in total and merchantable stands for specified study areas.

	Species or Species Groups					
Study areas	Spruce	Fir	Hemlock	Hardwoods*	Pine**	Total
	(%)	(%)	(%)	(%)	(%)	(%)
Total stand***						
T1R1	22.7	47.6	4.3	24.0	1.4	100.0
T6R1	54.9	3.2	25.9	14.1	1.9	100.0
T5N.D.	34.5	15.9	31.2	16.2	2.2	100.0
G.L.S. Plt.	37.8	10.0	32.6	19.0	0.6	100.0
Merchantable stand****						
T1R1	28.2	64.1	7.7	——	——	100.0
T6R1	65.3	4.2	30.5	——	——	100.0
T5N.D.	39.2	20.3	40.5	——	——	100.0
G.L.S. Plt.	41.9	14.2	43.9	——	——	100.0

* All trees four inches and above in diameter (o.b.) at breast height.

** Includes only fir, spruce, and hemlock with minimum diameters (o.b.) of six, eight, and nine inches, respectively.

*** *Acer rubrum* L., *Acer saccharum* Marsh., *Betula Allagheniensis* Britton., *Betula papyrifera* Marsh., *Fagus grandifolia* Ehrh., *Populus grandidentata* Michx., *Populus tremuloids* Michx.

**** *Pinus strobus* L.

Table 2. Volume per acre, d.b.h., trees per acre, and basal area per acre for total and merchantable stands based upon data developed around individual landing locations within specified study areas.

Study Areas		Total Stand* Volume per acre	Total Stand* D.b.h. (o.b.)	Total Stand* Trees per acre	Total Stand* Basal area per acre	Merchantable Stand** Volume per acre	Merchantable Stand** D.b.h. (o.b.)	Merchantable Stand** Trees per acre	Merchantable Stand** Basal area peracre
		(cords)	(inches)	(number)	(sq. feet)	(cords)	(inches)	(number)	(sq. feet)
	All-landing								
T1R1	Average	23.6	8.0	398	96.2	13.0	8.8	139	45.6
	Range	14.5-34.3	6.3-9.6	145-548	52.5-139.2	5.9-26.3	7.8-10.7	65-208	22.5-94.2
	All-landing								
T6R1	Average	34.0	10.2	398	130.2	22.4	12.3	139	73.4
	Range	19.6-41.9	8.1-12.0	278-589	87.1-150.0	15.4-30.0	8.8-14.9	64-292	54.2-116.7
	All-landing								
T5N.D.	Average	35.7	10.1	432	138.9	22.4	11.6	123	71.7
	Range	25.7-47.1	8.1-12.5	306-589	100.8-168.3	10.4-36.5	9.4-13.5	53-205	32.5-118.3
	All-landing								
G.L.S. Plt.	Average	32.7	10.9	367	123.3	19.5	12.8	94	61.7
	Range	26.5-37.3	8.9-13.7	199-576	90.0-140.0	12.9-23.1	11.6-14.9	46-129	38.3-75.8

* All trees four inches and above in diameter (o.b.) at breast height.

** *Includes only fir, spruce, and hemlock with minimum diameters (o.b.) of six, eight, and nine inches, respectively.*

ever, there was no terrain which seriously inhibited the harvesting operation.

The stands on this area were typically second growth and were composed mainly of fir, spruce and hardwoods.

Township 6 Range 1. The operation on this area, begun in May of 1965, was conducted in steep rocky terrain which afforded very difficult operating conditions. The stands operated at this location were typically old growth and were composed mainly of spruce and hemlock.

Township 5 N. D. The terrain on this area presented widely varied operating conditions. On some of it very steep slopes were encountered while in other parts the terrain was fairly level with only a few swampy areas occurring. The stands on this area were both old growth and second growth; however, the composition was predominantly spruce and fir.

Grand Lake Stream Plantation. This operation also had varied terrain condition. On some of the area, very steep slopes were encountered while in other parts only gently rolling terrain was operated. Rocks were not a major problem for the most part; however, a few extreme conditions were found. The stands on this area were old growth and were composed predominantly of spruce and hemlock.

Data collection

The landing with its surrounding forest area and operating crew was the basic unit around which data was sought. The data collected from each of the 29 landing areas can be categorized into two types: data collected before and data collected after each landing operation commenced. In the first category, the data collected included stand information (volume per arce, trees per acre, basal area per acre, average DBH, and species composition) and also a subjective prerating on the difficulty of the operating chances. Information obtained under the latter category included: DBH of yarded trees, trees per load, man-hours per week, machine-hours per week, production per week and an operating condition rating.

Stand information was obtained by a systematic point-sampling cruise. A fixed number of 12 plots constituted the sample for each landing. This number was established from preliminary sampling results as approximating a relative accuracy of ± 10% with 70% confidence. The sampling area for each landing was defined as a circular area encompassed by a 20 chain (1320 feet) radius from the landing center. Since the cruise was intended to show timber volumes on merchantable areas only, any plots which fell in unmerchantable areas were systematically removed and replaced.

Production and work-hour figures were obtained from company weekly production summaries. Since production of hemlock was measured in peeled cords, it is necessary to divide by a conversion factor of .85 to put hemlock production in terms of rough cords.

Data analysis

The primary form of analysis used in this investigation was stepwise multiple regression, with specific emphasis on linear relationships employing a standard computer program to perform the computations. The reason for the use of stepwise regression is that it sequentially removes the independent variables which account for the greatest amount of variation in the dependent variable. This is particularly useful for exploratory research, such as this project, since it allows the testing of a large number of independent variables.

The computer was also utilized to prepare the cruise data for analysis. Using a program which was especially designed for this study to interpret the point-sampling cruise,[8] computer computations provided the stand characteristics previously mentioned for both the total and merchantable stand. These stand characteristics and the figures derived from them were considered to be the independent variables in the regression. The independent variables can be broken down into four classes: stand statistic variables, percent composition variables absolute composition variables, and unmerchantable species variables. The stand statistic variables include average DBH, volume per acre, trees per acre, and basal area per acre for both the total and merchantable stand. The composition variables represent the merchantable stand only and include the absolute and percent composition by volume per acre, trees per acre, and basal area per acre. The unmerchantable species variables represented the amount of unmerchantable species in the stand both on an absolute and percentage basis, by volume per acre, trees per acre. and basal area per acre.

There were two dependent variables, production per machine-hour[9] and production per man-hour, used in the regression. These figures were obtained from a summary analysis of the company's production records. The man-hours figure included the hours incurred by both the skidder operator and the persons operating as fellers and buckers.

RESULTS AND DISCUSSION

Using ten different sets of independent variables made up of the variable classes previously defined or combinations of these variable

[8] See appendix B.

[9] This figure excludes any downtime.

classes and the two dependent variables, 20 regression relationships were established. Preliminary analysis of these relationships indicated that four sets of the independent variables were representative of all other sets. The four sets of independable variables included:

(1) stand statistic variables (X_1 thru X_8);

(2) stand statistic and absolute composition variables in combination (X_1 thru X_{17});

(3) stand statistic, absolute composition, and percent composition variables in combination (X_1 thru X_{28}); and

(4) the unmerchantable species variables (X_{29} thru X_{34}).

See appendix A for a complete list of variables used in the regressions.

Although stepwise multiple regression was the main form of analysis used in this study, simple linear and partial regression were also used in this section to aid in the interpretation of the results. In conjunction with the simple linear regressions to be discussed, a t-test was conducted to determine if the slopes of the regression lines, shown in figures 3, 4, 5 and 10, differed significantly from zero. The results showed that only two regression lines were not significant (5%). These were for the regression of production per man-hour on the total and merchantable volume per acre; however, the results of these regressions are interpreted in subsequent discussion on the basis of their absolute slopes, to provide some generalized insight into relationships that may exist.

Stand statistic variables

Since the stand statistics are the variables most commonly associated with productivity, they will be discussed first as to their single effects on productivity and secondly as to their combined effects on productivity. To determine the degree of influence that each of these variables had on productivity, simple linear regressions were established for variables exhibiting significant correlation with productivity. By use of the correlation coefficients (table 3), it was possible to assess which variables were significantly correlated with productivity. Analysis indicates that only two of these variables were significantly correlated with production per machine-hour (hereafter referred to as PPSH), while four variables were found to be significantly associated with production per man-hour (hereafter referred to as PPMH). This suggests that productivity in terms of man-hours may be sensitive to a wider range of factors than was productivity in terms of machine-hours.

The two measure variables which affected PPSH were the average DBH of the total stand (X_1) and the average DBH of the merchantable stand (X_8). The results of the regressions of PPSH on these variables

Table 3. Correlation coefficients between the stand statistic variables, production per machine-hour and production per man-hour.

Variables	X_8	X_7	X_6	X_5	X_4	X_3	X_2	X_1	Y_2	Y_1
Y_1 - PPSH	.412*	.128	–.157	.188	.244	–.041	.288	.410*	.832**	—
Y_2 - PPMH	.397*	.306	–.011	.367*	.476**	.299	.446*	.291	—	—
X_1 - Avg. DBH Total Stand	.909**	.387*	–.319	.510**	.353	–.490**	.547**	—	—	—
X_2 - Total Vol./Acre	.591**	.802**	.264	.884**	.954**	.264	—	—	—	—
X_3 - Total Trees/Acre	–.223	.056	.225	.052	.446*	—	—	—	—	—
X_4 - Total Basal Area/Acre	.431*	.801**	.349	.842**	—	—	—	—	—	—
X_5 - Merch. Vol./Acre	.451*	.971**	.488**	—	—	—	—	—	—	—
X_6 - Merch. Trees/Acre	–.466*	.607**	—	—	—	—	—	—	—	—
X_7 - Merch. Basal Area/Acre	.307	—	—	—	—	—	—	—	—	—
X_8 - Avg. DBH Merch. Stand	—	—	—	—	—	—	—	—	—	—

* coefficients statistically significant at the 5% level.
** coefficients statistically significant at the 1% level.
degrees of freedom = 27.

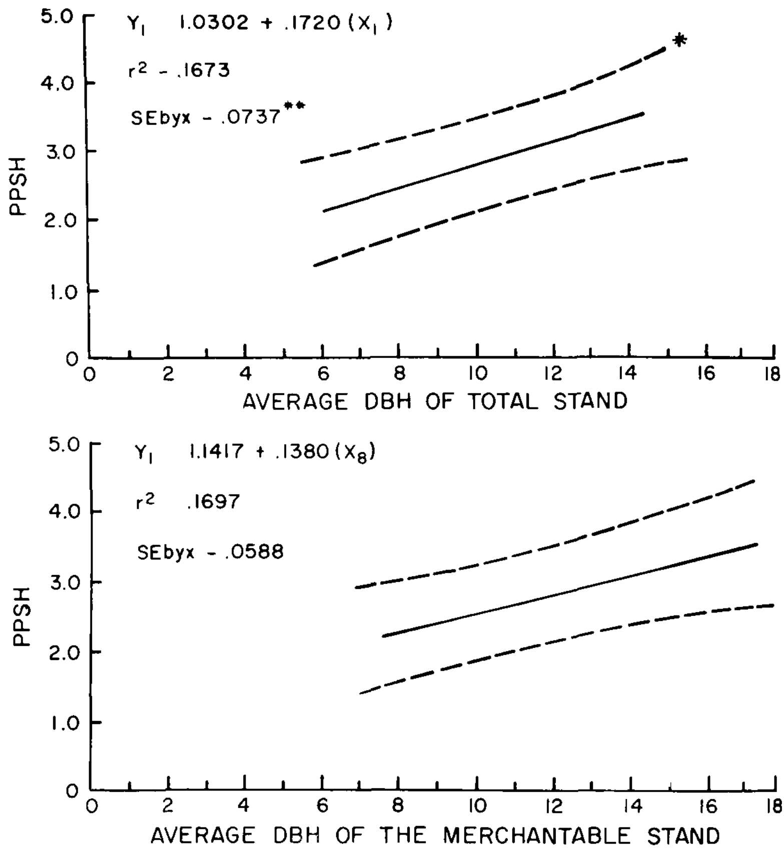

FIGURE 3. Average DBH of the total and merchantable stands as related to PPSH.

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* Confidence bands were calculated for one standard deviation. Unless otherwise noted, this holds true for all subsequent confidence bands.

** SEbyx is the standard error of the regression coefficient.

appear in figure 3. While neither variable accounts for a relatively substantial amount of the variation evident in PPSH, the average DBH of the merchantable stand appears to have the strongest effect. Also it should be noted that these two variables were closely associated (table 3), indicating that they both may provide a measure of the same phenomenon.

The four measured variables significantly associated with PPMH were: total volume per acre (X_2), total basal area per acre (X_4), merchantable volume per acre (X_5), and average DBH of the merchantable stand (X_6). The results of the simple regressions of PPMH on the above mentioned stand statistics appear in figures 4 and 5. In this case, total basal area per acre (X_4) had the strongest simple effect followed closely by the effect of total volume per acre (X_2). Since both of these factors were associated with the total stand, it may suggest that the total stand has a greater effect on PPMH than the merchantable stand. However, it should be noted that these variables were in themselves closely associated (table 3). As is evident, the merchantable stand factors account for very little of the variation in PPMH.

A reason for the response of PPSH to total or merchantable stand average DBH lies in the fact that DBH was instrumental in determining the volume of any given tree, therefore, the greater the diameter, the greater the volume.[10] In most cases, since a machine skids the same number of trees per trip, the greater the DBH the greater the volume skidded. The basal area per acre of the total stand which had the greatest single effect on PPMH was probably important because it measured the amount of land actually covered by wood. The more wood per unit area, the less delay time incurred, hence an increase in productivity. The reason for the effect of total volume per acre on PPMH was that volume per acre provided a direct measure of what was available to harvest. It seems reasonable to expect that as the volume per acre increases production will also increase. Also, it should be noted that total volume per acre is highly correlated with the total basal area per acre (table 3). The explanation of why the merchantable stand did not exhibit a stronger effect on PPMH is unclear, for it would seem reasonable to expect even a stronger relationship between PPMH and merchantable volume per acre than exists between PPMH and total volume per acre. One thing that this may suggest is that the stand volume harvested per acre was closer to the total stand volume per acre than the merchantable stand volume per acre because of the cutting practices used on the operations studied. However, it should be kept in mind that both of the variables had regression lines with non-significant slopes. Although the average DBH of the merchantable stand did affect PPMH, the degree of its influence on PPMH was somewhat less than that on PPSH. The reason for the response of PPMH to the average DBH of the merchantable stand was essentially the same as it was for PPSH.

The results of the analysis of single variable effects indicate that there is no stand statistic variable which is dominant in its effect on

[10] The volume table used in this study gave volume by diameter classes.

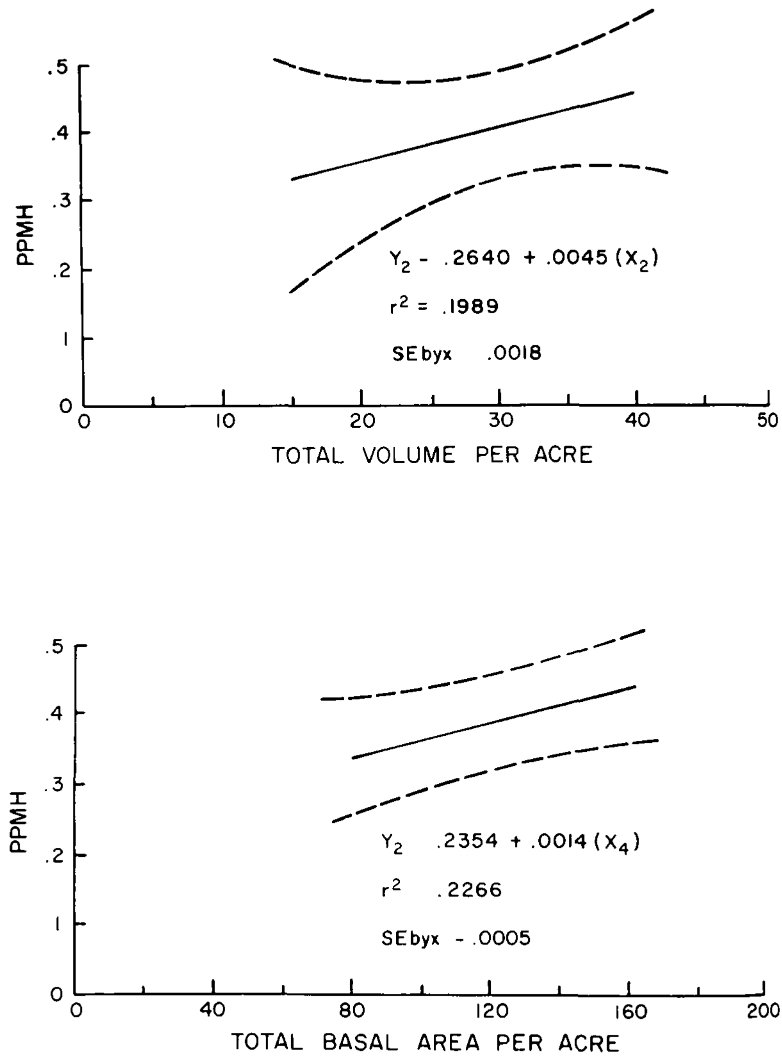

FIGURE 4. Total volume per acre and total basal area per acre as related to PPMH.

productivity. Although total basal area per acre has the greatest single effect of any stand statistic variable, it did not account for an appreciable absolute amount of the variation in productivity. It also appears that the output of the skidder is not responsive to as many factors as is the man-hours output.

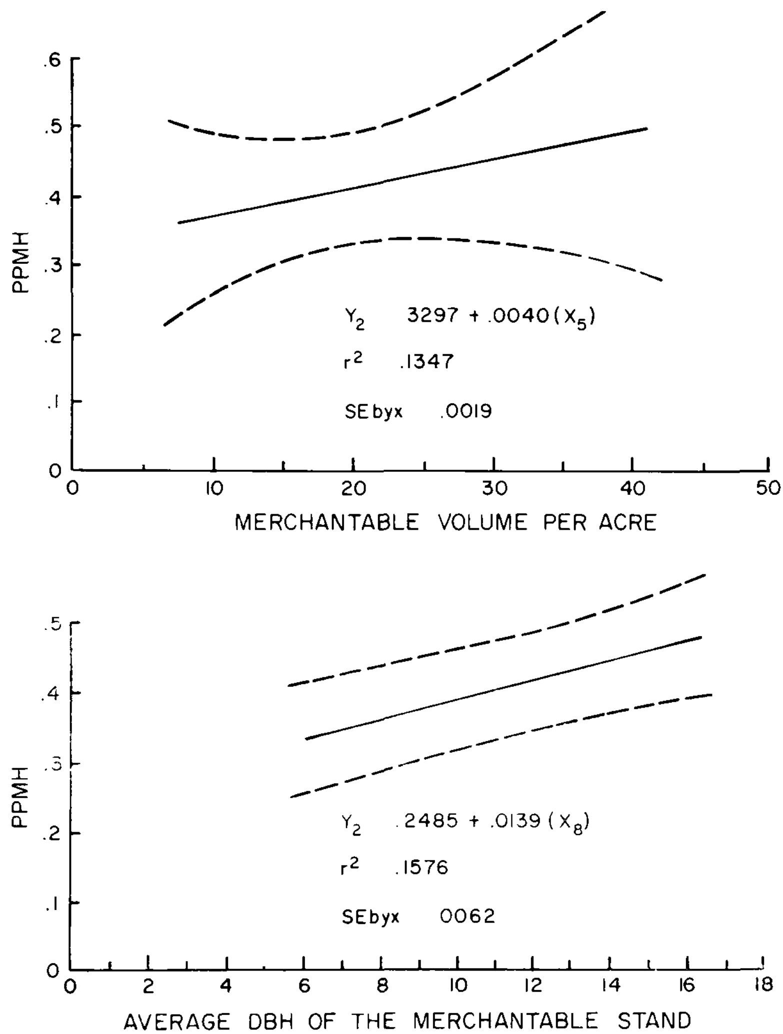

FIGURE 5. Merchantable volume per acre and average DBH of the merchantable stand as related to PPMH.

When all eight stand statistic variables were evaluated by multiple regression, results somewhat similar to the single effects were obtained. The regression of PPSH on stand statistics yielded only one variable, average DBH of the merchantable stand, with a significant F ratio. The same was true of PPMH, where total basal area per acre proved to be the only significant variable. The actual equations were as follows:

(1) $Y_1 = 1.1417 + .1380\ (X_8)$
$R^2 = .1697$
$SEbyx = .0588$
(2) $Y_2 = .2354 + .0014\ (X_4)$
$R^2 = .2266$
$SEbyx = .0005$

These relationships are identical to the ones found when the stand statistic variables were considered singly in relation to both production variables (figures 3 and 4). The other variables considered in the step-wise regression were excluded from equations (1) and (2) because they were non-significant at the 5% level or they followed a variable whose F ratio was not significant at the 5% level. Because of this, it would seem that the most important stand statistic variables affecting PPSH and PPMH respectively are the average DBH of the merchantable stand and the basal area per acre of the total stand.

Stand statistic and absolute composition variables

The results of the multiple regression of PPSH and PPMH on the combined stand statistic and absolute composition variables (X_1 thru X_{17}), established the same relationships which existed between PPSH, PPMH and the stand statistic variables (X_1 thru X_8). Again, average DBH of the merchantable stand and the basal area per acre of the total stand were found to be the significant factors affecting PPSH and PPMH respectively. Since these variables were removed in the first step of the regression, the equations were identical with those previously shown (equations 1 and 2). Because of this, it might be assumed that absolute composition of the stand has no effect on productivity when considered in combination with the stand statistic variables. Even when the absolute composition variables were considered singly as to their effect on productivity, there are only two which were even associated with productivity and then only to PPMH. The amount of variation accounted for by either of these variables was somewhat less than 15%.

Stand statistic, absolute composition and percent composition variables

When the three variable classes, stand statistics, absolute composition, and percent composition were combined into one set of independent variables, the outcome of the multiple regressions of PPSH and PPMH on these variables were entirely different from any previous results. The variables which proved to be significant were: percent fir in basal area per acre (X_{25}), cords per acre fir (X_{10}), trees per acre hemlock (X_{14}), basal area per acre fir (X_{16}), and percent fir in volume per acre (X_{19}). The equations for PPSH (Y_1) and PPMH (Y_2) are as follows:

$$(3)\ Y_1 \quad 2.900 + .0867(X_{19}) \quad .0945(X_{25})$$
$$(.0438)^{11} \quad (.0419)$$
$$R^2 = .3090$$
$$(4)\ Y_2 = .4538 + .0506(X_{10}) \quad .0011(X_{14}) - .0108(X_{16})$$
$$(.0155) \quad (.0005) \quad (.0050)$$
$$.0032(X_{25})$$
$$(.0008)$$
$$R^2 = .6449$$

Here again it can be seen that PPSH was not affected by as many factors as was PPMH, and that not much of the variation in PPSH was accounted for. However, a reasonable amount of the variation in PPMH was accounted for. Since equation (4) does account for a substantial amount of the variation in PPMH, it was broken down and each variable analyzed separately by use of partial regression. It was felt that by doing this some insight into what was occurring in the equation might be gained and one might ascertain what possible effects these variables might have on the harvesting system as a whole. The amount of variation accounted for in equation (3) is not particularly great; therefore, partial regression will not be used to break down equation (3). However, it should be noted that in equation (3) percent fir in volume per acre (X_{19}) has a positive coefficient, but that it is negatively correlated with PPSH (appendix C). The positive regression coefficient is probably the result of the interaction of the independent variables that were considered in this equation.

In each partial regression one factor was varied while the others were held constant at their means. Along with these partial regressions, the simple correlation coefficients between PPMH and the independent variables in equation (4) are shown in table 4.

Table 4. Correlation coefficients between variables in equation (4).

Variables	X_{25}	X_{16}	X_{14}	X_{10}	X_2
Y_2 - PPMH	-.493**	-.222	.107	-.121	—
X_{10} - Cords/Acre Fir	.812**	.986**	-.384*	—	—
X_{14} - Trees/Acre Hemlock	-.583**	-.402*	—	—	—
X_{16} - Basal Area/Acre Fir	.852**	—	—	—	—
X_{25} - Percent Basal Area per Acre Fir	—	—	—	—	—

* coefficients statistically significant at the 5% level.
** coefficients statistically significant at the 1% level.
degrees of freedom = 27.

[11] The figures in parentheses are the standard errors of the regression coefficients.

It should be noted that only one variable, percent basal area per acre fir, was significantly associated with PPMH, but that all of the independent variables were correlated significantly with each other. Figure 6, illustrates the results of the partial regression varying percent fir in basal area per acre As figure 6 indicates, an increasing percentage of fir in basal area per acre causes decreased PPMH. This may result from the fact that as the percent basal area per acre of fir increases the average DBH of the merchantable stand and the total basal area per acre decrease, which in turn results in lower PPMH. This relationship would seem to be entirely reasonable since the percent basal area per acre fir was negatively correlated with the average DBH of the merchantable stand and the total basal area per acre which were both positively correlated with PPMH (table 5).

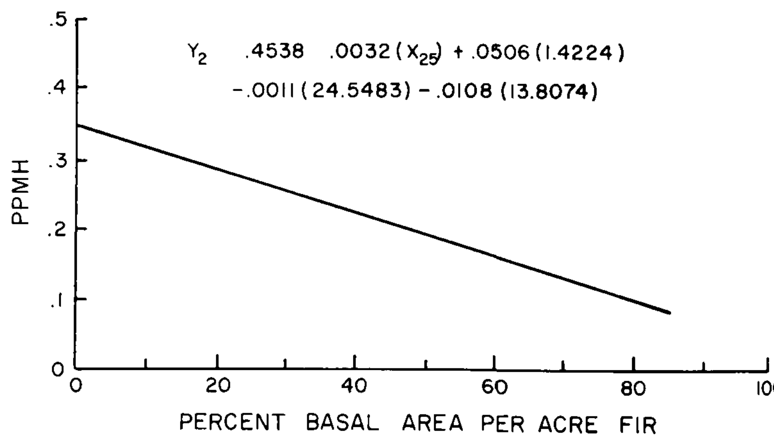

FIGURE 6. Partial regression of PPMH on percent basal area per acre fir.

Table 5. Correlation coefficients between production per man-hour, total basal area per acre, merchantable volume per acre, merchantable average DBH and percent basal area per acre in fir.

Variables	X_{25}	X_8	X_4	Y_2
Y_2 - PPMH	-.493**	.397*	.476**	—
X_4 - Total Basal Area/Acre	-.553**	.431*	.—	—
X_8 - Merch. Avg. DBH	-.762**	—	—	—
X_{25} - Percent Basal Area/Acre Fir	—	—	—	—

* coefficients statistically significant at the 5% level.
** coefficients statistically significant at the 1% level.
degrees of freedom = 27.

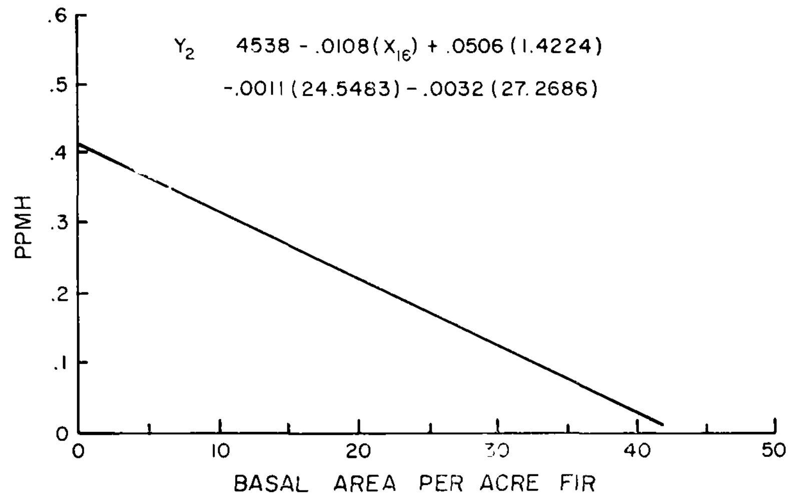

FIGURE 7. Partial regression of PPMH on basal area per acre fir.

The partial regression of PPMH on basal area per acre fir, as shown in figure 7, produced results similar to those in figure 6. As basal area per acre fir (absolute) increased, PPMH decreased. The reason for this was essentially the same as it was with percent basal area per acre fir. Basal area per acre fir was negatively associated with the average DBH of the merchantable stand while the average DBH of the merchantable stand was positively correlated with PPMH. Therefore as the basal area per acre of fir increases, PPMH would decrease because of decreasing diameters (table 6). From table 6, it can also be seen that basal area per acre fir was not significantly associated with PPMH; however, it becomes significant in the regression because it was in combination with other variables.

Table 6. Correlation coefficients between production per man-hour, merchantable average DBH and basal area per acre in fir.

Variables	X_{16}	X_8	Y_2
Y_2 - PPMH	-.222	.397*	—
X_8 - Merch. Avg. DBH	-.669**	—	—
X_{16} - Basal Area/Acre Fir	—	—	—

* coefficients statistically significant at the 5% level.
** coefficients statistically significant at the 1% level.
degrees of freedom = 27.

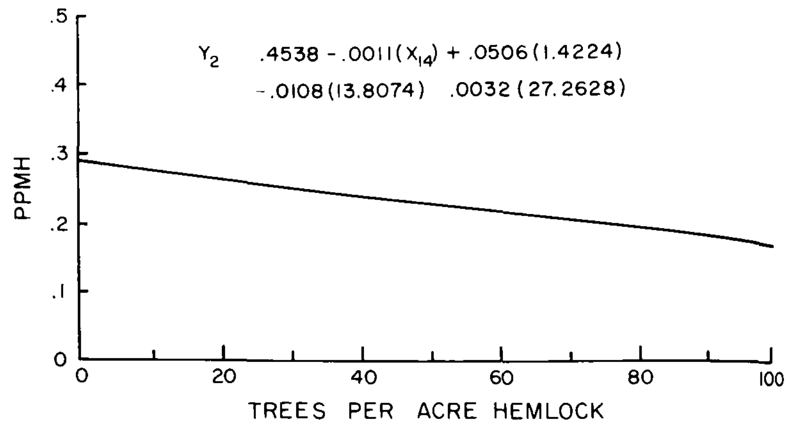

FIGURE 8. Partial regression of PPMH on trees per acre hemlock.

The outcome of the partial regression of PPMH on trees per acre hemlock is illustrated in figure 8. The cause of the negative relationship between trees per acre hemlock and PPMH is not entirely clear. At this point the relationship would appear to be the result of the interaction of trees per acre hemlock with the other variables in the equation. The simple correlation coefficients between trees per acre hemlock and the other variables in equation (4) are presented in table 4.

The sequel to the partial regression of PPMH on cords per acre fir is exemplified in figure 9. Here also, the relationship was apparently produced as a result of the interaction of the independent variables. By reference to table 4, it can be seen that cords per acre fir was not associated with PPMH at all; therefore, even the fact that it was significant in the regression was a result of the interaction of the independent variables. All of the variables which were concerned with fir were negatively correlated with PPMH (appendix C).

Unmerchantable species variables

The multiple regression of PPSH on the unmerchantable species variables produced no significant factors to indicate that the occurrence of unmerchantable species in the stand has no effect on the productivity of the machine. However, the regression of PPMH on these variables produced one factor, percent other in total stand volume, which was significant. Since this variable was taken out in the first step of the regression the relationship can be illustrated as in figure 10. The relationship shown in figure 10 is one which could be assumed to exist,

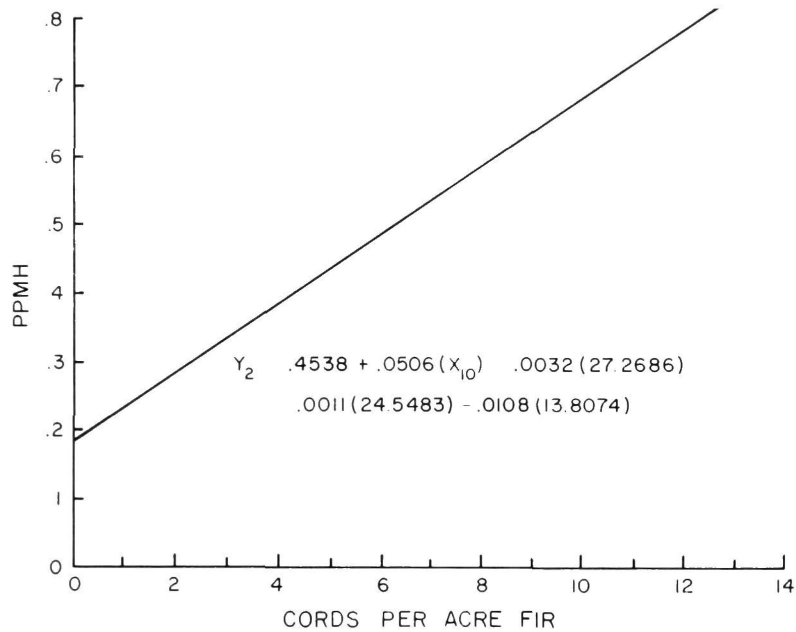

FIGURE 9. Partial regression of PPMH on cords per acre fir.

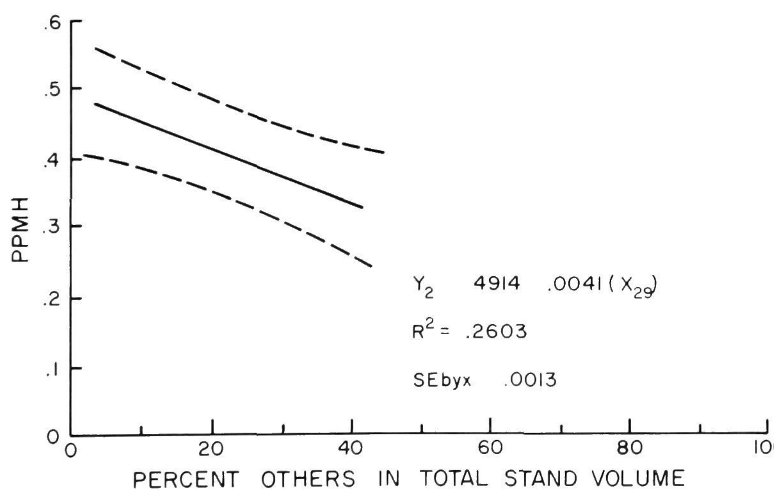

FIGURE 10. Percent others in total stand volume as related to production per man-hour.

because as the percent others (hardwoods, pine and cedar) increase in volume in proportion to the rest of the stand, PPMH would decrease due to the fact that more delay time would be incurred as the cutters move through the stand in search of merchantable trees. This was borne out by the fact that percent others in total stand volume was negatively correlated with total basal area per acre (r = —.568**). This indicates that as the percent of others in total stand volume increases that the total basal area per acre will decrease, and since the total basal area per acre was positively associated with PPMH (r = .476**) a decrease in total basal area per acre will cause a decrease in PPMH. Also it should be noted that percent others in total stand volume accounts for more of the variation in PPMH than any other single variable.

Finally, it might be well to note the relationship which exists between the two dependent variables, PPSH and PPMH. These were two of the most highly correlated variables (table 3), which is what would be expected since the number of machine hours incurred will depend to a high degree on how many hours the men work. From this one might conclude that the stand characteristics and composition variables related to each of the productivity variables would be similar in nature and degree. This, however, was not the case since even between these two variables, 31% of the variation was left unaccounted for.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study provide useful insight into relationships which exist between operating conditions and the productivity of wheeled skidders and their associated crews. From the study the following general conclusions might be drawn. It seems evident that the gross data technique of collecting information can provide the proper data for a study of this type in an easily usable form with a limited amount of effort. It also seems evident that statistical regression techniques provide a valid and useful tool for analyzing the relationships between operating conditions and harvesting outputs. Because of a one-year time limit to the study and by the very nature of the operations investigated, the amount of data collected was limited which in turn limited the type and amount of analysis that could be performed. Had more data been available, it would have been possible to break down the data by specific operating areas and to perform the analyses within these areas. This might have provided stronger, less general, relationships. Also it should be recognized that there are factors affecting productivity, such as crew motivation, skill, and training, that were not measured. This, therefore, may account for the fact that a limited amount of the variation was accounted for in most cases. In conjunction with these more general conclusions, the following specific conclusions, based on the assumed linear models, are presented:

(1) Production per man-hour seems to be sensitive to a wider range of factors than is production per machine-hour.

(2) Of all measured variables the average DBH of the merchantable stand appears to be the most important stand statistic affecting production per machine-hour.

(3) Of all measured variables the total basal area per acre seems to be the most important stand statistic affecting production per man-hour.

(4) When in combination with stand statistics, absolute composition variables exhibit no effect on production per machine-hour or production per man-hour.

(5) When considered in combination with stand statistic and absolute composition variables, the variables in the percent composition classification provided the strongest effect on both production per machine-hour and production per man-hour.

(6) Production per machine-hour does not appear to be affected by the unmerchantable species in the stand.

(7) Production per man-hour is seemingly affected by the percent of unmerchantable species in total stand volume.

To give direction and possibly encouragement to any future studies the following recommendations are presented:

(1) A substantial number of replications of data should be collected.

(2) Data could be classified and analyzed by specific operating areas or cover types.

(3) Non-linear models for relating productivity to variables selected for study could be employed.

(4) The possibility of using weighting techniques in regard to the variance of individual variables should be carefully investigated.

(5) An attempt should be made to insure that stable operating crews are used during the study period.

(6) If possible, an attempt should be made to relate daily productivity to the variables being considered.

(7) If practical, some attempt should be made to measure the human factors involved in the pulpwood production process.

APPENDIX A

Variables used in the Regression Analysis:

Dependent Variables:

Y_1 = Production per Machine-Hour

Y_2 = Production per Man-Hour

Independent Variables:

Stand Statistics Variables:

X_1 = Average DBH of the Total Stand

X_2 = Total Volume per Acre

X_3 = Total Trees per Acre

X_4 = Total Basal Area per Acre

X_5 = Merchantable Volume per Acre

X_6 = Merchantable Trees per Acre

X_7 = Merchantable Basal Area per Acre

X_8 = Average DBH of the Merchantable Stand

Absolute Composition Variables:

X_9 = Merchantable Spruce Cords per Acre

X_{10} = Merchantable Fir Cords per Acre

X_{11} = Merchantable Hemlock Cords per Acre

X_{12} = Merchantable Spruce Trees per Acre

X_{13} = Merchantable Fir trees per Acre

X_{14} = Merchantable Hemlock Trees per Acre

X_{15} = Merchantable Spruce Basal Area per Acre

X_{16} = Merchantable Fir Basal Area per Acre

X_{17} = Merchantable Hemlock Basal Area per Acre

Percent Composition Variables:

X_{18} = Percent Spruce in Volume Merchantable Stand

X_{19} = Percent Fir in Volume Merchantable Stand

X_{20} = Percent Hemlock in Volume Merchantable Stand

X_{21} = Percent Spruce in Trees per Acre Merch. Stand

X_{22} = Percent Fir in Trees per Acre Merch. Stand

X_{23} = Percent Hemlock in Trees per Acre Merch. Stand

X_{24} = Percent Spruce in Basal Area per Acre Merch. Stand

X_{25} = Percent Fir in Basal Area per Acre Merch. Stand

X_{26} = Percent Hemlock in Basal Area per Acre Merch. Stand

Subjective Rating Variables:

X_{27} = Landing Rating

X_{28} = Operating Condition Rating

Unmerchantable Species Variables:

X_{29} = Percent "others"[1] in Total Stand Volume

X_{30} = Percent "others" in Total Stand Trees per Acre
X_{31} = Percent "others" in Total Stand Basal Area
X_{32} = Cords per Acre "others" in Total Stand
X_{33} = Trees per Acre "others" in Total Stand
X_{34} = Basal Area per Acre "others" in Total Stand

---

[1]"others" refers to all species not included in the merchantable stand.

B. *Computer program point sampling cruise computations.*

```
   TOTAL STAND AND MERCHANTABLE STAND CALCULATOR   HARVEY
   OCTOBER, 1965
   SW 3 ON TO SUPPRESS HALTS AFTER ERROR CHECKS
   DIMENSION SP(15), VOL(500),          JSIZE(60)
   DIMENSION K1(55), KOL(55), JMIN(55), JMAX(55)
   DIMENSION ASP1(15), ASP2(15), ASP3(15), ASP4(15)
   DIMENSION FACTR(60)
   COMMON NI, NJ, SP, VOL,   JSIZE, K1, KOL, NL
   COMMON JMIN, JMAX, FACTR
   COMMON ASP1, ASP2, ASP3, ASP4
   CHANGE IN DIMENSION OF XIN(I) AFFECTS STATEMENT 48.
   DIMENSION XIN(20)
   REQUIRES PRIOR RUNNING OF TABLE LOADER MAINLINE PROGRAM
   DIMENSION TREES(9), TPA(9), VOLUM(9), SMER(3), BMER(3)
              READ DESCRIPTION CARD
 1 READ 2
   TYPE 2
 2 FORMAT(40H)
              READ NUMBER OF POINTS
   READ 233, POINT
33 FORMAT (F3.0)
   NI = 6
              READ MERCHANTABLE STAND LIMITS
   DO 5 I=1,3
 5 READ 6, SMER(I), BMER(I)
 6 FORMAT (5X, A3, 2X, F2.0)
   FIRST = 1.
              READ A DATA CARD
 3 READ 4, KLAND, KSHN, SPEC, XIN
 4 FORMAT (10X, 213, 1X, A3, 10 (1X, 2F2.0)
   IF (SPEC- .797979) 7,200,7
 7 IF (FIRST) 8, 12, 8
 8 FIRST = 0.
11 ILAND=KLAND
   TYPE 9, KLAND
 9 FORMAT (/11HLANDING NO., 13)
   DO 10 I=1, 9
   TREES(I)=0.
   TPA(I)=0.
```

Table B. (continued)

```
   10 VOLUM(I)=0.
      AVG=0.
      AVGM=0.
      TOTAL=0.
      TOTLM =0.
C                 TEST SAME LANDING
   12 IF (ILAND-KLAND) 200, 48, 200
C     DETERMINE DBH+SPECIES
   48 DO 55 INVAR=1, 20, 2
      KSIZE=XIN(INVAR)
      SIZE = KSIZE
      IF(KSIZE) 56, 3, 56
   56 TALLY=XIN (INVAR+1)
C                SET MERCHANTABLE INDICATOR (1=NOT MERCH)
      MERCH=0
      DO 57 LL=1, 3
      IF (SPEC-SMER (LL)) 57, 59, 57
   57 CONTINUE
   58 MERCH=1
      GO TO 71
   59 IF (SIZE-BMER (LL)) 58, 71, 71
C                 ENTER ROUTINE
C     LOOK UP SPECIES NUMBER
   71 DO 52 I=1, NI
      IF(SPEC-SP(I)) 52, 54, 52
   52 CONTINUE
      PRINT 711
  711 FORMAT (/20HSPECIES NOT IN TABLE)
      N999=1
      GO TO 999
C     CONVERT AND CHECK SIZE
   54 DO 899 NSIZE=1, NJ
      IF (KSIZE-JSIZE (NSIZE)) 902, 901, 899
  899 CONTINUE
  906 PRINT 712, SPEC, KSIZE
  712 FORMAT (/A3, I3, 1X, 17HNOT IN SIZE TABLE)
      N999=1
      GO TO 999
  902 IF (NSIZE-1) 906, 906, 907
  907 NSIZE=NSIZE-1
      PRINT 903, SPEC, KSIZE, JSIZE (NSIZE)
  903 FORMAT (/8HSPECIES A3, 6H, SIZE I3, 11H CHANGED TO, I3)
      N999=4
      GO TO 999
C     LOOK UP VOLUME
  901 IF (NSIZE-JMIN (I)) 87, 21, 21
```

B. (continued)

```
87 NSIZE=JMIN(I)
   GO TO 88
21 IF (NSIZE-JMAX (I)) 22, 22, 53
53 NSIZE=JMAX(I)
88 PRINT 904
'04 FORMAT (1X)
   PRINT 713, KSIZE, JSIZE (NSIZE)
13 FORMAT (28HNO ENTRY IN VOLUME TABLE FOR13,19H D.B.H.
     CHANGED TO13)
   PRINT 905, SPEC
05 FORMAT (8HSPECIES A3)
   N999=3
   GO TO 999
   ACCUMULATE TALLY AND VOLUME
22 K- K1 (I)-JMIN(I)+NSIZE
               LEAVE ROUTINE
70 AVG=AVG+TALLY*SIZE
   TOTAL=TOTAL+TALLY
   TPP = TALLY/POINT

   TREES(I)=TREES(I)+TPP
   TEMP=TPP*FACTR (NSIZE)
   TPA(I)=TPA(I)+TEMP
   IF (SPEC- .434544) 61, 62, 61
61 VOLUM(I)=VOLUM(I)+TEMP*VOL(K)
               CALCULATE IF MERCHANTABLE
62 IF (MERCH) 55, 63, 55
   63 AVGM=AVGM+TALLY*SIZE
   TOTLM=TOTLM+TALLY
   LL=I+6
   TREES (LL)=TREES(LL)+TPP
   TPA(LL)=TPA(LL)+TEMP
   VOLUM(LL)=VOLUM(LL)+TEMP*VOL(K)
55 CONTINUE
   GO TO 3
               PUNCH REPORT
)0 MERCH=1
   LOOP=6
               HEADING CARDS
)1 PUNCH 2
   PUNCH 202
)2 FORMAT (40X, 40X)
   PUNCH 203, ILAND
)3 FORMAT (11HLANDING NO., 13, 40X, 24X, 1H-)
   IF (MERCH-1) 206, 204, 206
)4 PUNCH 205
```

Table B. (continued)

```
  205 FORMAT (11HTOTAL STAND, 40X, 27X, 1H-)
      GO TO 208
  206 PUNCH 207
  207 FORMAT (18MERCHANTABLE STAND, 40X, 20X 1H-)
  208 IF (TOTAL) 231, 230, 231
  231 AVG=AVG/TOTAL+.005
  230 PUNCH 209, AVG
  209 FORMAT (3X, 11HAVERAGE DBH, 5X, F7.2)
      PUNCH 210
  210 FORMAT (32X, 7HPERCENT)
C                   VOLUME/ACRE
      PUNCH 211
  211 FORMAT (3X, 11HVOLUME/ACRE)
      TOTAL=0.
      T2=0.
      T3=0.
C                   CHANGE PINE FROM BD/FT TO CORDS
      VOLUM(6)=VOLUM(6)/500.
      LL=MERCH
      NN=LOOP
      DO 212 I=LL, NN
      TOTAL TOTAL+VOLUM(I)
      T2+T2+TPA(I)
  212 T3=T3+TREES(I)*10.
      LL=MERCH
      NN=LOOP
      DO 213 I=LL, NN
      AVG = 0.
      IF (1-5) 222, 223, 222
  222 IF (TOTAL) 232, 225, 232
  232 AVG = 100.*VOLUM(I)/TOTAL
  225 AMT=VOLUM(I)
      N999=1
  GO TO 400
  223 PUNCH 224
  224 FORMAT(6X, 5HCEDAR)
  213 CONTINUE
C                   TREES/ACRE
      PUNCH 214
  214 FORMAT(3X, 10HTREES/ACRE)
      TOTAL=T2
      LL=MERCH
      NN=LOOP
      DO 215 I  LL, NN
      AVG = 0.
      IF (TOTAL) 226, 227, 226
  226 AVG = 100.*TPA(I)/TOTAL
```

le B. (continued)

```
227 AMT=TPA(I)
    N999=2
    GO TO 400
215 CONTINUE
                    BASAL AREA/ACRE
    PUNCH 216
216 FORMAT (3X, 15HBASAL AREA/ACRE)
    TOTAL=T3
    LL=MERCH
    NN=LOOP
    DO 217 I=LL, NN
    AVG = 0.
    AMT=TREES(I)*10.
    IF (TOTAL) 228, 229, 228
228 AVG = 100.*AMT/TOTAL
229 N999=3
    GO TO 400
217 CONTINUE
    PUNCH 219
219 FORMAT (40X, 35X, 1H-)
                    RESET TO PUNCH MERCHANTABLE
    IF (MERCH-1) 220, 218, 220
218 MERCH=7
    LOOP=9
    AVG=AVGM
    TOTAL=TOTLM
    GO TO 201
220 IF (SPEC-.797979) 11, 221, 11
221 PAUSE
    GO TO 1
                    SUBROUTINE TO PRINT DETAIL LINES
400 J=1
    IF (MERCH-1) 401, 402, 401
401 J=J-6
402 AMT = AMT+.0005
    AVG = AVG+.005
    IF (J-2) 411, 412, 403
403 IF (J-4) 413, 414, 404
404 IF (J-6) 415, 416, 416
411 PUNCH 421, AMT, AVG
421 FORMAT (6X, 6HSPRUCE, 5X, F10.3, 4X, F7.2)
    GO TO 450
412 PUNCH 422, AMT, AVG
422 FORMAT (6X, 3HFIR, 8X, F10.3, 4X, F7.2)
    GO TO 450
413 PUNCH 423, AMT, AVG
```

```
423 FORMAT (6X, 7HHEMLOCK, 4X, F10.3, 4X, F7.2)
    IF (MERCH-1) 427, 450, 427
427 PUNCH 202
    GO TO 428
414 PUNCH 424, AMT, AVG
424 FORMAT (6X, 6HOTHERS, 5X, F10.3, 4X, F7.2)
    GO TO 450
415 PUNCH 425, AMT, AVG
425 FORMAT (6X, 5HCEDAR, 6X, F10.3, 4X, F7.2)
    GO TO 450
416 PUNCH 426, AMT, AVG
426 FORMAT (6X, 4HPINE, 7X, F10.3, 4X, F7.2 40X, 1H-)
428 TOTAL = TOTAL+.0005
    PUNCH 430, TOTAL
430 FORMAT (9X, 5HTOTAL, 3X, F10.3, 11X, 40X, 1H-)
450 GO TO (213, 215, 217), N999
C                   ERROR PRINT SUBROUTINE
999 PRINT 4, KLAND, KSHN, SPEC
996 IF (SENSE SWITCH 3) 997, 998
998 PAUSE
997 GO TO (55, 3, 22, 901, 48), N999
    END
```

Table C. Variables significantly correlated with production per machine-hour and production per man-hour.

Y_1		Y_2	
Variable	Coefficients	Variable	Coefficients
X[illegible]	.409*	X_2	.446*
X[illegible]	.412*	X_4	.476**
		X_5	.367*
		X_8	.397*
		X_9	.368*
		X_{15}	.384*
X_{19}	-.417*	X_{19}	-.449*
X_{20}	.409*	X_{20}	.301*
X_{21}	.370*	X_{21}	.381*
X_{22}	-.374*	X_{22}	-.404*
X_{25}	-.452*	X_{25}	-.493**
X[illegible]	.382*	X[illegible]	.378*
X_{27}	.409*		
		X_{29}	-.510**
		X_{30}	-.405*
		X_{31}	-.369*

* coefficients statistically significant at the 5% level.
** coefficients statistically significant at the 1% level.
degrees of freedom = 27.