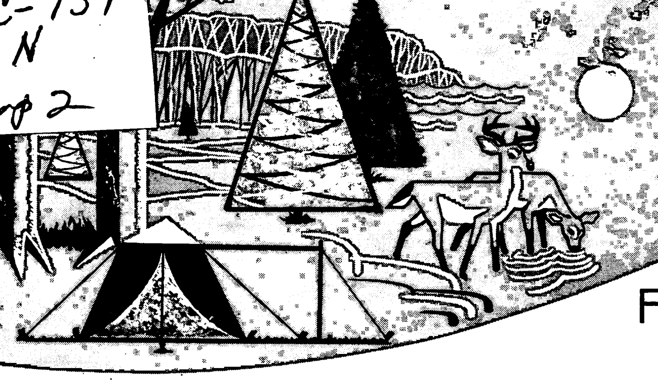

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# Factors Affecting the Productivity of Logging Crews Using Chain Saws and Wheeled Skidders in Tree-length Aspen

**ABSTRACT. — Describes the productivity of selected aspen pulpwood loggers in northern Minnesota. The most important factors affecting productivity were the ratio of harvested trees per acre to total trees per acre, harvested volume per acre, and the spacing of nonharvested trees.**

**OXFORD: 305:31(776):176.1 Populus spp. KEY WORDS: logging system analysis, stand factors, regression, wheeled skidders, gross data method.**

There has always been a need to relate timber stand and terrain factors to logging productivity and the chance for financial success. This information is useful not only to the logger himself but also to equipment designers, systems analysts, and resource planners who must know what is economically harvestable if they are to promote increased utilization. This need has recently been accentuated by rapidly increasing labor and equipment costs with little change in delivered wood prices.

As part of a study of factors affecting the harvest and transport costs of pulpwood, the Marketing Project in Duluth, Minnesota, and the Forest Engineering Project in Houghton, Michigan, examined the productivity of selected aspen pulpwood loggers in northern Minnesota.

The objective was to derive prediction equations relating stand, terrain, and climatic factors to productivity (and eventually costs) per man and machine hour. These derived equations were to be used in conjunction with forest inventory data to aid in answering resource availability questions facing local and regional planners. They were *not* intended to answer day-to-day production and cost questions for specific logging chances.

Data were collected from five loggers who were recommended by area forest industries or fellow loggers and were believed to be above average in productivity. Each of the cooperating loggers used one or two medium-sized 60 to 90 hp. wheeled skidders and integral arches to move tree-length wood felled by chain saw to a central landing. Total crew size was predominantly two but occasionally three men per skidder. Tree lengths at the landing were either (1) bucked by chain saw into 100-inch lengths and piled by loader, (2) processed by a portable slasher using additional manpower, or (3) decked tree length. All limbing and topping were done in the woods.

The aspen pulpwood stands harvested were typical of Itasca, Koochiching, and St. Louis Counties, Minnesota. Terrain was flat to gently rolling with occasional wet areas, representative of glacial moraine. While aspen predominated, paper birch and balsam fir were also common. Total volume per acre ranged from 2.5 to 38.0 cords per acre and averaged 17.6 cords per acre.

In contrast to a detailed time study, our approach related total daily *man and machine inputs* to *wood output* on a sampling unit called a "work area." A work area was not of a constant size but was the area harvested by the logger in a 7- to 10-day period. Work areas averaged about 15 acres.

Stand and terrain factors were measured by study personnel at the beginning of this period. While harvesting the work area the logger recorded daily man and machine inputs and wood output as well as climatic factors and estimated skidding distances. At the end of the period, stand and terrain factors were measured for a new work area and the process repeated.

Factors studied included: (1) *stand* — volume per acre, trees per acre, volume per tree, basal area, tree spacing, brush density (both qualitative and quantitative); (2) *terrain* — slopes, ground roughness (qualitative); (3) *climatic* — snow depth, temperature, wind, precipitation; and (4) *operating* — skidding distances, logger.

Dependent variables were: (1) cords/man-hour or machine-hour, and (2) trees/man-hour or machine-hour.

Data from the first 9 months, summer through spring, 1969-1970, were used to derive equations relating productivity to stand and environmental factors. Data from the remaining 5 months, summer and fall 1970, were used to test these equations.

## SYNOPSIS OF THE PRODUCTION DATA

A combined summary of all data reveals that five loggers worked a total of 238 working days from the summer of 1969 to the fall of 1970 on 42 work areas. Harvested volume per acre averaged 17.6 cords per acre and ranged from 2.5 to 38.0 cords per acre. Harvested trees per acre averaged 151 and ranged from 35 to 383. Harvested trees per cord averaged 8.6 and ranged from 2.6 to 16.1.

Total daily production in cords averaged 24.8 and ranged from less than a cord to 96 cords. Daily production in trees averaged 203 and ranged from 3 to 898.

*For the entire felling through skidding functions:* Productivity in cords per man-hour averaged 1.26 and ranged from 0.03 to 7.49. Productivity in trees per man-hour averaged 10.3 and ranged from less than 1.0 to 38.7.

*For the skidding function only:* Productivity in cords per machine-hour averaged 2.66 and ranged from less than 1.0 to 7.59. Productivity in trees per machine-hour averaged 21.8 and ranged from less than 1.0 to 56.1.

## STEPWISE REGRESSION USED TO SELECT BEST MODEL

A stepwise, forward-solution regression procedure was used to select the "best" prediction equation from the data for the first 9 months. This procedure selectively adds variables to a regression model starting with the best single predictor. It then computes partial correlation coefficients for the remaining variables and includes the variable with the greatest partial correlation coefficient in the next equation, and so on for subsequent variables (University of California, Los Angeles 1968).

In addition, the procedure checks the variable included in the previous iteration to see if it is still significant. The process continues until a specified lower limit of significance is reached or until no variables remain.

## TREES PER MAN OR MACHINE HOUR MORE ACCURATELY PREDICTED THAN CORDS PER HOUR

For similar sets of independent variables, $R^2$ values ($R^2 =$ that percentage of the variation in the dependent variable associated with the regression equation) were higher when predicting trees per man hour than when predicting cords per man hour. This is undoubtedly related to the variation introduced when scaling from trees to cords. Since all logging jobs, mechanized or not, are geared to individual trees, the attempt to directly predict cords per hour obscures real relationships between tree size and productivity. Given average tree volume, the conversion from trees to cords can be made later.

## DIFFERENCES BETWEEN LOGGERS ARE LARGE

Because each logger operated on a unique set of work areas, it was not possible to measure absolute quantitative differences in productivity between them. However, it was possible, using a convenient statistical device called a "dummy variable," to measure the contribution to variation (Suits 1957) from our sample of loggers.

The logger as a factor in this study accounted for approximately 40 percent of the variation in productivity. This does conform to conclusions reached in other studies (Bennett *et al.* 1965; Hamilton *et al.* 1961).

Because the proportion of variation associated with "logger" only applies to our sample of loggers, it is not included in the general equation described below. However, based on this and other work cited above, one may reasonably expect a similar contribution to variation from any sample of loggers.

## RATIO OF HARVESTED TREES TO TOTAL TREES IS MOST IMPORTANT VARIABLE

Disregarding individual logger differences, the most important variable was the ratio of harvested trees per acre to total trees per acre. As one would expect, production increased as the proportion of harvested trees approached 1.0, because there were fewer nonharvested trees to hinder movement. This variable explained 35 percent of the variation.

Our best prediction equation relates: (1) ratio of harvested trees to all trees, (2) harvested volume/acre, and (3) spacing of nonharvested trees:

$$\text{Trees per man-hour (felling through skidding)} = \underset{}{8.343} + \underset{(4.559)}{19.455\, x_1} - \underset{(0.138)}{0.347\, x_2} - \underset{(0.091)}{0.138\, x_3}$$

where:

$x_1$ = ratio of harvested trees per acre to total trees per acre (dimensionless),

$x_2$ = harvested volume per acre (cords), and

$x_3$ = equilateral spacing of nonharvestable trees (feet) =

$$\sqrt{\frac{43{,}560}{(\text{No. of remaining trees})\ 0.866}}$$

The numbers in parentheses immediately below each coefficient are the coefficients' standard deviations. Standard error of estimate = 3.6521; $R^2 = 0.49$. Additions of variables beyond this stage did not increase the $R^2$ significantly.

## EQUATION TESTED

Data from the remaining five months were tested on this prediction equation by an analysis of covariance. This analysis showed no significant difference in either slopes or intercepts. Thus, it appears that data from both periods conform to the same underlying model.

## SOME FACTORS DID NOT SIGNIFICANTLY AFFECT PRODUCTION

Past studies have shown that skidding distance, brush, terrain, and weather can affect productivity. However, our analysis did not show these factors to be significant, primarily because they were not studied in sufficient detail.

For instance, our approach did not allow us to correlate individual trip skidding distances with their associated trip volumes. Our choice of a work area as the sampling unit for stand factors required the averaging of productivity and skidding distances over the entire work area. Finally, brush, terrain, and weather were too variable within work areas to be significantly different between areas.

## CONCLUSIONS AND RECOMMENDATIONS

The original objective of relating *stand factors* to productivity was successful. Our final equation explained 49 percent of the variation in our dependent variable, which was trees per man hour for the combined processes of manually felling, limbing, topping, and articulated wheeled skidding of the timber to a landing. In addition, we were able to attribute approximately 40 percent of the variation to individual logger differences, although we could not include this factor in the final equation.

Somewhat disappointing was our attempt to relate skidding distances, terrain, and climate to productivity. The gross-data approach did not allow us to study these factors in sufficient detail.

Our experience with the gross-data approach pinpoints some of its advantages and disadvantages. Its principal advantage seems to lie in the economy of data collection — at the expense, however, of detail. The time required seems to be excessive. In our case, does the system studied still represent a significant share of the wood coming from the forest? Because of rapid mechanization there is doubt that it does, and a more flexible and faster way must be found for examining how man-machine systems interact.

Simulation would seem to offer substantial advantages. Instead of dealing with whole systems, the effect of stand, terrain, and operating factors on individual components could be studied in controlled experiments. Given various system characteristics, computers could rapidly evaluate many alternative combinations. Only prototypes of highly promising systems would have to be built for field testing.

Recent advances in general simulation languages, especially their ability to handle random variation, make the construction of highly realistic systems relatively easy.

This approach, already pioneered by other research groups, is being examined closely by the North Central Forest Experiment Station.

## LITERATURE CITED

Bennett, W. D., H. I. Winer, and A. Bartholomew. 1965. Measurement of environmental factors and their effect on the productivity of tree length logging with rubber tired skidders. Woodland Res. Index, Pulp & Paper Res. Inst. Can. 166, 49 p.

Hamilton, H. R., R. G. Bowman, R. W. Gardner, and J. J. Grimm. 1961. Factors affecting pulpwood production costs and technology in the southeastern United States. Battelle Mem. Inst., 44 p.

Suits, Daniel B. 1957. The use of dummy variables in regression equations. Am. Stat. Assoc. J., p. 548-551.

University of California, Los Angeles. 1968. Biomedical computer programs. Univ. Calif. Public., Autom. Comput. 2, 600 p., illus.

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