SELECTED ECONOMIC ALTERNATIVES FOR LOGGING LODGEPOLE PINE

BY

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THESIS FOR THE DEGREE OF PH. D.

MICHIGAN STATE UNIVERSITY

Ben M. Huey

1958

This is to certify that the

thesis entitled

SELECTED ECONOMIC ALTERNATIVES FOR
LOGGING LODGEPOLE PINE

presented by

BEN M. HUEY

has been accepted towards fulfillment
of the requirements for

Ph. D. degree in Forestry

Lee M. James
Major professor

Date August 6, 1958

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SELECTED ECONOMIC ALTERNATIVES FOR LOGGING LODGEPOLE PINE

By

Ben Meyer Huey

A THESIS

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1958

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ABSTRACT OF THESIS

Lodgepole pine has always been useful to man in the West. Currently, increased utilization of the species is due mainly to the declining supply of other larger species and improved technology for logging and manufacturing lodgepole. There are 14.5 million acres and 15 billion cubic feet of lodgepole pine timber in the West -- a tremendous and largely untapped resource. Due to the remarkable possibilities for salvaging lodgepole pine timber heretofore not used and improving forest management of this neglected species, this study of the peculiar logging problems involved seemed to be one of the areas most in need of research. The aim of the study was to provide objective answers concerning the relative merits of several alternative methods of logging lodgepole pine. The scope of the study extended from stump to mill yard or railhead. Field data was collected in Colorado, Idaho, and Montana during the three summers of 1955-57.

Economic theory, statistical techniques, and motion and time study are well-developed and waiting to be applied to logging as they have been successfully used in other industries. This study was an attempt to bring these areas of knowledge to bear upon lodgepole pine logging problems. Several, separate time-cost prediction equations were developed for the processes of (1) felling, (2) skidding, (3) loading, and (4) hauling. When a machine-crew cost factor per time unit is multiplied by the predicted time in each case, a dollar-cost figure results. The equations are as durable as the technology employed and

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the machine-crew factors easily can be revised as often as necessary. The individual costs for the four processes can be summed to determine total cost of logging.

The study provides a statistical basis to objectively estimate logging cost for lodgepole pine stands in advance of operations; hence it should be useful to logging companies, contractors, and forest appraisers. The technique also would be helpful in determining marginal logs, trees, and stands. It provides an approach to answer which is the better method for logging lodgepole, although there is probably no single best method of exploiting the species. There may be a certain combination of felling, skidding, loading, and hauling techniques that represents the best compromise of alternatives for most situations. However, this universal compromise is not the answer sought, for such a combination may be grossly inefficient under specific operating conditions.

The greatest success in developing the cost predicting equations occurred in the felling process. However, it is believed that additional verification and testing is necessary before the results can be properly appraised. Some statistical measures were presented, telling how well the multiple, linear, regression equations fitted the sample data. The next step is to test their predictive accuracy in other lodgepole pine stands and also augment the sample for some processes. Additional information is needed on delay time and indirect production time in all processes. Such time studies, in order to include unusual and infrequent delays such as equipment failure, accidents, and inclement weather, must cover many days of operation.

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ACKNOWLEDGMENTS

This study could not have been made without the generous cooperation of the contractors and loggers involved. Those who assisted in the study are too numerous to thank here again individually, but special acknowledgment is given to Merlin J. Horen, and Olaf Johnson, pulpwood contractors at White Sulphur Springs, Montana and Charles J. Erickson, Republic, Michigan, who formerly shipped pulpwood from Island Park, Idaho. William C. Hodge, then Manager of Tree Farmers, Inc., Missoula, Montana provided employment and incorporated the study in the company's research program during its formative stages. Dave Irwin, a sawyer at Bozeman, Montana and Wilson Lowry, a trucker at Laramie, Wyoming, provided much helpful information.

Among the U.S. Forest Service men to whom acknowledgment is due for their indispensable assistance, Lincoln A. Mueller, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado arranged for a research grant from the Division of Forest Economics, U.S. Forest Service, for the terminal field work, computations, and reporting. Robert O. McMahon, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon helpfully checked the computations which took several days. Paul D. Kemp, retired research mensurationist for the U.S. Forest Service, Northern Region, Missoula, Montana contributed much to the study during stimulating discussions of the project while the author stayed at the Kemp household during the early part of the research. William Ibenthal, Bozeman, Montana, Walter Sindell, White Sulphur Springs, Montana, and Rex Naanes, Island Park, Idaho are particularly mentioned for their cooperation and assistance during the collection of the field measurements.

Acknowledgment is given to Dr. Lee M. James, major professor of the writer at Michigan State University, for his careful counsel and encouragement. The support and helpful suggestions of Dr. Terrill C. Stevens, William D. Baten, and Raleigh Barlowe on the Graduate Committee are also deeply appreciated. Gratitude is also expressed for the kindness and assistance extended by Dean Ross A. Williams, School of Forestry, Montana State University, and Dean Clinton H. Wasser, College of Forestry and Range Management, Colorado State University during different phases of this study.

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INTRODUCTION

American Indians used lodgepole pine[1/] for fuel, travois and tepee poles. The latter usage accounts for the common name of the species, since the dwellings were also called lodges. Early settlers, trappers and miners in the West also made abundant use of the smooth, straight stems that were so plentiful, easy to work and handle. They were almost perfect for building logs, mine props and timbers, fence posts and poles, as well as fuelwood. Now, and in addition to the above mentioned uses, lodgepole pine helps to satisfy the demand for railroad cross-ties, mine stulls, transmission

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1/ Little, Elbert L., Check List of Native and Naturalized Trees of the United States (Including Alaska), Forest Service, U. S. Dept. Agriculture, Agricultural Handbook No. 41 (Washington: Government Printing Office, 1953), p. 263. "Some authors distinguish two varieties, of which *Pinus contorta* var. *contorta*, shore pine, is a low scrubby tree of the Pacific coast from southeastern Alaska to Northern California. *Pinus contorta* var. *latifolia* Engelm., lodgepole pine, is the taller, inland tree form of the mountains from Yukon southeast to Colorado. However, the differences are largely in habit rather than in botanical characters." Critchfield, William B., Geographic Variation in Pinus Contorta, Maria Moors Cabot Foundation Publication No. 3. Cambridge: Harvard University Press, 1957. p. iii. Lodgepole pine"...has undergone evolutionary differentiation into several geographic races....Several regional forms, exhibiting geographic unity and heritable differences, merit recognition as subspecies; Coastal Region: *Pinus contorta* Douglas ex Loudon ssp. *contorta*, Mendocino White Plains: *Pinus contorta* ssp. bolanderi (Parl.) stat. nov., Rocky Mountains: *Pinus contorta* ssp. *latifolia* (Engelm. ex Wats.) stat. nov., and Sierra Nevada: *Pinus contorta* ssp. *murryana* (Balf.) stat. nov."

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poles, converter poles,[2] lumber and pulpwood. Beside utilization as timber, lodgepole pine forests are beneficial from the watershed and recreational aspects, including the scenic, hunting, and fishing environments. (See Pictures 1-4).

For as long as people have lived in the West[3] lodgepole pine could be classed as a resource, according to the definition by Ciriacy-Wantrup.[4] The technology and use of the species by the Indians gave the lodgepole pine resource a relatively insignificant value at that time. The value of the resource increased with the coming of the white man; however the increment was largely due to growth in Western population

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2/ Poles 24 to 30 feet long and from 3 to 5 inches in diameter used in the smelters at Anaconda and Great Falls, Montana in the final process of deoxidizing the matte.

3/ Zischke, Douglas A., Lodgepole Pine, Forest Products Laboratory, Madison, Wisconsin. Report No. 2052. March, 1956, p. 1. "The first recorded mention of lodgepole pine was made by Meriwether Lewis and William Clark in their reports of Montana..."

4/ A resource is a planning estimate of anything that exists in nature that is accessible and we know how to use. cf. S. V. Ciriacy-Wantrup, Resource Conservation, Economics and Policies (Berkeley: University of California Press, 1952), p. 28.

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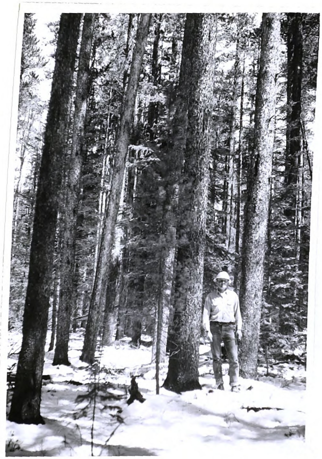

Picture No. 1, taken in the Shields River Drainage in the Crazy Mountains north of Livingston, Montana, shows a good pocket of lodgepole pine timber. This stand contains 20 to 25 thousand board feet per acre. Lodgepole pine of this size and volume per acre---the cream of the resource---is the exception rather than the usual occurrence. Logs from this area are hauled 55 miles to the Downer Mill at Livingston.

Picture No. 2 was taken near Island Park, Idaho, just west of Yellowstone Park. In the study area nearby, the average tree measured 7.3 inches in diameter at breast height. Here trees were being cut for pulpwood and shipped 1700 miles by rail to Wisconsin mills.

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Pictures 3 and 4 show examples of large areas of the lodgepole pine resource that present problems in utilization. Many of such stands developed from dense reproduction following forest fires. Too many trees have survived per acre to allow much growth per tree. Most of the trees are too small for current utilization and the prospects of their growth to merchantable size is not bright. How to manage these areas is a challenge to forestry. The pictures were taken in northern Colorado near the Laramie River.

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rather than economic development.[5/] The lodgepole pine resource reached a peak in its value level just after the turn of the century, when it

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5/ An attempt to explain Joseph A. Schumpeter's, The Theory of Economic Development (Cambridge: Harvard University Press, 1949), in a footnote would be indeed presumptuous. However, perhaps an indication of his distinction between economic growth and economic development can be made.

Speaking of mere growth, he states on page 62 that, "Continuous changes, which may in time, by continual adaptation through innumerable small steps, make a great department store out of a small retail business, come under the 'static' analysis." However, in contrast to mere growth, spontaneous and discontinuous changes appear in the sphere of industrial and commercial life that represent true economic development, according to Schumpeter. These changes or innovations do not just change the course of economic events within the framework, they change the framework. On page 63 he emphasizes, "Nor will the mere growth of the economy, as shown by the growth of population and wealth, be designated here as a process of development. For it calls forth no qualitatively new phenomena, but only processes of adaptation of the same kind as the changes in the natural data....

"By 'development', therefore, we shall understand only such changes in economic life as are not forced upon it from without but arise by its own initiative, from within. Should it turn out that there are no such changes arising in the economic sphere itself, and that the phenomenon that we call economic development is in practice simply founded upon that fact that the data change and that the economy continuously adapts itself to them, then we should say that there is no economic development...." On page 64, in a footnote, Schumpeter defines economic development more exactly as, "... that kind of change arising from within the system which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitisimal steps."

Several examples may crystallize the distinction: When Goodyear spilled some raw rubber and sulphur on his stove and discovered vulcanization, this was a technological innovation and was economic development. The expansion of the pneumatic tire industry based upon this discovery was economic growth. Likewise, Watt was the innovator when he discovered the steam engine and this was economic development. The adaptation of the machine to various uses resulted in much economic growth. Eastman's invention of spreading silver salt on plastic film represented economic development; whereas, the size of the photographic industry today is the result of economic growth. In short, economic growth involves use of the same production functions. Economic development is some new combination of inputs that shifts the entire production function discontinuously upward.

Innovations need not be as dramatic as those mentioned to be classed as economic development. Schumpeter identifies entrepreneurs with innovations and economic development, while those who supervise and plan economic growth are mere managers. However, he did not glorify the former, stating on page 90, "...But we neither style every entrepreneur a genius or a benefactor to humanity, nor do we wish to express any opinion about the comparative merits of the social organization in which he plays his role, or about the question whether what he does could not be effected more cheaply or efficiently in other ways."

was being logged extensively in the Wind River drainage in Wyoming for hewed cross-ties and on the Deerlodge National Forest in Montana, where the bulk of the products were used in mining or smelting.[6/] At one time the Deerlodge National Forest, which is essentially a lodgepole pine forest, had the largest timber harvest of all the national forests in Region One of the Forest Service.

6/ Flume logging of lodgepole pine is of historical interest. D. T. Mason, Utilization and Management of Lodgepole Pine in the Rocky Mountains, U. S. Department of Agriculture Bulletin No. 234, July 12, 1915, pp. 113-14 reported that, "...All the material from the French Gulch timber sale on the Deerlodge National Forest is removed by a flume about 18 miles long crossing the Continental Divide. The timber from above is hauled on sleds or trucks or is chuted down to the flume, where it is banked for fluming during the open season, which usually lasts from about May 1 to November 1. The timber from below is first banked along a tramway, up which the loaded cars are later hauled by a cable, operated by a stationary engine, to the banking grounds above the flume. A large proportion of this timber is delivered at the foot of the tram by means of secondary flumes located considerably below the main flume. The latter is V-shaped, with 24-inch sides. About 100,000 board feet of lumber per mile were used in its construction, and the original cost per mile was approximately $4,000. It has one tunnel 685 feet long, 29 trestles over 25 feet high, the highest being 72 feet and the longest 775 feet, and 20 rock cuts from 8 to 20 feet deep. The minimum grade is one-half of 1 percent and the maximum 12½ percent. The sharpest curve is 20°. The flume carries from 200 to 800 inches of water, the supply of which is maintained by frequent feeders from small streams along its length. It can handle stulls up to 18 inches in diameter and poles up to 30 feet long, and has a capacity of about 1,800 stulls, 2,200 converter poles, 6,000 lagging poles, or 170 cords of wood in 10 hours. It is operated on the average for about 170 days each year....

"A similar V-shaped flume, 25 miles long, has been used for the last 7 years on the Bighorn National Forest for transporting ties, props and logs from the woods to the mill and railroad. The larger logs are slabbed in a small sawmill at the head of the flume before being sent down."

Hutchison, S. Blair and John H. Wikstrom, Industrial Opportunities in the Headwaters Timber Development Unit, Intermountain Forest and Range Experiment Station, Ogden, Utah. Research Paper 45, April, 1957, pp. 1-2 tell of logging long ago when, "Between 1872 and 1875, a 36-mile flume, locally labeled "Sloan's Folly', was built in the mountains south of Evanston, Wyoming, to bring out timber products. Millions of board feet of sawlogs, hewed ties and charcoal wood were floated out of the hills in this flume and in the rivers....At one time, Evanston, Wyoming had 12 beehive-type charcoal kilns, Hilliard had 36 and there were others in nearby communities. Information about these kilns is skimpy but apparently all or most of the charcoal went to copper smelters in the West."

Demand and technology changed. Railroad, and truck and tractor loggers by-passed the modest-size lodgepole in favor of other larger species. The value of the lodgepole pine resource declined to its pioneer level. However, since World War II the lodgepole pine resource has perhaps regained or even surpassed its former peak for two reasons: First, the decline in quantity and quality of accessible supplies of other species of timber have caused lumbermen to take a closer look at lodgepole pine. Second, improvements in technology have made the species ever more attractive.[7/] For example in lumbering, fast, horizontal, band mills can now saw small diameter logs into boards which are in turn edged parallel to the bark. The tapered boards are then edge-glued with new, strong, quick-setting glues so that taper is compensated by turning every other board end-for-end.[8/] End gluing is also used to include short pieces in panels.

7/ The rediscovery or increased utilization of the species has been somewhat likened to a well-known fairy tale. R. E. Mahaffay, Timber Cinderella, American Forests, 54(1):24-25,43 and R. O. McMahon, Lodgepole Pine Forsakes Cinderella Role, The Timberman, October 18, 1957, pp. 34-38.

8/ Wikstrom, John H., Lodgepole Pine--A Lumber Species, Intermountain Forest and Range Experiment Station, Ogden, Utah. Research Paper 46, May, 1957, pp. 9-10 lists three ways the competitive position of lodgepole pine can be improved: (1) Reduce manufacturing costs which are much higher for small trees, (2) Increase lumber recovery which is low for small diameter logs, and (3) Overcome the handicap of narrow boards. While gluing was mentioned as a possible solution for items (2) and (3), it should also be pointed out that since a premium is not paid for glued, lodgepole pine boards in ordinary widths, due to competition by boards from other species, gluing may not be economical, except to salvage narrow material. A company that incurs the added cost of gluing may manufacture the product further, marketing the material as box shook, caskets, panels, furniture, etc., thereby escaping competition with other lumber.

McMahon, op. cit., p. 35, adds three additional requirements affecting the future success of lodgepole pine, namely: (1) Log grades to enable the proper separation of pulp logs from saw logs, (2) Specialized equipment for handling lodgepole pine size logs and trees, and (3) More Western markets for logs too small for economical lumber production.

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The panels are marketed in a variety of ways, including squares that can be fitted together on walls or ceilings, standard knotty pine paneling, and plain panels that can be used for sheathing, sides for farm trucks, or other uses. Likewise, when technological development in the paper industry in the 1930's permitted the expansion into the pineries of the South, it also increased the value of the lodgepole pine resource in the West.[9/]

9/ Hatch, R. S. and W. F. Holzer, Pulpwood Stands, Procurement, and Utilization, Technical Association of the Pulp and Paper Industry, Monograph Series No. 4. Chapter XVI Pacific Coast Pulpwoods. 1947, p. 157. As is the general case of pines, this species (lodgepole pine) is not readily reduced in the sulphite digester, and its use is confined to the kraft process. It will produce a good pulp that has better than usual forming characteristics on the paper machine.

McGovern, J. N., Pulping Lodgepole Pine, Forest Products Laboratory, Madison, Wisconsin. Report No. R1792, June, 1951, p. 1. Several types of green-cut and insect-killed lodgepole pine (Pinus contorta) from Montana were evaluated by physical and chemical tests in connection with groundwood, sulfite, the sulfate pulping experiments at the Forest Products Laboratory....The several samples of green wood used in these experiments were satisfactorily pulped over a range of sulfate pulping conditions that gave pulps in good yields and with excellent strength properties, as is typical for green lodgepole pine. The green and the sound dead woods showed similar pulping characteristics and gave nearly the same pulp yields and pulp strengths. The dead wood with decay showed a slight tendency to pulp more rapidly and to give lower permanganate numbers, lower pulp yields, and lower pulp strengths....Sulfite pulping tests were made on sound green and on dead lodgepole pine. Easily bleaching pulps were made from both woods with satisfactorily low screening rejects. The unbleached pulps, however, contained considerable amounts of dark fiber bundles, which were readily bleached....The pulp from the dead wood was equal to spruce sulfite pulp in strength.... The lodgepole pine pulps had ether-solubility values sufficiently high to indicate the possibility of pitch troubles....Groundwood pulping tests were also made on the sound green and on the dead lodgepole pine. The tests showed that pulps of good color and strength could be made from both materials with moderate energy consumptions.

Since about 1950, several Wisconsin pulp mills have been shipping lodgepole pine pulpwood over 1000 miles by rail from Eastern Montana forests. In that year 48,000 cords were cut and sent to Wisconsin.[10/] In 1953, a lodgepole pine pulpwood operation began producing just west of Yellowstone Park in Idaho, shipping pulpwood 1700 miles to Wisconsin mills. In 1954, 36,060 cords of lodgepole pine were shipped east from Eastern Montana and 5,447 cords were loaded from the Idaho operation.[11/] The Erickson operation at Island Park, Idaho shut down in the summer of 1957.

The first successful pulpmill manufacturing local timber in the Rocky Mountain Region began operating in 1951 at Lewiston, Idaho.[12/] This mill is owned by Potlatch Forests, Incorporated, a subsidiary of Weyerhaeuser Timber Company, Tacoma, Washington. At first they planned to use lodgepole pine pulpwood, but later found that waste from their sawmill provided an ample supply of raw material.

The Waldorf Paper Products Company, St. Paul, Minnesota installed a pulp mill at Missoula, Montana to utilize waste wood from local sawmills and began shake-down operation in early 1958. The St. Regis Paper Company, New York City, purchased the J. Neils Lumber Company in late 1956 and indicated it would build a pulp and paper plant at Libby, Montana of at

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10/ Hutchison, S. Blair and John H. Wikstrom, Resource Factors Affecting the Feasibility of Pulp Mills in Eastern Montana, Northern Rocky Mountain Forest and Range Experiment Station, Missoula, Montana. Station Paper No. 34. July, 1952. p. 9.

11/ Wikstrom, John H., Pulpwood Production in Idaho and Montana, 1954, Intermountain Forest and Range Experiment Station., Ogden, Utah. Research Note No. 21, July, 1955.

12/ Hutchison and Wikstrom, op. cit., p. 3.

least 400 tons capacity. Interest has fluctuated in building other pulp mills in the Rocky Mountain Region. The Columbine Development Company of Denver was formed and successfully bid on a 4.5 million cord, U. S. Forest Service, insect-killed, spruce pulpwood sale in March, 1950.[13/] It planned to install a mill at Newcastle, Colorado but failed in 1952. Subsequently, the J. and J. Rogers Pulp and Paper Company, Au Sable Forks, New York planned to build a pulp mill at Silt, Colorado, but this venture likewise failed in 1957. Other Central Rocky Mountain sites that have been suggested as possible pulp mill sites are Green River, Wyoming and Roberts, Idaho.[14/]

At Klammath Falls, Oregon the Johns-Manville Products Corporation has built a groundwood pulp plant scheduled to begin operations in early 1958.[15/] It will have an estimated capacity of 40,000 cords of lodgepole pine per year. The International Paper Company plans to build a pulp and paper plant to utilize lodgepole pine in the same locality.[16/] These and perhaps other western pulp mills would further increase the value of the lodgepole pine resource.

In addition to technological improvements in secondary manufature of lodgepole pine logs and bolts, there have been many technical improvements in logging which also tend to increase the value of the lodgepole pine resource. These will be treated later in the paper. In effect, all of these technical improvements can be compared to those technical

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13/ Bryant, Ralph C., The Economic Feasibility of a Permanent Pulp and Paper Industry in Central Colorado, Ph.D. dissertation, Duke University, Durham, North Carolina. 1953. p. 4.

14/ Hutchison and Wikstrom, op. cit., p. 17.

15/ McMahon, op. cit., p. 38.

16/ The Oregonian, Portland, Oregon, December 14, 1957. p. 1.

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improvements in mining and smelting that permit a periodic reprocessing of its waste piles to profitable advantage. The analogy between mine or smelter dumps and the lodgepole pine resource is admittedly obscure, but the point that time and circumstances change the view of what is useful and useless appears applicable in both cases.

In extent, the lodgepole pine resource covers a tremendous area, extending from the Yukon River down the coast of Alaska and British Columbia, through Washington, Oregon and California and most of the Rocky Mountain Region. It grows from sea level to elevations of 11,500 feet.[17/] The U. S. Forest Service estimated that in 1953 the total net volume of live lodgepole pine sawtimber on commercial forest land in Western United States was 30 billion board feet.[18/] It ranks ninth in terms of volume of western softwoods. In growing stock, which includes the volume of all trees above five inches in diameter at breast height, the volume of lodgepole pine on commercial forest land in Western United States amounts to 15 billion cubic feet.[19/] In these terms, lodgepole pine ranks fifth among western softwoods in volume. Lodgepole pine is the third largest timber type in the West, covering 14.5 million acres.[20/] Only Douglas-fir and

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17/ Collingwood, G. H. and W. D. Brush, Knowing Your Trees, (Washington: The American Forestry Association, 1947). p. 32.

18/ Forest Service, U. S. Department of Agriculture, Timber Resources For America's Future, (Forest Resource Report No. 14, Washington: U. S. Government Printing Office, January, 1958). Table No. 27, p. 556.

19/ Forest Service, U. S. Department of Agriculture, Timber Resource Review, (Preliminary Review Draft), September, 1955, Ch. IX, Table 10, p. 19.

20/ Wikstrom, op cit., p. 1.

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ponderosa pine types are more extensive with 32 and 37 million acres, respectively. Eighty percent of the lodgepole pine acreage is in Montana, Idaho, Wyoming and Colorado. The rest is in the three coastal states. These figures give only an imperfect idea of the lodgepole pine resource; first, because they are inventory or stock resource[21/] concepts; and second, because they would change with accessibility and technological assumptions. The stock resource concept is useful for some purposes, but the flow resource[21/] concept is a more helpful tool in forestry. The latter concept of a forest is based upon growth and, since there must be a growing stock to have growth, obviously the stock and flow concepts must be considered together. This is the point that Wikstrom[22/] made in showing that while lodgepole pine lumber production had jumped from less than 50 million board feet per year during 1910-1935 to about 200 million board feet in 1956, this was still only one-fifth of the annual lodgepole pine growth in the Rocky Mountain States, and a cut of 1,000 million board feet could be sustained annually by the species.

At this point a very brief look at the silviculture of the species is relevant, since it has a bearing upon the logging problem. Hawley and Smith[23/] state that, "Clear cutting has been found to be a good method for regenerating stands of species of pine which have serotinous cones. Since

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21/ Ciriacy-Wantrup, op. cit., pp. 35-37, Resources are defined as "Stock Resources" if their total physical quantity does not increase significantly with time....Strictly speaking, some stock resources may increase over time, but at a rate too slow to be economically relevant; ....Resources are defined as "Flow Resources" if different units become available for use in different intervals...

22/ Wikstrom, op. cit., p. 3.

23/ Hawley, R. C. and D. M. Smith, The Practice of Silviculture, (New York: John Wiley and Sons, 1954), pp. 85-86.

it is rarely desirable to duplicate the severe crown fires that bring these stands into being in nature, the effects of the fires must be simulated by other means.... The first prerequisite is exposure of mineral soil which is a far better seedbed than undisturbed litter.... (but, for lodgepole pine) intensive treatment of the forest floor and scattering of slash are ... less desirable because of the risk of producing excessively dense stands that may stagnate in the dry climate and remain in the sapling stage for decades. The scarification and scattering of slash accomplished in logging are usually regarded as adequate. Only the dense concentrations of slash should be burned; broadcast burning destroys too much seed. As with other closed-cone pines, so much of the regeneration comes from seeds already on the cutover area that the size, shape, and arrangement of the areas is rarely influenced by problems of seed dispersal. Ordinarily it is regarded as desirable to set 50 acres as the maximum size (LeBarron, 1952). Clearcuttings in narrow, alternate strips have also been used for special conditions where seeding from the side is essential. If it is necessary to burn all the slash or to provide an additional supply of seed on dry southerly exposures, it is desirable to confine clearcuttings to strips less than 180 feet wide (Lexen, 1949). "On the other hand, with species like lodgepole pine, in which the cones are only partially serotinous, partial shade (from shelterwood cuttings) has been found advantageous in reducing the danger of overstocking (Bates, Hilton, and Krueger, 1929)."[24/] (See Pictures 5-7).

24/ Hawley and Smith, op. cit., p. 134

Pictures 5-7 show clear-cut blocks in lodgepole pine forests. The upper view is across a cutting area similar to those in the distance. The lower picture is also across a cutting area where the slash has been burned and the dense, uniform character of the type shows in the background. The cutting areas are approximately 40 acres in size. Pictures 5 and 6 were taken in the Little Belt Mountains north of Martinsdale, Montana. Picture 7 was taken on Moose Mountain north of White Sulphur Springs, Montana.

Perhaps it is due to the long and slackened rate of use between the two World Wars that accounted for the modest research and limited amount of factual information about the species. In some respects this is currently being corrected. This paper is aimed at providing some insight into the cost of alternative logging methods used in harvesting lodgepole pine. Loggers have tried to log lodgepole timber with methods and equipment adapted to large sawlogs and have generally been disappointed. Some are quick to admit that their method of production could be improved and are continually making minor experiments in that direction. The question of what is the best way to log the species seems ubiquitous,[25/] but there is probably no single best method of exploiting the species under all conditions. There may be a certain combination of falling, skidding, loading and hauling techniques that represents the best compromise of alternatives for most situations. However, this universal compromise is not the answer

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25/ The same question but for different species was asked forest economists from Harvard University by farm woodlot owners in New England. However, their report did not emphasize the compromise feature involved in any "best" logging method. Unless the farm woodlot is uniform in species composition, size, quality, terrain, accessibility and other factors, different equipment and logging methods might be indicated for different parts of the woodlot, but due to available equipment and other cost considerations, a compromise solution best adapted for the conditions encountered would be the aim.

"In addition to collecting the simple case histories..., a parallel research project is needed to design improved operating methods. The owners of the nine farms, for example, were not only interested in estimating inputs under alternative forest management intensities but also wanted to find the most economical operating methods, machinery and equipment to use...." Solon L. Barraclough and Ernest M. Gould, Jr., Economic Analysis of Farm Forest Operating Units, Harvard Forest Bulletin No. 26, Petersham, Mass., p. 130.

sought, for such a combination may be grossly inefficient under specific operating conditions. The objective is to furnish a clear comparison of alternatives studied to guide an operator in making the best choice.

For reasons explained in the next chapter, this paper cannot provide faultless formulae for logging lodgepole timber. Furthermore, the seasoned logger, who knows his unit costs and the time required for performance, may not find the results illuminating. The theoretical economist and statistician will likewise search in vain for stimulation at rarefied levels. Perhaps the major use and purpose of the paper is to provide some statistically sound and durable cost data that can be used by those who need guides in approaching logging cost appraisals in lodgepole pine timber. It should be useful to predict by equations the cost of felling, skidding, loading, and hauling different diameters of lodgepole pine trees and logs under various conditions.

The principal contributions of this paper are the determination of time-cost prediction equations for each of the four logging processes in lodgepole pine timber:

1. A statistical study to develop a time-cost of felling equation suitable to predict the time required for felling individual trees and to estimate daily production. Also, a machine-crew, monetary factor to apply to time-cost to obtain dollar-cost. Separate equations are developed for felling and bucking into 100-inch bolts, and felling and leaving in tree-length.

2. A statistical study in several parts covering the skidding process. Separate time-cost-of-skidding equations are developed for skidding with horses and with small, crawler tractors. The equations are suitable to predict the time required for skidding individual trees a given distance or to estimate daily production. Also, a machine-crew or animal-crew, monetary factor for each skidding method is developed for application to time-cost to convert it to dollar-cost of skidding. The amount of time required for various delays is also indicated.

3. A statistical study in several parts covering the loading process. Separate time cost of loading equations are developed for each of the three loading methods tested. The equations are suitable to predict the time required for loading individual trees or to estimate daily production. Also, a machine-crew, monetary factor for each loading method is developed for application to time-cost to convert it to dollar-cost of loading. The amount of time required for various delays is also indicated.

4. A statistical study to derive the time-cost of hauling from the woods to the mill or railhead by motor truck. The equation is suitable to predict the time required for hauling individual trees or logs or to estimate daily production. Also, a machine-crew, monetary factor is developed for application to time-cost to convert it to dollar-cost of hauling. The amount of time required for various delays is also indicated.

Chapter II

THEORETICAL ASPECTS OF THE PROBLEM

Marginal Analysis in Production Economics

Production economists would prefer to have the production function given. This is not an economic relationship but a problem in engineering technology, being a mathematical relationship between input factors or resources (q's) and the output of product (Q) during a given unit of time. The production process[1/] is arbitrarily delineated and all production can be regarded as resulting from various input-output combinations. In this study, which extends from stump to mill pond, the four productive processes of falling, skidding, loading and hauling are separately considered and then summed, rather than to regard logging as a single production process. This stratification procedure not only results in determinations of greater practicability, but also reduces error. With the production function given,

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1/ Production concerns itself with changing the want satisfying power of goods. These changes may be grouped under changing the (1) form or substance of the good (manufacture), (2) place or position of the good (transportation), or (3) time when the good is available (refrigeration, etc.). There are other groupings and effects of production. In contrast, eating, drinking, sleeping, and listening to music are forms of consumption. Productive activity is always intended either to satisfy someone else's wants, or to build up potential want-satisfying power in something or somebody. Thus, consumption satisfies wants directly, production satisfies them indirectly. Cf. John D. Black, Production Economics, (New York: Henry Holt, 1926), Ch II. The Nature of Production.

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the economist can readily introduce the price of factors (p's) as illustrated below to develop the total cost function. The first derivative of the latter relationship results in marginal cost with respect to output (MC_Q). Likewise, the first derivative of the production function with respect to a given input factor results in the marginal physical productivity (MPP_q) of that input factor, others held constant. Entrepreneurs usually strive to expand or contract production, using combinations of factors where total cost is least, since this is a condition of profit maximization.[2/] Upon this least cost expansion line, cost productivity ratios are equal to marginal cost with respect to output.[3/]

$$MC_Q = \frac{p_1}{MPP_{q1}} = \frac{p_2}{MPP_{q2}} = \frac{p_3}{MPP_{q3}} = \dots = \frac{p_n}{MPP_{qn}}$$

To complete the goal of the firm in maximizing profit, the entrepreneur should alter output along the least cost route until the

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2/ It is well to consider that the productive process has in general no real leader. Rather the real leader is the consumer. The people who successfully direct business firms only foresee and execute what is prescribed for them by the wants or demands of their customers. Notwithstanding this basic relationship, production leadership frequently moulds consumer tastes to suit business goals.

3/ Sune Carlson, The Pure Theory of Production, (London: P. S. King and Son, Ltd. 1939). Alfred Marshall, Principles of Economics, (London: MacMillan, 1936), p. 355. states the principle of substitution of factors in these words: "At the beginning and at every successive stage, the alert businessman strives so to modify his arrangements as to obtain better results with a given expenditure, or equal results with a less expenditure. In other words he ceaselessly applies the principle of substitution, with the purpose of increasing his profits..."

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greatest spread occurs between total cost and total revenue. This point is most readily identified where the first derivative of these functions are equal, i.e., where marginal cost with respect to output equals marginal revenue with respect to output. Where the output of the firm is so small that it does not influence the price of the product, marginal revenue is identical to the price of the product, and profit is maximized when operations are adjusted to the point where marginal cost equals price of the product.

The above paragraph indicates two major uses of research in production economics at the firm level; namely, it provides guides to optimum combinations of input factors, and it identifies the ideal level of output. However, the production function which is fundamental to the above development, is not easily determined. Furthermore, the optimum size of the firm is one of the many assumptions included in the production function concept. Thus, a major practical problem in logging is assumed away in this theoretical approach. In other words this theoretical tool is not designed to solve the problem of scale, which in this study is identified with the proper equipment for each logging process. The generalized statements below show the theoretical transformation of the production function into the total cost function.

The generalized production function to connote the more important relationships among dependent and independent variables can be written:

$$Y = f(X_1, X_2, \mid X_3, \ldots\ldots X_n) + u$$

where Y is output in physical units per time period, X_1 and X_2 are variable inputs in physical units per time period and the remaining

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X's to indicate fixed inputs measured physically in the relationship. For example, in the skidding process, Y might be the volume of logs skidded to a landing measured in thousands of board feet per day. The X_1 might represent number of men employed on the skidding crew measured in man days, while X_2 might designate gallons of fuel consumed per day by the tractor. The fixed input factors accounted in the relationship might include such factors as X_3 for the specified number of tractors, X_4 for timber volume per acre, X_5 for slope, and ....X_n would cover the other specified fixed factors in the relationship. The task in developing a production function for just the skidding process may now be more fully appreciated, since for each set of constants included in the relationship as well as for the significant range in the variable factors, a suitable number of experimental observations are required to determine the coefficients with the desired accuracy. Those variables that are regarded as fixed (weather, for example) may be equally as important in predicting the output, Y, as the variable input factors, since the relationship would be conditioned by all of the variables in the function.

In addition, the "u" term in the function is of strategic importance. This term partly reflects a relationship to many unspecified and uncontrolled variables. To the extent that these relationships can be considered randomly and independently distributed with respect to the controlled variables, statistical procedures can cope with the problem.

The type of the relationship (shape of curve in two dimensions, surface contours for three dimensions, etc.) which is to be fitted to the experimental observations is a subjective decision that should be based upon logical reasoning.[4/] The completely general type of production function written below is not necessarily an equation of the first degree, since the X's may stand for exponential quantities of inputs. Including the possibility of both negative and positive terms in the production equation together with the use of fractional and whole powers, the number of different types of equations is very large.[5/]

The generalized production function can be written in the general equation form and transformed into a total cost (TC) equation by multiplying the X's, which are physically quantified inputs per unit of time, by their respective market prices, the p's.

4/ Mordecai, Ezekial, Methods of Correlation Analysis, (New York: John Wiley, 1930) p. 110 states that, "...when there is some logical basis for the selection of a particular equation, the equation and the corresponding curve may provide a definite logical measurement of the nature of the relationship. When no such logical basis can be developed, a curve fitted by a definite equation yields only an empirical statement of the relationship, and may fail to show the true relation."

5/ Two popular types of production functions are the Cobb-Douglas function, $Y = aX_1^{b_1} \ldots . X_n^{b_n}$, Paul H. Douglas and Charles W. Cobb, A Theory of Production, American Economic Review XVIII Supplement, March, 1928. pp. 139-165; and the Spillman function, $Y = M - AR^{X_i}$, where if $M = A$, it can be written, $Y = M(1 - R^{X_1})(1 - R_2^{X_2}) \ldots . (1 - R_n^{X_n})$, William J. Spillman, Use of the Exponential Yield Curve in Fertilizer Experiment, USDA Technical Bulletin No. 348, 1933. Both functions plot linearly when expressed in logarithms, but the Cobb-Douglas function has a disadvantage from the standpoint of economic theory in assuming constant elasticity, which the Spillman function avoids.

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$$Y = X_1 + X_2 + X_3 + \dots\dots\dots\dots + X_n + u$$

$$TC = p_1X_1 + p_2X_2 + p_3X_3 + \dots\dots\dots\dots + p_nX_n + u$$

If it can now be assumed that in logging operations that the total cost is a direct function of time, the former can be measured by the latter. In other words, if the average, machine-crew cost per unit of time is known, this figure when multiplied by the number of time units gives total cost. The use of this average, machine-crew cost concept nullifies the hope of theoretically pure marginal analysis, however it permits closer practical application of marginal productivity theory.[6/]

Unfortunately, research in the theory of cost has not as yet developed a completely satisfactory technique to handle marginal cost

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6/ In tracing the development of marginal concepts, John F. Bell, A History of Economic Thought (New York: Ronald Press, 1953), states on page 416, "...Lauderdale, Lloyd, Senior, Whately, Longfield, and others all scored 'near misses' on the target of a marginal utility concept. Gossen in 1854, Jevons and Menges in 1871, and Walras in 1874 are the ones generally honored with the 'discovery'. While their contributions are indeed considerable, it is the Austrian economists...who are credited with the full development of marginalism." Kenneth E. Boulding, Economic Analysis, page 887, states about A. A. Cournot (1801-1877) that, "...the concepts, though not the names, of the marginal analysis were first developed by him."

An article by G. Robinson Gregory, An Economic Approach to Multiple Use, Forest Science, March, 1955, p. 6, illustrates the powerful and practical use of marginal productivity theory in forestry.

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theory in practice. Vigorous arguments to the contrary,[7/] marginal cost principles are employed not only by high level executives, but by woods

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7/ Richard A. Lester, Shortcomings of Marginal Analysis for Wage-Employment Problems, The American Economic Review Vol. XXXVI, No. 1, March, 1946, pp 63-82, challenges the conventional explanation of the output and employment policies of individual firms in terms of maximizing profits by equating marginal revenue and marginal cost. On page 81 he, "....raises grave doubts as to the validity of conventional marginal theory and the assumptions on which it rests." And on page 82 continues, "The practical problems involved in applying marginal analysis to the multi-process operation of a modern plant seem inescapable, and business executives rightly consider marginalism impractical as an operating principle in such manufacturing establishments."
Fritz Machlup, Marginal Analysis and Empirical Research, The American Economic Review, Vol. XXXVI. No. 4, part 1. September, 1946, pp 519-554 answered the challenge and defended marginal analysis on p. 519, "....as the logical process of 'finding a maximum', is clearly implicit in the so-called economic principle -- striving to achieve with given means a maximum of ends." On page 520 he counters the critics of marginal analysis, that their, "....alleged 'inapplicability' of marginal analysis is often due to a failure to understand it, to faulty research techniques, or to mistaken interpretation of 'findings' ....This is not to deny that a goodly portion of all business behavior may be non-rational, thoughtless, blindly repetitive, deliberately traditional, or motivated by extra-economic objectives..."

Machlup succinctly meets the issue of the complexity and extreme difficulty of calculation by comparing decisions of the entrepreneur with that of an automobile driver on page 534. "What sort of considerations are behind the routine decision of the driver of an automobile to over-take a truck proceeding ahead of him at slower speed? What factors influence his decision? Assume that he is faced with the alternative of either slowing down and staying behind the truck or of passing before a car which is approaching from the opposite direction will have reached the spot. As an experienced driver he somehow takes into account (a) the speed at which the truck is going, (b) the remaining distance between himself and the truck, (c) the speed at which he is proceeding, (d) the possible acceleration of his speed, (e) the distance between him and the car approaching from the opposite direction, (f) the speed at which that car is approaching; and probably also the condition of the road (concrete or dirt, wet or dry, straight or winding, level or uphill), the degree of visability (light or dark, clear or foggy),

foremen and other cost-conscious loggers. For example, every decision whether to fall or leave a tree, when made upon a cost and return basis, is a marginal cost decision. With the faller standing with saw in hand appraising that tree, all logging costs incurred to that moment are historical and fixed costs. The only variable costs are those that may be incurred if he decides to fell the tree. Once felled the falling cost joins the other historical and fixed costs. Likewise, in successive

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the condition of the tires and brakes of his car, and -- let us hope -- his own condition (fresh or tired, sober or alcoholized) permitting him to judge the enumerated factors.

"Clearly, the driver of the automobile will not 'measure' the variables; he will not 'calculate' the time needed for vehicles to cover the estimated distances at the estimated rates of speed; and, of course, none of the 'estimates' will be expressed in numerical values. Even so, without measurements, numerical estimates, or calculations, he will in a routine way do the indicated 'sizing-up' of the total situation. He will not break it down into its elements. Yet a 'theory of overtaking' would have to include all these elements (and perhaps others besides) and would have to state how changes in any of the factors were likely to affect the decisions or actions of the driver. (Machlup footnote: Very cautious drivers are apt to work with so wide safety margins that small changes in the 'variables' may not affect their actions. Timid souls may refuse to pass at all when another car is in sight.) The 'extreme difficulty of calculating' the fact that 'it would be utterly impractical' to attempt to work out and ascertain the exact magnitudes of the variables which the theorist alleges to be significant, show merely that the explanation of an action must often include steps of reasoning which the acting individual himself does not consciously perform (because the action has become routine) and which perhaps he would never be able to perform in scientific exactness (because such exactness is not necessary in every day life). To call, on these grounds, the theory 'invalid', 'unrealistic', or 'inapplicable' is to reveal failure to understand the basic methodological constitution of most social sciences."

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bucking cuts, again the only relevant costs for comparison with the prospective returns are the variable costs incurred by the decision at each bucking cut.[8/] In practice, the application of marginal productivity theory is as exact as the altertness and intelligence of the decision maker permits. Perhaps this is as close as formal cost theory can come to the actual decision making process, when marginal costs are incurred and where average costs are used to forecast at the margin prior to a decision, whether or not a decision would result in profit or loss.[9/]

8/ For further elaboration of this approach to the economic classification of costs into fixed and variable, see Donald Bruce, Economic Log and Tree Limits, West Coast Lumberman, 66(8):41-45. August, 1939 and G. R. Gregory, Costs of Harvesting or Processing Timber, Research in the Economics of Forestry, W. A. Duerr and H. J. Vaux, Editors, (Baltimore: Waverly Press, 1953), pp 298-304.

9/ Little is known about the decision making process. Irving F. Fellows, Applying Production Functions in Farm Management, Journal of Farm Economics, 31(2):1058-1064, November, 1949, p. 1453 states that it can be described briefly as (1) An awareness of a problem, (2) As collection and appraisal of information relevant to the problem, (3) As decision or solution of the problem, and (4) As action in line with the solution.
George Katona, Psychological Analysis of Economic Behavior, (New York: McGraw-Hill, 1951), p. 49 states, "....Genuine decisions are made occasionally. They require the perception of a new situation and the solution of the problem raised by it, they lead to responding to a situation in a new way. In contrast, habitual behavior is rather common. We do what we did before in a similar situation. Whether we use the word 'decision' in such circumstances is immaterial. The main point is that the psychological process involved is different from that in genuine decision. Routine behavior or using rules of thumb, are suitable terms to describe the second form of behavior."

Glenn L. Johnson of Michigan State University has made significant contributions in this area as it applies to agriculturists. See bibliographical references 87 and 88.

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The unsolved problem in business practice is how to handle costs for economic analysis where their fixed or variable character changes at every decision. The importance of this concept warrants additional study.

With these theoretical limitations in mind, it would be helpful still to develop sound estimates of cost for the four logging processes that could be used as guides for decisions. However, it is recognized that there is no substitute for shrewd and sagacious entrepreneurship. Rules of thumb and more precise mathematical and statistical guides may be helpful, but the responsibility of the final decision cannot be avoided by the logger. The mere addition of variables in the predictive equation is not a complete solution because inferences always must be drawn from the experimental sample to another situation facing the operator. His decision is determined by an appraisal of the many factors both variable and fixed as well as controlled and uncontrollable. His payment (profit) is for his appraisal process and for the responsibility borne for action taken in the light of the appraisal. If the form of the relationship among the variables and the probability distribution were known with certainty, there would be no need for the management function. Entrepreneurship under this condition would have advanced or reverted, depending on viewpoint, to a routine or mathematical process. The fact that exact cost

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prediction and appraisals usually cannot be made is no reason for condemning methods aimed toward providing better approximations.[10/]

Motion and Time Study to Appraise Cost

Since nothing can be accomplished instantaneously, an obvious way to measure production is on a time basis. The cost of production may be taken in man-hours, machine-hours or a combination termed machine-crew-hours. Any other convenient time period could be used. Cost data collected and reported in physical terms is as durable as the technology of the environment, and for this reason is far more useful than costs expressed in monetary terms. The former is readily converted to the latter, corresponding to any shift in prices, by multiplying the number

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10/ A somewhat comparable criticism of economic prediction was made by Ellery Foster, Forest Planning: How Far Can We See?, Journal of Forestry 35:1066-1067, November, 1937 of H. R. Josephson, Economic Research and Forest Planning, Journal of Forestry 35:744-746, 1937. The issue was that, since the future is unknowable, economic prediction is invalid. H. J. Vaux, Some Economic Goals in Forest Policy, Journal of Forestry, 47:612-617, August, 1949 replied that, "...Many foresters reject completely the idea that such long range planning is of any value. They argue that any forecast over such a long period assumes a degree of prescience which is ridiculously presumptuous in the light of the known impact of such things as cyclical economic fluctuations, changes in labor and capital productivity, changes in patterns of income distribution and other economic variables subject to political control, wars, and technological improvements. Devastating as this argument is, it misses the fundamental point. For as soon as we adopt a policy which has implications for the long run, and as soon as we make use of those long run implications in defense of our policy, we have either consciously or unconsciously made a 'forecast' of those future conditions which are here in question."

of time periods by the monetary cost per time period. Some industrial engineers regard the close control of motion and time in efficiency and cost estimates as the very essence of scientific management.

Since about the turn of the century, industry has successfully used scientific management as developed by Frederick W. Taylor, Henry L. Gantt, Carl B. Barth, Dwight V. Merrick, Henry R. Towne, Frederick A. Halsey, Harrington Emerson, Frank B. and Lillian M. Gilbreth and others.[11/]

11/ Franklin G. Moore, Manufacturing Management (Homewood, Ill.: Richard D. Irwin, 1955), p. 12. "Taylor is sometimes referred to as the father of scientific management, but to credit him with originating it is claiming too much. He certainly did a great deal to develop the field of management into a scientific study, but his greatest contribution was to develop and dramatically publicize the field of management. He was the movements catalytic agent. His imagination and zeal in carrying through his investigations were perhaps equal to the task of originating the ideas. The fact is, however, that he arrived too late on the scene to be credited with the whole job....

"Taylor's contributions to scientific management were nonetheless of utmost importance. He rightly deserves credit for originating what is today considered the best practice in time study, i.e., timing jobs in small parts rather than in an over-all way. He was the first to emphasize, in speeches and in writings, the need to select men to fit the jobs for which they were hired. He was the first to stress the obligations of management to find the best way of doing jobs and to train the workers to work in that way. He was by no means the first to emphasize that employees should do their jobs in a manner most economical of time and effort, but he was the first to insist that management should study and analyze alternative methods, select the best and then train the workers to do the work that way."

Ibid. pp 16-17. "Gantt is best known as an author and an engineer... He developed an incentive wage payment plan which was used by some companies and developed a chart which helped control manufacturing operations. Such charts, known as 'Gantt Charts', are still used occasionally today...Barth is best remembered as the inventor of slide rules with which the proper machine speeds, feeds, and depth of cut for metal cutting machines could be calculated. Merrick was the first well-known time study man. Towne installed efficient procedures in his plant while Taylor was yet in his teens. His

However, R. W. Starreveld[12/] states that, "Scientific management is still to a large extent a matter of rather vague notions, personal opinions, and individual experiments."

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papers before the Franklin Institute and the A.S.M.E. were outstanding and undoubtedly strongly influenced the younger Taylor. Halsey is remembered today for his gain-sharing wage incentive plan presented in a paper before the A.S.M.E. in 1891.

"Harrington Emerson was a contemporary (but not a colleague) of Taylor and an engineering consultant with a western railroad. He was more responsible than the Taylor group for introducing the line and staff form of organization into manufacturing concerns....

"Franklin B. and Lillian M. Gilbreth did important pioneer work in motion study. Taylor and his predecessors had made some progress in motion study but did not carry it as far as the Gilbreths did. They introduced charts and moving pictures (or 'micromotion' study) to help analyze, study, and improve jobs. Gilbreth, a bricklayer by trade, became an outstanding industrial engineer in the decade before his death in 1924. Mrs. Gilbreth, a psychologist by training, worked with her husband during his lifetime and after his death continued the practice of industrial engineering.

"The two Gilbreths did very important pioneer work in fatigue analysis as well as motion study. They also developed the idea that all human work is composed of various combinations of basic human movements which they called 'Therbigs'. Although their work was done many years ago, only recently has their therbig idea been taken up by industrial engineers generally. Today many leading industrial engineers think it offers a valuable approach both to improving jobs and to setting time standards."

12/ R. W. Starreveld, Public and Collective Management Research, Eighth International Management Congress, Stockholm. Vol. 1, Swedish National Committee of Scientific Management, Esselte Aktiebolag. Stockholm. pp. 149-173.

Most manufacturing industries are characterized by concentrations of individuals doing highly repetitive tasks on standardized materials resulting in identical products. The leadership of such large organizations often employ management engineers to design methods and processes for efficient production. In many respects this characterization of industry does not fit logging and lumbering. For example, the latter is not an assembly line process, but rather a disassembly procedure where logs are sawed into boards. Again, the typical logger is a small operation and his operation is anything but repetitive with the variables of weather, terrain, timber size and quality and products causing almost continual adjustments and modifications to be made. Logging more closely approximates farming than typical manufacturing and scientific management in logging could follow the suggestions to agriculturists given by Dan M. Brown that "...Most farmers have to be their own production engineers, in a small way. As in industry scientific farm management must follow an orderly process for defining objectives, selecting suitable materials and facilities, determining the best possible methods under specific circumstances, then making plans and setting schedules with just enough follow-up to insure completion. The use of such a process makes the farmer a master of his situation. With this mastery he can better utilize available ideas, goods and services to increase his output to still higher levels."[13/]

13/ Dan M. Brown, Progress in Scientific Farm Management, Eighth International Management Congress, Stockholm. Vol. 1, Swedish National Committee of Scientific Management, Esselte Aktiebolag. Stockholm. pp. 319-329.

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Even though logging is different from the usual manufacture, modern developments in logging make it expedient to try to rationalize the work, making it more effective, thereby saving labor, equipment and to make the product less expensive. Logging work, like any manual effort, can be reduced to the execution of one or several series of movements in space. The fourth dimension of time is all that remains to fully account for the exertion and describe it. The facility of chronometry explains its popularity and its use for the elimination of some delays and the calculation of standard time for work. Motion study intended to suppress unnecessary movements, to reduce the duration of necessary movements and to diminish fatigue has not been developed to the same degree.[14/]

14/ Ralph M. Barnes, Motion and Time Study (New York: John Wiley, 1949) p. 1-2. "The terms 'time study' and 'motion study' have been given many interpretations since their origin...Common practice today requires that motion study and time study be used together, since the two supplement each other.

"Motion and time study is the analysis of the methods, of the materials, and of the tools and equipment used, or to be used, in the performance of a piece of work -- an analysis carried on with the purpose of (1) finding the most economical way of doing this work; (2) standardizing the methods, materials, tools and equipment; (3) accurately determining the time required by a qualified person working at a normal pace to do the task; and (4) assisting in training the worker in the new method.

"...Motion study is commonly defined as the study of the motions used in the performance of an operation for the purpose of eliminating all unnecessary motions and building up a sequence of the most useful motions for maximum efficiency."

Ibid. p. 333. "Time study is used to determine the time required by a qualified person working at a normal pace to do a specified task. This is the third part of the definition of motion and time study which appears on page 1. It should be noted that while motion study is largely analysis, time study involves measurement. Time study is used to measure work. The result of time study is the time in minutes that a person suited to the job and trained in the specified method will need to perform the job if he works at a normal or standard tempo. This time is called the standard time for the operation."

Luthman and Lungren[15/] used the "microscopic" or "therbig"[16/] approach to determine the cost in physical effort in sawing with a bow saw. They calculated as a measure of efficiency, the quotient between a given amount of work and the energy expended by the body. The latter they measured indirectly from the carbon dioxide exhaled by the sawyer. Timing the production from each stroke of the saw and relating this to the conditions which determine the total number of strokes required enables a cost prediction in physical terms for felling and bucking a stand of timber. They indicated that this micro-approach gave results that can be calculated under the most universal conditions.[17/] Barnes[18/] reported

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15/ Gosta Luthman and Nils Lungren, Studies of Working Methods in Swedish Forestry, Eighth International Management Congress, Stockholm. Vol. 1. Swedish National Committee of Scientific Management. Esselte Aktiebolag. Stockholm. pp. 149-173.

16/ Moore, op. cit., p. 541. "Two different methods -- (1) therbig time values and (2) formulas using elemental time -- are used to set synthetic standards. William Gomberg, A Trade Union Analysis of Time Study (Chicago: Science Research Associates, 1948. Ch. 13) characterizes them as 'microscopic' and 'macroscopic' methods. The microscopic method (therbig time values) regards all jobs as combinations of certain basic minute human movements, much as one might regard houses as being made up of bricks, nails, and boards. The macroscopic method (formulas) might be likened to a prefabricated house where whole wall, roof, floor, or cabinet units comprise the building..." Ibid. p. 543. "Standards set by formulas include appropriate allowances for personal time, fatigue, and minor essential parts of the job and are thus complete time standards..."

17/ Ibid. p. 169.

18/ Barnes, op. cit., pp. 196-197.

that, "it has long been known that physical work results in changes in oxygen consumption, heart rate, pulmonary ventilation, body temperature, lactic acid concentration in the blood, 17-ketosteroid excretion in the urine, and other factors....In recent years considerable interest has developed in the use of change in pulse rate as a measure of muscular activity. It is much simpler to measure pulse rate than oxygen consumption....For any job in which the physiological expenditure is great enough to produce significant changes in heart rate, the heart rate recovery curves will determine the physiological cost of the job and will permit evaluation of any modification that is made in attempting to reduce stress and fatigue."

Numerous foresters have used time studies to develop input-output relationships.[19/] Diameter of trees and logs is usually an important independent variable in determining production and cost per unit thereof. Unit cost of production in felling, skidding and loading varies inversely with diameter of trees or logs up to a point where size exceeds the design of the equipment employed. In so far as the size of load influences unit cost, the same relationship holds for hauling because more volume can be hauled in large logs than small logs. However, in transportation, whether skidding or hauling, the direct relationship between distance and cost is usually more important.

19/ Input-output relationships are nothing more than production recipes. Just as a food cookbook specifies quantities of inputs to achieve a certain output, the production function or input-output relationship gives the output results to be expected from combining exact amounts of resources factors. S. L. Barraclough and E. M. Gould, Jr., Economic Analysis of Farm Forest Operating Units, Harvard Forest Bulletin No. 26, Petersham, Mass., in Chapter IV, titled, "Input-Output Relationships for Forest Production," give a condensed and popular treatment of the subject. For additional information, bibliographical references 25, 30, and 77 are suggested.

Several time studies in forestry resulting in input-output relationships are cited as examples: 35, 36, 51, 73, 74, 85, 97, 126, 127, 132, 136, 147, and 164.

Hasel, Tennas et al, and Jensen are examples[20/] of the formula or macroscopic method of time study. In this approach a formula is determined, incorporating the more important variables influencing production. When the independent variables or inputs are employed according to the assumptions for a specified time, the dependent variable or output changes in an explicit manner. Thus, with the production relationship established, output can be predicted by timing the inputs. Since cost is also largely and directly correlated with time, this important control of management can also be accurately estimated.

In addition to these advantages of the formula approach, when the independent variables are appropriately expressed, the equation can be manipulated to allocate logging cost to log sizes or tree sizes. This method of approach was suggested by R. A. Fisher, the eminent English statician, and reported by Bessie B. Day[21/] in 1937. Hasel[22/]

20/ A. A. Hasel, Logging Cost as Related to Tree Size and Intensity of cutting in Ponderosa Pine, Journal of Forestry 44:552-60. August, 1946. M. E. Tennas, R. H. Ruth, and C. M. Berntsen, An Analysis of Production and Costs in High-Lead Yarding, USDA, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper No. 11. 1955.
Victor S. Jensen, Cost of Producing Pulpwood on Farm Woodlands of the Upper Connecticut River Valley, USDA. Northeastern Forest Experiment Station, Upper Darby, Pa. Occasional Paper No. 9. April 5, 1940.

21/ Bessie B. Day, A Suggested Method for Allocating Logging Costs to Log Sizes, Journal of Forestry 35:69-71. January, 1937. p. 69. "One of the most difficult problems involved in logging cost studies is the apportioning of costs to logs of varying sizes. The assumption that each log should bear a cost in direct proportion to its size has in the past been adopted by some investigators. This infers a straight line relationship between cost and log size. Others interested in this problem have believed this assumption to be fallacious and so have endeavored to find what the true relation of logging costs to log size is."

22/ Hasel, op. cit.

used this technique to develop cost prediction equations for the felling and bucking, skidding, and loading operations in ponderosa pine on the Blacks Mountain Experimental Forest in California. He was able to obtain his results at a fraction of the cost of the usual time study partly because the trees were measured, numbered and mapped in advance of logging, which greatly facilitated the data collection. Unfortunately, this technique for collecting information had to be modified in this study for lodgepole pine stands and practices. Nevertheless, a point of great interest to forest economists is that by Hasel's technique the cost for the different logging processes could be logically allocated to standing individual trees. This holds great promise in marginal tree determination and other forest appraisals where it is important to relate the effect of log or tree size upon cost of production.

Some Cost Concepts[23/]

Fundamentally, anything which is an obstacle or a resistance to production is a real or economic cost. Money costs, out-of-pocket costs, or cash outlays are self-explanatory, being cash expenditures which have to be made in order to maintain production. Economic costs include costs that do not require any cash outlay, for example: the cost of a tractor purchased on credit or the risk in accepting a logging contract. In operating a business many costs accrue or are experienced without there being a cash outlay. Daily depreciation on a truck occurs whether it is in use or not and in either case no cash outlay is made, but it can be

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23/ For a thorough treatment of cost see, J. M. Clark, Studies in the Economics of Overhead Costs (Chicago: University of Chicago Press, 1923).

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expressed in money terms. Similarly, an owner-operator does not pay himself a wage, yet his services are certainly a real cost of production.

Clark[24/] points out that different analysts use costs for different purposes which accounts for the numerous cost terms and concepts employed. Accountants, for example, have an arbitrary classification of cost items into fixed and variable categories, whereas; economists have no rigid classification in this regard.[25/] Fixed costs for economists

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24/ Ibid., p. 35.

25/ G. R. Gregory, Costs of Harvesting or Processing Timber. Research in the Economics of Forestry. W. A. Duerr and H. J. Vaux, editors. pp. 300-301 (Baltimore: Waverly Press, 1953). "There are two general approaches to the cost problem: the accountant's and the economist's. The basic tool of analysis for either is cost classification. Both approaches require the separation of costs into two broad classes: fixed, often called overhead or indirect costs, and variable, or direct costs. But the basis by which the accountant makes this classification is different from that used by the economist.

"The cost accountant, interested in measuring costs, has built up a system of cost classification based on convention, judgment, and ease of measurement, by which each cost can be classified. Thus costs such as taxes, rent, electricity and other utilities, payments to administrative and sales personnel, and many other items are classified as fixed, while payments for hourly wages, materials, etc. are termed variable costs. It is recognized that the cost accountant does not classify costs in quite the simple and arbitrary manner indicated here, that other classes of costs are reognized, and that the classification is modified to fit the needs of the particular situation. However, for clarity in the argument to be presented, these details, though admittedly significant in the majority of cases, are omitted.

"The accountant's approach leads directly to the study of unit costs. Since cost-accounting activities are typically confined to the measurement of total costs, or convenient subdivisions of them, these unit costs are usually presented on a total basis -- a combination of both fixed and variable costs.

"The economist approaches the problem of costs through the determination of marginal, rather than unit, costs. Like the accountant, the economist separates costs into fixed and variable categories. But when dealing with a specific study, the investigator of marginal costs must ask, Will this cost change under the impact of the decision to be made or the alteration proposed?

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are those costs for the decision in question that do not vary with output. Variable costs in economic theory are those costs for the decision in question that do vary with output. The difficulty of applying this cost concept of the economist has been mentioned on page 23 . Other cost terms such as direct and indirect costs, prime and supplementary costs, particular costs, past costs, sunk costs, and overhead costs need not be elaborated here.

Average cost of production or cost of production per unit of output is a concept of general utility and of particular importance in this paper. Gregory[26/] states that, "Unit costs are the sum of those costs entailed in the production of some unit of product or group of products. The product unit may be a thousand board feet, a cubic foot, or any other logical unit. Unit costs may be stated in monetary or other quantitative terms such as man-hours, machine-hours or a combination of

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If it will not change, it is a fixed cost and thus is not germane to the problem. If it will change, it is a variable cost, and the determination of the amount of change is a principal objective of the economist's study.

"No analysis of cost data can be made, or secondary data interpreted, without clear recognition of these differences in concept. The principal distinction between the two approaches is the classification and treatment of fixed costs. Unlike the accountant who has devised rules and conventions to separate fixed costs from variable, the economist can make no general cost classification. His classification will vary with almost every study he undertakes. To the economist there are few costs that can invariably be classified as fixed, and the number of costs so classified will decrease as the time period is extended. In the long run there can be no such thing as a fixed cost."

26/ G. R. Gregory, op. cit., p. 298.

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these. The unit-cost concept is a general one and can be applied to any specific process or combination of processes." The aim in this project is to determine volume of production per time period for each logging process together with an applicable machine-crew cost for the same time period. A simple division of total cost over total volume results in the average or unit cost of production.

The opportunity cost or alternative cost concept is a powerful tool in certain situations where goods and services are not evaluated in the market. The opportunity cost of a factor of production is the profit foregone to that factor in its next best alternative use.[27/] For example, if a tractor owner has the choice between employing his machine in road construction for a net profit of $6 an hour or in skidding logs for a net profit of $5 an hour, he would normally choose to make roads and the $5 skidding profit foregone is the opportunity cost of the tractor when used for road construction. The same result could be reached, using total cost and returns in appraising the two jobs.

Economists make the distinction, that if the cost will be changed by the decision to be made, it is classed as a variable cost. Therefore, it is well to note that opportunity costs are ante-decision concepts, influenced by the decision and for that reason are variable costs. In the

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27/ Jacob Viner, Cost, Encyclopaedia of the Social Sciences (New York: MacMillan, 1931), p. 468. "The opportunity cost doctrine, first given that name by David I. Green ('Pain-cost and Opportunity-Cost' in Quarterly Journal of Economics, vol. viii 1893-94, p. 218-299) and developed with some elaboration by Davenport (Value and Distribution, Chicago 1908, ch. vii), is essentially a variant of the Austrian theory of cost...."

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example above, whether the opportunity cost will be $5 or $6 depends on the decision whether he builds roads or logs timber. This accounts for the absurdity that arises when the opportunity cost of every factor of production having an alternative use is used in computing cost of production. With this approach all costs are variable costs, since those factors having no alternative use have zero opportunity cost.

A firm is said to produce joint products and encounter joint costs when as a result of a single process two or more products are made. Where the joint products are independent multiple products and separate costs and returns are determinable there is no problem in cost allocation. Where the joint products are produced in fixed proportions, like so many tons of sawdust to a certain volume of lumber produced in a sawmill, the output can be regarded as a single complex product or package of sawdust and lumber and the joint cost problem avoided. However, where the joint products are produced in varying proportions as when pulpwood, sawlogs and veneer bolts are produced by a logging firm, the task of determining the cost of producing each is problematical.

A cost distinction may be made upon the basis of who pays the cost. Entrepreneurial costs are those items which the business manager recognizes as having an influence on his profits. Social costs are those which can be shifted to someone other than the owner of the business.[28/] When a logger tears down a rancher's fence or exceeds the weight limit in log hauling and "gets away with it" social costs have been incurred. Social costs are excluded by definition from economic analysis at the level of the firm.

28/ Cf. Karl W. Kapp, The Social Costs of Private Enterprise (Cambridge: Harvard University Press, 1950).

Marginal Land, Operators, and Units

One use of the results of this paper is to provide a guide in identifying marginal lodgepole pine trees and logs. This concept employs the general and powerful economic tool of marginal analysis. Marginal analysis in production economics or marginal productivity theory was briefly discussed on page 18. In order to present a broader picture of the marginal concept, a brief discussion of marginal land, operators and units is presented prior to a treatment of marginal logs, trees and stands.

Webster's dictionary[29/] defines a margin as, "1. A border; edge. 2. A condition approximately marking a limit; limit. ..." Such a definition causes some difficulty because it over-simplifies the issued as some fixed, physical periphery. The idea is important to foresters because there is a quite widespread, vague belief that there is some line or boundary that separates agricultural land from forest land, good forest land from poor forest land and merchantable trees from non-merchantable trees within a forest. The line or margin depends altogether upon the criteria established by definition.

Physical margins are easiest to conceive. Going up a mountain, timberline is one such physical margin. Somewhere lower down a physical margin to field cultivation exists, due to such physical characteristics as rockiness or slope. Cost is not a criterion in physical margins, hence the concept is not precise, because trees or crops

29/ Webster's New Collegiate Dictionary (Springfield, Massachusetts: G. & C. Merriam Co., 1953), p. 513.

could be grown on Mount Everest if cost was disregarded. Black[30/] points out that all lands produce something counting jackrabbits, mice, any vegetation whatsoever, polar ice, rain or simply space -- scenic or otherwise. Hence in a sense there is no marginal or submarginal land. However, we are usually not so generous in our assumptions as to count production of anything at all as excluding land from being sub-marginal. Therefore, we cannot intelligently speak of marginal land (or anything else) unless we specify that which is our basis of classification, i.e., that with respect to which it is marginal.

In the physical margin concept the key point is a technical restriction or barrier. In the economic margin consideration, the key point is profitable operation. A number of factors influence profitability and therefore the economic margin on land: (1) The grade of land or its productivity, (2) Capacity of operator, (3) Acceptable standard of living of the operator, (4) Size of the land unit, (5) Price of the products, (6) Cost of production, and others. Therefore, there may be economic margins on land with respect to any of these factors influencing profitability. To speak precisely of an economic margin the factor with respect to which the land is marginal, as well as the level at which the other factors are assumed to be held constant must be specified.

Item (4) above implies the extensive margin of the unit. Black[31/] explains that the intensive and extensive economic margins of cultivation are not two different margins, but two ways of looking at the

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30/ John D. Black, Notes on "Poor Land and "Submarginal Land", Journal of Farm Economics, 27:345-374, Map, 1945, p. 361.

31/ Black, op. cit., p. 362.

same margin. To illustrate these two margins simultaneously, imagine an early homesteader settling on the great plains. Even with free land his extensive margin is set by what he and his family can operate profitably. Furthermore, even with equal and uniform fertility, the settlers would not logically farm each acre with equal intensity. Near the house, for example, the land is more conveniently located and the housewife might farm a small patch of ground quite intensively and profitably with garden crops. Outlying land might receive only token management, being left in pasture for greatest profitability. Thus, there are intensive and extensive margins on the unit, which in this case is a farm, but it could just as well be a forest. The two margins might be visualized in three dimensions. The extent of the area is bounded by the extensive margin, while the depth or intensity of application of labor and other inputs is set by the intensive margin. They are views of the same margin in the same sense that any side of a cube is called a side or margin.

Peterson and Galbraith[32/] define three possible levels for economic margins. The Absolute Economic Margin with respect to grade of land would be identified if an operator was chosen with the highest productive capacity, of a nature to accept the lowest standard of living possible, put on a land unit of the most efficient size, then the lowest grade of land that he could cultivate profitably at prevailing prices would be the absolute economic margin.

The Average Economic Margin would attempt to reach a "mean sea level" concept. Operators of average capacity, on average-size units,

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32/ G. M. Peterson and J. K. Galbraith, The Concept of Marginal Land, Journal of Farm Economics, 14:295-310, April, 1932.

willing to accept an average standard of living would be applied to grades of land and the lowest grade that could be cultivated profitably at prevailing prices would be termed the average economic margin with respect to grade of land. However, Peterson and Galbraith state that there is a tendency for poor operators to be associated with poor soil which distorts the average concept and even if one could work with averages one would not want to.

The two authors settle on a General or Representative Economic Margin for Practical application, since the absolute economic margin is too hypothetical. The General or Representative Economic Margin with respect to grade of land is that particular grade which, with an operator representative of the capacity of operators generally associated with about that grade of land, on a representative size unit, willing to accept the lowest standard of living representative for that group, could cultivate profitably at prevailing prices.

Marginal Logs, Trees and Stands

Similar distinctions regarding the economic marginal log, tree or stand could be made; however, in the remainder of this paper it is assumed that the term marginal refers to the general or representative economic margin concept, except where it is identified regarding a specific firm.

Trees standing on the margin of a mountain meadow or other ecological distinction represent a physical concept. However, all forests can be reached physically, so there are only economically inaccessible forests from a resource standpoint. This explains the elastic nature of timber resource statistics and utilization standards. It

also explains why there will never be a timber famine, but possibly exorbitant prices for forest products. Likewise, it also accounts for the change in marginal logs, trees and stands as the price of these commodities vary.

A marginal product is one which when sold, just meets its cost of production. This applies to logs, trees, stands or any other product. Products yielding a profit are termed supra-marginal. Those yielding a loss are called sub-marginal. Thus, zero profit is the key to the economic margin; profit being the difference between total revenue and total cost for each additional unit of product.

For example, speaking of trees but the concept applies also to logs or stands, if all the trees in a stand were of identical species, volume, and quality with the only difference between them due to location, then one could think of the marginal trees as defining a sort of economic periphery of profitableness. If the trees were to be taken out through a tunnel on level ground, the periphery would be circular. Topography would alter the shape in so far as it altered transportation and other costs. Notice the implication here that the marginal tree is being defined with respect to transportation cost alone; all other factors are presumed to be held constant. Because in actuality the other factors are not constant, marginal trees are scattered all over an area. Some are marginal economically because of quality, some for reasons of volume, some because of species and some for other or a combination of these reasons. The problem is how to identify the economic marginal tree, log, or stand.

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In figuring the profit in a log, tree or stand, the revenue side presents no problem. Between stands, over a single stand of trees or among logs in felled trees, the price per thousand board feet in graded lumber is standardized. Price times volume by lumber grade gives total revenue. However, the task of assigning the proper cost of logging and milling to each log, tree, or stand is not so easy.

The problem is one of marginal costs. As the logger proceeds from log to log in a felled tree, from tree to tree in a stand or between stands he wants to stop in each case where the additional revenue to be derived just equals the additional cost, i.e., where marginal revenue equals marginal cost. It has been established in economic theory that profit will be greatest when output is pressed to this point of expansion. The point of zero profit that identifies the margin can be determined by computing total cost and total revenue for each log, tree or stand, but this is cumbersome. It is sufficient to know only the costs that will be changed by the decision to take the additional log, tree or stand. These are particular or variable costs, attributed entirely to the decision in question. As mentioned above, the particular revenue presents no problem of determination.

Using the schema of the science of economics in trying to make profit larger before the job is undertaken, there must be a choice between alternatives.[33/] In the case at hand the choice is to take or

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33/ Henry J. Vaux, Content of Forest Economics, Research in the Economics of Forestry, W. A. Duerr and H. J. Vaux, editors (Baltimore: Waverly Press, 1953), p. 15. "Economics is concerned with problems of allocating productive resources among the several alternatives which may be available, so as to maximize the net monetary and other returns obtained from them."

leave a log, tree or stand. The word "before", underlined above, accents the importance of chronology in determining whether or not a cost is variable and hence to be included in marginal costs. After a decision has been made all costs are committed, becoming historical or fixed. A time-flow chart will indicate the time of commitment of various costs and their conversion from variable to fixed costs at the moment of decision.[34/]

TIME FLOW CHART FOR INDICATING VARIABLE COSTS

Cost category	1949 entering business margin	1955 Stand margin	1955 Tree margin	1955 Log margin
Stumpage	Variable	Fixed	Fixed	Fixed
Main road	Variable	Fixed	Fixed	Fixed
Spur road	Variable	Variable	Fixed	Fixed
Falling	Variable	Variable	Variable	Fixed
Skidding	Variable	Variable	Variable	Variable
Hauling	Variable	Variable	Variable	Variable

In the above chart it is apparent that in deciding whether to enter the logging business in 1949 all costs and revenues were relevant in determining profitability. Whereas, after entering the business, in 1955 with a tree down and deciding on taking logs from it, only the influence of each additional log upon revenue and cost of skidding and hauling is pertinent to the decision.

Prior to investing in stumpage in 1949 the investor presumably held liquid funds and debated the advisability of investing in stumpage and the lumber business or of placing his funds elsewhere. To

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34/ For the time-flow chart and elaboration of the concept presented in the article by Donald Bruce, op. cit., the author gratefully acknowledges the classroom lectures by Dean H. J. Vaux, School of Forestry, University of California, Berkeley, California.

such an investor with no commitments made, all costs are variable costs and relevant to the decision. However, once the decision is made to purchase the stumpage, it becomes a fixed cost, and the next decision becomes a choice between stands to log. The only costs relevant to this decision are the future or variable costs involved, for past, historical or fixed costs are no costs, i.e., irrelevant. Thus, at the stand margin stumpage cost is fixed and irrelevant to the decision, but all other costs from access roads on down are variable, will change or influence the decision and so must be included in a careful appraisal of which stands to log.

Once a stand has been chosen, the cost of access roads, log and skid trails join stumpage cost as being committed and fixed. It does not matter now whether one or a thousand trees are taken out; the logger must look elsewhere to determine his tree margin. He looks to those costs that will be influenced or will vary with each additional tree cut, and considering all costs below and including falling, he reaches the marginal tree when these costs equal the revenue contained in the tree in question.

Falling cost does not enter the determination of the marginal log for the tree is already down and falling cost is historical and fixed. Again, only the variable costs of bucking, skidding, loading and hauling will be influenced by taking an additional log, so these costs for the log in question should be considered and the marginal log in a tree is the one where the returns by taking it just equal the particular cost of logging it.

The opportunity cost concept was presented on page 39 and it will be found that these costs must be included also in marginal cost analysis. To illustrate the principle, using the same tractor example previously given, imagine the tractor owned by a road contractor but available to the logger on a rental basis. Assuming a cost of $20 for operation, depreciation and maintenance, plus the $6 per hour net profit in road construction, the total rental charge would be $26 per hour. In this situation when the logger is appraising the marginal costs of each additional log prior to bucking, he must consider the rental cost of the tractor to skid that log. Thus, tractor rental for skidding is certainly a variable cost to be included in marginal skidding costs.

Now assume the logger owns his own tractor and in theory rents it from himself to skid his logs. How much should he charge per hour for rental? Obviously, the total charge is the market rate of $26 per hour. However, in intra-company accounting procedures, profit is not computed for each piece of equipment, but only computed on an over-all or company basis. Furthermore, profit is computed residually and it would distort the picture if it were included in marginal costs. For the marginal log is one that neither adds to or detracts from profit, but is identified where marginal returns equals marginal costs. Therefore, neither the $6 net profit foregone in the alternative of road construction, nor the $5 net profit to be earned in skidding logs is included in marginal costs. The $5 net profit eventually arises from the differential between costs and returns in supra-marginal logs. Cost of operation and maintenance, included in the remaining $20 are classed as variable costs by the logger and are already included in marginal

costs. Depreciation is all that remains and because it is usually regarded as a fixed charge, it may seem peculiar that it should also be included in marginal cost when the asset has an alternative use.

It is well to recall at this point that the logger was only able to rent the tractor because the machine had an alternative use. When there is no alternative use for an asset such as a road system or a sawmill, the opportunity cost is zero and the depreciation on such assets should not be included in marginal costs. Bruce[35/] mentions this peculiarity in regard to a sawmill, indicating that a mill that is liquidating can press utilization further to the marginal log than a mill on a sustained operation basis. As the liquidating mill theoretically takes successively smaller diameter classes of logs, those of lower quality, further in skidding and hauling distance, etc. the alternative uses of the mill become exhausted and ever lower opportunity costs are incurred that must be included in marginal costs. Finally, with zero opportunity cost to charge against the marginal log for the mill, every log will be taken whose particular returns will cover the particular costs of delivering that log to the mill deck. Whereas, with a mill operating on a sustained-yield forest, the utilization of small logs, low quality logs, logs at greater distances, etc. must include the opportunity cost for the mill and all other equipment when employed on the alternatives offered by larger logs, better quality logs, logs closer to the mill, etc. Because of these additional opportunity costs included in marginal costs, the marginal log for the sustained-yield mill will be larger, of higher quality, closer to the mill, etc.

35/ Bruce, op. cit., p. 43.

Depreciation

It has been pointed out above that to be theoretically correct in appraising logs, trees, and stands at the margin, all variable costs must be included in marginal costs as well as the charge for depreciation on those assets having an alternative use. A brief discussion of deprecation and the related topic of maintenance follows.

One definition of depreciation refers to the actual loss in value of physical property due to use, supersession, or obsolescence which cannot be off-set by current repairs.36/ The extent of this process can only be appraised by competent valuation engineers. Appreciation, the opposite of deprecation, occurs in some cases such as the maturing of wines and other liquors through time and the improvement of the tonal qualities of some violins with age. Depreciation of capital assets may be classified by causal distinctions, although in practice such distinctions cannot always be made. One such arbitrary classification follows:

I - Physical depreciation or deterioration

A. Wear and tear from operation

1. Period of use

Presumably, the longer the use, the greater the wear and tear. This is the reason for looking at the odometer on a car in a used car lot -- one registering 27,000 miles is better than one registering 72,000 miles, other factors being equal.

37/ Anson Marston, Robley Winfrey, Jean C. Hempstead, Engineering Valuation and Depreciation (New York: McGraw-Hill, 1953), p. 175. "Depreciation is a word well known to all businessmen, men of many other walks of life, and to the accountant, lawyer, and engineer. Yet in spite of its widespread usage the word depreciation is often applied loosely and in several meanings....Currently, the word depreciation is used in three distinct meanings....(1) decrease in value, (2) a cost of operation, and (3) physical condition..." Eugene L. Grant, Depreciation (New York: Ronald Press, 1955) devotes a chapter (Ch. 2) to the various meanings of depreciation.

2. Rate of use

Presumably, the faster the use, the greater the wear and tear. This is what the used car dealer is accenting when he mentions that the former owner was a careful driver and not a speed demon.

B. Decrepitude or deterioration due solely to time

Cars setting on blocks in garages deteriorate without use. Tires, upholstery, and wiring rots. Bodies and engines rust; batteries become useless. Similarly, other equipment, bridges and buildings deteriorate without any traffic or use. This is due to the action of the elements through time, including freezing and thawing, decay organisms and chemical reactions.

C. Contingent depreciation

1. Accidents

These include explosions, collisions, falls, failure of buildings, or other structures, or the breaking of machinery by extraneous agencies.

2. Disasters

Included are fires, storms, floods, earthquakes, etc.

3. Organic causes

Such as pollution of water, growths in water mains, parasites and disease in work animals, etc.

II - Functional depreciation

A. Inadequacy

This is a functional inefficiency due to the unsatisfactory capacity of the unit for the job. This is the case when D6 tractors are being retired and greater economy gained by replacing them with D8 machines or vice versa, due to the change in requirement demanded of the equipment.

B. Obsolescence

This is a functional depreciation due to technological improvements such as the invention or development of later, improved models. Obsolete is the extreme extent of obsolescence.

1. Supercession

Supercession may be considered a type of obsolescence where the same service can be rendered with greater efficiency by quite different kinds of structures or equipment. When tractors superceded horses or trucks superceded railroads in logging are examples of this category.

2. Change in consumer demand

All goods and services are produced for ultimate consumption. Consumers may change their tastes without apparent reason or warning, necessitating a revaluation or depreciation of both inventories and productive assets. The fading of the miniature golf craze is one example. The possible shift in public taste for houses made with lumber has many implications for the lumber industry. Obviously, taste changes can occur in either direction, causing depreciation of assets in one case and appreciation of assets in the other.

It is important to recognize that in estimating the life of industrial units that they may require replacement long before they are physically worn out. The hobby of antique cars kept in excellent running condition is evidence that machines can be rebuilt and repaired to serve an almost endless life. Furthermore, the rebuilt machine, incorporating later innovations and development, may be better than the original machine when new. Some logging companies rebuild their tractors each winter, maintaining that they are kept as good as new. In effect, care and maintenance can off-set physical depreciation, the question is when does such effort become uneconomical and it would pay to obtain a new machine. The solution is clean-cut in theoretical economics, but again the practical application of the theory is problematical. The key is profit and the technique is marginal analysis.

Bradford and Johnson[37/] state that, "The fundamental economic principle with respect to the profitable use of machines is the same as that with respect to other production factors. One must equate the marginal cost of using a machine with its marginal value product. Marginal returns include labor saved, value of marginal physical product, timeliness,

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37/ Lawrence A. Bradford and Glen L. Johnson, Farm Management Analysis (New York: John Wiley, 1953), p. 302.

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and increased quality of product." Pure production economics is not very helpful, practically, in this problem because the optimum maintenance and replacement plan on equipment and structures is built into the production function and it is assumed as given in pure economic theory. With this and other assumptions, the expansion line represents the least cost expansion route. However, the maintenance-replacement policy to maximize profits can be indicated in the following equality as presented previously on page 19.

$$MC_Y = \frac{P_1}{MPP_{X_1}} = \frac{P_2}{MPP_{X_2}} = \ldots\ldots = \frac{P_n}{MPP_{X_n}}$$

where: MC_Y = Marginal cost with respect to output

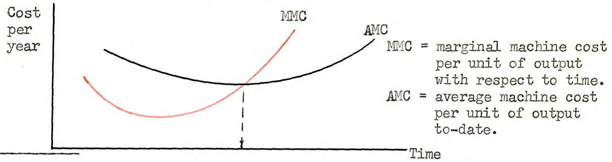
MPP = Marginal physical productivity

$X_{1..n}$ = Various pieces of equipment, structures and other input factors

$P_{1..n}$ = Price of various input factors, which for prices of equipment and structures, includes maintenance and charge for depreciation. The assumption in the production function is that the optimum maintenance and replacement policy exists.

Larson[38/] proposes a method to identify the point in time to replace a piece of equipment. His somewhat modified diagram is presented below:

Point in Time to Replace Machine[39/]



38/ George H. Larson, Methods for Evaluating Important Factors Affecting Selection and Total Operating Costs of Farm Machinery (Unpublished Ph.D. dissertation, Michigan State University, East Lansing, Michigan, 1955). He also gives on p. 80 the following summary of some methods which have been advocated and used for making replaement determinations in industry:

(a) Replace every X years or Y hours. This method has the disadvantage that the costs involved in operating the machine are not solely a function of age or total hours of use, since operating conditions, skill of operator and kind of maintenance will influence the operating costs. It also ignores the price and productivity of the new machine.

(b) Replace when the machine is fully depreciated. The disadvantage of this method is that the rate of depreciation used may not be the true value and does not take into consideration the increased maintenance cost due to excessive use and poor maintenance.

(c) Replace when the maintenance cost of old machine exceeds the depreciation charge of the new machine. This method is based on the fact that direct operating costs such as fuel, lubricants, and other incidentals will be the same for the new machine and the old machine. This may not be true for a particular machine. It also assumes that the rate of depreciation is the same for the new machine as for the old machine, which may not be true.

(d) Replace when the unit cost of the old machine is lowest. The chief disadvantage of this method according to Dean (Dean, J. 1948. How to Determine When a Motor Vehicle Should Be Replaced. SAE Quarterly Transactions, 2:518-531) is that the point at which decline of depreciation cost is just canceled off by the rise of maintenance and other costs, has no economic significance except when compared with an alternative course such as average life cost of new machine.

(e) Replace when the machine is "worn out" beyond repair. This method does not appear to have any reasonable justification since with modern methods of maintenance a machine can be made to run almost indefinitely by merely replacing or rebuilding worn parts.

(f) Replace when expected machine costs (capital and operating) during the next year are higher than average annual costs (capital and operating) of a new machine sufficient to yield an adequate cost-savings return. Dean (1948) calls it the capital earnings method and highly recommends it. However, he says this method also has limitations and that it can have errors in projecting costs into the future. This method requires training in economic analysis and capital budgeting.

39/ The author has taken the liberty to place a title on the graph and label

It appears that the diagram shows that equipment should be replaced when its average machine cost per time period is least. This seems synonymous with Item (d) in Footnote No. 38.

The goal of physical efficiency is not the criterion to use, because while it can be achieved, the cost may be excessive. The aim should be the economic optimum of producing the output at least cost, including the charge for depreciation. Thus, repairs and maintenance cost is weighed with the charge for depreciation and the optimum is achieved where all costs through time are least for the output desired.

Computing Depreciation and Capital Recovery

The determination of repair and maintenance cost is a matter of bookkeeping. It has been mentioned that actual, expired utility (depreciation) or its complement, the remaining value, of an asset is a matter for determination by an expert. However, for accounting purposes, approximations of depreciation and remaining value can be made

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the curves as he presumes they should be labeled. Larson had labeled them only as "Marginal Cost" and "Average Cost To-date". The full label distinguishes the curves from the customary economic curves of marginal cost with respect to output and Average Cost of Output. Larson states on page 81 , regarding his minimum-cost method that, "The criterion for this method is the theory of maximum profit as used by production economists. When the marginal cost equals the average total cost, a point has been reached on the production function curve which is considered to be the maximum profit point. It should be noted that when this point is reached the average total cost curve will be at a minimum." It should be noted that even when the usual curves of marginal cost with respect to output and average cost of output are drawn in economic theory, profit is not maximized at the output designated by the inter-section of those curves. That intersection merely designates the output of least unit cost.

in several ways. Likewise, for appraisals of the profitability of enterprises, allowance must be made for the recovery of invested capital with interest. Estimates of depreciation and capital recovery are different views of the same scene. That there is a distinction is evident in the statement that sales must be made to recover capital; whereas, depreciation, at least in part, continues with or without sales. Economic appraisals involving capital recovery computations are made to aid in the choice between alternatives <u>before</u> an enterprise is undertaken. <u>After</u> the enterprise has started, actual depreciation arises. Accountants usually make estimates of depreciation expense in advance and in this case the computation is comparable to capital recovery procedures, except that for the latter to be correctly done an interest charge on invested capital should always be included.

Numerous textbooks[40/] present formulae to approximate (1) the annual[41/] charge for depreciation, (2) the depreciation at the end of A years, and (3) the book value at the end of the Ath year. These values by three common methods of approximation of actual depreciation follows:

40/ Three textbooks containing such formulae are cited: 70, 114, and 162.

41/ Any other uniform time period could be used.

let: L = Useful life of the asset in years
C = The original cost of the asset
C_L = The salvage or scrap value at the end of the life of the asset, including gain or loss due to removal
d = The annual charge for depreciation
C_A = The remaining book value at the end of A years
D_A = The depreciation through A years
k = Rate of depreciation, a constant equal to $1 - \sqrt[A]{C_A/C}$
i = Market rate of interest
r = Rate of return on investment
$1/S_{\overline{n|}}$ = Sinking fund factor, $\left[\frac{i}{(1+i)^n - 1}\right]$, (see tables in textbooks)
$S_{\overline{n|}}$ = Amount of an annuity of 1, $\left[\frac{(1+i)^n - 1}{i}\right]$, (see tables in textbooks
M = Average, periodic return on investment
X = Annual capital recovery charge, including return on investment

1. The <u>Straight-line Method</u> of computing depreciation assumes that the loss in value is directly proportional to the age of the asset. This method is simple, has a uniform, periodic charge, and is more widely used than any other method.

$$(1) \qquad d = \frac{C - C_L}{L}$$

$$(2) \qquad D_A = \frac{A(C - C_L)}{L}$$

$$(3) \qquad C_A = C - \frac{A(C - C_L)}{L}$$

2. The <u>Fixed Percentage or Exponential Reduction Method</u> of computing depreciation assumes that the periodic loss in value is a constant percentage of the book value at the beginning of the period. Since a constant percentage is applied against a declining base or book value, the amount charged for depreciation is large in early years, declining exponentially to small charges in later years which never reach zero. Some argue that this is good, when both depreciation expense and repairs and maintenance are considered together, because they tend to

[illegible]

balance each other. When the equipment is relatively new, repairs and maintenance is low, but depreciation high. In later years, the reverse is the case. This method is used by the National Automotive Dealers Association to arrive at their "Blue Book" values.

$$(1) \quad d_A = (C_{A-1})k$$

$$(2) \quad D_A = C\left[1 - (1 - k)^A\right] = C - C_A$$

$$(3) \quad C_A = C(1 - k)^A$$

3. The <u>Sinking Fund Method</u> assumes that a sinking fund is established in which funds will accumulate for replacement purposes. The greatest criticism lies in the fact that few businesses ever maintain an actual depreciation sinking fund.

$$(1) \quad d = (C - C_L)\frac{1}{s_{\overline{L|}}}$$

$$(2) \quad D_A = (C - C_L)\frac{s_{\overline{A|}}}{s_{\overline{L|}}}$$

$$(3) \quad C_A = C - (C - C_L)\frac{s_{\overline{A|}}}{s_{\overline{L|}}}$$

I. The <u>Straight-line Method</u> of computing capital recovery with a return on investment involves: (a) the recovery of the investment which is similar to straight-line depreciation, plus (b) an interest charge on invested capital which amount is usually taken as the average amount of capital invested in the asset over the period. The main advantage of this method is its simplicity and the uniform capital recovery charge.

$$M = \frac{Cr + Cr/L}{2}$$

$$= C\left[r \frac{(L + 1)}{2L}\right]$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

adding capital recovery, assuming no salvage value:

$$X \quad C\left[r\frac{L+1}{2L}\right] + C/L$$

$$C\left[r\frac{L+1}{2L} - 1/L\right]$$

including salvage value:

$$X \quad (C - C_L)\left[r\frac{L+1}{2L} + 1/L\right] + C_L r$$

A different way of computation, giving the same results, for the average periodic return on investment, M, is to take an average of the assumed, linear-decline of the percent of capital investment over the years of life of the equipment. This is the approach taken in some equipment handbooks.[42/]

Where L = 5 Years

Value 1st year	=	100%	of delivery price
Value 2nd year	=	80%	of delivery price
Value 3rd year	=	60%	of delivery price
Value 4th year	=	40%	of delivery price
Value 5th year	=	20%	of delivery price
		300%	

Average investment for 5 years = $\frac{300\%}{5}$ = 60% of delivery price

Where L = 4 Years

Value 1st year	=	100%	of delivery price
Value 2nd year	=	75%	of delivery price
Value 3rd year	=	50%	of delivery price
Value 4th year	=	25%	of delivery price
		250%	

Average investment for 4 years $\frac{250\%}{4}$ 62.5% of delivery price

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42/ Allis Chalmers Mfg. Co., Tractor Division, Earthmoving and Construction Data. (Milwaukee, Wisconsin, 1953) p. 92.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

These or similarly derived average investment percentages are also called average fixed investment factors and are identical to the $\frac{L+1}{2L}$ term in the formulae above.

II. The Fixed Percentage or Exponential Method of computing capital recovery is used in England, Canada and infrequently in the United States. The changing annual capital recovery charge makes it inconvenient to use. By this method the magnitude of k, the constant percentage, determines whether the invested capital will be recovered exactly or whether a rate of return on investment will be included. Consequently, the capital recovery formula is identical to the depreciation formula by this method.

$$X_A = (C_{A-1})^k$$

III. The Sinking Fund Method of capital recovery assumes that a real or fictitious sinking fund is established in which funds accumulate for the recovery of invested capital with interest. A two-rate capital recovery formula (Hoskold's)[43/] has been developed on the reasoning that the sinking fund is not speculative and a relatively risk free rate, i, should be applied to it. Whereas, the rate of return on the original investment is entirely speculative, and is entitled to the rate, r. The capital recovery charge is thus made up of two parts: (a) the periodic, uniform payment into the sinking fund, $C\frac{1}{S_{\overline{n|}}}$, and (b) the uniform, speculative return on the original investment, Cr.

43/ H. H. Chapman and W. H. Meyer, Forest Valuation. (New York: McGraw-Hill, 1947), p. 474.

[illegible]

On this premise, the two-rate capital recovery formula may be written:

$$X = C \frac{1}{s_{\overline{n|}}} + Cr$$

$$= C\left[\frac{i}{(1 + i)^n} + r\right] \quad \text{Salvage value} = 0$$

To include a salvage value:

$$X = (C - C_L)\left[\frac{i}{(1 + i)^n - 1} + r\right] + C_L r$$

When only a fictitious sinking fund is established and it is assumed that the sinking fund is promptly re-invested in the business, it is logical to use the same interest rate for both i and r. This method, called the exact method of capital recovery or compound interest modification[44/] of the two-rate sinking fund premise, shows an increasing periodic payment (a) into the fictitious sinking fund over time due to the compounding of the reinvested interest. The rate of return on original investment (b) declines because the original investment, C, declines as capital is recovered, paid into the fictitious sinking fund and reinvested. However, the total of (a) plus (b) remains uniform as in the two-rate method. The formula for the exact method is simpler and may be derived by beginning with the two-rate formula and the assumption that salvage equals zero:

$$X = C\left[\frac{i}{(1 + i)^n - 1} + r\right]$$

44/ An informative comparison of the two sinking fund premises is given by J. E. Rothery, Some Interest Factors, Journal of Forestry, 39:680-684 August, 1941.

Introducing the assumption that i = r

$$X = C\left[\frac{r}{(1 + i)^{n-1}} + r\right]$$

$$= C\left[\frac{r + r\ \{(1 + r)^n - 1\}}{(1 + r)^n - 1}\right]$$

$$= C\left[\frac{r + r\ (1 + r)^n - r}{(1 + r)^n - 1}\right]$$

$$= C\left[\frac{r\ (1 + r)^n}{(1 + r)^n - 1}\right]$$

To include a salvage value

$$X = (C - C_r)\left[\frac{r\ (1 - r)^n}{(1 + r)^n - 1}\right]$$

The factor in brackets is called the capital recovery factor and is tabulated in textbooks as the annuity whose present value is 1.

Chapter III

MENSURATION

Measurement of Wood Volume

Man has established certain standards for measurement. The length of the metric meter is standardized by a single bar of metal kept in the city of Sevres, France, a suburb of Paris.[1/] In practice, meter

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1/ Encyclopaedia Britannica, Vol. 15, 1946, p. 363. Metrology (is the name) for the science of pure measurement....The problem of metrology is twofold. First to provide and maintain unaltered standards of reference by which other quantities are compared and measured; and secondly to provide means by which the comparisons may be made with accuracy sufficient for the particular purpose in view....No measurement is ever absolutely correct. Some degree of experimental error is always necessarily present....The metre was originally intended to be the 10,000,000th part of the earth's quadrant. But it was soon found that not only was the determination of this natural standard an extremely laborious undertaking, but the accuracy attainable was less than that possible in the comparison of material standards, and the material metre des archives, a platinum end standard became the accepted standard of reference for the metric system until superceded in 1889 by the present international prototype metre, a platinum iridium line standard.

pp. 136-137. (The prototype metre)...is 90% platinum and 10% iridium. The distance between the central one of the group of three lines at each end when the bar, being subjected to normal atmospheric pressure, is supported on two rollers at least 1 centimetre in diameter placed symmetrically 572 mm. apart and the bar is at a temperature of $0^{o}C$. is defined as one metre....the metre is now defined in terms of the international prototype metre without reference to the metre of the archives or to the length of the earth's quadrant....In the U.S. its (the metric system) use was legalized by the act of July 28, 1866.

p. 135. ...in 1893, after receipt of the metric standards, it was decided that a more stable basis for the system of customary weights and measures in the United States would be obtained by defining the yard in terms of the metre and the pound in terms of the kilogram.... The U. S. yard is defined as 3600/3937 metres and the U.S. pound as 0.4535924277 kilograms.

sticks variously approximate the length of that bar, and these approximate meter sticks when used result in secondary approximates of length. Similar standards for weight and volume exist and likewise primary and secondary approximations occur in practical measurement of these quantities. The problem of measuring or scaling defective logs of numerous sorts results in a variance that may be classified as an example of the secondary approximation group. The measurement of volume of sound, straight logs of uniform quality generates a tertiary approximation when the log scale or standard attempts to predict the volume of a manufactured commodity that can be derived from the log. The waste in manufacture of such logs varies (1) over time, due to technology and economic conditions affecting utilization; (2) from place-to-place, due to transportation charges and other economic factors as well as differences in species of timber; and (3) because of different wastage between different log size classes.

The basic complexity causing the tertiary approximation of prediction stems from two considerations: First, a board foot of lumber, equal to one-twelfth of a cubic foot, is absolutely different from a board foot log scale, which is an ambiguous unit of no certain size. The same difference exists between a cubic foot of lumber and a cubic foot of log scale. However, where no waste in manufacture occurs, this

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...For industrial purposes...a relation between the inch and the millimetre has been adopted by the American Standards association... (as)...1 inch = 25.4 millimetre (exactly) whereas the relation (above for) 1 U. S. yard gives 1 inch = 25.4000508 millimetres.

p. 136. The gram, the unit of mass, was to be equal to the mass of a cubic centimetre (1 centimetre = 0.01 metre) of pure water at the temperature of its maximum density (4°C.)...

p. 136. The stere was defined as the measure of volume, especially for cordwood, equal to a metre cube.

difference would disappear, except for shrinkage in seasoning. Secondly, the ambiguous standard of a board foot of log scale varies not only with time, place, method of sawing the logs, dimensions of lumber sawed, and log size, but also depending upon the log scale used. That these log rules are inconsistent between each other for different log sizes is treated in forest mensuration texts,[2/] where the construction and peculiarities of various log rules are discussed. In general, the gross inaccuracy of the Doyle Rule in estimating the board foot contents of small logs is deplored, the greatest accuracy is admitted for the International Rule, and the choice between the Scribner Decimal C Rule and the International Rule on some national forest timber sales is given. A brief comparison of the last two rules for those log sizes encountered in lodgepole pine is pertinent to this study.

The Scribner Log Rule was constructed by Reverend John Marston Scribner (1805-1880), an ordained minister and mathematics teacher. It was published in its presently used form in 1846 at Rochester, New York.[3/] The Scribner Rule is based on a saw kerf of ¼-inch, boards 1-inch thick, probably not less than 8 inches wide, and the full length of the log. The log was squared in sawing. The rule eliminated the variation due to different methods of squaring and slabbing by drawing diagrams of circles of different diameters and plotting on each area the ends or

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2/ Three such texts are: Donald Bruce and Francis X. Schumacher, Forest Mensuration (New York: McGraw-Hill, 1950), Herman H. Chapman, Forest Mensuration (New York: John Wiley, 1921), and Harold C. Belyea, Forest Measurement (New York: John Wiley, 1931).

3/ Collingwood, Harris, The Lost Identity of Doyle and Scribner, Journal of Forestry, 50:943-944. December, 1952. Belyea, Harold C., A Postscript on the Lost Identity of Doyle and Scribner, Journal of Forestry, 51:326-329. May, 1953.

cross-sections of the boards which might be sawed from it. The inch-class circles represent diameter inside bark at the small ends of logs and therefore all taper is disregarded. Rounding the board widths downward to even-inch widths (i.e., 4, 6, 8, etc.), the cross-sectional area of the boards in square inches was reduced to board feet by the divisor, 12. He then got the standard log contents by multiplying this result by the length of the log in feet. "The fact that his diagrams were in some cases eccentric and that the resulting values for successive inch-classes increased in an irregular manner was ignored. The diagram was the standard. The original values still hold good, regardless of later efforts to introduce modifications or improvements in the standard. ... The Scribner Log Rule has been extended downward (from 12 inches) to cover logs of 6 inches in diameter, and upward from the original 44 inches to 120 inches for Pacific Coast timber".[4/] The practice of rounding off the last figure in the scale of a log to the nearest 10 board feet was soon adopted by makers of scale sticks, hence the popular Scribner Decimal C. Rule.

Bruce and Schumacher[5/] plotted Scribner Rule volumes for 16-foot logs over the diameter range of 6 to 40 inches and fitted a parabola thereto by the method of least squares with the resultant regression equation:

4/ Chapman, Herman H. and Dwight B. DeMeritt, Elements of Forest Mensuration, (Albany, N. Y.: J. B. Lyon Co., 1936), p. 232.

5/ Bruce, Donald and Francis X. Schumacher, Forest Mensuration, (New York: McGraw-Hill, 1950), p. 195.

$$V = 0.79D^2 - 2D - 4$$

This is the Scribner Rule by formula which is almost universally used by professional foresters in scientific work involving Scribner volumes. Unfortunately, there exists a lack of precision in the forestry profession, due to slovenly use of the designation "Scribner". This is particularly significant in the small diameter logs characteristic of lodgepole pine, where the Scribner Decimal C. Rule over-scales the Scribner Rule by formula 67 per cent in the 6-inch class and 43 per cent in the 7-inch class (see Table 1.). The same discrepancy exists for these two log size classes between the International Rule ¼-inch kerf and the Scribner Rule by formula.

The International Log Rule was constructed by Judson F. Clark in 1900 for a saw kerf of 1/8th inch plus 1/16th inch allowance for shrinkage. This rule has been accepted as the standard by foresters for scientific measurements of board foot contents. The published values are rounded off to the nearest 5 board feet. "Its high values, however, have interfered with its commercial acceptance. In recent years the more conservative International Rule ¼-inch kerf has been increasingly used commercially in some regions and there is a present tendency to prefer them for scientific work as well".[6/] The formula for 4-foot sections of a log, using 1/8th inch kerf and ½-inch taper per 4 feet is:

$$V = 0.22D^2 - 0.71D$$

For a ¼-inch kerf under the same other conditions a correction factor of about 9.5% is applied, resulting in:

$$V = 0.199D^2 - 0.642D$$

6/ Bruce and Schumacher, op. cit., p. 169.

[illegible]

A comparison of the International Rules with the Scribner Rules over the range of small diameter logs characteristic in lodgepole pine is presented in the table below. Accepting the International Rule ¼-inch kerf as standard, the percent deviation in volume estimates for 16-foot logs by using the other ¼-inch kerf rules is noted in Table 1.

The separate definitions of a board foot of lumber and a board foot of log scale were mentioned above. The difference between the board feet of rough, green lumber and the board feet of log scale is termed overrun or underrun, and is usually expressed as a percentage of the log scale.[7/] Sawmill men and other timber appraisers take this important consideration into account. For example, Bruce and Schumacher show the characteristic relation of the overrun of 16-foot sawlogs from the Scribner Rule by log size classes to be about 10% for 16-inch logs, 15% for 12-inch logs, 25% for 8-inch logs, and 30% for 6-inch logs.[8/] For the 6- and 7-inch log size categories, so prevalent in lodgepole pine utilization, is the lumberman to expect a lumber yield 30% above the optimistic International Rule 1/8th inch kerf on the 6-inch log size class and 27% above International Rule 1/8th inch kerf in the 7-inch class? This is the

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7/ To speak precisely of overrun or underrun of a log rule, two sources of discrepancy should be identified: (1) Inaccuracy of the log rule in predicting the volume of rough, green lumber resulting when sound, straight logs of specified taper are sawed in a mill having the specified kerf, by the method and in the dimensions assumed equivalent to those incorporated in the log rule specifications. (2) Errors in prediction resulting from misapplication of the log rule. These include errors in measurement as well as variance due to voided assumptions; for example, where a ¼-inch kerf rule is used in a mill cutting a 3/16ths inch kerf, or where the logs contain improperly accounted defect. Obviously, a log rule cannot be criticized logically upon inaccuracy due to reasons of the second sort.

8/ Bruce and Schumacher, op. cit., p. 166.

Table 1

Comparison of International Log Rules and

Scribner Log Rules for 16-foot Logs

Log D.i.b. Class	International Board Feet				Scribner Board Feet, 1/4 inch					
	1/8 Inch		1/4 Inch		Extended Original		Decimal C		Formula	
	Volume	Per Cent	Volume	Per Cent	Volume	Per Cent	Volume	Per Cent	Volume	Per Cent
4	5	100	5	100	--	--	--	--	1	20
5	15	150	10	100	--	--	--	--	6	60
6	20	100	20	100	18	90	20	100	12	60
7	30	100	30	100	28	93	30	100	21	70
8	45	112	40	100	32	80	30	75	31	77
9	55	110	50	100	40	80	40	80	42	84
10	70	108	65	100	50	77	60	92	55	85
11	90	112	80	100	65	81	70	87	70	87
12	105	110	95	100	79	83	80	84	86	90
13	130	113	115	100	97	84	100	87	104	90
14	150	111	135	100	114	84	110	81	123	91
15	175	109	160	100	142	89	140	87	144	90
16	200	111	180	100	159	88	160	89	166	92

Comparison in per cent is made on the basis that the International Rule, 1/4-inch kerf, equals 100 per cent. The log rule volumes are found in various forest mensuration texts.

implication, for by looking at Table 1., it can be seen that in the 6- and 7-inch log size classes the predicted volume is the same for both International Rules and the Scribner D.C. Rule. Or to put it another way, if a 30% overrun above Scribner D.C. should be expected for 6-inch logs, then the highly reputable Scribner Rule by formula underscales that class of logs by 97%. Similarly, the Scribner Rule by formula would underscale the 7-inch log class by 70%. By such reasoning sawmill operators would be advised to buy even smaller logs because of the ever increasing overrun. A more reasonable assumption is that the increasing trend of overrun in small logs culminates at a log size close under 10 inches and then declines sharply. It is highly doubtful that any overrun should be expected below the 8-inch class. A careful test for overrun in the 6- and 7-inch log size categories has not been done to the author's knowledge. Until such a study is made, the buyers of the characteristically small-size lodgepole pine timber might well question the imposition of a 25% overrun factor that is sometimes used in public and private timber appraisals. The importance of such a question is indicated by the easy possibility that 40 to 50 percent of the total volume of some lodgepole pine timber sales may be found in these two log size classes.

It has been proposed that the cubic foot[9/] be substituted as a national log-scaling standard.[10/] This was done by statute, for example, in British Columbia, September 8, 1952.[11/] However, as Laver points out, "Measurers will not in many cases have the freedom to make radical changes in the established practices of the undertakings or authorities to which they are attached; and managers and others who possess that power are apt to use it sparingly."[12/] The cubic foot cannot be regarded as a magic, cure-all standard for log and lumber measure,

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9/ Laver, C. F., Principles of Log Measurement, (London: Ernest Benn, Lts., 1950), on p. 17 explains that in England, "There are four distinct units of log measure in common use in the timber trade, which contain in their names the word, cubic foot; but only one of them actually corresponds to the Imperial Standard Cubic Foot. Because of their divergencies from the standard measure, the other three units have qualifying phrases incorporated in their full names:
 The Cubic Foot, Hoppus Measure (144 divisor)
 The Cubic Foot, Caliper Measure (144 divisor)
 The Cubic Foot, Tape Measure (144 divisor)
The last two are used for measuring slabbed or squared logs; whereas, the Hoppus Foot is used exclusively for measuring round logs. It is 1.2732 times as large as the standard cubic foot, which results from squaring one-fourth of the measured circumference of the log instead of one-3.545th in computing the area of the log section in square inches. The Hoppus Foot may be visualized as a cylinder one foot in length and one foot in quarter-girth; but it could also be any other shape of equivalent volume. If V = volume in Hoppus feet, L = length of log in feet, and Q = quarter girth at mid-point of the log, the Hoppus Foot formula is: $V = (LQ^2)/144$

10/ Rapraeger, E. F., The Cubic Foot as a National Log-Scaling Standard, Northern Rocky Mountain Forest and Range Experiment Station, Missoula, Montana. Station Paper No. 24, June, 1950. (originally published Jan., 1940).

11/ Forestry Handbook For British Columbia (Vancouver: University of British Columbia, 1953), p. 245.

12/ Ibid., p. 194.

since as was indicated previously, a cubic foot of lumber is a different commodity than a cubic foot of wood in the log. Nevertheless, there are some important advantages connected with its use.

A definite advantage of scaling the cubic foot contents of logs is that no assumption need be made regarding the product to be made or the intensity of utilization. It would seem to be an advantage to operators, scalers and forest producers to measure wood by the definite, readily-visualized, standard cubic foot to apply in identical concept to all log sizes. However, size of log is an important variable in lumber recovery which must be accounted in a factor which changes for each diameter class of logs.

The relationship between board feet of lumber and the cubic foot contents of the log is called the Board Foot-Cubic Foot Ratio.[13/] "If all the cubic foot volume of a tree could be converted into lumber, the board foot-cubic foot ratio would of course be 12. Because of the losses from slabbing, saw kerf, edging, inability to fully utilize taper, and other related factors, the board foot-cubic foot ratio is commonly between 5 and 6, and seldom greater than 7."[14/] For a given sawmill, sawing a single species into essentially the same lumber dimensions, the board foot-cubic foot ratio should be very stable for each log size class. This ratio becomes the "catch-all" factor to convert cubic foot contents of logs into board feet of lumber. However, it is important that cubic foot log volumes be tallied by log size classes.

13/ This ratio may be between rough-green or finished lumber and cubic contents of logs either inside or outside bark.

14/ Spurr, Stephen H., Forest Inventory (New York: Ronald Press, 1952), p. 165.

The practical mechanics of constructing and using a cubic foot scale stick to scale cubic foot volume from the single, small end measurement of a log is presented by Rapraeger.[15/] He assumes a uniform taper of one-half inch in four feet and has computed cubic volumes for different diameters and lengths. For particular application to lodgepole pine this generalized assumption would have to be tested for accuracy. Deduction for volume of defect is easy to visualize and Rapraeger points out a rapid method of calculation.

For reasons mentioned above and because in logging, the work involved is more closely correlated with cubic foot volume than board foot volume, the cost equations in this study were developed upon a cubic foot basis. More precisely, they were computed on a cubic foot volume including bark basis. This approach seemed logical because the weight and volume of bark is included on logs delivered to the mill or railhead.

Actually, the bark is so thin on lodgepole pine trees that it is questionable whether bark thickness would influence the cost equations appreciably. However, if this type of logging cost analysis is to be expanded, bark thickness is a factor that should be studied. Parker[16/] found that bark thickness at breast height on lodgepole pine trees apparently varies with age and with site. For a given age and diameter class it is thicker on the poor sites than on good ones. His

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15/ Rapraeger, op. cit., pp 15-24.

16/ Parker, H. A., Bark Thickness of Lodgepole Pine, Forestry Branch, Division of Forest Research, Department of Resources and Development, Ottawa, Canada. Silvicultural Leaflet No. 49, November, 1950.

[illegible]

regression for all ages and all sites showed a 9-inch d.b.h. tree as having bark about 0.2 inches thick. Also, for a given site, the change in bark thickness at d.b.h. is slightly greater in young than in the older stand. How bark thickness varied through the length of the stem was not reported, but should be included in a logging study of bark thickness.

The scaling of individual logs, either in cubic feet or board feet, is costly due to the numerous lodgepole pine logs contained in the usual truckload. For this reason there have been attempts to scale by weight. Schumacher studied volume-weight ratios for pine logs on the Virginia-North Carolina Coastal Plain and found, "...the avoirdupois green weight of carloads or truckloads....serves as an efficient scale of raw material product....it submits to accurate, quick, and routine determination at the mill yard;..."[17/] The Biles-Coleman Lumber Co. at Omak, Washington buys long, lodgepole pine logs on an average, year-around, weight basis of 4,820 lbs. per cord. The Yellowstone Pine Lumber Co. at Belgrade, Montana uses a weight-volume figure for lodgepole pine of 11,000 lbs. per thousand board feet. The weight factor for the latter company provides a net scale result, allowing for some defect and a "fair" overrun.

Weight per cubic foot or thousand board feet is influenced by several factors. Moisture content of the log varies depending upon the

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17/ Schumacher, Francis X., Volume-Weight Ratios of Pine Logs in the Virginia-North Carolina Coastal Plain, Journal of Forestry 44:583-586. August, 1946. p. 586.

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[illegible]

[illegible]

[illegible]

season and whether the logs were cut from trees actually growing or dormant, whether the trees were alive or dead and the wood in different degrees of air dryness, and how long the logs were cut and in process of drying before being hauled. The weather is also a factor. Logs cut in a rainy season may not dry out at all, and again snow, ice, water and mud on the logs add some weight in passing over the scales. There are other weight differences in the moisture content as well as the wood material itself between logs cut on different sites. Schumacher demonstrated that, "...the ratio of volume to green weight does not tend toward identity over all the tracts but tends, rather, to values peculiar to individual tracts."[18/] Rot, catface, checks, hollow butt, sweep and other log defects as well as improperly manufactured logs cannot be appraised by weighing and must be determined by inspection. Because a weight factor cannot account for such items that fluctuate erratically, only a weight factor to predict gross volume was contemplated. A percentage correction could be applied to it to alter the gross volume scale for any contingent situations that might be encountered. The weighing part of this study could not be completed as planned because the necessary truck scales from a state highway department were not made available.

18/ Schumacher, *op. cit.*, p. 584.

Measurement of Time and Work

One can climb a flight of stairs fast or slow with identical expenditures of energy, however the work is spread over a different time interval. Likewise a logging job can be pursued liesurely or rapidly with the same crew and equipment, accomplishing the same result in days or months. On the other hand, the same logging job can be done using different degrees of mechanization, which logically would alter the time required to do the job. In short, two variables are involved: (1) the time interval required to do the job, and (2) the method of accomplishing the work.

The measurements of the time required to do a clearly defined activity or series of operations is simple and needs little elaboration. In timing logging processes usually an ordinary, sweep-second-hand watch is satisfactory, although a stop watch may be useful. However, the task of defining what is to be timed requires careful consideration. The traditional approach is to recognize at the outset two time categories involved in production. The first category is a direct productive time which varies directly with production. The second sort is an indirect or supplemental time required to do the job, including delays of various sorts. The second category is presumably unrelated or only indirectly related to production. Because time is one way of measuring cost, these two categories are roughly comparable to a sort of variable and fixed costs. It has been regarded as proper technique to time these categories separately to achieve greater accuracy. However, the purpose which will be served by the time data and the practical difficulty of accurate separation may override tradition and indicate a more expedient technique.

[illegible]

The traditional approach in timing can be elaborated to any degree of detail. A recent example of a rather complex time classification of a high-lead yarding study follows:[19]

- I - Productive time
  - A - Basic time
    1. Maintime
       - a. Haul-in
       - b. Haul-back
       - c. Choker set
       - d. Unhook
    2. Supplementary time
       - a. Changing yarding road
       - b. Changing corner block
       - c. Moving yarding machine
       - d. Swing blocks on spar tree
       - e. Tightening guylines
  - B - Delay time
    1. Necessary delays
       - a. Personal delays
         - (1) Rest
         - (2) Personal
       - b. Operational delays
         - (1) Working delays
           - (a) Hang-up
           - (b) Lost logs
           - (c) Shaking
           - (d) Landing
           - (e) Miscellaneous
         - (2) Equipment delays
           - (a) Machine
           - (b) Chokers
           - (c) Drums
           - (d) Lines
           - (e) Miscellaneous
    2. Unnecessary delays

The footnote quotation from Barnes[20] on page 32 of this paper indicates that time and motion study are somewhat inseparable. If the

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19/ Tennas, M. E., R. H. Ruth, and C. M. Berntsen, An Analysis of Production and Costs in High-lead Yarding, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper no. 11, February, 1955. p. 6.

20/ Barnes, op. cit., p. 3.

above outline were carried some stages further, the timing of basic motions such as bending an arm, leg, or turning the head would result. Thus, by defining what is to be timed, a definition of the method of accomplishing the work becomes explicit or is at least implied. In this study the method of accomplishing the work is handled for reasons of expediency in the assumptions. Then, on the basis of this standardization, the amount of work can be measured by the volume of production. This is manifestedly acceptable to business management because it is only interested in cost of production to the firm.

From an academic standpoint it is notable that the laborer or society should not accept production as an accurate measure of human effort performed.[21] Consider, for example, workers in two different logging operations, paid identical piece rates and the companies are experiencing equal unit costs of production. However, one company employs inferior methods and/or equipment, which difference is made up by greater manpower exertion. Of course, under the assumption of free competition and mobility of labor, workers would flow to the easier jobs. But, pending this movement and readjusted equilibrium, indirect measurement of human effort by production would be inaccurate. Furthermore, social costs are excluded from economic analysis at the firm level.

An important factor in all time studies is whether the worker speeds up or slows down from the normal or other assumed pace specified in the study. Some willing workers in great sincerity may try to work

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21/ Techniques for measuring human effort were discussed on p. 33.

the defined pace under observation, but this very conscientious attempt is not normal nor are the results likely to be according to definition. Other workers are quick to sense possible, detrimental, rate adjustments so they slow down to avoid being held to a higher production standard. Attempt by the time recorder to get his data secretly is not a good practice and cannot be justified. Some workers seeking commendation or other satisfaction, speed up and distort the data. The problem is one of assuring reasonable conformance by the worker to a defined, standard pace while under observation. People in general and loggers in particular, either resent or are pleased with such special attention and therefore work at an unusual pace.

No satisfactory way was discovered to wholly solve the problem. However, in timing the falling production over entire days for a number of days, it was believed that the tendency of the worker to work at an unnatural pace was minimized. Minimizing the distortion due to timing under observation for skidding, loading and hauling is open to larger doubt because these activities were timed by the turn, truckload and trip. The chance for this sort of distortion was most likely in the skidding process where the operator was under constant observation through a day's production. It is hoped that attempts at friendly relations with the operators, casual-as-possible use of a watch, fully explaining the need for working at the accustomed pace, and the timing of as many operators as possible kept the distortion from this cause within reasonable limits.

[illegible]

Chapter IV

ASSUMPTIONS

In visualizing the over-all problem, some of the alternatives are assumed away. This procedure is expedient to narrow the problem to approachable size. Some of the possible alternatives are currently so economically implausible that they can be tabled in focusing attention on the more debatable techniques. The use of the helicopter, Rolligon, or forest harvester falls in this category.[1/] Among the remaining logging techniques only a few could be tested, and this study is further simplified by the assumptions listed below.

1. Products and Prices.

It was assumed that sawlogs or pulp wood bolts were the principal product and only logging techniques currently in use for these products were tested. However, logging for some other timber products, at least through some of the processes, may be considered nearly identical to those logging techniques tested. Other timber products such as transmission poles, converter poles, mine stulls, corral poles, railroad ties, fuelwood, etc. are not included in this study.

1/ The use of an helicopter to lift logs from stump to landing has been suggested. The Rolligon is a transport machine-developed for the military to negotiate rough terrain, rolling on large, low-pressure, sausage-like balloons instead of wheels. See Parker W. Kimball, Look, Mom -- No Wheels!, Saturday Evening Post, June 4, 1955. Forest harvesting machines to accomplish the felling, limbing, bucking, skidding, and loading operations, somewhat comparable to a wheat combine, have been envisioned.

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[illegible]

[illegible]

[illegible]

Product prices in a competitive market result from the intersection of supply and demand curves.[2/] The demand curve for stumpage

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2/ Supply and demand curves are basic economic tools conceived by Alfred Marshall, Principles of Economics (London: MacMillan & Co., 1936), p. 346.

The usual economic meaning of supply is a list of amounts of a commodity that will be forthcoming at all possible prices in a given market at a specified time. In other words, it is a schedule (or curve) relating all possible prices of a commodity and the amounts of the commodity which will be supplied at each of the prices. Likewise, the economic meaning of demand is a schedule (or curve) presenting all possible prices of a commodity and the amounts of the commodity which will be taken in a given market at those prices and at a specified time. The intersection of these two curves on the same set of cordinates gives the equilibrium price or price that satisfies everyone in the market. This relationship between supply, demand and price is termed the market law.

Large sectors of the science of economics lie behind these curves. A quick glance beyond the curves can only hint at some of the problems involved. For examples, the commodity may be sawlogs. Then, the market, or instantaneous supply curve, relates only to those quantities of logs instantly available for sale and their prices, i.e., logs cut and floating in booms or standing in decks. If the time restriction is relaxed somewhat to permit additional logging, then the concept is a short-run supply curve which would include the log volumes from existing and prospective logging chances and their prices. If the time restriction is relaxed completely so that all production factors are variable, then the long-run supply curve becomes operative and log volumes and prices include the concept of growing the timber to produce the logs. Similar concepts are involved for the supply of stumpage as well as lumber, and likewise on the demand side of the market.

Furthermore, logs are not an homogeneous commodity. Thus, there must be supply curves not only for different species, but also for different sawlog grades, to say nothing of veneer logs or pulp bolts. Likewise, lumber is not an homogeneous commodity, notwithstanding the mill-run category. Hence, there must be market, short-run, and long-run demand and supply curves not only for ponderosa pine lumber, for example, but for each grade of ponderosa pine lumber. Finally, all of these markets have boundaries and there are national supply and demand curves as well as more localized markets.

A peculiarity of these powerful economic thinking tools is that they exist only in the minds of producers and consumers. Should they if they could be published would invalidate them, for reaction would be immediate. However, through such successive readjustments, the supply and demand curves of perfect knowledge would emerge.

derives from the demand for logs. The demand curve for sawlogs derives from the ultimate consumer want which may be housing, ends served by other construction, and similar intermediate uses and ultimate products made of wood. Likewise, the demand for pulpwood stems from ultimate products such as newsprint, various other papers, paper-board, insulating board, hard board, rayon, plastics, etc. Perhaps fuelwood and Christmas trees are the principal wants satisfied directly by timber products. For a particular mill, the level of manufacture to which the raw material is finished as well as the efficiency of logging and manufacturing influence the price that this mill can pay for its logs and bolts. In other words, on the supply side, cost of production is all important. There was no competitive log market in the area where this study was made so prices for this commodity were not available.

2. Capital Restrictions.

An assumption that must be made by anyone seriously contemplating economic alternatives is that they have sufficient credit or capital to validate the choice. In this study it was assumed that reasonable financial requirements were not a problem.

3. Silvicultural and Utilization Specifications.

It was assumed that national forest specifications were governing, but these are not fully crystallized. Small, irregular tracts up to approximately 40 acres were assumed to be commercially clear-cut. It was assumed that nothing was done regarding slash disposal and the state forester or national forest was paid the stated fee for this task.

Utilization specifications vary between pulpwood and sawlog sales on national forests. Lodgepole pine pulpwood sales usually include the 4-inch, d.i.b., log diameter class, implying that pieces are taken down to and including 3.6 inches d.i.b.[3/] at the top. Lodgepole pine sawlog sales include the 6-inch, d.i.b., log diameter class, implying that pieces are taken down to and including 5.6 inches d.i.b. at the top. The length specification also is a factor in appraising utilization differences. Pulpwood sales may indicate that the last 100-inch section should be taken to a 4-inch, d.i.b. class. Sawlog sales have been written to include the last 2-foot section that can be cut within the 6-inch, d.i.b. class. Theoretically, this represents a considerable difference, but for the data collected in this study, it was believed and presumed that the difference between pulpwood and sawlog utilization specifications in lodgepole pine are an insignificant influence on logging costs.

4. Logging Chances.

By the Law of Probability Distributions, the majority of acres in the lodgepole pine type may be assumed to fall somewhere between the extremes of difficult and easy logging chances. Also, since lodgepole pine logging is in the pioneering stage, it may be assumed that the more difficult logging chances will be most likely left for later development. For these reasons, it appeared more economically fruitful to concentrate on studies applicable on easy to moderately difficult logging chances. Therefore, only easy to moderately difficult logging terrain

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3/ Diameter inside the bark taken at the small end of the log.

was assumed. This becomes even more rational when it is understood that under some difficult situations perhaps only one method of logging is feasible, in which case the situation dictates whether to log by this method alone or not to log at all.

The location in the forest of the tracts to be clear cut; the shape of the tracts; the number, terrain, and lay-out of the landings; and the placing of skidroads all have some influence on logging costs. Economic necessity dictated the solution of these problems by assumption. It was assumed that in setting up logging operations that reasonable experience and skill by the company and others concerned went into the logging plan and execution of it on the ground. Thus, these costs plus cruising, surveying and other developmental costs were not a part of this study.

5. Equipment and Crews

All equipment was assumed to be in reasonably good running condition and the horses to be healthy and sound. In an attempt to standardize, somewhat, the skill of equipment operators, the novices and other unskilled were eliminated from measurement by arbitrary selection, after talking with the logging operator. It is doubtful that really exceptionally skilled and experienced equipment operators are encountered among small gyppo loggers, although some owner-operators might fall in this category. Thus, by arbitrary selection and assumption, the range in skill of equipment operators was narrowed about what may be taken as the "representative" operator. A considerable number of observations were taken upon as many operators as was feasible in this moderately-skilled category. It was presumed that the averaging of this

number of operators in the more nearly representative stratum will result in a closer approximation of the desired predictive specification of an operator having representative skill.[4/]

6. Felling and Bucking.

In felling in tree-lengths, it was assumed that felling, topping, and limbing on three sides was done by a single faller using a powersaw and axe. For felling and bucking by one man with powersaw and axe into 100-inch pulp bolts, it was assumed that the process included felling, topping, limbing on four sides, bucking into 100-inch lengths, and manual piling into ricks along the felling strip. Small, light powersaws were used; the condition of which and the skill of the operator is discussed under item #5. No distinction was made between make of powersaw or whether the chainsaw drive was geared or direct. This would make some difference, since for example, the direct drive is more efficient for limbing. However, these differences in equipment were believed to be of relatively minor influence in daily production time.

4/ "...On the surface, several other methods of determining normality appear to be available, but, upon analysis, none is satisfactory. One such approach is to study all of the workers in a group and to use their average time as the normal time. Actually, this is not feasible. If all the workers were good, not enough time would be allowed, and the rate would be too tight. Conversely, if all were poor, too much time would be allowed and the rate would be too loose...

"Other attempts to avoid performance rating include selecting an 'average' worker and using his performance time. Disagreement on whom to choose and as to whether he works at a 'normal' pace while being studied rules out this method....

"Some engineers today claim that the use of standard times for minute parts of jobs, called 'therbigs', eliminates judging normality.... When he accepts the therbig times, however, he has already accepted the judgment of normality of the engineer who set up the therbig times...." Franklin G. Moore, Manufacturing Management, (Homewood, Illinois: Richard D. Irwin, Inc., 1955), p. 537.

7. Log Length and Size of Load.

The question of what log length is most efficient for logging lodgepole pine could not be completely answered within the limitations of this study. As many different equations for different log lengths were developed as were possible, which included felling in tree-lengths and 100-inch lengths, skidding by horse of 16-foot and shorter logs and tractor skidding in tree lengths, and loading of 16-foot and shorter saw-logs and 100-inch pulp bolts. Perhaps the most significant omission in studying log length as a cost influencing factor was the loading and hauling of 32-foot logs. Hauling of tree-length logs is generally excluded by highway restrictions. The principal advantage claimed for logging in long lengths is the time saved in producing and handling fewer pieces coupled with greater use of the capability of the machines involved. An important disadvantage is that additional cost is incurred in hauling rot and other defective material to the mill where it must be handled and disposed. Furthermore, it is said that a good faller can appraise a felled tree and make better logs in the open woods than can be done when they are floating in the pond or crowding on the mill deck. It is probable that there is no firm answer to the log length question, because in addition to the machinery and number of pieces factors must be included the skill and responsibility of the men as well as the quality of the timber.

Size of load in skidding or hauling is an important variable influencing cost. This seems to be quite well understood by truckers who generally try to load to either the limitations of the truck or the restrictions imposed by the highway department. Therefore the assumption

of reasonably full loads in hauling seemed logical and representative for this study. For skidding it was assumed that the loads were representative for the machines, animals, and skill of the men employed. The infeasibility of specifying a load standard may be the reason for the relatively unsatisfactory results in the skidding equations.[5]

8. Thickets, Brush, and Patchiness of Timber.

Thickets, brush, and distribution of merchantable volume over the area were not assumed to be of significant influence upon logging cost in representatively merchantable lodgepole pine stands and, therefore, specific measurements were not taken on these variables. However, brush branch diameters were encountered and included in several instances in the windfall index data.

9. Residual Stand and Volume Per Acre.

Residual stand was not assumed to be a significant variable influencing logging cost because lodgepole pine is generally characterized by nearly pure stands and it was assumed to be logged by the commercial clear-cut method.[6]

5/ Campbell, op. cit., p. 10. "Difference in size of load is the major reason for the difference in cost of skidding between our study and a recent TVA study (Tennessee Valley Authority, Hardwood Logging Costs in the Tennessee Valey, TVA, Div. Forestry Relations, Tech. Note 16. 19 pp., ilus. processed.) We used full loads for all tree sizes in computing team and tractor costs, whereas they used smaller loads. This difference resulted in skidding costs double or triple ours."

6/ In the commercial clear-cut method, theoretically all of the trees that will produce useful products above some minimum diameter are cut. However, this may leave many small trees, defective trees, and dead snags standing in the area.

Volume per acre is a significant variable in felling and skidding cost, since for example, it importantly influences walking distance between trees in falling and the assembly time in skidding. It also influences the average cost per unit of output in slasher sawing and loading, due to differences in volume per setting. In a similar manner, cost of roads per unit of output would be smaller with increasing volume per acre had they been included in this study. However, it was not feasible[7/] to accurately obtain this measurement and, therefore, it was assumed that data collected through a selection of operable lodgepole pine timber would be representative without this factor entering into the selection.

7/ Volume per acre is an ambiguous term. For example, does it mean average volume per acre on the clear-cut, 40-acre tract; or does it mean average volume encountered upon each individual acre? In the latter case, shape of the acre and its location must be identified. The statistic under the former definition is inapplicable, since the variable must be measured for each timed period of production. For falling the timed period was a day, for skidding it was the individual turn, and in neither case does average volume per acre over 40 acres apply. Furthermore, falling and skidding does not proceed acre-by-acre. For example, in skidding, turns are often assembled at points all over the tract to insure a steady flow to the landing. Also, due to economic restrictions on the study, the data could not be taken simultaneously for all logging processes, and after the trees are down it is especially difficult to measure volume per acre as a variable in skidding. Greater accuracy in obviating this variable could have been achieved by stratification or purposefully selecting samples through the range of this variable. However, measurements had to be taken on going operations with the time and place subject to little flexibility.

Chapter V

THE FELLING PROCESS

The felling process in logging may be considered to include the felling of the trees, the limbing, and bucking of the stems into logs. The faller does all of these tasks and occasionally others such as digging snow around the tree, felling hazardous snags, etc. where necessary. Hasel[1/] indicated that a day's work in felling and bucking may be measured by the number of trees felled and the square inches of wood sawed. Diameter at breast height squared may be used conveniently in place of the cross-sectional area at stump height.

In this study a similar approach was taken and felling production per day was timed for a total of 75 man-days, including 14 different sawyers in Hyalite Canyon, near Bozeman, Montana, and Island Park, Idaho, just west of Yellowstone Park. The measurements in Hyalite Canyon were taken during the summers of 1955 and 1956 on the M. J. Horen operation, a sub-contractor to the Corcoran Company which procures pulpwood in Montana to ship to several Wisconsin paper mills. Measurements at Island Park were taken in the summer of 1957 on the

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1/ Hasel, A. A. Logging Cost as Related to Tree Size and Intensity of Cutting in Ponderosa Pine. Journal of Forestry, August, 1946. pp. 552-560.

Charles J. Erickson and Son operation, who also shipped pulpwood to Wisconsin by rail. The rail haul from Island Park to destination is 1700 miles. Separate time-cost prediction equations were developed for each of these operations, since in Hyalite Canyon the trees were felled and topped to be skidded in tree-lengths. The terrain was moderately steep-sloped and the trees rather large size for lodgepole. At Island Park, the terrain was flat, the trees smaller, and the fallers bucked the stems to 100-inch lengths and stacked them manually into ricks. In both localities the sawyers worked individually with light powersaws.

Because there was little slope or windfalls on the Island Park operation, these independent variables were not used. However, both of these variables plus number of trees cut per day and the sum of their $(DBH)^2$ were tested in Hyalite Canyon. Slope was measured with a percent abney at three different points in the area that was going to be cut that day and the three measurements were averaged. The windfall measure was an improvised index to approximate the impediment to felling caused by windthrown timber. A staff compass was set up in the approximate center of the cutting area for the day and a direction chosen to measure out one chain from the compass. Any fallen stems encountered were measured in diameter at the transect and multiplied by the foot class in height above the ground. Thus, a six-inch windfall three feet above the ground was assumed equivalent in hindrance to an 18-inch tree lying on the ground. Care was not taken in choosing the original compass direction and chain transect, and the possibility of bias was further reduced by subsequently taking two additional chains of transect measurements

for windfalls in directions that trisected the compass face with the original bearing.

A method for obtaining daily volume felled and number of trees cut per day enabled the timing of up to seven sawyers per day. However, this many sawyers could not be easily handled by one man and perhaps from three to five sawyers more likely would be the average number to expect one timer to serve. After obtaining permission of the operator, the purpose of the study was outlined to the sawyer. Then, working ahead of the sawyer, diameter of trees at breast height was taken with a diameter tape. This measurement was pencilled on a small, white card made by quartering the usual 3 x 5 filing card. It was then stapled on the tree at eye level facing the sawyer. As the sawyer prepared to fall a tree, he pulled the tag and placed it in a spring clip to pocket it. At the end of the day, the cards were collected, furnishing number and diameter of trees cut per day. The method worked nicely, since the pulling of the tags took an insignificant amount of time, the timer was safely ahead of falling trees and therefore did not slow or worry the sawyer, and the researcher could keep busy working ahead of the sawyers and time as many fallers as he could handle. The sawyers seemed to enjoy the attention of being the subject of research and cooperated completely. A minor drawback was that pitch from the staple holes in the trees made the tags messy when a day or so elapsed before they were pulled. The tags were only used once and the information was transferred to standard, ruled data sheets following each work day.

This method implies the availability of a local volume table to get volume from diameter alone. In this study local volume tables

were constructed for each area by the convenient method outlined by Girard and Gevorkiantz.[2/] Tree measurements were easily obtained on trees that had been felled. The volume tables constructed are shown in Figures 1 and 2.

In the felling process in Montana, the stems were limbed on three sides, topped and left in tree-length. Although four independent variables were introduced, the single independent variable given below produced nearly as great an adjusted coefficient of multiple determination,[3/] R^2, as was obtained with the additional independent variables of: (1) number of trees cut, limbed, and topped per day, (2) slope percent, and (3) windfall index. The equations showing the influence of these variables are given in Appendix 2. Theoretically, the fraction of a day required for felling an individual tree can be determined by substituting

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2/ Girard, James W. and Suren R. Gevorkiantz. Timber Cruising. Forest Service, USDA. 1939.

3/ According to the nomenclature of Mordecai Ezekial, Methods of Correlation Analysis, (New York: John Wiley and Sons, 1930) p. 177. "The square of the coefficient of multiple correlation, R^2, may be termed the coefficient of multiple determination." He continues on p. 178, "It cannot be demonstrated that the coefficient of multiple determination will measure in all cases that proportion of the variance in the dependent factor which is associated with the independent factors." Nevertheless, this statistic commonly carries such a connotation. Frederick E. Croxton and Dudley J. Crowden, Applied General Statistics, (New York: Prentice-Hall, Inc., 1939) p. 742 state, "R^2 states the proportion of total variation that is present in the variations....which has been explained by reference to the independent variables." The addition of independent variables increases R^2, hence to correct for this automatic increase and adjustment downward is required. The adjusted statistic is distinguished as $\bar{R}^2$ and may be termed the adjusted multiple coefficient of determination. Both R and R^2 are often termed multiple coefficients of correlation.

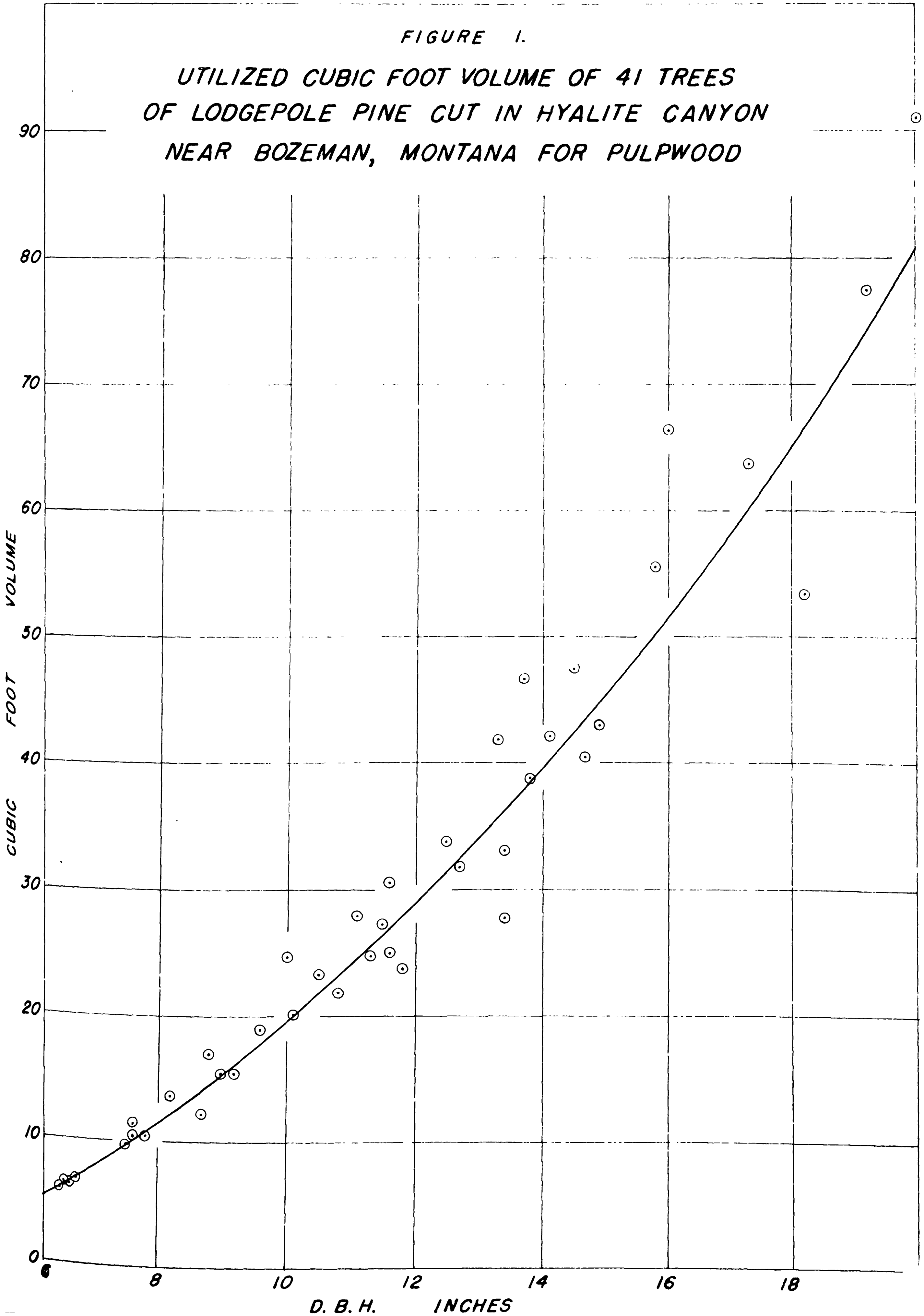
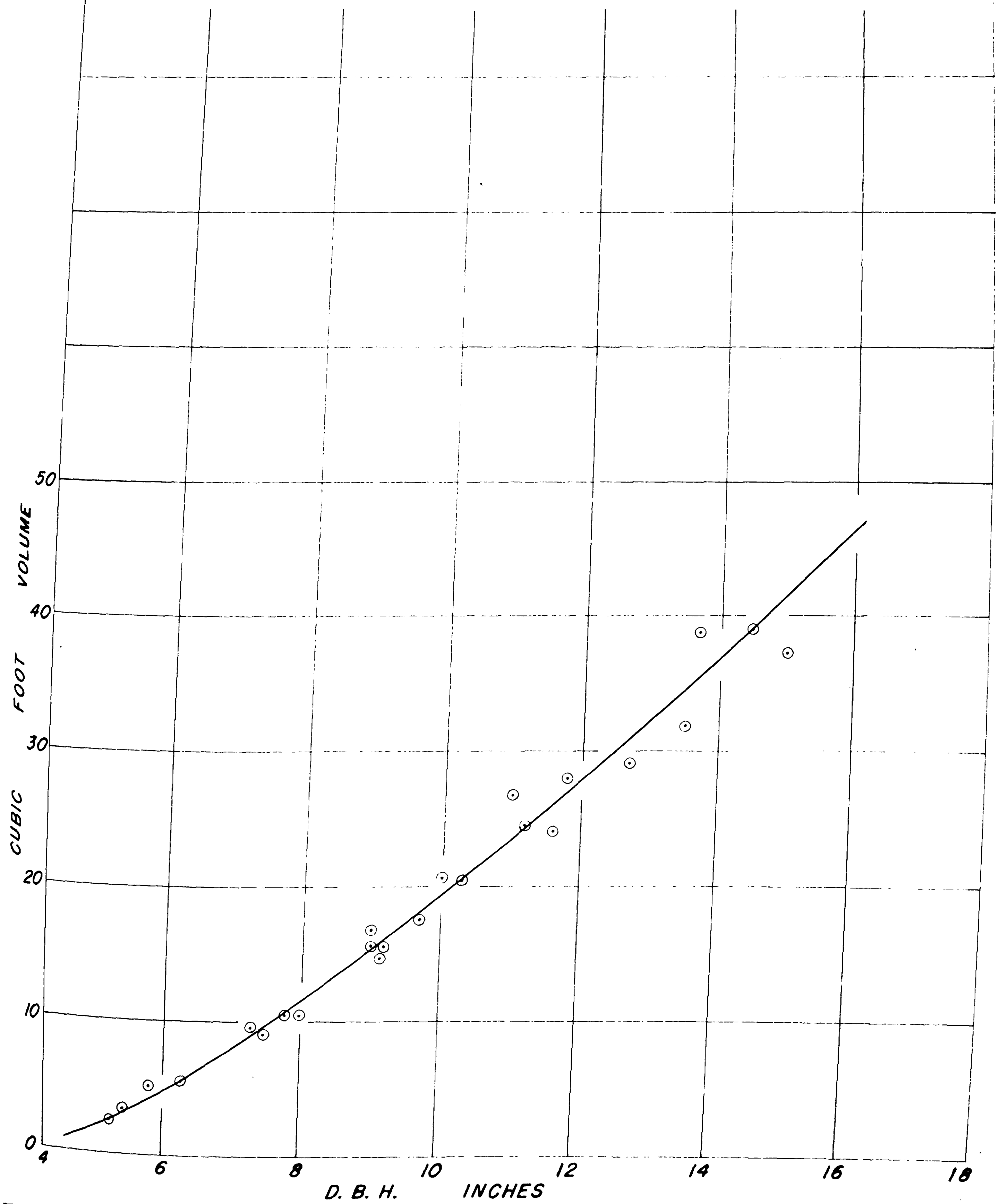


FIGURE I.
UTILIZED CUBIC FOOT VOLUME OF 41 TREES
OF LODGEPOLE PINE CUT IN HYALITE CANYON
NEAR BOZEMAN, MONTANA FOR PULPWOOD
CUBIC FOOT VOLUME
D. B. H. INCHES
0
10
20
30
40
50
60
70
80
90
6
8
10
12
14
16
18

FIGURE 2.

UTILIZED CUBIC FOOT VOLUME OF 24 TREES OF LODGEPOLE PINE CUT NEAR ISLAND PARK, IDAHO FOR PULPWOOD



$(DBH)^2$ in the equation below and dividing the volume of the given tree by the resultant Y. However, this reasoning is precarious, because the linear regression was fitted only for daily production and while the coefficients are valid for those ranges in volume, it cannot be inferred that the equation is therefore valid for all ranges, i.e., for the volume of a single tree. In fact, for a 6-inch tree containing 5 cubic feet, this procedure results in 5/63.3 = .079 or 7.9 percent of a day required for felling a tree of this size, which is obviously not correct.

Felling, limbing, and bucking to tree-length
Basis: 45 man-days by 7 sawyers

$$Y = 56.515657 + 0.188398X_1$$

$$21.796 = t$$

where Y = Cubic feet of tree-length felling production per day.

$\bar{Y} = 1,277.517778$

X_1 = Sum of tree diameters squared, measured at breast height, of trees felled per day, sum $(DBH)^2$.

$\bar{X}_1 = 6,480.971778$

S = 64.014553 cubic feet per day[4/]

$r_{y1} = .957862$

$\bar{R}^2 = .807531$

4/ S measures the dispersion of the associated measurements about the regression line. In other words, it measures the unaccounted variance. If the unaccounted variance in the 45 associated measurements in this felling study approached a normal distribution, one S on either side of the regression curve would include 68.27 percent of the measurements taken, 2S would enclose 95.45 percent of the data, and 3S would contain nearly all of the 45 measurements. The smaller the S statistic, the greater the explained variance included in the regression equation, and therefore the more substantial the inference of predictive accuracy of the equation other things equal. However, S is not a direct measure of predictive accuracy and to call it the standard error of the regression or standard error of estimate may foster unwarranted conclusions regarding the accuracy of estimates using the regression equation for other samples in the same or similar populations. It is extremely unlikely that the same population could be implied, since that would involve the same sawyers working under the same conditions in the same timber.

[illegible]

[illegible]

[illegible]

Averages over-simplify in describing either a sample or a population. It is almost a truism that the average sawyer, the average tree or stand, average terrain, or average windfall conditions seldom exist singly and even less likely occur in combination. One of the major reasons for using regression equations is to overcome some of the shortcomings of the camouflaging average. Nevertheless, averages have an importance. Table 2 summarizes some of the statistics on felling in tree-lengths given in Appendix 1. The names used in the table are not the real names of the sawyers.

Much of the unexplained variance in Table 2 and the regression equation is contained in the individuality of the sawyers timed. Personal drive, skill, stamina, and experience of the seven men covered a considerable range. Joe and Jim were two young, married, college men eager to earn as much as possible during the summer season. Tex was a seasoned, year-around professional and was active and energetic although in his fifties. Roy and Tom were seasonal sawyers from Minnesota, both were farm owners and experienced fallers, but Tom had the advantage of youth, the physical build of Swedish strength, and the urge to pay for his farm as quickly as possible. Above 1400 cubic feet of felling output per day appears to be well-above average felling production in tree-lengths for this type of timber. A good average production rate per day would perhaps fall between 1200 and 1300 cubic feet per day. Doc and Bud produced below average for different reasons. The former had only a modest urge to work and diluted that occasionally with alcohol in the loggers tradition. Woods work and rustic living conditions were hardly the best environment for the latter who was suffering from gastric ulcers.

[illegible]

Table 2

Felling Production in Tree Lengths

awyer	Days	Trees			D.B.H.		Cubic Foot Volume			Average Earnings		
		Total	Average Per Day	SD	Average	SD	Total	Average Per Day	SD	Dollars Per 100 Cu. Ft.	Dollars Per Day	SD
ex	10	569	56.90	10.08	10.01	4.10	13076.6	1307.66	172.64	1.340	17.52	1.58
oy	9	601	66.78	12.82	9.61	2.78	11508.6	1278.73	155.82	1.659	21.21	3.09
oc	7	327	46.71	11.16	10.14	2.98	7060.8	1008.69	169.00	1.810	18.26	3.19
om	2	250	125.00	49.50	8.04	1.73	3097.3	1548.65	205.70	1.840	28.50	9.19
oe	6	394	65.67	23.06	9.74	2.60	8070.9	1345.15	146.06	1.569	21.10	3.13
im	7	438	62.57	14.26	10.47	2.62	10477.8	1496.83	134.17	1.349	20.20	2.13
ud	4	145	36.25	9.74	11.44	2.67	4196.3	1049.07	58.16	1.296	13.60	2.31
otals	45	2724	60.53	22.50	9.87	3.11	57488.3	1277.52	217.86	1.519	19.41	4.07

D stands for standard deviation. Totals for averages and standard deviations are not additive, but computed on the basis of otal production during the 45 days. The real names of the sawyers are not used. This table summarizes data contained in ppendix I.

Several full days of production by Doc and Bud fell below volumes produced in a half a day on Saturday by the others so these were excluded as not being representative.

The sawyers customarily arrived in the woods about six o'clock in the morning, an hour ahead of the rest of the woods crew. They usually worked between eight and nine hours for the day, which was in addition to an approximate hour for lunch and coffee break. They quit work about four in the afternoon. The sawyers tallied their own production for payment by the piece. Piece count was by diameter measurement across the stump in six-inch classes. Trees from six inches to 12 inches in diameter on the stump were counted as "singles", for which payment of 20 cents[5/] was made for felling, limbing, and topping. Trees from 12 to 18 inches across the stump were "doubles" and 40 cents[5/] was paid for them. The 18- to 24-inch category was paid at the "triple" rate of 60 cents each. The average daily wage was $19.41 and the highest observed wage was $35.00 for a day made by Tom in a stand averaging 7.58 inches D.B.H. where he cut 160 trees to produce 1,694.1 cubic feet in nine hours of work. The large standard deviations for Tom is due to only two days of timing and these in stands of rather widely divergent character.

Wages for falling by piece rate must be adequate to attract men in the labor market. It is intimately related to the going wage rate per day in other logging jobs and elsewhere. In other words, the piece

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5/ This was reduced in 1957 to 18¢ and 36¢ due to an increase in industrial accident insurance rates in Montana.

Picture No. 8 shows a part of a clear-cut block on the M. J. Horen operation in Deep Creek, southwest of White Sulphur Springs, Montana. Abney measurement of the slope read 45 per cent. The tree-length stems were felled with the slope for easier skidding by D4 tractors. The landing for the slashersaw-loader was to the right of the picture. The 100-inch pulpwood was hauled 27 miles to railhead at White Sulphur Springs for shipment to Wisconsin papermills.

Picture No. 9, taken in the same locality as the one above, shows a deck of transmission poles that had been sorted out of the tree-length stems skidded to the slashersaw-loader at the landing. In this area, in addition to pulpwood and transmission poles, the contractor also was hauling the larger 100-inch bolts to a stud mill in White Sulphur Springs. However, such diversification in lodgepole pine logging is not common and in this case was occasioned by cutbacks in pulpwood orders.

rate must be such to enable a faller to earn daily wages that are competitive with other similar work.[6/] For this reason, precise payment for production may be over-emphasized. Perhaps the advantage a sawyer feels in measuring the stumps mostly across the major axis helps keep him happy with frequent winning fudges during the day. The same man might feel unduly constricted with a more accurate volume measure for payment. On the other hand, a loose system of payment for volume produced generates problems in cost control. In any case, two factors are involved in the variance of payment per 100 cubic feet in Table 2: First, the loose correlation between method of payment and cubic foot volume produced, and second, the opportunity for voluntary and involuntary mismeasure. A point of unknown importance in the first factor is the accuracy of the cubic foot volume table used in estimating the volumes of trees felled per day. If not the lowest, but $1.340 were assumed to be the correct payment per 100 cubic feet produced, then the highest payment made of $1.840 per 100 cubic feet is 37 percent in excess. Both the average of $1.519 per 100 cubic feet and $19.41 per day are somewhat inaccurate because only half of the involuntary mismeasurements could be assumed to be below the correct stump measurement, the other half plus all of the voluntary mismeasurements would tend to bias the measurements and resultant payments upward.

Some of the resultant details of adding additional independent variables to the regression equation are given Appendix 2. An attempt was

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6/ Alvin K. Wilson and Gordon H. Greenway, Costs of Logging Virgin Ponderosa Pine in Central Idaho, Intermountain Forest and Range Experiment Station, Ogden, Utah. Research Paper No. 51, June, 1957, p. 8. states that, "Since fallers are paid on a per thousand board feet basis (Gross saw scale) dollar costs per thousand board feet are of less interest than log production rates because pay scales are determined by negotiation between union representatives and contractors...."

was made to add number of trees felled each day to the equation on page 96 but the resulting equation seemed illogical. Due to the understandably high intercorrelation, r_{12} = .660387, in volume by using number of trees and their diameter, the peculiar situation of a positive coefficient of correlation between volume and number of trees felled was coupled with a negative regression coefficient for that variable.[7/] In other words, the more trees felled, the smaller the volume produced. If both coefficients had been negative, an explanation for the inverse relationship could have been made that volume production is more difficult in small timber.

When the overriding importance of the intercorrelation mentioned above became apparent, attempt was made to avoid it by using an average diameter variable. In other words, dividing sum of felled-tree diameters squared per day, measured at breast height, by number of trees felled per day, sum $(DBH)^2/X_1$, gave a new X_2 variable in which the influence of X_1 was eliminated. The intercorrelation between these two variables, r_{12} = -.761031, can be seen in Appendix 2, and the fact noted that now correlation coefficients and regression coefficients are in agreement. The results of the addition of independent variables seem to point out the

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7/ In discussing this point with several staticians, apparently such a contingency is logically possible, although it is unusual. Croxton, Frederick E. and Dudley J. Cowden, Applied General Statistics (New York: Prentice-Hall, Inc., 1939) p. 665 are more dogmatic, stating that, "The sign of r is always the same as the sign of b in the equation of relationship." This point apparently was not of importance in felling and bucking sawlogs in ponderosa pine, perhaps due to the larger size and fewer trees cut per day working with that species. According to Hasel op cit. p. 555, "Using number of trees and sum of squares of diameters as independent variables resulted in regression coefficients that differed from zero..." Both regression coefficients were positive; correlation coefficients were not reported.

relative unimportance of slope and windfalls in felling production in this study. To be sure, the full range of possible conditions of slope and windfalls were not sampled, but these two variables appear to be of minor importance under reasonable or average operating conditions. By comparing the second equation given in Appendix 2 to the one given on page 96 , it can be seen that the latter is simpler and has a smaller S and larger $\bar{R}^2$. Therefore it is presumed that little would be gained by using both number of trees felled per day and sum of their $(DBH)^2$ in an equation to predict volume of felling production per day.

Felling production per day where the stems are limbed, bucked into 100-inch lengths for pulpwood, and hand piled in ricks for loading is obviously a more time consuming method, where only this process is considered, i.e., where the influence on loading is disregarded. As previously mentioned, this method of felling was timed in Idaho just west of Yellowstone Park where the terrain was flat, windfalls were negligible, and the trees were smaller. There, the average tree diameter of those measured was 7.32 inches with S.D. 2.25; whereas, in Hyalite Canyon where the tree-length felling study was made, the trees averaged 9.87 with S.D. 2.25; whereas, in Hyalite Canyon where the tree-length felling study was made, the trees averaged 9.87 with S.D. 3.11. As would be expected under these two different situations and production specifications, average number of trees manufactured per day would be different. However, the variation is the reverse of expectations due to the smaller timber and was found to be 60.53 trees per day with a S.D. of 22.50 for tree-length production and 67.97 trees per day with a S.D. of 28.56 in 100-inch

felling. Average cubic foot volume produced per day was 1277.52 cubic feet, S.D. 217.86, for tree-length cutting and 676.98 cubic feet, S.D. 217.44, for 100-inch production. It must be remembered in making these volume comparisons that the products at the end of the process are in different form and the work in manufacture is different also for the two methods of production. Earnings per day were higher in 100-inch production, but they too are not directly comparable with felling in tree-length because the method of payment was different and the physical exertion in the two methods was also not the same. Wage payments and other additional comparisons between the two methods of felling may be made in Tables 2 and 3. Table 3 showing averages for the 100-inch felling process may be useful if their limitations are kept in mind.

As in tree-length felling, the individuality of the sawyer was a variable that could not be measured even though it was recognized to be of major importance. Of the seven sawyers timed, Ned seemed to most nearly approximate a good average producer, and perhaps 600 cubic feet of production per day would be representative of production per day in this category. Ned was in his thirties, married, a consistent worker, and a good technician, but not obsessed with a drive for high production. Ted and Rex were older men and paced their work at a level below the above figure for a good average. Wes was a boy without the drive of family responsibilities and this plus his relative inexperience placed him slightly below a consistent output of 600 cubic feet per day. The production of Don, Red, and Cal ranged above average, some of which could be attributed to their wives who worked with them, doing such lighter tasks as holding the measuring stick and piling brush. Of the

[illegible]

Table 3

Felling Production in 100-inch Bolts

Sawyer	Days	Trees			D.B.H.		Cubic Foot Volume			Average Earnings		
		Total	Average Per Day	SD	Average	SD	Total	Average Per Day	SD	Dollars Per 100 Cu. Ft.	Dollars Per Day	SD
Ted	4	143	35.75	4.65	8.93	2.56	2278.9	569.73	60.25	4.16	23.66	1.94
Rex	5	297	59.40	8.23	6.26	1.46	1805.8	361.16	32.16	6.09	22.00	1.14
Don	4	274	68.50	17.56	8.21	2.54	3630.2	907.55	133.89	4.66	42.32	7.79
Ned	5	324	64.80	22.02	7.42	2.13	3326.9	665.38	37.60	4.13	27.48	2.36
Red	4	334	83.50	22.88	7.49	2.31	3535.3	883.83	160.54	4.30	38.02	2.96
Cal	4	440	110.00	37.56	6.77	1.92	3519.1	879.76	138.54	3.78	33.25	5.04
Wes	4	227	56.75	21.81	7.28	2.16	2213.2	553.30	48.12	3.94	21.78	1.95
Totals	30	2039	67.97	28.56	7.32	2.25	20309.4	676.98	217.44	4.35	29.45	2.64

SD stands for standard deviation. Totals for averages and standard deviations are not additive, but computed on the basis of total production during the 30 days. The real names of the sawyers are not used. This table summarizes data contained in Appendix 3.

three, Red had the greatest professional experience. Indeed, he had been a pulpwood cutter for most of his life, winning a number of citations from his employers in the Lake States for outstanding production records. Perhaps now past his prime, he was still a giant of a man, loved to work and took pride in the amount he produced. Perhaps 1000 cubic feet per day would be a maximum daily production figure for 100-inch pulpwood that could scarcely be maintained by good cutters.

Payment for felling, limbing, bucking to 100-inch bolts, and piling in small ricks along the strip was by piece-rate. Pieces were tallied in the ricks by a woods foreman. The basis was diameter (presumably average diameter at the small end, although the details were apparently not this specific) of the 100-inch bolt. Below 4 inches did not count, and pieces 4 to 8 inches in diameter were tallied as one piece. Bolts 8 to 12 inches across were counted as two pieces. When the diameter measured 12 to 16 inches, they were counted as three pieces and so on upward in four-inch diameter classes. The foreman made a chalk mark across the face of the log for each piece of count which permitted the sawyer to verify the results. Attention is called to the variation in payment per 100 cubic feet of wood produced even though personal bias of the sawyer in tallying was not a factor. Presumably, most of the variation is explained in the loose correlation between the local volume table used and the method of payment.

Most of the sawyers worked on a 7½ or 8 hour day, usually beginning about seven o'clock in the morning and stopping for the day around four in the afternoon, with an hour out for lunch and coffee break.

For the days timed, Don earned the most in any one day with $50.30. However, there were four different days when a man earned over $40 per day in cutting pulpwood. The average for the thirty days of timed production by the seven sawyers was $29.45 with a S.D. of $2.64. A precaution is made in comparing this figure directly with the $19.41 average daily earnings in tree-length felling, due to the different conditions of the two studies -- mainly: different sawyers, timber, and terrain -- and the different degree of manufacture in the two methods. The high average payment per 100 cubic feet to Rex apparently resulted from his working in uniformly low diameter timber which perhaps gave a relatively higher piece-rate count for the volume produced.

At Island Park, Idaho the woods operation was more dispersed. Fallers were working in a number of blocks marked for clear-cutting simultaneously, and were thus completely independent of the loading and hauling processes. Within the blocks the fallers worked in strips about 100 feet wide. The fallers neatly felled their trees in herring-bone pattern on their strips so the tops became piled as felled along the strip boundaries. Then the stems were limbed, bucked to 100-inch lengths and stacked in ricks on either side of the strip just inside the rows of tops (see pictures 10, 11 and 12). Stumps were cut nearly at ground level because, subsequently, a truck would be driven down the center of the strip and loaded over the end with a Drott Skid Loader from the ricks on either side of the strip. The ricks were also aligned in herringbone pattern to facilitate forking and loading.

Picture No. 10 shows Wendelin Czeczok, a pulpwood cutter for Charles Erickson and Son, Island Park, Idaho, stacking 100-inch bolts along his cutting strip. The tool is a pickaroon made by cutting one blade on a double-bitted axe with an acetylene torch to a slender hook. In 30 man-days of timed output for the 7 sawyers included in this study, the average, daily production for felling and stacking 100-inch pulpwood was about 68 trees and 677 cubic feet. The machine-crew cost of a sawyer working with a light powersaw was $25.48 per day. Payment was by the piece and $29.45 was the average gross amount earned per day. This amounts to an average cost to the contractor of $4.35 per 100 cubic feet of pulpwood felled and stacked in 100-inch bolts.

Pictures 11 and 12 illustrate the felling method used by Charles Erickson and Son, Island Park, Idaho, where the sawyers produce 100-inch pulpwood. The trees are felled herringbone fashion, so the tops lie essentially as shown in neat rows between avenues piled on either side with pulpwood. Notice the low stumps which permit trucks to drive down the lanes for loading. The ricks are manually piled and angled to the lanes to allow easier loading by Drott Skid Loader (see Pictures 35 and 36). In this particular area the terrain was flat and the trees of uniform size with no dead snags or windfalls, hence the unusually clean appearance after logging.

Charles J. Erickson and son, Gordon, live in Negaunee, Michigan and came to Idaho and began shipping pulpwood to the Thilmany Pulp and Paper Co., Kaukauna, Wisconsin during the summer of 1953.[8/] The operation terminated midway through the 1957 summer season. Whether the shutdown came as a result of the softening pulp and paper market is conjectural; the reason given for not renewing a bid on national forest stumpage centered on a recreational use standard for logging roads in the sale area. In any case, the locality suffered a considerable economic blow, for at the peak of the operation there were several hundred fallers and dozens of trucks shuttling pulpwood to the Union Pacific siding at Trude.

In the 100-inch felling process timed in Idaho, again the single independent variable of sum of felled-tree diameters squared per day measured at breast height, sum $(DBH)^2$, gave a more favorable result than when another variable was added. Appendix 4 gives the results of adding number of trees as an additional variable, which may be compared with the simpler and evidently better equation below:

Felling, limbing, bucking to 100-inch lengths, and hand stacking in ricks. Basis: 30 man-days by 7 sawyers.
$Y = -5.417427 + 0.171229X_1$

where Y = Cubic feet of 100-inch-length felling production per day.
$\bar{Y} = 676.983333$

8/ Curtis, James D. and David Tackle, "Pulpwood Moves East From the Targhee", The Timberman (July, 1954) 55(9)122-123.

[illegible]

X_1 = Sum of tree diameters squared, measured at breast height, of trees felled per day, sum $(DBH)^2$

$\bar{X}_1 = 3985.310667$

S = 58.766988

r_{y1} = .965309

$\bar{R}^2$ = .929386

As before in the tree-length felling study, the attempt to use both number of trees felled per day with the sum of their D.B.H. squared as independent variables caused illogical results due to intercorrelation. In this case, r_{12} = .730622. When number of trees felled per day was added to the above equation as X_2, it produced a negative regression coefficient with a positive correlation coefficient for the X_2 variable. Reference is made to the footnote on page 102 and Appendix 4, where the same technique as used before was employed to eliminate the intercorrelation, but the results appear inferior to the equation given above.

From the nature of the timing of felling production by the day, both productive work time and delays of various frequently recurring categories were included in the above equations. Probably little if any of the delays are associated with tree diameter, so they are all presumably included in the constant in each of the above equations and those equations in Appendices 2 and 4. Both of the felling studies were not continued long enough to obtain a representative sample of all of the various delays. For example, two powersaw failures occurred during the 75 man-days of timing and the two fallers took their saws to town for repair. These two days were excluded from the study. Until the vagaries of weather, accidents, and other infrequent delays can be studied sufficiently for accurate prediction along with the more frequent powersaw

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[illegible]

[illegible]

failures and still more frequent delays for saw filing, smoking, resting, conversation, personal delays, et cetera, it seems expedient to predict what delays we can and add something more for the others. How much more time should be allowed for these as yet unpredictable delays requires a straightforward, clairvoyant guess. Campbell[9/] stated that 22.9 man-minutes delay time per tree was required for hand felling and 3 man-minutes per tree was required with powersaw. This study was made in the Southern Appalachians for southern pine and hardwood species, but the point is that such averages are not very helpful when the delays are only indirectly, if at all, associated with number of trees cut per day. Shames,[10/] in a detailed study of logging and milling costs in the same region found that average delays per day for felling and bucking amounted to 5.3 percent for rest, 6.8 percent for tools, and 8.2 percent for miscellaneous, leaving 79.7 percent for productive work time. This seems a more logical basis for delay averages, but even by this method the infrequent delays remain a problem that an average figure may obscure as much as solve.

It remains to develop an average, machine-crew monetary figure that can be applied to the time unit to convert it to cost in dollars. The dollar factor needed is the total average cost per day of operation of a faller using a light powersaw. The actual figures collected in 1955, 1956, and 1957 are already out of date, but the machine-crew factor

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9/ Campbell, op. cit., p. 3

10/ L. M. Shames, Logging and Milling Studies in the Southern Appalachian Region, Part II -- Time Studies, Southeastern Forest Experiment Station, USDA, Asheville, North Carolina. Technical Note No. 63, July 1, 1946. p. 2.

[illegible]

[illegible]

can be made current by substituting current costs for labor, equipment, and operating expenses in the detailed development in Appendix 5. The total average cost per day for a sawyer and light powersaw, determined for the dates and conditions of this study, were $21.73 per day for felling in tree-lengths and $33.27 per day for felling in 100-inch lengths. Caution should be employed in applying average dollar cost per day figures to production in stands that deviate considerably from average conditions. For example, felling in stands with heavy windfalls and much standing dead timber may be much more expensive than usual not only in time but in the extra sawing expense of the dead material which if not utilized will not add piece-rate wages to compensate the sawyer. Under such conditions both the time cost predicted by the equations and the machine-crew monetary factor should be adjusted upward. Similarly, decidedly better than average conditions might require adjustment in the other direction. However, this contingency is less likely due to the assumption previously noted that the lodgepole stands currently being logged, and in which the study was made, may be considered of average or better logging situation.

Chapter VI

THE SKIDDING PROCESS

After the trees have been felled, limbed, topped and perhaps bucked into logs, the next process in logging is to skid them to a landing or assembly point where they can be further processed. Various methods of skidding are employed in logging lodgepole pine, and some possibilities have not been adequately explored. Several cableway systems in this latter category are the Wyssen System,[1/] Lasso System,[2/] and Wire-Gravity Systems,[3/] all designed for log assembly from steep

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1/ Fobes, E. W., Wyssen Cable System, Forest Products Laboratory, Madison, Wisconsin. Report No. R1637-27. November, 1948. Matson, E. E., The Wyssen Skyline System, Proceedings Society American Foresters. 1955. Pestal, Ernst, Holztransport mit Langstrecken-Seilkranen (The Transportation of Wood by Long Skylines), Zentralblatt fur die gesamte Forst- und Holzwirtschaft. 72:31-46, 1953. Translation No. 15, Faculty of Forestry, University of British Columbia, Vancouver, Canada.

In the latter article, Dr. Pestal compares the Doppelmeyer machine built at Voralberg, Austria in 1948 with the Buko-Universal System, and the Wyssen System and concluded the latter is the most suitable one to-date for transportation of wood on steep slopes.

The cost of a Wyssen Skyline Crane, complete with 1¼ miles of cables and including duty and freight in 1955 was approximately $22,000. It is manufactured by Wyssen Skyline-Cranes Company, Reichenbach, Kandervalley, Switzerland. The device was invented by F.Wyssen in 1939.

2/ Endless "Lasso" Logging Cableways, Forestry Equipment Notes, Food and Agriculture Organization of the United Nations, Rome, Itay. April, 1957. E. W. Fobes, Single Line Continuously Moving Cable Systems, Forest Products Laboratory, Madison, Wisconsin, Equipment Survey Notes, Report No. R1637-29, January, 1949.

3/ Koroleff, A. and R. D. Collier, Wire Skidding Wood Transportation by Gravity Over a Suspended Wire, Pulp and Paper Research Institute of Canada, Montreal, Canada. 1954.

slopes. In the Wyssen System a taut cable serves as a high-line to which logs are lifted by means of an ingenious block and tackle arrangement which enables transporting the logs down the high-line by gravity to an assembly point. The Lasso System is a continuous, moving, taut cable looped around a block of timber and supported by special sheaves attached to trees. A small gasoline engine moves the cable at a slow rate and logs are hooked to the cable and brought suspended to a loading point. Both the Wyssen and Lasso systems were developed in Switzerland. Sliding bolts and logs to a landing over a suspended wire by gravity is a particularly intriguing possibility due to the easy mobility and small investment required.

Several variations of cable skidding offer possibilities in skidding lodgepole pine, but have either not been fully explored or tried. Simmons[4/] pointed out that improvements in wire rope and its accessories and fittings in smaller sizes are making it easier to rig up light cable systems. Manganese steel choker hooks, swivels, clevises, and real loggers' blocks are now available in sizes down to 3/8ths inch. Also, hydraulic torque converter drive is giving internal combustion motors the ability to take shocks and overloads formerly possible only with steam. Various systems of tightlining on high-lead installations are extending the usefulness of this system to lift rigging and even heavy loads of logs over obstructions a quarter of a mile from the skidder.

4/ Simmons, Fred C., New Developments in Harvesting Sawlogs, Proceedings Forest Products Research Society, Vol. 3, 1949. p. 36.

Semi-mobile arrangements for high-lead yarding in tree-lengths[5/] or in bundles of pulpwood[6/] have been tried in Canada. A careful study by regression analysis of high-lead yarding costs in the Douglas-fir region was published in 1955.[7/]

Fully mobile cable yarders of several makes are becoming increasingly common.[8/] Some are specifically designed for the job and by means of a haulback line can yard logs to roadside and subsequently load them with a swinging boom. Others are adaptations of mobile cranes, which may also be fitted with haulback lines. In some places, a haulback line is not used and the operator casts the cable much as in fishing. In such cases a slack puller is frequently added to the boom to pull the cable off the drum and spew it out toward the tong setter more efficiently. Some of these machines are used in lodgepole logging operations and have greatest effectiveness in skidding uphill to roadside. In cases where roads cannot be economically placed below the timber in steep terrain, this is about the only way it can be logged

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5/ Tateishi, M., High Lead Yarding in Tree Lengths, Pulp and Paper Magazine of Canada. December, 1951.

6/ Husak, N., High Lead Yarding in Bundles, Pulp and Paper Magazine of Canada. December, 1951.

7/ Tennas, M. E., R. H. Ruth, and C. M. Berntsen, An Analysis of Production and Costs in High-Lead Yarding, Pacific Northwest Forest and Range Experiment Station, USDA, Portland, Oregon. Research Paper No. 11. February, 1955.

8/ Bennett, W. D., Cable Yarding Developments in Eastern Canada, Pulp and Paper Magazine of Canada, April, 1955.
Turner, J. S. and R. W. Upton, 37th Annual Meeting of the Woodlands Section CPPA - 1955, Pulp and Paper Magazine of Canada, April, 1955. p. 148.

[illegible]

economically. Even where a grid of roads can be laid out on a mountainside, it may be more economical to skid almost all of the logs uphill by this means. Time restrictions on this study prevented measurements of this method, even though in practical importance it appears to rank with tractor and horse skidding in methods currently employed in lodgepole pine logging.

Rubber-tired tractors are interesting machines of unknown potentiality for use in lodgepole pine logging. These are manufactured by several companies in the United States and Canada in a number of different sizes. However, very little specific information seems to be available on their application to lodgepole pine timber and terrain. One of the greatest problems concerns the stability of a wheeled vehicle on slopes. A notable piece of research in logging equipment development was sponsored by the Woodlands Section of the Canadian Pulp and Paper Association during 1949-51 in the development of the Mark IV Logger.[9/] This is a pneumatic-tired prehauler designed as a complete material handling machine for the movement of short length pulpwood from the stump to an intermediate landing under a wide range of logging conditions. Initial trials over distances of approximately 1000 feet averaged between 70-80 cords of pulpwood moved per 9 hour day. The experimental machines were made by the Bonnard Manufacturing Co., 2575 Rembrance St., Lachine, Quebec and are presumably now available for

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9/ Upton, R. W., Mechanical Hauling Field Meeting Featuring: The Mark IV Bonnard Logger, Pulp and Paper Magazine of Canada, November, 1955.

commercial distribution through the Clark Equipment Company, Benton Harbor, Michigan.

The "Tomcat" logging tractor designed and constructed by the U. S. Forest Service in Portland, Oregon has definite possibilities for skidding lodgepole pine. The outstanding feature of this experimental machine is that the fair-lead arch is built over the tractor and is essentially a part of it and not an attachment towed behind.

Another logging possibility for lodgepole pine is the technique of full tree skidding to a landing where the limbing, bucking, and loading processes are centralized. Alexander Koroleff (95) wrote a stimulating problem appreciation and research compilation on this topic in 1954. Slash disposal at the landing is a problem with such a plan. A rather startling disposal technique by fire in what may be likened to an unconfined refuse burner may be a future solution. The slash might be piled and electrically ignited at the proper time to assure a fully controlled and spark-free combustion. Windrowing by net skidding is a less dramatic possibility, where the slash is piled on cable and wire nets for the tractor to pull away. Some advantages claimed for the centralized landing operation are:

1. Better supervision and labor utilization.
2. Better safety and working conditions.
3. Better chance for specialized equipment economies, such as power limbing saws, strapped bundles of stems, logs, or bolts, etc. The opportunity for developing new, cost-reducing equipment is magnified. For example, since axe work may be dangerous to others on the landing, it might be feasible to fit a suitable blade to a jackhammer for limbing.

4. Better chance for fuller utilization, including more skilled sorting of raw material. Peeling and chipping machines might be economically justified.

5. Opportunity for more economical scaling techniques.

6. The chance for leaving the area in better silvicultural condition, including minimized fire hazard.

It is believed that skidding by horse may be the most economical method under certain operating conditions encountered in lodgepole pine logging. The small size of the tree species, terrain, and stand conditions coupled with the relatively low cost and upkeep of horses are factors that should be considered. Also, a better balance between other processes in logging and milling may be accomplished. For example, the output of a small portable mill may keep a couple of fallers and a couple of horse skidders fully occupied throughout the day in supplying an even flow of logs almost directly to the saw carriage. See Pictures 13 and 14. Whereas, to use a tractor may not only be more expensive, but might unbalance the operation. The machine might have to sit idle a large part of the day and result in a lumpy flow of logs to the carriage, meaning more physical labor in rolling logs. If such an operator owns a road-building tractor it is too large a machine to double efficiently in skidding lodgepole pine logs.

However, there are some important disadvantages in using horses. First, horses in general and good skidding horses in particular are becoming ever more difficult to find, and their price has tended to rise accordingly. Second, experienced men in the handling of horses are almost non-existent, notwithstanding the spread of dude ranches, western costumes, and televised western movies. The interest of young American

Pictures 13 and 14 indicate how close small, portable sawmills are moved to the trees. Skidding was by single horse, but when the picture was taken the log deck was full and one of the skidders (man on the right) was helping at the mill. A board is being run through the edger in the lower picture. Later, they will be trimmed to length on the machine at the right. In the extreme lower left corner is the ramp to the hand-fed, slab kicker, a whirling, toothed, drum that throws slabs and edgings on the refuse pile. The sawmill setting was on Deadman Mountain in northern Colorado.

men in mechanics is well-known and their willingness to jump from powerful automobiles to powerful tractors has been utilized in logging. However, in general and fully subject to the errors of generalities, they seem to lack the kindness, patience, and feeling for horses, perhaps because in some cases the animal apparently outranks them in courage and intellect. It should be recognized that it takes a more mature man to command a horse than to command horsepower in a machine. A third disadvantage to using horses for skidding is that they require food and care whether working or not. This may be particularly inconvenient on week-ends, holidays and during inclement weather or seasonally when the logging operation is shut down. Perhaps some of the disadvantages and problems of horse skidding can be minimized or completely overcome by attacking them with modern techniques and research, instead of concluding that horses are old-fashioned and inefficient simply because improved roads have made wagons and carriages unpopular. An example of this type of research is the portable, 2-section stable for eight horses.[10/] A further research possibility is that of combining animal power with machines. Perhaps the greater maneuverability of horses could be utilized in assembling logs for a tractor to skid to a landing, or a team might skid tree-lengths to a landing where they could be bucked with powersaws as is done in Quebec, Canada with other species.[11/]

10/ Portable, 2-section Stable for 8 Horses, Pulp and Paper Magazine of Canada, January, 1956. p. 113.

11/ Owen, E. T., Private Land Management Boosted. Report of Woodlot Management Field Meeting, Pulp and Paper Magazine of Canada, November, 1957. p. 195.

A modern example of efficient skidding by horses is found at the Brown Company, Berlin, New Hampshire, where the animals are trained to shuttle back and forth between stump and landing by themselves.

The method used for timing both tractor and horse skidding operations in this study followed techniques presented by Matthews[12/] and Hasel.[13/] Separate equations were developed, the one estimating the variable time required which is largely dependent upon distance. The other equation predicts the remainder of the variable time required in hooking and assembling the logs in the woods and unhooking them at the landing. Hasel used number of logs and board foot volume in the turn[14/] as independent variables in both equations. In this study additional variables were tested. A more detailed description of the skidding study follows, first for horse skidding, then for tractor skidding.

The complete turn was the unit timed, but this was broken into five parts for measurement: (1) time required to travel the distance from landing to the logs in the woods, (2) time required to hook and assemble the logs, (3) time necessary to skid the logs to the landing,

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12/ Matthews, Donald M., Cost Control in the Logging Industry, (New York: McGraw-Hill Co., 1942). p. 72.

13/ Hasel, op. cit., p. 556.

14/ A turn is a round trip in skidding logs, beginning and ending at the landing. A turn of logs also refers to the group of logs or their volume brought in at one time.

(4) unhooking time at the landing, and (5) any delays that could readily be separated as indirect or non-productive time. It was found that an ordinary sweep-second-hand watch worked well in timing the first four parts of a turn, recording the time chronologically to the nearest five seconds. Whenever a delay occurred it was timed with a stop watch, not because of the need for greater accuracy, but because it was usually inconvenient to record delays when they occurred. Recording time measurements in this way enabled a complete accounting for the day either in productive time or some form of delay or indirect production time.

Distance out and in was paced for each turn, however after a few turns to the same place in the woods over the same route, a check point could be noted from which to make pacing adjustments, eliminating the need to pace the entire distance each time. A slope reading by per cent abney was taken at a convenient time to apply to each turn.[15/]

15/ Campbell, op. cit., p. 7, gives a multiple regression equation for team skidding in the Southern Appalachians. He predicted skidding time in minutes using (1) distance, (2) number of logs, (3) sine of slope in degrees, (4) cosine of slope in degrees, and (5) volume of load. Replying September 4, 1956 to an inquiry regarding the choice of trigonometric functions for incorporating the slope variable, he said that they, "...were mainly a concession to developing a hypothetical equation which would describe the physical forces at work in skidding. The sine represents a theoretical force associated with the down-hill weight of the team, and the cosine the drag of logs on the ground. We are not sure that such an analysis is superior to a simpler notion as percent slope, but have not made the tests necessary to choosing between the trigonometric function and the simpler expressions. Our final decision in favor of the former was solely because it appeared to be better theory...."

It was believed that adverse slope and favorable slope were so different for horse skidding that separate time-distance equations should be developed for each. For an expedient measure of the hindrance of windfalls, diameters of windthrown trees were noted where crossed enroute and multiplied by their height above the ground in foot classes. The total of the windfall diameters crossed and adjusted for height above the ground going out and coming in became the windfall index measure. The logs skidded by horse were all 16 feet or shorter and their cubic foot volume was obtained by measuring their diameter at the mid-point with calipers, usually during the time the horse was given a rest on the way to the landing. Later these diameters converted to square feet of cross-sectional area were multiplied by log length plus trim allowance to obtain cubic foot volume (Huber Formula).

Table 4 presents the time required during the five-day measurement period for delays and indirect production activities that could be separately measured. Tony and Joker were being used to skid logs directly to the saw carriage of a small portable mill, hence the large delays encountered in waiting at the landing. However, this was not generally lost time for the skidder, since he doubled on odd jobs around the mill. Nevertheless, the horse did stand idle because of this reason nearly half of the work day. Mare One and Mare Two were used to skid sawlogs to decks at roadside, hence there were only very small delays at the landing. Skidding by these two men and horses seemed about as efficient as the job could be done on a continuous basis. One man rested the horse more enroute, the other more at the landing. Both took full lunch hours, but when they worked they worked and the horse knew

Table 4

Daily Delay and Effective Work Time, Horse Skidding Sawlogs 16-feet and Under

Near Red Feather Lakes, Colorado

Delay Category	Tony Horse July 15, 1957		Joker Horse July 17, 1957		Mare One July 19, 1957		Mare Two July 22, 1957		Charley Horse July 30, 1957		Five Day Average	
	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%
Tend horses AM & PM 1/	79.00	12.9	47.92	7.8	54.50	8.8	22.00	3.8	46.83	8.0	50.05	8.3
Wait at landing 2/	269.28	44.1	318.83	51.7	8.80	1.4	40.78	7.0	57.20	9.7	138.98	23.0
Rest, drink, smoke 3/	20.55	3.4	3.62	0.6			55.48	9.6	11.10	1.9	18.15	3.0
Clean trail, hang-ups 4/	21.05	3.4	12.02	1.9	32.35	5.2	45.72	7.9	11.48	2.0	24.52	4.1
Wait on other horse	0.41	0.1	0.80	0.1							0.24	0.1
Log too big to pull	19.17	3.1									3.83	0.6
Balky horse	6.90	1.1									1.38	0.2
Lunch hour	53.08	8.7	41.92	6.8	72.25	11.7	83.42	14.4			50.13	8.3
Rest horse					48.55	7.8					9.71	1.6
Help trucker load					23.58	3.8					4.72	0.8
Prepare landing							20.67	3.5			4.13	0.7
Horse down							7.67	1.3			1.53	0.3
Weather: Wait on rain									122.00	20.7	24.40	4.0
Clear truck trail									19.00	3.2	3.80	0.6
Rainy lunch hour									130.25	22.1	26.05	4.3
Total delays	469.44	76.8	425.11	68.9	240.03	38.7	275.74	47.5	397.86	67.6	361.63	59.9
Total effective work time	141.88	23.2	191.73	31.1	379.38	61.3	305.28	52.5	190.97	32.4	241.85	40.1
Total timed components	611.32	100.0	616.84	100.0	619.41	100.0	581.02	100.0	588.83	100.0	603.48	100.0
Total work day	610.67		616.83		620.33		581.00		588.83		603.53	
Unaccounted error	0.65		0.01		0.92		0.02		0.00		0.05	

1/ Also includes starting delays in morning.
3/ Also includes conversation.
2/ Also includes deck full, rolling logs, and knot bumping delays.
4/ Also includes scouting for logs, picking up lost logs, and retrieving tongs.

[illegible]

this and conformed to the pattern. Charley horse was also used in skidding logs to roadside decks; the notable feature of that day being the influence of rain on delays in skidding. For a five-day average, the total of delays and indirect production time amounted to 60 percent of the work day, leaving but 40 percent for direct skidding production. This proportion may be about right, however, additional verification studies are needed. In contrast, Boldt[16/] reported delay time for horse skidding in Colorado at 19 percent of total time. Studies in the Southern Appalachian Mountains are also revealing. Shames[17/] found that 41.7 percent of total time in skidding with teams was taken up in delays, including delays due to bad weather, travel to and from the job, and other miscellaneous causes. Campbell[18/] gave the total delay time for teams as averaging 2.8 minutes per turn and an additional 20 percent of the total time for weather and other infrequent delays.

Averages for effective work in horse skidding sawlogs for five different skidders and as many days is presented in Table 5. In the five days of work 339 turns of logs were brought in, representing a total, round-trip, paced distance of 23 miles. The average round-trip distance per turn was 358 feet. The average volume per turn was 10.73

16/ Boldt, Charles E., A Time and Cost Study of a Colorado Logging Operation, Master of Science thesis, unpublished, Colorado State University. 1955. p. 51.

17/ Shames, op. cit., p. 5.

18/ Campbell, op. cit., p. 12.

Table 5

Average Measurements and Standard Deviations for Five Days (339 Turns) of Horse Skidding

16-foot and Shorter Sawlogs near Red Feather Lakes, Colorado

Skidder	Turns per day	Seconds out and in per 100 ft.	SD	Seconds hooking assembly unhooking	SD	Round trip distance feet	SD	Slope per cent	SD	Wind-fall index	SD	Turn volume cu. ft.	SD	Earnings: Per 100 cu. ft.	Earnings: Per day
Sol	39	31.29	7.17	67.72	27.26	387.4	77.34	8.3	5.14	1.4	3.43	10.14	5.67	$3.21	$12.71
Kit	47	39.04	14.80	76.70	40.11	445.5	138.84	14.8	5.19	7.2	5.00	12.48	3.63	2.49	14.63
Tad	102	47.94	16.90	62.22	37.33	379.6	184.28	14.8	5.34	23.0	17.36	9.68	4.10	2.28	22.50
Lex	93	45.88	12.79	77.28	42.78	268.8	149.78	14.8	4.77	19.3	27.04	10.74	4.83	2.25	22.50
Zeb	58	43.62	11.87	33.53	15.48	373.4	119.66	9.3	4.67	6.6	8.30	11.56	7.73	2.24	15.00
Average	68	43.49	14.72	64.08	39.43	358.2	159.66	13.1	5.67	14.5	19.28	10.73	5.27	2.40	17.47

Includes performance on both favorable and adverse slopes. The five day averages and standard deviations (SD) are computed on the basis of the 339 turns and not the mean of the averages and standard deviations given. The real names of the skidders are not used. The measurements were taken during July, 1957.

cubic feet, which is a 16-foot sawlog approximately 11 inches in diameter at the mid-point.[19/] It took, on the average, about 43½ seconds going out and coming in with the logs,[20/] and a little over a minute for hooking, assembling, and unhooking. When skidding to a small portable mill, as Sol and Kit were doing, only 40 to 50 turns were made per day due to waiting on the mill. The other three skidders were decking logs at roadside and made more turns per day. For all five skidders, 68 turns per day was the average. Zeb was skidding with Charley Horse in the rain and delays on that account reduced the number of turns per day. Sol was a novice of high school age and was paid beginners wages of $1.25 per hour, but due to delays of various sorts and the smaller volume brought in, his wages per 100 cubic feet of wood skidded were the most expensive. Tad and Lex, working with Mare One and Mare Two, respectively, seemed to be most representative of good average skidding performance. Each was paid at the rate of $4.50 per thousand board feet of logs skidded to roadside, since the horse, including his feed, was furnished by the company. The rate was $6.00 per thousand board feet where the skidder furnished his own horse and feed. They estimated that they averaged about 150 logs per day. In terms of board feet, they said they could produce 6 to 7 thousand board feet of logs skidded to roadside

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19/ This is not the average log size, since about a third of the turns contained two logs. The average log size was 8.49 cubic feet, which is a 16-foot log just under 10 inches in diameter at the mid-point.

20/ The average, out-and-in time per turn for favorable slopes was 39.7 seconds, and for adverse slopes it was 50.7 seconds.

per day, but that 5 thousand board feet represented a full horse day of work, with from 4 to 5 thousand board feet being an average figure for a day of skidding. The skidders did not work with double tongs all of the time, but out of the 339 turns 123 or 36 per cent were two-log turns and the others were singles.

The results of the multiple regression analysis (1) horse skidding on favorable slopes, (2) horse skidding on adverse slopes, and (3) time required for hooking, assembly, and unhooking when skidding with horses, are given, respectively, in Appendices 6a, 6b, and 6c. Note that Y_2 is to be added to Y_1 for total skidding time. The results were disappointing in the amount of variance that was explained by the equations as indicated by the coefficient of determination. Number of logs per turn and slope proved insignificant at the 5 per cent level for favorable slope skidding, but on adverse slopes, number of logs per turn and average cubic foot volume per log in the turn were the insignificant variables. On both favorable and adverse slopes, windfall index was the only independent variable that appeared significant at the 5 per cent level. For hooking, assembly, and unhooking, the independent variables of slope and windfall index were both measured enroute to and from the landing, since it was believed that these measurements would be quite applicable to the assembly areas. However, slope proved insignificant and windfall index was significant at the 5 per cent level. Because the results of the horse skidding equations do not seem to be very conclusive, they are not reported other than in the Appendix.

The skidding equations predict time in seconds required for horse skidding and this can be readily converted into cost in dollars, when a daily, horse-crew, cost factor is available. Such an average,

dollar-cost-per-day factor is computed in Appendix 7 and amounts to $22.83. The great advantage in using horses is immediately apparent in the low investment and operating expense for a horse which amounts to $2.13 per day.[21/]

A second, alternative method for skidding lodgepole pine is to use small, crawler tractors. See pictures 15 to 17. In this study such tractor skidding was timed for six days (a different machine and skidder each day), for a total of 130 turns in 1956 and 1957. Four of the men were timed on the M. J. Horen pulpwood operation in Hyalite Canyon, near Bozeman and the other two men were working for Olaf Johnson, a pulpwood operator on Moose Mountain, near White Sulphur Springs, Montana. On both operations trees were felled, limbed, and topped, but left in tree-length for skidding to portable slasher saws where the stems were cut into 100-inch lengths and loaded in one operation. The tractors had power winches, and after driving as close as possible to the logs, the winch cable was unspooled and a choker on the end placed on the furthermost log for the turn. About five other chokers were threaded on the winch cable by steel rings, and these chokers were placed on intermediate logs. When the winch wound in the cable, the steel rings slipped along the cable until finally the whole turn of logs was in place behind the tractor for skidding to the landing. This winching technique is dangerous where there are numerous dead snags which are frequently toppled toward the machine by the moving logs.

21/ Norman P. Worthington, Skidding with Horses to Thin Young Stands in Western Washington, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Note No. 138, February, 1957. p. 6. gives four case studies of horse skidding costs. Cost per hour for horse maintenance was reported at (1) $0.273 in 1949-50, (2) $0.420 in 1950, (3) $0.465 in 1950-51 and (4) $0.427 in 1955-56.

Pictures 15-17 show HD5 tractor skidding with fairlead, rubber-tired arch on the Olaf Johnson operation, Moose Mountain, north of White Sulphur Springs, Montana. The slashersaw-loader and partly loaded truck can be seen in the background. During most of the study the arch was not used, because it is troublesome on slopes and in windfalls. The wheels and tires on the arch are from World War II bomber aircraft.

As previously indicated, the turn was the unit timed, and this was broken into five parts for measurement. The skidders began work in the morning at about seven o'clock at the same time that the slasher saw began operating and worked until five o'clock or later. Much depended upon the operation of the slasher saw for usually the landing had limited space and filled up quickly when the slasher saw stopped due to a breakdown or to wait on a truck. The skidders tried to keep a steady flow of logs to the landing by bringing in turns from points both near and far.

For this type of operation, the small crawler tractor appeared to be a very efficient machine for skidding. In this study two D4 tractors made by the Caterpillar Tractor Company and four HD5 tractors made by the Allis-Chalmers Company were timed. It is believed that the differences in these machines are of relatively minor importance in an equation predicting time in skidding logs by small tractors and, therefore, make of machine was not used as an independent variable. Campbell[22/] found that the greater the horsepower of the tractor, the fewer the significant variables in the time prediction equation. In particular, he found that slope was significant for D2 and TD6 tractors, but became insignificant for D4 and TD9 tractors. Therefore, in contrast to horse skidding, slope was not used as an independent variable in this study. Campbell also pointed out that size of load was the most important single cost variable studied for either horse or tractor skidding, and

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22/ Campbell, op. cit., p. 7. In his regression equation for estimating skidding time in crew minutes per trip (T) for D4 and TD9 tractors, $T = .36 + .94D + 1.6L$, where D is distance in chains one way and L is number of logs.

that loading to capacity should always be emphasized for economical operation. He states that "...with ample power the degree of slope and load volume become less important." In watching the machines operate in this study it seemed that only seldom was the complete capacity of the machine taxed. However, with a lighter tractor these occasions would have been multiplied. It may be efficient to employ this size of tractor that may not be taxed on the bulk of the turns in order that the exceptional turn, whether due to slope, load or other reason, will not unduly slow the over-all operation. Slope and load would logically become significant as the capacity of the machine was approached. The advantages of tractor skidding focus on their greater power, speed, lack of fatigue, and freedom from the need for feed and care when not operating. The major disadvantage centers on the large initial investment and expensive maintenance, resulting in rather high hourly cost of operation and comparable cost when standing idle.

Timing of the tractor turns was easier than timing horses due to the fewer turns per day. However, in other respects it offered more problems. Skidding distances were greater and they were paced, although hope had been raised by a tractor odometer developed by the Caterpillar Tractor Company.[23/] Obtaining the turn volumes presented more difficulty than with horse skidding, since the stems could not be measured until the chokers were placed, and by that time it was becoming unsafe and might slow the worker. There were seldom any pauses enroute in, so the diameter at breast height was estimated enroute or on the landing for full-length stems. These were subsequently converted to cubic foot volume by the

23/ Anonymous, Caterpillar Adds New Feature, Journal of Forestry, March, 1957. p. 256.

local volume tables constructed from tree measurements taken in the same area during week-ends. Broken stems were treated as logs and the Huber Formula was applied to a diameter estimated at their mid-point. One man was easily able to take and record all measurements as Pope[24/] had found.

An attempt was made to use both number of logs in the turn and cubic foot volume of the turn as independent variables, but this again produced illogical results.[25/] The correlation of these two independent variables with skidding time was negative, and when a positive regression coefficient for cubic foot volume occurred upon introduction into the equation, it was suspected that the inter-correlation, $r_{12} = .496745$, was great enough to cause undue influence. To avoid the intercorrelation difficulty, the cubic foot volume per turn was divided by number of logs in the turn, giving an independent variable that was the average cubic foot volume per log in the turn. This resulted in an improvement from $r_{y2} = -.030102$ to $r_{y2} = .208400$. The positive correlation indicates that the greater the average volume per log in the turn, the more time it takes for skidding, which seems reasonable. On the other hand, the negative regression coefficient for number of logs per turn, X_1, agrees with $r_{y1} = -.318328$, but it somewhat

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24/ Pope, Clem L., How to Control Costs of Tractor Skidding, The Timberman, August, 1954. p. 66.

25/ Hasel, op. cit., p. 556 used number of logs and board-foot volume in his equations, apparently without this effect, which might be due to the different character of yarding ponderosa pine logs. See footnote p. 102, regarding this difficulty encountered in the felling equations.

illogically states that the more logs in the turn, the easier or faster the skidding time. A possible rationalization is that when only very few logs are hooked, they bounce around and come loose during skidding, causing delay and inconvenience to the tractor driver. Hence, he proceeds more cautiously with a light load than with a full load.

The time required during the six-day measurement period for delays and indirect production activities that could be separately measured are presented in Table 6. In September, 1956 the measurements were taken in Hyalite Canyon, near Bozeman, Montana. The timing during August, 1957 was made on Moose Mountain, near White Sulphur Springs, Montana. The data is insufficient to conclusively compare the two operations. The slightly larger delays in 1957 were caused by an hour wait on a truck the one day and over two hours of waiting at a very small landing on the other. For the six days, rest breaks, waiting at the landing, and lunch hour were about equally important and accounted for 23 percent of the average daily delays. Total average daily delays amounted to 37 percent, leaving 63 percent of the time for effective work.[26/] The lowest total delay measured was 24 percent for Abe, and the highest was over half of the work day for Ole, which included the large, unavoidable waiting at the tight landing.

Table 7 shows averages for effective work in small tractor skidding for the six man-days of yarding. The tractors moved fewer miles

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26/ Pope, op cit., p. 70, reports that in working with larger tractors in Douglas-fir and ponderosa pine in Oregon, operating efficiency never exceeded 73.6 percent, or 5.88 hours of productive work per day.

Table 6

Daily Delay and Effective Work Time, Skidding Tree-length Logs with Small, Crawler Tractors Hyalite Canyon, near Bozeman, Montana and Moose Mountain, Near White Sulphur Springs, Montana

Delay category	Lew1/ Sept 7,1956		Ken1/ Sept 10,1956		Mel1/ Sept 11,1956		Ned1/ Sept 12,1956		Ole1/ Aug 15,1957		Sam1/ Aug 24,1957		Six day average	
	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%
Starting delays in AM	35.67	5.1	27.33	4.1	10.33	1.6	22.17	4.5	4.50	0.7			16.67	2.8
Lost logs, hang-ups2/			3.92	0.6	13.09	2.1	10.24	2.1	11.42	1.9	15.90	3.2	9.09	1.5
Rest breaks3/	90.00	12.9	29.58	4.5	51.66	8.2	21.74	4.4	56.63	9.5	36.05	7.3	47.61	8.0
Tractor repairs			47.00	7.1					64.92	10.8	3.27	0.7	19.20	3.2
Landing delays4/	20.66	3.0	102.25	15.4	4.17	0.6	4.92	1.0	133.20	22.2	28.25	5.7	48.91	8.2
Lunch hour	67.00	9.6	42.75	6.4	45.83	7.3	40.17	8.1	35.37	5.9	24.48	5.0	42.60	7.1
Wait on truck5/			6.08	0.9							60.08	12.2	11.03	2.0
Weather: rain6/							17.75	3.6					2.96	0.4
Wait on other tractor	55.50	8.0											9.25	1.5
Slasher breakdown									28.58	4.8			4.76	0.8
Moving slasher											41.73	8.4	6.95	1.2
Total delays	268.83	38.6	258.91	39.0	125.08	19.8	116.99	23.7	334.62	55.8	209.76	42.5	219.03	36.7
Effective work time	427.25	61.4	405.25	61.0	505.83	80.2	376.08	76.3	265.55	44.2	284.18	57.5	377.36	63.3
Total timed components	696.08	100%	664.16	100%	630.91	100%	493.07	100%	600.17	100%	493.94	100%	596.39	100%
Total work day	696,08		664.67		630.00		493.25		600.00		493.67		596.28	
Unaccounted error	0.00		0.51		0.91		0.18		0.17		0.27		0.11	

1/ The real name of the skidder is not used.
2/ Includes also: resetting and adjusting chokers, scouting logs, and cable snarles.
3/ Includes: conversation, cigarettes, coffee breaks, water and personal.
4/ Includes: bunching logs at landing, and filled or blocked landing.
5/ When the slasher saw stopped for want of a truck to load, the skidders stopped when the landing was full.
6/ Showers interrupted skidding by amount shown. Amount that work day was cut short by rain is not shown.

Table 7

Average Measurements and Standard Deviations for Six Days (130 turns) of Small, Crawler Tractor Skidding of Tree-length Logs, Hyalite Canyon, near Bozeman, Montana and Moose Mountain, near White Sulphur Springs, Montana

kidder	Turns per day	Seconds out and in per 100 ft.	SD	Minutes hooking assembly unhooking	SD	Round trip distance feet	SD	Number trees per turn	SD	Wind fall index	SD	Turn volume cu. ft.	Earnings Per 100 cu. ft.	Earnings Per day
ew	14	50.44	14.28	19.05	7.16	1441.7	394.60	7.50	1.87	129.7	161.33	192.65	$ 0.93	$ 25.00
en	22	40.85	6.12	9.83	2.88	1265.2	121.22	8.04	1.07	83.7	109.04	114.44	0.93	23.50
el	27	79.42	22.31	11.07	3.89	592.4	129.96	5.33	0.97	325.0	118.67	103.15	0.79	22.00
be	21	61.09	12.43	9.94	2.38	803.4	214.90	4.76	0.63	51.6	169.72	92.47	1.18	23.00
le	21	48.34	24.36	7.09	1.52	704.3	149.69	5.14	1.46	249.9	120.53	98.31	0.78	16.00
am	25	54.13	9.49	6.53	1.57	564.5	235.24	4.68	1.25	163.4	93.77	79.37	0.81	16.00
verage	22	56.92	18.66	10.02	4.93	839.9	388.72	5.78	1.76	250.7	189.64	107.62	1.11	20.92

he six day averages and standard deviations (SD) are computed on the basis of the 130 turns and not the mean of the averages and tandard deviations given. The real names of the skidders are not used. The measurements were taken in the fall of 1956 and ummer of 1957.

in six days (20.6 miles) than the horses did in five days (23 miles), but the average, round-trip distance per turn was more than double for tractors (840 feet) as compared to horses (358 feet).27/ There were fewer average tractor turns per day of larger volume (22 turns per day of 108 cubic feet each) in contrast to more average turns with lesser volume for horses (68 turns per day of 11 cubic feet each). In a daily volume comparison of average turns times average volume, an HD5 or D4 tractor might be expected to skid 2368 cubic feet per day; whereas, a horse would produce about 730 cubic feet. Such superficial comparisons are easily misleading. A single horse probably could not skid a medium-size, lodgepole pine in tree length, which emphasizes the fact that the operating conditions are not the same in the two cases and therefore the averages are not directly comparable. The average time for hooking, assembling, and unhooking in tractor skidding was about 10 minutes compared to a little over a minute for horses. It takes very little time when skidding with horses to place tongs on one or two logs and unhook them at the landing, but unspooling cable from a tractor winch, setting an average of 5 to 6 chokers, winching the logs to the tractor and unhooking the often-jammed turn of logs at the landing takes much more time.

The skidders and slasher crew worked as a team and were paid by piece-rate on the number of cords that were produced and loaded on

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27/ Norman P. Worthington and Elmer W. Shaw, Cost of Thinning Young Douglas-fir, The Timberman, August, 1952. p. 136. report that skidding 8-foot logs in diameters 7 to 14 inches, the maximum skidding distance was 800 feet with an average of 300 feet and that a good horse can skid economically up to 500 feet. The 300-foot average is about double that experienced in this study.

railroad cars. The slasher saw operators and the skidders received 50¢ per cord loaded at the railhead. The skidders knew about how much they earned each day by the number of truckloads hauled and the usual cord volume carried. Ole and Sam were both good, experienced skidders but they were at a disadvantage in working on a rather tough and marginal logging chance the days that they were timed. Therefore, their earnings and volume output were lower. Lew brought in the fewest turns but over the greatest average distance with a high average number of logs per turn (7.5) and the highest average volume per turn of 192.65 cubic feet. His total volume produced for the day was 2,697 cubic feet. He estimated he earned $25 that day which resulted in a labor cost (without payroll additions) of 93¢ per 100 cubic feet skidded. The greatest daily cubic foot volume was produced by Mel who skidded a total of 2,785 cubic feet, but with also the greatest number of turns per day his average volume per turn was about average.

Pope[28/] working with larger tractors in Oregon on Douglas-fir and ponderosa pine sawlog operations listed the following conclusions that seem obvious but are apparently frequently forgotten:

1. Keep the landing clear; tractors that cannot be unhooked cannot produce.

2. Build adequate sized landings and have enough room for the deck and for the tractor to maneuver.

3. Landings that serve both sides of the road are preferable.

4. When more than one tractor is being used, stagger the skidding distances to stabilize production.

28/ Pope, *op. cit.*, p. 70.

5. When possible, keep the skidding and loading crews separated. So-called "hot" logging is generally more expensive than decking ahead.

6. Do not use inexperienced men for choker setters.

7. Never sacrifice a capacity load for speed. A tractor will go just so fast, so keep it loaded. This means having extra chokers in the woods, but the small additional cost will be well repaid.

Appendices 8a and 8b show the results of multiple regression analysis of small tractor skidding. Note that Y_2 is to be added to Y_1 for total skidding time. The results were about comparable with horse skidding in the disappointing amount of variance explained by the equations as indicated by the coefficient of determination. In the equation predicting out and in time, all three slope coefficients of the independent variables were significant at the 5 per cent level. However, for the hooking, assembly, and unhooking equation, the regression coefficient for windfall index was insignificant at the 5 per cent level. This is in contrast to what was found for horse skidding (see Appendix 6c). Because the results of the tractor skidding study appear to require additional confirmation, they are not reported other than in the Appendix.

An excellent form for presenting daily or hourly cost data for the operation of small tractors is found in Campbell,[29/] and this form and the machine data that he quotes from the Caterpillar Tractor Company,

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29/ Campbell, *op. cit.*, p. 29.

dated January, 1953, is presented in Appendix 9. The price data collected at the time of this study is as out-dated as the 1953 figures, and the fuel consumption and maintenance estimates collected from individual operators seem less authoritative than those given by the manufacturer. The labor cost figures given were those experienced in Montana in 1956 and 1957. Using a blunt, round figure of $5 per hour as an average, machine-crew factor, when applied to the average length of work day encountered in this study, results in an average, daily, machine-crew factor amounting to $49.70 or an even $50 after rounding.

Chapter VII

THE LOADING PROCESS

The loading process in logging consists of loading logs on the turck for hauling. Various methods have been used to accomplish the fundamental work of lifting heavy logs the necessary vertical and horizontal distance. These methods have included inclined ramps or rollways, cable and sheaves, or machine lifts of some sort. In pulpwood loading and in lodgepole pine sawlog loading, the problem involves the handling of a relatively large number of rather small logs. This problem has not been completely solved, but progress in that direction may be indicated by some of the innovations described below:

The great use of pallets in handling materials in other industries perhaps inspired their use in pulpwood handling in the South, Lake States, Canada, and New England. The main advantage is that pallet loading or preloading can proceed continuously and, subsequently, the pallets can be loaded quicker enabling greater hauling efficiency due to reduced delay in loading. The "pallet" can be a wheeled trailer as used in Sweden[1/] or a typical semi-trailer[2/] parked in the woods in the

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1/ Skogen, April 1, 1956. Advertisement illustrations.

2/ One type of detachable, semi-trailer crib looks something like an auto transport trailer. The International Paper Company, Georgetown, South Carolina had a fleet of these cribs which were spotted in farmers' yards or at small gyppo settings. When the crib holding 5 to 7 cords is loaded, a truck tractor is dispatched to bring it to the mill. The trailer cribs were made by the John Evans Manufacturing Company, Sumpter, South Carolina.

[illegible]

[illegible]

[illegible]

United States. It might be a detachable truck bunk arrangement[3/] or such a device mounted on inclined ramps so when the truck is backed under, the whole thing is launched like a ship into position on the truck.[4/] On the other hand the pallets may be simple, tubular steel racks.[5/] Such steel racks are manually filled with pulp bolts in the woods as pulled behind horses or tractors. For loading on the truck, they are pulled up inclined skids over the end.

Strapping with thin iron hands is common in industries having certain kinds of piece-handling problems. In pulpwood handling, tight strapping has been tried by the West Virginia Pulp and Paper Company, Georgetown, South Carolina, where 63-inch bolts were strapped by 3/8ths

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3/ Upton, op. cit., p. 208
R. H. P. Miller and E. W. Fobes, Preloading Detachable Truck Body, Forest Products Laboratory, Madison, Wisconsin. Equipment Survey Notes, Report No. R1637-9. March, 1947.
C. R. Cayouette and J. J. Fitzmaurice, Report on a Pallet Hauling Operation, Pulp and Paper Magazine of Canada, June, 1955. p. 140.

4/ Simmons, op. cit., p. 38.

5/ W. S. Bromley, Improved Methods of Handling Pulpwood, Proceedings Forest Products Research Scoiety, 1950. p. 143. Illustrates the use of the Dixie Pallet System, made by the Tidewater Equipment Company, P.O. Box 14, Brunswick, Georgia.
E. W. Fobes, Preloading Pulpwood Racks, Forest Products Laboratory, Madison, Wisconsin. Equipment Survey Notes. Report No. R1637-9 November, 1948.

inch iron bands in 80 cubic foot bundles.[6/] Tight strapping of long logs has been tested in the West and is particularly useful for increasing the storage capacity of mill ponds.[7/] Pictures 21 and 22 show log cradles tested in strapping lodgepole pine logs at Downer Lumber Co., Livingston, Montana. Loose bundling is used by the International Paper Company at Georgetown, South Carolina. In this operation 63-inch wood is piled close to the cutting in units of 160 cubic feet. Then, these ricks are lifted and moved in cable slings by a high boom arch. The loose bundles of wood are hauled directly to semi-trailer units on woods roads and neatly piled thereon and the slings removed.[6/] At the Biles-Coleman Lumber Company, Omak, Washington, long log lengths of lodgepole pine are loosely bundled in cable slings for loading onto logging truck-trailer units. A number of the sling loads make a truck-load and the cable slings are left on the loaded logs for use in lifting them off directly on the mill deck.[8/] See Picture No. 23. The argument for loose bundling is that the logs load better than when they are tightly strapped. Cost of the iron straps is also a factor to be considered in their use.

Belt and chain conveyors are common in all industries for materials handling and are being improved for use in pulpwood logging. Powered conveyors to load trucks with pulp bolts are of two general types. One is the end-to-end loading type as built by the Bosworth Manufacturing Company, Cleveland, Ohio. The other is the side-to-side

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6/ Bromley, op. cit., p. 145.

7/ Ralph G. DeMoisy, Packaged Logs, New Wood Use Series, Forest Products Institute, University of Washington, Seattle, Washington, Circular No. 6.

8/ Ralph G. DeMoisy, Biles-Coleman Lumber Company Logging Methods for Lodgepole Pine, Forest Products Institute, University of Washington, Seattle, Washington. Circular No. 4., November, 1949.

loading type which is the most common and widely used now, as typified by the Montague "Cord a Minute" loader manufactured by the B. L. Montague Company, Sumter, South Carolina.[9/] With a cut-off saw or slasher saw incorporated in the loader, the tree-lengths are cut to pulpwood size and loaded in one operation.[10/] See Pictures 29 to 34. When such a slasher saw and loading arrangement is built on rubber-tired wheels and self-propelled, a very mobile and promising logging machine, particularly adapted to harvesting lodgepole pine, results.[11/]

In Contrast to rather continuous loading by conveyor, other machines have been developed to take "bites" of stacked pulp wood and lift them onto trucks. Two types may be generally identified. The Drott Skid Loader is a type of fork-lift, mounted on the front of tractors, to slide under ricks of wood, then after an overhead member clamps the logs in the fork, the load is transferred to the truck. This

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9/ Bromley, op. cit., p. 144.
E. W. Fobes, Mobile Pulpwood Conveyor, Forest Products Laboratory, Madison, Wisconsin. Equipment Survey Notes. Report No. R1637-43, May, 1951.

10/ E. W. Fobes, Mobile Pulpwood Harvesters, Forest Products Laboratory, Madison, Wisconsin. Equipment Survey Notes. Report No. R1637-18, October, 1947.

11/ Anonymous, Mobile Wood Saw Harvests Lodgepole Pine, The Timberman, October, 1957. p. 40.
E. A. Lunam, Mechanical Slashing of Pulpwood by Marathon, Pulp and Paper Magazine of Canada, December, 1951. The Slashmobile as used on the Marathon operation is manufactured by the Northern Engineering Supply Co., Ft. William, Ontario. The machine is 49 feet long by 8 feet wide, mounted on rubber-tired wheels and self-propelled. The price in 1956 was $37,500.

type of loader was used on the pulpwood operation in Idaho that was timed in this study. (See Pictures 35 and 36). The second type uses a grapple or clamshell, seizing device with cable, boom, and winch or other power to lift bites of pulpwood aboard truck. The Hiabob Hydraulic Loader (See Picture No. 37) is an ingenious invention of this type which, when mounted behind the cab of a truck, converts it into a self-loading vehicle. Manufactured in Sweden, it is distributed in the United States by Robert Larson, Diesel Power Equipment, Ely, Minnesota. This loader features a hydraulically activated clam on a boom 13 to 15 feet in length. In 1956, the 13-foot boom model was priced at $2,250 and the 15-foot boom model at $2,550. The boom is attached to a hydraulic piston. The angle of the boom is altered by a separate hydraulic unit. The cable from the clam goes down the boom and through sheaves on the vertical hydraulic support. When the vertical hydraulic piston is activated, the cable going over the 3-pulley blocks is shortened (or lengthened) six feet for every foot of piston travel. This raises the clam without need for winches. A comparable, experimental device made by Charles J. Erickson and son for their Idaho pulpwood operation is shown in Picture No. 38.

Another loader of the cable-winch type is used to make a self-loading truck for hauling sawlogs. A boom is mounted on a sturdy support behind the cab and a winch connected to the truck transmission powers the cable.[12/] Logs are either hooked with tongs at their midpoint or

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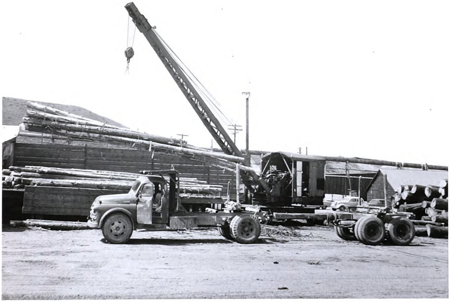
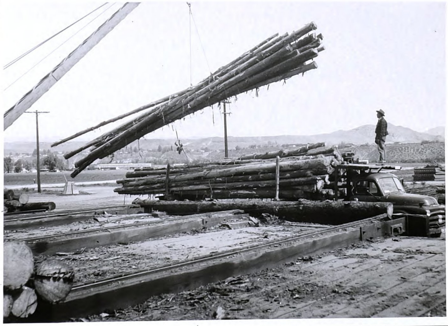
12/ E. W. Fobes, Truck-Loading Booms, Forest Products Laboratory, Madison, Wisconsin. Equipment Survey Notes, Report No. 1637-55, September, 1953.

Pictures 18-20 show pre-hauling of bundles of 100-inch pulpwood from stacked ricks on the Heggie Bros. operation north of Martinsdale, Montana. The upper picture shows how the wood is stacked by the fallers over a bolt placed at one end to provide cable passage. The lower pictures show how the ricks are winched upon an arch for delivery to the loader. This method of logging was not timed in this study.

Pictures 21 and 22 show single and double type, log-strapping cradles made and tested by the Downer Lumber Co., Livingston, Montana. The single cradle was initially made adjustable, pending the determination of the proper size for the bundle. The size package for 16-foot logs was set at 200-300 board feet. On one side of the double cradle, 16-foot logs were cradled and strapped. On the other side, 24- and 32-foot lengths were placed for banding. At first 1000 board feet per bundle was tried for the longer lengths, but this was too much so they dropped back to 600 board feet per bundle. Among the reasons for discontinuing log strapping was the fact that tight bundled logs do not load well on trucks and the iron bands were not easily re-usable which added to the cost of logging.

Picture No. 23 shows a technique in loading lodgepole pine in pole lengths at the Biles-Coleman Lumber Co., Omak, Washington. Neil Clark and Henry Miller, logging contractors to the company, prefer the gin pole for loading as pictured above, due to the small investment required. They indicated that only $250 was invested in the cables and blocks. Four, 3/8 -inch cables guy the pole, which is inclined at an angle, enabling the truck to drive directly under the tip. A tractor pulls the cable on the drawbar to lift a sling of logs into place. Slings are left on the bundles for unloading at the mill. Seven or eight logs make a sling load with eight or nine sling loads required to load a truck. Although it takes only an hour to rig the gin pole by fastening the guys then bulldozing the butt forward, changes in the setting are infrequent. This method of logging was not timed in this study.





Pictures 24 and 25 show two views of unloading slings of logs to the mill deck at the Biles-Coleman Lumber Co., Omak, Washington. The cable slings were left on the logs when loaded.

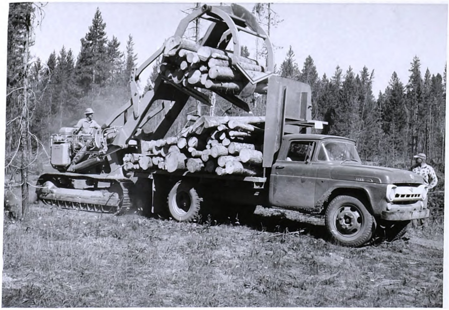
Picture 26 shows how the pole lengths are fed under a cut-off saw for cutting into 7½-foot lengths. The man at the saw controls the bull chain with his right heel to move the poles forward.

Pictures 27 and 28 show two views of the side-to-side, chain-lift loader used by Heggie Bros. north of Martinsdale, Montana. The upper member of the machine can be raised or lowered by an hydraulically activated piston (visible underneath) so the logs do not drop so far onto the truck. The gasoline engine that powers the chain is situated between the wheels and the inclined ramp. Two men feed logs to the loader and the trucker stacks his own load as shown. The pulpwood is delivered to the loader by tractor and arch as shown in the lower picture and in pictures numbered 18-20.

Pictures 29 and 30 show the slashersaw-loader made and used by Olaf Johnson, Neihart, Montana. The setting is on Moose Mountain, north of White Sulphur Springs, Montana. In the upper picture the man on the far right hooks a tree-length stem at the mid-point with tongs. By pulling the rope he holds in his hand a clutch engages the winch which pulls the tree onto the live rolls. The saw operator controls the live rolls with a foot lever to move the tree forward under the saw. As the 100-inch bolts are cut off and drop down, the chain-lift conveys them to the truck. About 8 truckloads averaging 6 cords, or more exactly 604 cubic feet, constitute a day's production.

Pictures 31 and 32 show two slashersaw-loader machines. The upper picture is a back view of the machine made by Olaf Johnson, Neihart, Montana. The winch mechanism for cross-hauling trees onto the machine receives torque through the shaft and pneumatic-tired wheel. A rope pulled by the cross-haul man pushes an engine-powered wheel against the rubber tire, when the tongs are set and the tree is ready for winching. The lower picture was taken on the M. J. Horen operation in Deep Creek, southwest of White Sulphur Springs, Montana. A truck was being loaded with the larger diameter bolts for delivery to a stud mill. The smaller diameter pieces were pulled off the lift by the man at the left who loaded them on the second truck parked there.

Pictures 33 and 34 show the slashersaw-loader made by Olaf Johnson, Neihart, Montana being moved to a new setting. The pictures show how the loader and slasher-saw are separated for moving. The chain-lift on the loader is powered from the saw engine through a universal joint and adapted automobile differential. The single move timed took an hour and twelve minutes to disassemble, move 95 paces, and set up in the new location.



Pictures 35 and 36 show truckloading of pulpwood by Drott Skid Loader on the Charles Erickson and Son operation, Island Park, Idaho. The light trucks were loaded as they were driven-and-parked ahead of the loader in the cutting lanes as shown in Pictures 11 and 12. The loads were not large, as indicated by the short stakes at the rear of the truck, but frequent, quick trips over the 8-mile, round trip distance to the railhead produced volume. Binding of the load was not necessary, which saved time in loading and unloading. Pictures 43-45 show the unloading operation.

Pictures 37 and 38 show two clamshell-type pulpwood loaders. Robert Larson, Diesel Power Equipment, Ely, Minnesota, distributor for the Hyabob Hydraulic Loader, supplied the upper picture of the machine in operation. The lower picture shows the experimental machine made by Charles Erickson and Son for their Idaho Pulpwood operation.

Pictures 39 and 40 are before-and-after loading views of a self-loading truck for hauling sawlogs. The upper picture shows the winch mechanism. Pulling on the long, rope-control powers the winch and lifts the logs over the side. Tongs are placed in the middle of the log as shown in the lower picture. The loading device was made and installed by Wilson Lowry, trucker for the Otto Lumber Co., Laramie, Wyoming.

Pictures 41 and 42 show additional loads of lodgepole pine sawlogs loaded by self-loading truck in northern Colorado. The 16-foot and shorter sawlogs were skidded to roadside decks by single horse. The average truck-load contained 81 logs and 632 cubic feet. The average time for loading was 89 minutes, and two loads per day were hauled 50 miles to Laramie, Wyoming.

dogged on the ends with a crotch line to be lifted over the side. The loader shown in Pictures 39 to 42 was made and installed by Wilson Lowry, trucker for the Otto Lumber Company, Laramie, Wyoming. A similar loader is sold as the B & K Loader and is made in Spokane, Washington.

Appendix 10 presents the regression equations for estimating the seconds required to load 10 cubic feet (100 cubic feet for the Drott Loader) of lodgepole pine logs. Only the slasher saw and chain lift equation shows much promise. In the other two the coefficients of determination were small and none of the slope coefficients were significant at the 5 percent level. While this is less puzzling for the Drott Loader, an explanation is lacking why number of logs is not significant when they are loaded individually on a self-loading truck. For the Drott Loader, the somewhat illogical, negative slope coefficient for X_1 indicates that the more bolts the less time it takes to load 100 cubic feet. It may be rationalized that with smaller sticks the ricks are larger, due to easier carrying, and therefore the Drott Loader can take a larger bite. This seems to be verified by the negative intercorrelation, $r_{12} = -.478542$, showing that the more bolts the fewer the ricks and *vice versa*.

Working with the slasher saw, it appeared that the number of trees pulled onto the machine for cutting into 100-inch bolts would be an important second independent variable. However, when it was introduced, high intercorrelation ($r_{12} = .940273$) unduly influenced the results, as previously noted on page 102 of this study. To avoid the intercorrelation, but still use both variables, a compound independent variable was tried, using number of 100-inch bolts per load divided by

[illegible]

number of trees per load. However, this produced a somewhat smaller $\bar{R}^2$ and a slightly larger S.

For the loading measurements with self-loading trucks, two truck drivers were timed for four loads each. These men were of different skills; one being the owner and the other a man of moderate experience. The loading time of the owner was more consistent, so his performance was worked up separately to see how much variance could be excluded between drivers. This raised the R^2 from .153997 to .436680, but $\bar{R}^2$ dropped back to .155020 and S was reduced to 12.213544. However, still the independent variable was not significant at the 5 percent level. Table 8 presents the measurements in loading lodgepole pine logs by the three methods studied.

The timing of the loading process was a simple matter, but the determination of the volume loaded took more work. For the Drott Loader, the end diameter of the 100-inch bolts in a rick were written on a small card and stapled to the top log. The bolts could not be measured in the rick at the mid-point, but it is believed that the slight taper in lodgepole pine plus the short distance involved, as well as the mixture of large and small ends encountered on each face of a rick would reduce error from this source to an acceptable level. As the tractor picked up each rick to load, the card was pulled and the cards for the load stapled together. Later, the load volumes were computed using the Huber Formula. The piece count also was made easily from the cards. For the slashersaw-loader, the diameters were estimated from the ends and checked by caliper as they were raised on the chain lift in loading.

Table 8

Measurements in Loading Lodgepole Pine Logs by Three Methods

Load	Pulpwood by Drott Skid Loader					Slashersaw-loading Pulpwood					Sawlogs by Self-loading Truck			
	Time in seconds		Per load			Time in seconds		Per load			Time in seconds		Per load	
	Total	Per 100 cu. ft.	Cu. ft. Volume	Number bolts	Number ricks	Total	Per 10 cu. ft.	Cu. ft. Volume	Number bolts	Number trees	Total	Per 10 cu. ft.	Cu. ft. volume	No. logs
1	385	104.614	368.02	151	7	2701	50.755	532.17	213	32	4755	87.651	542.49	64
2	440	136.613	322.08	256	4	2908	51.953	559.74	206	40	6985	131.696	534.22	80
3	610	177.126	344.39	149	5	2823	40.494	697.14	115	17	7479	124.577	600.35	99
4	310	85.789	361.35	121	4	2832	45.034	628.86	142	24	6205	103.622	598.81	86
5	435	127.428	341.37	109	6	2296	38.677	593.63	131	15	3310	46.020	719.25	77
6	795	221.525	358.88	118	7	2145	35.540	603.54	123	18	4200	62.629	670.61	76
7	590	173.321	340.41	119	12	2605	37.902	687.30	194	28	4706	69.561	676.53	81
8	520	154.990	335.51	93	14	3300	53.935	611.85	287	56	5088	71.208	714.53	89
9	415	141.004	294.32	106	15	4075	70.651	576.78	280	72				
10	490	133.279	367.65	109	7	3100	52.371	591.93	157	35				
11	665	187.449	354.76	112	9	2582	43.922	587.85	175	36				
12	405	125.459	322.82	75	12	2180	38.003	573.64	110	20				
13	435	126.453	344.00	105	11	3037	53.153	571.36	212	44				
14	500	139.619	358.12	165	11	3463	53.792	643.77	301	67				
15	500	152.094	328.74	94	7									
Mean	499.7	145.784	342.83	125.5	8.7	2860.5	47.584	604.25	189.0	36.0	5341.0	87.120	632.47	81.5
SD	123.1	33.867	20.12	43.1	3.6	525.2	9.505	46.63	64.9	18.3	1427.2	30.504	72.72	10.3

These were tallied individually and later the volumes and piece count per load were determined as before. The sawlogs loaded on the self-loading truck were calipered at the mid-point as they were loaded to get volume by the Huber Formula, subsequently. The individual recordings of the diameter gave the log count per load as before.

The relatively short periods of different days when timing of loading was measured in conjunction with hauling was hardly a good way to time delays in loading. Therefore, the few delays that were encountered were not considered sufficiently representative to be included in this report. Since the equations also require additional verification, machine-crew costs are not presented in detail, although some cost items may be of interest. The April, 1958 prices for an Allis-Chalmers HD5 crawler tractor and Drott Skid Loader attachment are $9,600 and $2,200, respectively, in Fort Collins, Colorado. The B & K Loader to attach on trucks was priced at $1,900 in Spokane in 1956. The two, operator-made slashersaw-loaders were appraised by their owners at $4,000 and $5,000. Both estimated a 10-year life for the machines with $500 to $1,000 per year maintenance. One burned 12 gallons of gasoline per day on the average and the other about 10 gallons of diesel fuel. About 8 truckloads averaging 6 cords (or more exactly, 604 cubic feet of wood) each constitutes a day's production. The crew consists of the saw operator, the cross-haul man who sets tongs on tree-lengths to winch them onto the live rolls, possibly a red rot puller assisting at the loader, and the trucker stacking his own load. The men received about 50 cents per cord in 1957, except the trucker who was paid $6 by the trip.

Chapter VIII

THE HAULING BY MOTOR TRUCK PROCESS

The motor truck was first used for logging in 1913 in the Douglas-fir region.[1/] Since World War II, it has been greatly improved in power, efficiency and size. This, coupled with better and more frequent hard-surfaced roads, has made it the most important means of major log transportation. However, the increased use of trucks in the woods could not have gone far without the crawler tractor and bulldozer blade to punch in roads. The first practical steam tractors were made in the 1880's, and their first application in logging came in 1893 in California.[2/] Steam power gave place to the gasoline engine for tractor power in 1905 and in 1931 the first practical diesel tractor entered the woods. Benjamin Holt of Stockton, California invented track-type traction about 1900, but it took the experience gained with tanks in World War I to perfect the idea. The bulldozer blade was invented by Earl L. Hall of the U. S. Forest Service in 1929 and the stage was set for the revolutionary impact of truck and tractor logging on American forestry.

Several types and numerous makes of trucks are used in logging lodgepole pine. It is probably that there is no one best type or make

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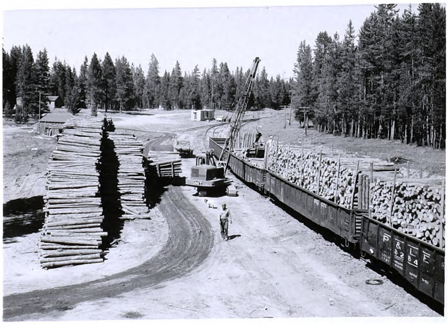
1/ Nelson C. Brown, Logging (New York, John Wiley, 1949), p. 295.

2/ Brown, *op. cit.*, p. 152.

for all the varied situations encountered in lodgepole pine logging. Some lodgepole pine sawmills have found the hauling of long logs on logging truck-trailers the best solution of their particular problems in log transportation. A different and perhaps equally efficient system is to skid 16-foot and shorter logs to roadside, where they are loaded and hauled on dual-axle trucks. When lodgepole pine is cut into 100-inch pulpwood, it can be loaded either cross-wise or lengthwise on the truck or trailer bunks (see Pictures 28 and 47), but the basic transportation problem remains the same. The size of truck and method of loading are only two factors in the whole logging scheme. All factors must be considered together and the task is a formidable one.

Another consideration in trucking lodgepole pine logs is the flexibility required of the machine. While lodgepole tends to grow in dense, even-aged stands, the terrain, if nothing else, will introduce variation in demands on the truck. In the same category, although not a problem in company logging, is the case of the part-time logger who ranches and hauls logs occasionally. In such a case the optimum truck may not be the optimum logging truck or the optimum truck for ranch use, but a compromise somewhere in between. Compromise is usually the policy in the world in general. It seems to pervade logging and is particularly notable in truck hauling. For example, one western pulpwood operator believes it is more economical to buy 2-ton trucks and overload them with 14-tons of pulpwood. The haul was almost all favorable grade, and even though the trucks took an awful beating, their life was longer than one would expect under such treatment. Here, the economical compromise was made on the basis of a lower initial cost, a higher maintenance charge, and a shorter life.



Pictures 43-45 show the railhead at Trude, Idaho, 10 miles west of Yellowstone Park, where Charles Erickson and Son loaded pulpwood for Wisconsin paper mills. Chicken wire around the cars is specified to prevent accidents from logs slipping out enroute.

Picture 46 shows the transfer of pulpwood from truck to gondola car at the railhead at White Sulphur Springs, Montana. The pulpwood on the truck is divided in three sections by removable stakes. This helps in loading, tends to prevent side slippage enroute, and provides space to slip the sling over the ends as shown in unloading. Less than ten minutes is required to unload a truck by this method.

Picture 47 shows a flatbed trailer modified for lengthwise hauling of pulpwood by Heggie Bros., White Sulphur Springs, Montana.

The influence of a number of variables upon trucking output has been reported elsewhere.[3/] Pope[4/] pointed out that, "Until recently there has not been a simple, straightforward method of predicting the time it would take a logging truck to travel a given distance and return." It was believed that multiple, linear, regression analysis might be used to incorporate the more important variables into a rather basic time-cost prediction equation for logging lodgepole pine with dual-axle trucks. Of course, most truck hauling functional relationships are not linear, but for the range of the variables experienced in this study, which was assumed to be somewhat representative, it was hoped that the linear assumption would not be seriously in error. Truck hauling from woods to railhead was timed on two pulpwood operations in Montana and from the woods to mill yard on a sawlog operation in Colorado for a total of 22 round trips. There were six drivers and as many trucks. The trucks were dual-axle, 2-ton models of Chevrolet and International make. Change in elevation was obtained with an aeroplane

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3/ Highway Research Board, Time and Gasoline Consumption in Motor Truck Operation as Affected by the Weight and Power of Vehicles and the Rise and Fall in Highways (Research Report No. 9-A. Washington: National Research Council, February, 1950).
J. J. Byrne, R. J. Nelson, and P. H. Googins, Cost of Hauling Logs by Motor Truck and Trailer, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Revised May, 1956.
James W. Fitch, Motor Vehicle Engineering Guide (Chicago: Arrow Lithograph Co.)

4/ Clem L. Pope, Predicting Truck Performance for Given Distance, The Timberman, November, 1953. p. 86.

altimeter.[5/] The following variables were used and their measurements are given in Table 9.

Y = Round trip minutes per mile. This divided into 60 gives miles per hour, if desired. $\bar{Y} = 2.625545$ and $60/\bar{Y} = 22.8$ miles per hour.

X_1 = Percent of rise in direction of loaded haul, i.e., it is the per cent of the change in elevation, going one way, that is adverse grade when loaded. Thus, 100 per cent indicates all adverse grade and zero per cent signifies all favorable grade. $\bar{X}_1 = 19.473636$

X_2 = Round trip rate of rise and fall in per cent. This designates the total rise and fall in feet, divided by round trip distance in feet. $\bar{X}_2 = 2.361818$

X_3 = Weight-power ratio adjusted for elevation. Here, the gross engine horsepower times an efficiency factor [6/] for elevation above sea level, is divided by total vehicle-plus-load weight in thousands of pounds. The factor used for weight of green lodgepole pine logs was 39 pounds per cubic foot. $\bar{X}_3 = 3.167318$

X_4 = A speed index dependent upon road surface. The index is the sum of round trip miles on each of three categories of road surface, divided by a round-trip-minutes-per-mile standard for each category as reported by Reynolds and given below: $\bar{X}_4 = 11.896364$

Time Required Per Load Per Round Trip Mile.[7/]

Product	Type of Road		
	Woods	Graded Dirt	Gravel or Hard Surface
	Minutes	Minutes	Minutes
Pulpwood	22.7	7.9	4.7
Logs	21.1	8.6	4.5

5/ While the altimeter could be read for changes of 10 feet or less in elevation, it was not completely satisfactory. Separate trips over the truck routes were made on week-ends. The altimeter was adjusted at a point of known elevation, then readings from the car odometer and the altimeter were recorded at each sustained break in grade. However, changes in temperature and atmospheric pressure influenced the accuracy of the instrument and it would not check out at the same place and elevation after a round trip over the route taking several hours.

6/ Byrne, Nelson, and Googins, op. cit., p. 10.

7/ R. R. Reynolds, Pulpwood and Log Production Costs as Affected by Type of Road, Journal of Forestry, December, 1940. p. 928.

Table 9

Measurements in Hauling Lodgepole Pine Logs by 2-ton, Dual-axle Trucks from Four Locations in Montana and Colorado by Six Trucks and Drivers, Summer, 1957

Driver1/	Trip2/	Round trip Miles	Round trip Minutes	Cu. ft. volume	Associated variables3/ Y	X_1	X_2	X_3	X_4
Gil	1	58.4	139.15	576.78	2.383	12.79	2.14	3.051	10.06
Gil	2	58.7	145.38	591.93	2.477	12.64	2.15	2.985	10.07
Gil	3	58.7	133.23	580.87	2.270	12.64	2.15	3.033	10.07
Gil	4	58.7	131.31	587.85	2.237	12.64	2.15	3.033	10.07
Gil	5	58.7	127.88	573.64	2.178	12.64	2.15	3.064	10.07
Hap	6	53.7	150.55	532.17	2.803	26.32	2.14	2.570	9.64
Hap	7	53.4	191.25	680.09	3.581	26.32	2.16	2.114	9.70
Hap	8	53.4	173.78	597.09	3.254	26.32	2.16	3.072	9.70
Hap	9	53.7	160.55	593.63	2.990	26.32	2.14	3.086	9.64
Hap	10	53.4	146.30	595.16	2.740	26.32	2.16	3.080	9.70
Hap	11	53.7	143.08	611.85	2.664	26.32	2.14	3.013	9.64
Nat	12	53.7	142.21	559.74	2.648	26.32	2.14	2.471	9.64
Nat	13	53.1	127.34	608.57	2.398	26.32	2.17	3.025	9.71
Pat	14	53.4	133.47	571.36	2.499	26.32	2.16	3.181	9.67
Sox	15	104.6	231.73	542.49	2.215	17.63	1.59	2.980	18.19
Sox	16	104.6	238.80	537.22	2.283	17.63	1.59	3.002	18.19
Sox	17	104.6	219.17	600.35	2.095	17.63	1.59	2.762	18.19
Sox	18	104.6	232.84	598.81	2.226	17.63	1.59	2.768	18.19
Val	19	86.1	254.83	719.25	2.960	16.48	4.06	4.238	12.94
Val	20	84.9	239.63	670.61	2.822	13.73	3.81	4.477	12.88
Val	21	84.9	259.61	676.53	3.058	13.73	3.81	4.446	12.88
Val	22	84.9	253.05	714.53	2.981	13.73	3.81	4.260	12.88
Mean		69.7	180.69	605.48	2.625	19.47	2.36	3.167	11.90
SD		20.5	49.61	53.59	0.397	6.07	0.76	0.625	3.26

1/ The real name of the driver is not used.
2/ Trips 1-14 were 100-inch pulpwood. Trips 15-22 were 16-foot & shorter sawlogs.
3/ Y = Round trip minutes per mile.
X_1 = Percent of rise in direction of loaded haul.
X_2 = Round trip rate of rise and fall in percent.
X_3 = Weight-power ratio adjusted for elevation.
X_4 = Speed index dependent on road surface.

In the predictive equation given in Appendix 11, only the slope coefficients for the X_1 and X_2 were significant at the 5 percent level. This was surprising, since all were selected for suspected importance, and the adjusted coefficient of determination indicates that 61 percent of the variation in the data is explained by the equation. The small standard error of estimate for the equation of about .25 minutes or 15 seconds per round trip mile was encouraging. However, the positive r_{y3} and negative regression coefficient for X_3 and the reverse for r_{y4} and X_4 seems illogical. In this relationship the rather high r_{13} and r_{23}, which seems to be spurious, is a possible explanation.

Perhaps the seeming illogical significance of the variables can be explained by a glance at the measurements in Table 9 which show much conformity. The small (0.397) standard deviation in round trip minutes per mile probably emphasizes the fact that drivers tend to drive a set route at rather uniform speeds, although different whether loaded or empty. Hence, the rather uniform round trip average time per mile. Likewise, timing the hauling from only four logging areas hardly gave sufficient range in variation for X_1, which is also reflected in the four rather uniform groups of measurements for X_2. The horsepower of the trucks and the loads they carried did not cover much of a range either in X_3. Measurements for X_4 also are based upon hauling from the four logging areas involved in this study and therefore the range of road surfaces is limited. To sum up, perhaps the insignificance of the slope coefficients is accounted by the attempt to predict a rather uniform Y from independent variables that were dominated by factors associated with location of the logging chance and only four different logging

chances were included. Although the regression seems almost promising on the basis of the $\bar{R}^2$ and S statistics, it is reported only in Appendix 11, pending further testing and verification.

Delays and indirect productive time as well as direct productive time in hauling (moving or rolling) are reported for the 22 round trips timed in this study in Table 10. Separate presentation is made for pulpwood and sawlog loading and hauling, due to obvious differences, although the two are pooled in developing the direct time hauling equation given in Appendix 11. Many of the time categories are related to the trip as presented; however, others such as lunch time and most of the miscellaneous category which includes delay moving slasher, delay putting oil drum on truck, wait on road grader, wait on rain at railhead, delay retrieving lost truck stake, wait on train at crossing, delay spinning wheels on slick road, delay removing rock from road, and delay unloading oats and hay are not associated with the trip. A more complete study of delays and indirect hauling time would present these categories on a daily basis. Nevertheless, it is notable that only half of the trucker's time was spent rolling in hauling pulpwood from a slashersaw-loading operation. Perhaps the larger percentage (60.3) for rolling time in hauling sawlogs with a self-loading truck is due to the greater hauling distance (nearly double that for pulpwood, see Table 9). Trip-wise, the delays and indirect productive time for pulpwood hauling ranged as high as 88 percent and as low as 34 percent. This range was smaller in hauling sawlogs and is perhaps due to freedom from the slashersaw-loading association in trucking pulpwood.

[illegible]

Table 10

Delays, Indirect, and Direct Productive Time in Hauling Lodgepole Pine Logs by 2-Ton, Dual Axle Trucks from Four Locations in Montana and Colorado, by Six Trucks and Drivers, Summer, 1957

Driver 1/	Trip	Loading	Delay loading	Unloading	Delay Unloading	Binding	Gas up	Drink	Work on truck	Delay turn out	Lunch	Misc.	Other Seconds	Other Per cent	Rolling Seconds	Rolling Per cent	Total seconds
Pulpwood, 100-inch Bolts																	
Gil	1	4075	1005	727	1426	167	105	139					7644	45.8	9051	54.2	16695
Gil	2	3100	1525	551	499	148	217	194	473	95		4320	11122	88.0	1523	12.0	12645
Gil	3	2645	880	588	312	185	154	324	588	160			5836	42.2	7994	57.8	13830
Gil	4	2582	848	615		202	155	129					4531	36.5	7879	63.5	12410
Gil	5	2235	1005	604	716		151	181				268	5160	40.0	7725	60.0	12885
Hap	6	2701	2629	675	325	718	401	103	162	84			7798	46.3	9032	53.7	16830
Hap	7	3853	3397	648	1216	387	146	287	3035	70			13039	65.8	6786	34.2	19825
Hap	8	2712	4626	390	927	400	147	312	208	35		183	9940	48.4	10600	51.6	20540
Hap	9	2296	6527	575	2385	286	398	440	1729	471			15107	61.2	9593	38.8	24700
Hap	10	4611	709	561	767	393	141	312		50			7544	45.9	8881	54.1	16425
Hap	11	3300	4115	446	354	280	163		220	292		1160	10330	47.1	9185	52.9	19515
Nat	12	2908	1112	517	898	494	156	279		65		536	6965	44.6	8640	55.4	15605
Nat	13	2605	185	537	506	258	128						4219	34.5	7996	65.5	12215
Pat	14	2145	2525	365	674	235	170		448			139	6701	45.2	8134	54.8	14835
Mean		2983	2221	557	786	297	188	193	490	94		472	8281	50.6	8073	49.4	16354
Percent		36.1	26.8	6.7	9.5	3.6	2.3	2.3	5.9	1.1		5.7	100.0				
Sawlogs, 16-foot and Shorter																	
Sox	15	4755	790	1070		1120		141					7876	34.8	14749	65.2	22625
Sox	16	6985		1110		627	940	305			1560	266	11793	44.4	14792	55.6	26585
Sox	17	7479	1531	1115		720							10845	42.2	14825	57.8	25670
Sox	18	6205	355	935		905	850				2100		11350	44.4	14210	55.6	25560
Val	19	3310	585	1130		380		37				98	5540	25.8	15945	74.2	21485
Val	20	4200	630	905		665	810	80			1407	105	8802	37.1	14943	62.9	23745
Val	21	4706	519	660		673		221	890			2725	10394	38.9	16336	61.1	26730
Val	22	5088	496	1005		707	470	730			1450	1988	11934	46.5	13711	53.5	25645
Mean		5341	613	991		725	384	189	111		815	648	9817	39.7	14939	60.3	24756
Percent		54.5	6.2	10.1		7.4	3.9	1.9	1.1		8.3	6.6	100.0				

1/ The real name of the driver is not used.

Machine-crew rates per time unit are reported elsewhere[8/] and based upon more authoritative research than could be incorporated in this phase of the present study. In Appendix 12 is reproduced the form and cost items given by Reynolds. The figures are out-dated as are those truck cost components collected during this study. However, substitutions can be made easily in the form to obtain current cost figures.

8/ R. R. Reynolds, Pulpwood Production Costs in Southeastern Arkansas, 1950, Southern Forest Experiment Station, New Orleans, Louisiana. Occasional Paper No. 121, June, 1951.
Don Tufts and Bruce Mety, Truck Transportation of Logs in Southeast Arkansas, Proceedings Forest Products Research Society, 1951.
Campbell, op. cit., p. 28.
Byrne, Nelson, and Googins, op. cit., pp. 36 and 39.

Chapter IX

SUMMARY AND APPLICATION

Lodgepole pine has always been useful to man in the West. American Indians used it for fuel, travois, and tepee poles. The latter usage accounts for the common name of the species, since the dwellings were also called lodges. Early settlers, trappers, and miners also made abundant use of the smooth, straight stems that were so plentiful, easy to work and handle. Now, lodgepole pine helps to satisfy the demand for building logs, fence posts and poles, railroad cross-ties, transmission poles, lumber, pulpwood, and mine props, stulls and timbers. Beside utilization as timber, lodgepole pine forests are beneficial from the watershed and recreational aspects, including the scenic, hunting, and fishing environments.

Because a resource is a planning estimate of anything that exists in nature that is accessible and people know how to use, it is apparent that the value of the lodgepole pine resource has changed through time. It is thus somewhat misleading to limit a resource to physical terms and state that lodgepole pine ranks fifth among western softwoods in volume with 15 billion cubic feet, growing on the third largest timber type in the West, covering 14.5 million acres. The technology and use of the species by the Indians gave the lodgepole pine resource a relatively insignificant value. The value of the resource increased with the settling of the West by the white man. A peak in value was reached just after the turn of the century, when

lodgepole pine was being logged extensively in the Rocky Mountains for hewed cross-ties and in mining and smelting. The resource value declined when railroad, truck and tractor loggers by-passed the modest-size lodgepole in favor of other larger species. However, since World War II, the lodgepole pine resource has perhaps regained or even surpassed its former peak for two reasons: First, the decline in quantity and quality of accessible supplies of other species of timber have caused lumbermen to take a closer look at lodgepole pine. Second, improvements in technology have made the species ever more attractive.

Improvements in technology of processing lodgepole pine have occurred in several industries. In lumbering, for example, fast, horizontal, band mills can now saw small diameter logs into boards which are in turn edged parallel to the bark. The tapered boards are then edge-glued with new, strong, quick-setting glues so that taper is compensated by turning every other board end-for-end. End gluing is also used to include short pieces in panels. The panels are marketed in a variety of ways, including squares that can be fitted together on walls or ceilings, standard knotty pine paneling, and plain panels that can be used for sheathing, sides for farm trucks, or other uses. This technology aimed to reduce manufacturing cost from small logs and to overcome the handicap of narrow boards appears most promising where the product is processed beyond lumber into such secondary products as box shook, caskets, panels, furniture, etc. Since a premium is not paid for glued lodgepole pine boards in ordinary widths, due to competition from boards of other species, such manufacture may not be economical except to salvage narrow material. Nevertheless, it is intriguing to speculate on such possibilities

as an economically satisfactory way to glue 1 x 4 boards into 2 x 4 studding.

Preservative technology for lodgepole pine applied to transmission poles, railroad cross-ties, highway guardrail posts, fence posts, and other products has increased the value of the resource. Veneer and plywood possibilities for the species have also been research tested for the same effect. But, possibly the greatest potential of the resource was demonstrated when technological development in the paper industry in the 1930's permitted the expansion into the pineries of the South and simultaneously enhanced the value of the lodgepole pine resource in the West. Since about 1950, several Wisconsin pulp mills have been shipping lodgepole pulpwood over a thousand miles from Eastern Montana and Idaho forests.

Forester dreams of a Rocky Mountain pulp mill materialized with the successful establishment in 1951 of the Potlatch Forests, Inc. mill at Lewiston, Idaho. Originally conceived to utilize lodgepole pine pulpwood, it was later found that waste from their sawmill provided an ample supply of raw material. The Waldorf Paper Products Company, St. Paul, Minnesota installed a pulp mill at Missoula, Montana to utilized waste wood from local sawmills and began operation in early 1958. The St. Regis Paper Company, New York City, purchased the J. Neils Lumber Company in late 1956 and indicated it would build a pulp and paper plant at Libby, Montana of at least 400 tons capacity. In Colorado two separate pulpmill ventures, mainly based upon insect-killed spruce, did not succeed. The Columbine Development Company of Denver dissolved in 1950 and the J. and J. Rogers Pulp and Paper Company of Au Sable Forks,

New York failed in 1957. The situation is different near Klammath Falls, Oregon where the Johns-Manville Products Corporation has built a groundwood pulp plant scheduled to begin operations in early 1958. The International Paper Company also plans to build a pulp and paper plant in that locality. Both mills will utilize the considerable lodgepole pine resource in that area.

Value of a resource may also be increased by reducing the cost of production. By influencing profitability, this expands the economic margin and literally adds to the resource. One of the most challenging research opportunities in lodgepole pine utilization is in logging where small size trees, logs, and volumes per acre dominate the picture. Because lodgepole pine grows in dense, even-aged stands, often comparable to wheat, it is easy to suggest forest harvesting machines to accomplish the felling, limbing, bucking, skidding, and loading operations patterned after the wheat combine. But the difference between a grain of wheat and even a small log is considerable. Helicopters have been suggested to lift logs from stump to landing. Another possibility is to adapt a transport machine developed for the military that negotiates rough terrain by rolling on large, low-pressure, sausage-like balloons instead of wheels. More practical, at this date at least, are the Wyssen System, Lasso System and Wire-Gravity Systems which are all designed for log assembly from steep slopes. In the Wyssen System, a taut cable serves as a high-line to which logs are lifted by means of an ingenious block and tackle arrangement which enables transporting the logs down the high-line by gravity to an assembly point. The Lasso System is a continuous, moving, taut cable looped around a block of timber and supported by special sheaves attached to trees. A small gasoline engine moves the

cable at a slow rate and logs are hooked to the cable and brought suspended to the landing point. Sliding logs to a landing over a suspended wire by gravity is a particularly intriguing possibility due to the easy mobility and small investment required. These methods of logging could not be tested because only methods currently in use in lodgepole stands were within the scope of the study.

A number of other more conventional logging methods could not be tested due to time and money restrictions on the study. One of these that shows promise for use in logging lodgepole pine is skidding by light cable rigging. Semi-mobile arrangements for high-lead yarding in tree-lengths or in bundles of pulpwood have been tried in Canada. Fully mobile cable yarders of several makes are becoming increasingly common. Some of these machines are used in lodgepole pine logging operations and have their greatest effectiveness in skidding logs uphill to roadside. A second type of innovation particularly adapted to lodgepole pine logging is a fully-mobile, self-propelled slashersaw and truck loading machine. Rubber-tired tractors are interesting machines of unknown potentiality for use in lodgepole pine logging and they qualify as a third technique needing investigation. A fourth promising development to reduce cost of logging lodgepole pine is the use of pallet loading or preloading devices. The main advantage in their use is from the greater efficiency when both loading and hauling can proceed independently and continuously. The "pallet" can be a wheeled trailer or semi-trailer parked in the woods, a detachable, truck-bunk arrangement, or simple steel racks. In the South such steel racks are manually filled with pulp bolts in the woods as they are pulled behind horses or tractors.

[illegible]

For loading on the truck, they are pulled up inclined skids over the end. Among other logging techniques, the last to be mentioned specifically as a possibility for use on lodgepole, is the strapping of logs with iron bands or use of cable in bundling for easier handling.

For those alternative methods of logging lodgepole pine that were tested, the aim was to provide objective answers concerning their relative merits. The scope of the study extended from stump to mill yard or railhead. Field data was collected in Colorado, Idaho and Montana during the three summers of 1955-57. Basically, the research was a time study incorporating multiple, linear regression analysis to test the influence of a number of independent variables that affect the cost of logging. Separate time-cost predicting equations were developed for the processes of (1) felling, (2) skidding, (3) loading, and (4) hauling. Machine-crew cost factors per time unit were also derived to apply to the time equations to obtain a dollar-cost figure. The equations are as durable as the technology employed and the machine-crew factors easily can be revised as often as necessary. The individual costs for the four processes can be summed to determine total cost of logging. Equations were formulated for the following methods and processes:

1. Felling
    a. Felling with powersaw, leaving in tree-lengths
    b. Felling with powersaw, bucking to 100-inch lengths and manually stacking in ricks.

2. Skidding
    a. Skidding in tree-lengths with small crawler tractor
    b. Skidding of sawlogs by single horse

3. Loading
    a. Slashersaw and loading machine
    b. Drott Skid Loader
    c. Self-loading Truck

4. Hauling by motor truck

[illegible]

Practical application of the results of the study in objectively estimating logging cost for lodgepole pine stands in advance of operation, should be useful to logging companies, contractors, and forest appraisers. The implication is not to displace the experienced logging engineer or forest appraiser by mathematical equation, but rather to provide some stepping stones (although some are not very firm) for these technicians, particularly those inexperienced in logging lodgepole pine. The technique used in the study seems well-adapted to provide an approach to answer which is the better method for logging lodgepole pine. However, it is probable that there is no single best method for harvesting the species. There may be a certain combination of felling, skidding, loading, and hauling techniques that represents the best compromise of alternatives for most situations. But, this universal compromise is not the answer sought, for such a combination may be grossly inefficient under specific operating conditions.

The time cost predicting equations are closely related to production functions in economic theory. A production function is a mathematical relationship between physical inputs and outputs -- a production recipe, in other words. Such basic input-output relationships were too expensive to try and formulate in this study, so they were bypassed for the more easily measured cost functions measured in time units. Furthermore, rather than measure inputs of work by men and machines, independent variables were selected for measurement which importantly influenced the work required in production. Various production averages were also accumulated in the study. For example, the average cubic foot volume produced per man-day in tree-length felling was 1277 cubic feet

(standard deviation: 217.86) and for felling, bucking, and stacking in 100-inch lengths the daily output per man was 677 cubic feet (standard deviation: 217.44). The average round trip skidding distance with horses was 358 feet with an average volume per turn of about 11 cubic feet; whereas, by small, crawler tractor the same averages were 840 feet in distance and 108 cubic feet per turn. On the average, horses made 68 turns per day to produce about 730 cubic feet, while tractors made about 22 turns per day to skid 2,368 cubic feet. Such averages should be interpreted cautiously and cannot be directly compared. As an illustration of the incomparability, the horses were skidding 16-foot and shorter sawlogs and could not pull a single tree-length stem, which the tractors were skidding on the average of about six per turn.

An example will illustrate how the equations may be used to appraise the profitability of logging a given block of timber by two different methods. In order to include the fullest range of comparison, let us assume that a stud mill is debating whether to (1) skid 16-foot and shorter sawlogs with horses, or skid tree-length stems with small, crawler tractors, (2) load with a self-loading truck, or cut into 100-inch lengths and load with a slashersaw-loader. In both cases, felling is to be done with light powersaw with the assumption that bucking into 16-foot and shorter sawlogs increases machine-crew cost about 5 percent and reduces daily production about 10 percent over felling in tree-lengths. Hauling in both cases is to be by motor truck.

First, information to insert into the equations must be obtained by occular estimate or sampling for the block of timber to be logged.

For example, when a cruise of the area for volume is made, the estimator might also record the needed information on diameter of trees, windfalls, average skidding distance, and representative slope. Assuming some estimates for these measures for a 40-acre tract, containing 3,000 cubic feet per acre, we can proceed:

1a. <u>FELLING IN TREE-LENGTH</u>

Y	= Cubic feet of tree-length felling production per day.		
X_1	= Sum of tree diameters squared, measured at DBH, of trees felled per day.		
Y	= $56.516 + 0.188X_1$		
	Substituting 10 inches DBH as average tree and assuming that 60 trees will be felled on the average per day. Machine-crew cost = \$21.73 per day.		
1184.516	= 56.516 + 0.188(100)(60)		
101.3	= 120,000/1184.516	=	Days required for felling
106.4	= 101.3(1.05)	=	Days required for felling, including estimated unusual delays
\$2201.25	= 101.3(\$21.73)	=	Cost of felling on the 40-acre tract, payment by piece rate.

1b. <u>FELLING AND BUCKING INTO SAWLOGS 16-FEET AND SHORTER</u>

Same equation, except daily output assumed reduced 10 percent.
Y = .90(Y) = .90(1184.516) = 1066.064 cubic feet per day.
Daily machine-crew cost assumed increased by 5 percent.

\$22.82	= 1.05(\$21.73)		
122.6	= 120,000/1066.064	=	Days required for felling.
118.2	= 112.6(1.05)	=	Days required for felling, including estimated unusual delays.
\$2569.53	= 112.6(\$22.82)	=	Cost of felling on the 40-acre tract, payment by piece rate.

2a. <u>SKIDDING SAWLOGS BY HORSE</u>

Assuming an average round trip distance of 360 feet, average volume of each log in turn = 8.5 cubic feet, average number of logs per turn = 1.5, average and only favorable slope = 10 percent, average windfall index = 50, and animal-crew cost = \$22.83 per day.

Y_1 = Out plus in time in seconds per 100 feet

Y_2 = Seconds required for hooking, assembling, and unhooking logs

X_1 = Number 16-foot and shorter logs in turn

X_2 = Average cubic foot volume per log in turn

X_3 = Percent slope

X_4 = Windfall index

$Y_1 = 30.989 + 1.756X_1 + 0.481X_2 + 0.117X_3 + 0.098X_4$

$43.781 = 30.989 + 1.756(1.5) + 0.481(8.5) + 0.117(10) + 0.098(50)$

$Y_2 = -2.352 + 43.823X_1 + 1.335X_2 - 0.665X_3 + 0.626X_4$

$99.380 = -2.352 + 43.823(1.5) + 1.335(8.5) - 0.665(10) + 0.626(50)$

$157.612 = Y_1(3.6)$ = Seconds out and in per average turn

$256.992 = Y_2 + 157.612$ = Seconds work time per average turn

14,400 = 28,800(.50) = Seconds of assumed effective work in 8-hour day

56 = 14,400/256.992 = Turns per day

714 = (56)(1.5)(8.5) = Cubic feet skidding production per day

168 = 120,000/714 = Animal-crew days required for skidding on the 40-acre tract

\$3835.44 = 168(\$22.83) = Cost of horse skidding on 40-acre tract

2b. <u>SKIDDING TREE-LENGTHS BY SMALL CRAWLER TRACTOR</u>

Assuming an average round trip distance of 840 feet, average volume of each log in turn = 20 cubic feet, average number of logs in turn = 6, average windfall index = 250, and daily machine-crew cost = \$40 for an 8-hour day.

Y_1 = Out plus in time in seconds per 100 feet.

Y_2 = Minutes required for hooking, assembling, and unhooking logs

X_1 = Number of tree-length logs in turn

X_2 = Average cubic foot volume per log in turn

X_3 = Windfall index

$Y_1 = 56.069 - 3.631X_1 + 0.852X_2 + 0.022X_3$

$56.823 = 56.069 - 3.631(6) + 0.852(20) + 0.022(250)$

$Y_2 = 0.637 + 0.911X_1 + 0.184X_2 + 0.002X_3$

10.283 = 0.637 + 0.911(6) + 0.184(20) +).002(250)

$477.313 = Y_1(8.4)$ = Seconds out and in per average turn

$1094.293 = 477.313 + 60(Y_2)$ = Seconds work time per average turn

17,280 = 28,800(.60) = Seconds of assumed effective work in 8-hour day

16 = 17,280/1094.293 = Turns per day

1920 = (16)(6)(20) = Cubic feet skidding production per day

62.5 = 120,000/1920 = Machine-crew days required for skidding on the 40-acre tract

\$2500.00 = 62.5 (\$40) = Cost of tractor skidding on 40-acre tract

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3a. LOADING AND HAULING BY SELF-LOADING TRUCK

Assume average volume per truckload = 600 cubic feet, average number of logs per truckload = 80; round trip distance = 60 miles, consisting of 30 on hardtop, 20 on graded dirt, and 10 on woods road, giving a speed index of 5.131; percent of rise in direction of loaded haul = 20; round trip rate of rise and fall in percent = 2.4; and weight-power ratio adjusted for elevation = 3. Also, assume $59.00 = machine-crew cost per day, consisting of $27.50 in driver-loader salary, and $30 for the truck, made up of $15.24 for interest, license, taxes and depreciation for a dual-axle, $10,000 truck depreciated over 4 years and operating 200 days per year, plus $14.76 daily operating expense in driving 120 miles and $1.50 daily operating expenses while immobilized and loading. The amount prorated on a time basis is $42.74, comprised of the $15.24 fixed charge and the $27.50 salary.

Loading

Y = Seconds to load 10 cubic feet

X_1 = Number of logs per load

$Y = -7.636 + 1.163X_1$

$85.404 = -7.636 + 1.163(80)$

5124.240 = 85.404(600/10) = Seconds per load effective work time

6000.000 = Seconds to load including allowance for indirect work time and delays.

14.38 = $42.74(200/663.8) + $1.50 = Daily cost of loading two loads

Hauling

Y = Round trip minutes per mile

X_1 = Percent of rise in direction of loaded haul

X_2 = Round trip rate of rise and fall in percent

X_3 = Weight-power ratio, adjusted for elevation

X_4 = Speed index dependent upon road surface

$Y = 1.776 + 0.032X_1 + 0.656X_2 - 0.430X_3 + 0.003X_4$

$2.715 = 1.776 + 0.032(20) + 0.656(2.4) - 0.430(3) + 0.003(5.131)$

22.1 = 60/2.715 = Average, round trip miles per hour

162.9 = 60(2.715) = Minutes rolling time per round trip

Add the following assumed times:

12 minutes per trip for binding and checking load

17 minutes per trip for unloading

40 minutes per trip for other delays

231.9 = Minutes total round trip time

331.9 = Minutes total round trip time plus loading time

$44.62 = $42.74(463.8/663.8) + $14.76 = Daily cost of hauling two loads in an 11-hour day

100 = 120,000/1200 = Machine-crew days required for loading and hauling on 40-acre tract

$5900 = 100($59.00) = Total cost for loading and hauling on 40-acre tract.

3b. SLASHERSAW-LOADING AND HAULING BY MOTOR TRUCK

Assume using same trucks (less loader) as in 3a with same volume per load, hauling distance and route. However, the number of 100-inch bolts per load is assumed to be 190. Assume that \$96.70 = daily machine-crew cost in loading, consisting of \$50 in salary per day for two crew men (trucker not paid additionally for loading) and \$6 fixed and operating expense for slashersaw-loader, valued at \$5000, depreciated over 10 years, operating 200 days per year, and burning 12 gallons of gasoline per day. Also included in the \$96.70 figure is the standby cost of the truck and driver who assists in loading. This cost of \$40.70 consists of fixed charges for the truck of \$13.20, and the driver's salary of \$27.50 per day. The machine-crew cost per day of a truck (less loader) used in hauling is assumed to be \$55.50. The same dependent and independent variables are used in loading and hauling as in 3a.

Loading

$Y = 25.968 + 0.114X_1$

47.628 = 25.968 + 0.114(190)
2857.680 = 47.628(600/10) = Seconds per load, effective work time.
3600.000 = Seconds to load, including moving the setting and other indirect work time and delays.
8 = 28,800/3600 = Truckloads per day
25 = 120,000/4800 = Machine-crew days required on 40-acre tract
\$2417.50 = 25(\$96.70) = Total cost of slashersaw-loading on 40 acre tract

Hauling (Use same hauling equation, load, and rolling time as in 3a)

162.9 = Minutes rolling time per round trip
Add the following assumed times:
5 minutes per trip for binding and checking load.
9 minutes per trip for unloading.
40 minutes per trip for other delays.
216.9 = Minutes total round trip time plus loading time.
\$181.30 = \$55.50(4) - \$40.70 = Daily cost of hauling 8 loads with 4 trucks in 9-hour day, less the truck and driver standby charge while loading.
\$4532.50 = \$181.30(25) = Total cost of hauling from 40-acre tract
\$6950.00 = \$4532.50 + \$2417.50 = Total cost of slashersaw-loading and hauling from 40-acre tract.

Table 11

Summarizing the Cost Comparison of Logging by Two Alternative Methods

Process	Fell and buck in sawlogs, skid sawlogs with horse, load with self-loading truck, and haul by motor truck				Fell in tree-length, skid tree-lengths with tractor, use slashersaw-loader, and haul by motor truck			
	Machine-crew Units	Daily Output Cubic Feet	Daily Output Cost	Cost per Thousand Cu. Ft.	Machine-crew Units	Daily Output Cubic Feet	Daily Output Cost	Cost per Thousand Cu. Ft.
Felling	1	1066	$22.82	$21.407	4	4736	$86.92	$18.353
Skidding	2	1428	45.66	31.975	2	3840	80.00	20.833
Loading	1	1200	14.38	11.983	1	4800	96.70	20.146
Hauling	1	1200	44.62	37.183	4	4800	181.30	37.772
Total				$102.548				$ 97.104

The above comparison shows a possible application of the results of this study, but caution in interpretation is recommended because additional verification is needed for most of the equations. Many assumptions were made in the computations, although they are based upon experience encountered in the study. The daily output indicates the balance required between the different processes. Where horses are used it shows that roughly one faller and two horse skidders can keep one truck busy hauling two loads per day. In tree-length, tractor skidding, the slashersaw-loader sets the size of the operation and to keep pace with it about four fallers, two tractors, and four trucks are required. Minor adjustments between processes can usually be made by varying the length of the working day. Sometimes also, the owner-operator can assist in different ways to relieve the pressure whenever a bottleneck in production arises. Adding or subtracting machine-crew units does not change the cost per thousand cubic feet, since both daily cost and output change proportionally. With some reservations as explained below, processes can be appraised individually, or

cumulatively. Trucking obviously should be about the same under both alternatives, since the same trucks, loads, and route were assumed. The 59 cent difference per thousand cubic feet in hauling is accounted in the $2.05 fixed charge per day on the self-loader, and the differences in loading, binding, and unloading times for the two methods. The same truck driver salary used for days of different length may appear inequitable, but frequently in practice, drivers are paid by the load or similar piece rate and in both cases two trips per day were assumed.

It appears that the over-all difference between the two methods in cost of logging per thousand cubic feet is largely contained in the skidding and loading processes. However, the reservation is emphasized that direct comparisons by process or processes cannot be made, since in the one case tree-length stems are skidded and sawed into 100-inch bolts and loaded; whereas, in the other case sawlogs are skidded and simply lifted aboard. Direct and definitive logging comparisons can only be made when the methods can be examined comparably with respect to place, product, and degree of manufacture.

Results of the study may be helpful, but are not a complete solution for the practically difficult problem of determining marginal logs, trees, and stands. An economically marginal log, tree, or stand is one where harvesting results in zero profitability. For example, in tree-length felling the marginal log is synonymous with the marginal tree. Thus, considering only felling cost with other factors remaining equivalent and other costs assumed fixed, the cost-of-felling may be computed for trees of decreasing diameter at breast height (DBH), using the felling equation and the machine-crew cost factor ($21.73 per day for

a sawyer with light powersaw felling in tree-lengths). The assumption must be made that a day's production includes only trees of the given size-class, because the equation does not hold for all ranges of production, being based upon daily output. For this reason the equation cannot be used to predict the cost of felling a single tree.

In the felling equation, Y = cubic feet of tree-length felling production per day and X_1 = sum of tree diameters squared, measured at DBH, of trees felled per day. The average number of trees felled per day during the 45 man-day study period was 60.53 and the average DBH of the total number of trees felled was 9.87 inches. For illustrative purposes, if we assume that 70, 80, 90, and 100 trees per day could be cut if they were all, respectively, 8, 7, 6, and 5 inches in DBH, we can substitute in the time-cost equation, $Y = 56.516 + 0.188X_1$, thus:

DBH Class	Predicted Daily Felling Production in Cubic Feet
8	903.236 = 56.516 + 0.188(64)(70)
7	797.396 = 56.516 + 0.188(49)(80)
6	668.876 = 56.516 + 0.188(36)(90)
5	529.016 = 56.516 + 0.188(25)(100)

To continue the illustration, if the lumber grade recovery for these tree diameters or the pulpwood value is, say, $0.03249 per cubic foot contained in the log, then daily revenue can be obtained by multiplying Y by this factor, thus:

DBH Class	Total Revenue from Predicted Daily Felling Production
8	$29.35 = 0.03249(903.236)
7	25.91 = 0.03249(797.396)
6	21.73 = 0.03249(668.876)
5	17.19 = 0.03249(529.016)

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In the above illustration, with the rather heroic assumptions that other factors are equal and other costs remain fixed, the marginal tree with respect to DBH is the 6-inch class because in that category total daily revenue and total daily cost equals $21.73. Relaxing the rigorous assumptions to more practical conditions, a number of factors determine the marginal tree in felling. In addition to the revenue factors of size, quality, and amount of defect, those costs influenced by the decision to fell a tree must be considered. This includes all variable costs in felling, skidding, loading, hauling, and milling plus opportunity costs for any equipment or improvements used in those processes. Since a different equation and costs are reported where the felled stems are bucked and stacked in 100-inch lengths, a different criterion for the marginal tree would result under this method of production.

With comparable assumptions and using the skidding equations and machine-crew (or animal-crew) cost factors for skidding, marginal logs with respect to skidding distance might be computed. But, again, under actual conditions the assumptions would have to be relaxed to admit all of the factors above except felling cost. When the tree is felled, felling cost becomes historical and fixed and need not enter marginal log conputations. In practice, the sawyer in making bucking cuts decides whether or not a log is supramarginal and the skidder brings in all such logs produced. It would be foolish to produce submarginal logs only to leave them in the woods. And, of course, for those rare marginal logs encountered, it is immaterial from a profit standpoint whether they are bucked and brought in or not.

The above comparison of two alternative methods of logging a 40-acre tract will also serve as an illustration of the use of the results of this study to determine marginal stands. Total revenue from a stand expected to be harvested for lumber is readily obtained by multiplying anticipated volumes in the different lumber grades by their respective market prices. For illustration in this case, assume that by using this procedure and deducting milling costs it was found that the 120,000 cubic feet in the logs at the mill, (120,000 times an assumed board foot-cubic foot ratio of 5 equals 600,000 board feet on the 40-acre tract) produced an average, log value of \$100 per thousand cubic feet (\$100/5 = \$20 per MBF, which is a little over half the current market price for lodgepole pine logs delivered to the mill). With this assumed revenue bench mark of \$100 per thousand cubic feet, it can be seen in Table 11 that the stand is slightly submarginal for logging with horses and self-loading truck, and somewhat supramarginal if tractors and slashersaw-loader are employed. The particular costs of opening up a stand for logging were not included in the study and these must also be covered if the prospective undertaking is to prove profitable.

Finally, there is a definite advantage in scaling the cubic foot contents of lodgepole pine logs in that no assumption need be made regarding the product to be made or the intensity of utilization. Furthermore, the work involved in logging is more closely correlated with cubic foot volume than board foot volume, although the latter method of measurement is more customary in lumbering. Nevertheless a cubic foot volume standard is not a cure-all for measurement problems in logs and lumber,

because a cubic foot of lumber is a different commodity than a cubic foot of wood measured in the log. Size of log is an important variable in lumber recovery which must be accounted in a board foot-cubic foot ratio which changes for each diameter class of logs.

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APPENDIX

APPENDIX 1

Daily Tree-length Felling Production Measurements
Hyalite Canyon, near Bozeman, Montana

Date and Sawyer	Cubic Feet	Number Trees	Average D.B.H.	Slope Percent	Windfall Index	Piece-rate Wages
1955 Tex	1299.7	60	10.29	41	78	$ 16.40
	1281.8	65	9.87	41	119	17.00
	1588.8	60	11.32	31	20	21.00
	1419.3	54	11.15	34	52	18.00
	1578.3	44	13.12	37	88	16.40
	1305.8	48	11.37	40	122	15.40
	1145.9	79	8.65	34	37	19.00
	1204.6	52	10.52	46	91	17.00
	1133.4	58	9.87	29	582	17.00
	1119.0	49	10.60	34	528	18.00
1955 Roy	1239.8	60	9.88	35	52	20.20
	1563.1	70	10.34	36	52	22.10
	1308.6	57	10.49	23	30	22.20
	1322.4	58	10.44	32	0	20.60
	1101.3	68	8.79	38	48	19.40
	1268.1	94	7.46	37	62	26.60
	1079.5	50	10.21	48	165	17.00
	1179.8	70	9.21	42	404	18.00
	1446.0	74	9.87	41	592	24.80
1955 Doc	1230.4	55	10.40	24	64	22.20
	1053.6	47	10.34	32	45	18.80
	1217.6	45	11.42	32	110	20.20
	981.5	41	10.74	33	59	19.00
	821.4	67	7.97	37	69	19.80
	935.8	35	11.16	50	132	13.80
	820.5	37	10.29	38	36	14.00
1956 Tom	1403.2	90	8.85	15	239	22.00
	1694.1	160	7.58	4	161	35.00
1956 Joe	1400.1	78	9.37	7	173	22.00
	1449.0	54	11.06	7	208	20.40
	1395.0	33	13.35	12	158	17.40
	1220.1	69	9.23	10	106	21.00
	1492.1	101	8.59	4	96	26.60
	1114.6	59	9.59	23	243	19.20
1956 Jim	1389.1	89	8.86	7	211	22.20
	1718.5	59	11.44	7	132	22.20
	1422.4	42	11.99	12	132	17.00
	1489.0	69	10.04	11	64	20.00
	1411.3	59	10.46	10	54	19.80
	1395.5	57	10.73	7	106	18.00
	1652.0	63	11.06	13	116	22.20
1956 Bud	1021.0	50	9.99	7	192	17.00
	1062.6	31	12.28	7	161	12.00
	989.0	36	11.30	5	110	12.40
	1123.7	28	13.26	5	110	13.00
Total	57488.3	2724	---	--	---	$873.30
Average	1277.52	60.53	9.87	24.84	142.42	19.41

The real names of the sawyers are not used.

APPENDIX 2

Effect of Adding Additional Variables, Tree-length Felling Equation

Basis: 7 Sawyers, 45 days production. Hyalite Canyon, Near Bozeman, Montana

Y	= Cubic feet of tree-length felling production per day.	$\bar{Y}$	= 1277.517778
X_1	= Number of trees felled, limbed, and topped per day.	$\bar{X}_1$	= 60.533333
X_2	= Average of felled-tree diameters squared, measured at breast height. Sum $(DBH)^2/X_1$	$\bar{X}_2$	= 115.110667
X_3	= Slope percent in felling area.	$\bar{X}_3$	= 24.844444
X_4	= Windfall index.	$\bar{X}_4$	= 142.422222

Coefficient of Correlation Matrix

1.000000	+.454937	+.002552	-.353534	-.029201
	1.000000	-.761031	-.181708	+.075633
		1.000000	-.081833	-.131576
			1.000000	+.035583
				1.000000

$Y = 1007.818656 + 4.455382X_1$

$S = 198.471018$ cubic feet per day

$\bar{R}^2 = .188525$

$Y = -88.477342 + 10.632287X_1 + 6.275590X_2$

$S = 160.091231$ cubic feet per day

$\bar{R}^2 = .472022$

$Y = 33.095617 + 10.042793X_1 + 5.864384X_2 - 1551845X_3$

$S = 160.572957$ cubic feet per day

$\bar{R}^2 = .468840$

$Y = 33.574010 + 10.042205X_1 + 5.862862X_2 - 1.551621X_3 - 0.001918X_4$

$t =$ 5.536 4.216 0.861* 0.002*

$S = 162.543296$ cubic feet per day *Not significant at 5% level

$\bar{R}^2 = .455724$

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APPENDIX 3

Daily 100-inch Felling Production Measurements
Island Park, Idaho near Yellowstone Park

Date and Sawyer	Cubic Feet	Number Trees	Average D.B.H.	Piece-rate Wages
1957 Ted	544.9	41	8.31	$ 24.20
	635.9	36	9.39	26.00
	559.3	37	8.97	22.00
	498.8	29	9.20	22.50
1957 Rex	410.1	46	7.06	20.90
	370.3	61	6.27	22.10
	343.1	66	5.95	23.70
	326.0	66	5.98	22.30
	356.4	58	6.29	21.00
1957 Don	750.5	57	8.17	33.20
	1077.9	70	8.80	50.30
	903.3	53	9.11	38.80
	898.5	94	7.30	47.00
1957 Ned	626.5	43	8.70	26.30
	647.0	66	7.31	25.00
	663.4	99	6.39	31.20
	727.0	48	8.76	28.10
	663.0	68	7.28	26.80
1957 Red	661.9	84	6.72	35.60
	1003.3	112	7.03	40.60
	869.6	56	8.81	35.40
	1000.5	82	7.98	40.50
1957 Cal	1066.6	124	6.96	39.00
	759.3	54	8.46	27.00
	792.2	128	6.26	32.10
	901.0	134	6.41	34.90
1957 Wes	533.2	62	6.96	21.00
	615.2	85	6.56	24.60
	502.1	45	7.74	21.50
	562.7	35	8.97	20.00
Total	20309.5	2039	---	$883.60
Average	676.98	67.97	7.32	29.45

The real names of the sawyers are not used.

APPENDIX 4

Effect of Adding Additional Variables, 100-inch Felling Equation

Basis: 7 Sawyers, 30 days production. Island Park, Idaho, near Yellowstine Park

Y = Cubic feet of 100-inch-length felling production per day. $\bar{Y}$ = 676.983333

X_1 = Number of trees felled, limbed, bucked in 100-inch bolts, and hand stacked in ricks per day. $\bar{X}_1$ = 67.966667

X_2 = Average of daily, felled-tree diameters squared, measured at breast height. $\bar{X}_2$ = 63.421667
$\frac{\text{Sum } (DBH)^2}{X_1}$

Coefficient of Correlation Matrix

1.000000	+.529712	+.268035
	1.000000	-.623735
		1.000000

Y = 402.888990 + 4.032776X_1

S = 190.895128 cubic feet per day

$\bar{R}^2$ = .254902

Y = -628.189550 + 8.684053X_1 + 11.272910X_2

t = 12.692 10.899 Both coefficients highly significant at 5% level.

S = 83.661844 cubic feet per day

$\bar{R}^2$ = .856887

APPENDIX 5

Daily, Monetary, Machine-Crew Cost Factor in Felling

Light Powersaw Investment = $350

Fixed Cost:		
Capital recovery:1/ 300-day life; $50 trade-in. $300/300	$1.00	
Interest, risk, and profit on average investment @ 20%	.18	
Total fixed cost per day		$1.18
Operating Cost:		
Mixed fuel:3/ 3 quarts @ .45 per gallon	$0.34	
Saw chains: 1 each 6 weeks (36 operating days) @ $23.40	0.65	
Repair parts and labor per year $360 (200 operating days)4/	1.80	
Total operating cost per day		2.79
Total machine cost per day		$3.97
Labor:5/		
Ave. daily cost, tree-length = ($19.41 - 3.97)1.15 =	$17.76	
Ave. daily cost, 100-inch = (29.45 - 3.97)1.15 =	29.30	
Adding one or the other		
Average machine-crew cost per operating day, tree-length felling		$21.73
Average machine-crew cost per operating day, 100-inch felling		$33.27

1/ Assumed powersaw life equals 18 months with 300 operating days and a $50 trade-in value. Several methods of computing capital recovery are available, but all give essentially the same results if the equipment life results as planned and intermediate valuation is not required. The straight-line method was selected for its simplicity and because it is most used in Canadian and American business.

2/ Argument or apology is omitted for the rate chosen, since it is an individual decision ultimately made by the sawyer in accepting or rejecting the piece rate. The safe interest rate is much lower (about 3%), but when risk and profit are also included, 20 percent may be about right for investments made in felling or similar work. Average fixed investment per month = ($350 + 16.67)/2 = $183.33. Number of days operated per month = 300/18 = 16.67. Effective simple interest rate per month = .20/12 = .0167. Interest charge per month = 183.33(.0167) = $3.06. Interest charge per day of operation = 3.06/16.67 = 0.18.

3/ Fuel consumption averaged about 2 quarts per day in tree-length felling, and between 3 and 4 quarts per day in 100-inch production. Therefore, 3 quarts was taken as an over-all average.

4/ Whether or not a sawyer does his own powersaw repairing, he is entitled to payment for this work and reimbursement for the cost of parts.

5/ Since the sawyers in the study did not work by the time unit but were paid by the piece, the computed machine cost was subtracted from the average daily earnings in the two methods to arrive at the proportion that could be termed wages. Payroll additions vary between states, here 15% was used. For example, in Montana they consisted of 2% Social Security, 1.7% State Unemployment Compensation, 0.3% Federal Unemployment Tax, and 11.77% Industrial Accident Insurance.

APPENDIX 6a

Effect of Adding Additional Variables, Favorable Slope Horse Skidding

Basis: 7 Skidders, 293 Turns. Northern Colorado

Y_1 = Out plus in time in seconds per 100 feet. $\bar{Y}_1$ = 39.698498

X_1 = Number 16-foot and shorter logs in turn. $\bar{X}_1$ = 1.467577

X_2 = Average cubic foot volume per log in turn. $\bar{X}_2$ = 8.563037

X_3 = Percent slope. $\bar{X}_3$ = 12.808874

X_4 = Windfall index. $\bar{X}_4$ = 16.569966

Coefficient of Correlation Matrix

1.000000	+.041215	+.157384	+.062375	+.149926
	1.000000	-.338788	+.360669	+.154082
		1.000000	-.130836	-.132297
			1.000000	+.211923
				1.000000

$Y_1 = 38.320602 - 0.938892X_1$

$R^2 = .001699$

$Y_1 = 32.296423 - 2.432759X_1 - 0.447483X_2$

$R^2 = .034865$

$Y_1 = 31.515424 + 1.972460X_1 + 0.448759X_2 + 0.112859X_3$

$R^2 = .037646$

$Y_1 = 30.989380 + 1.755978X_1 + 0.481515X_2 + 0.117503X_3 + 0.097578X_4$

t = 1.194* 3.420 0.450* 2.714

S = 11.718658 seconds per turn. *Not significant at 5% level

$\bar{R}^2 = .048610$

Note: Y_1 is to be added to Y_2 (see Appendix 6c) for total skidding time.

APPENDIX 6b

Effect of Adding Additional Variables, Adverse Slope Horse Skidding
Basis: 6 Skidders, 104 Turns, Northern, Colorado

Y_1 = Out plus in time in seconds per 100 feet. $\bar{Y}_1 = 50.733750$

X_1 = Number 16-foot and shorter logs in turn. $\bar{X}_1 = 1.173077$

X_2 = Average cubic foot volume per log in turn. $\bar{X}_2 = 8.056635$

X_3 = Percent slope $\bar{X}_3 = 12.557692$

X_4 = Windfall index $\bar{X}_4 = 11.269231$

Coefficient of Correlation Matrix

1.000000	-.102102	+.146296	+.411557	+.441984
	1.000000	-.428012	+.206883	+.155171
		1.000000	-.004811	-.222552
			1.000000	+.498115
				1.000000

$Y_1 = 56.313398 - 4.756421X_1$

$R^2 = .010425$

$Y_1 = 48.236343 - 2.252012X_1 + 0.637883X_2$

$R^2 = .023312$

$Y_1 = 41.615127 - 7.450757X_1 + 0.406182X_2 + 1.161557X_3$

$R^2 = .211187$

$Y_1 = 38.340274 - 6.506247X_1 + 0.869421X_2 + 0.664223X_3 + 0.415298X_4$

$t =$ 1.471* 1.777* 2.556 3.760

$\bar{S} = 15.079550$ seconds per turn. *Not significant at 5% level.

$\bar{R}^2 = .281896$

Note: Y_1 is to be added to Y_2 (see Appendix 6c) for total skidding time.

Attention is called to the contrast in the sign for r_{y1} and the regression coefficient for X_1 between favorable slope and adverse slope skidding (see Appendix 6a). A possible rationalization might be made that greater care is taken in choosing smaller logs where more than one log is to be skidded uphill. This seems to be indicated by the larger, inverse correlation coefficient, r_{12}, for adverse slope skidding as compared to favorable slope skidding. However, in both cases the r_{y1} and r_{12} relationships are not strong.

APPENDIX 6c

Effect of Adding Additional Variables
in the Hooking, Assembling, and Unhooking Equation for Horse Skidding

Basis: 7 Skidders, 373 Turns. Northern Colorado

Y_2 = Second required for hooking, assembling, and unhooking logs.	$\bar{Y}_2$ = 70.262735
X_1 = Number 16-foot and shorter logs in turn.	$\bar{X}_1$ = 1.375335
X_2 = Average cubic foot volume per log in turn.	$\bar{X}_2$ = 8.494289
X_3 = Percent slope	$\bar{X}_3$ = 12.957105
X_4 = Windfall index	$\bar{X}_4$ = 15.353887

Coefficient of Correlation Matrix

1.000000	+.443369	-.044050	+.102245	+.299287
	1.000000	-.333510	+.284785	+.170383
		1.000000	-.119873	-.147285
			1.000000	+.263379
				1.000000

$Y_2 = 13.356665 + 41.376152X_1$

$R^2 = .196576$

$Y_2 = -1.031222 + 45.011703X_1 + 1.105188X_2$

$R^2 = .208703$

$Y_2 = 0.576439 + 45.602806X_1 + 1.099095X_2 - 0.182824X_3$

$R^2 = .209189$

$Y_2 = -2.352452 + 43.823525X_1 + 1.335422X_2 - 0.664675X_3 + 0.626028X_4$

t = 9.583 2.992 1.742* 5.640

S = 39.049285 seconds per turn

*Not significant at 5% level.

$\bar{R}^2 = .263963$

Note: Y_2 is to be added to Y_1 (See Appendix 6a or 6b) for total skidding time.

APPENDIX 7

Daily, Monetary, Horse-crew Cost Factor in Skidding

Investment:

Skidding horse	$150	5 years useful life
Harness	60	5 years life
	$210	

Fixed Cost: (Based on 200 operating days per year)

Capital recovery: $210/1000	$0.21	
Interest, risk, and profit on average investment @ 20%[1/]	0.13	
Total fixed cost per day		$0.34

Operating Cost:

Feed: 10 lb. oats @ 3.00/cut, 25 lb. bag @ 20.00/ton[2/]	$1.01	
Shoes, medicine, harness repair, tool replacement[3/]	.78	
Total operating cost		1.79
Total horse cost per day of operation		$2.13

Labor:

$18.00 per day plus 15% payroll additions		$20.70
Total horse-crew cost per day		$22.83

1/ For investments of similar risk and uncertainty, 20% may be about right. Average fixed investment per year = (210 + 42)/2 = $126. Average simple interest per year = (126).20 = $25.20. Interest charge per operating day = $25.20/200 = .126.

2/ 365 (.55 per day) divided by 200 operating days.

3/ Shoes each 6 weeks while working @ $10, 6 x 10.00 = $60.00 Annual medicine $20.00. Annual harness repair $25.00 Annual tool replacement $50.00. Total divided by 200 operating days, $155/200 = .775

4/ Payroll additions vary by state. In Montana, for example, they consisted of 2% Social Security, 1.7% State Unemployment Compensation, 0.3% Federal Unemployment Tax, and 11.77% Industrial Accident Insurance.

APPENDIX 8a

Effect of Adding Additional Variables,
Small, Crawler Tractors (D4, HD5) Skidding
Basis: 6 Man-days Skidding, 130 Turns. Montana

Y_1	= Out plus in time in seconds per 100 feet.	$\bar{Y}_1$ =	56.924616
X_1	= Number tree-length logs in turn	$\bar{X}_1$ =	5.776923
X_2	= Average cubic foot volume per log in turn	$\bar{X}_2$ =	19.162385
X_3	= Windfall index	$\bar{X}_3$ =	250.723077

Coefficient of Correlation Matrix

1.000000	-.318328	+.208400	+.288409
	1.000000	+.258799	-.251866
		1.000000	-.063021
			1.000000

$Y_1 = 76.390045 - 3.369515X_1$

$R^2 = .101333$

$Y_1 = 56.068791 - 3.631018X_1 + 0.852194X_2 + 0.021944X_3$

t = 4.131 3.865 2.758

S = 16.538344 seconds per turn. All slope coefficients significant at 5 percent level.

$\bar{R}^2 = .219812$

Note: Y_1 is to be added to Y_2 (see Appendix 8b) for total skidding time.

[illegible]

APPENDIX 8b

Effect of Adding Variables in the Hooking, Assembling, and Unhooking Equation for Small, Crawler Tractor (D4, HD5) Skidding
Basis: 6 Man-days Skidding, 130 Turns. Montana

Y_2 = Minutes required for hooking, assembling, and unhooking logs.	$\bar{Y}_2$ =	10.022000
X_1 = Number tree-length logs in turn	$\bar{X}_1$ =	5.776923
X_2 = Average cubic foot volume per log in turn	$\bar{X}_2$ =	19.162385
X_3 = Windfall index	$\bar{X}_3$ =	250.723077

Coefficient of Correlation Matrix

1.000000	+.369399	+.348782	+.034058
	1.000000	+.258799	-.251866
		1.000000	+.103945
			1.000000

$Y_2 = 0.637335 + 0.910917X_1 + 0.184472X_2 + 0.002343X_3$

t = 3.811 3.065 1.709*

S = 4.438879 minutes per turn.

$\bar{R}^2$ = .193686

*Not significant at 5 per cent level

Note: Y_2 is to be added to Y_1 (see Appendix 8a) for total skidding time.

APPENDIX 9

Computations of Total Hourly Cost for D4 Tractor and Operator

Investment:[1/]	
Tractor f.o.b. Asheville (ready to go)	$6300.00
Winch f.o.b. Asheville (no cable)	1475.00
Subtotal	$7775.00
Dozer blade and controls	2325.00
Total	$10100.00
Trade-in value after 5 years	2250.00
	Hourly Cost
Fixed Cost, tractor and winch:[1/]	
Depreciation 10,000 hours	.785
Interest, Insurance, Taxes	.237
Total fixed	1.022
Operating Costs, 1953 average:[1/]	
Fuel at 14¢ per gallon (no tax)	.280
Gas for starting	.030
Oil	.036
Grease at 15¢ per pound (incl. winch)	.041
Cable for winch	.199
Repairs and labor (incl. winch)	.649
Total variable	1.235
Total Fixed and Operating Cost (average)[1/]	2.26
Easy work = -15%	1.90
Hard work = +23%	2.80
Operator at $2.10[2/] + 15% Social Security, etc.	2.42
Total All Costs	
Average	4.68
Easy	4.32
Hard	5.22
Added rate when blade is used	.24

1/ Campbell, Robert A., Logging Methods and Costs in the Southern Appalachians, Southeastern Forest Experiment Station, Asheville, North Carolina, Station Paper No. 30, October, 1953. p. 29. Data furnished by Caterpillar Tractor Company, dated January, 1953.

2/ The six day average, hourly earnings this study.

APPENDIX 10

Regression Equation Predicting Time to Load Lodgepole Pine Logs by Three Different Methods

Slashersaw and Chain Lift. Pulpwood in Montana.
Basis: 14 truckloads, 4 trucks and drivers, two logging operations.
$Y = 25.967743 + 0.114374X_1$

Drott Skid Loader. Pulpwood in Idaho.
Basis: 15 truckloads, 4 trucks and drivers, one logging operation.
$Y = 136.154095 - 0.003270X_1 + 1.149662X_2$

Self-loading Truck. Sawlogs in Colorado.
Basis: 8 truckloads, 2 trucks and drivers, one logging operation.
$Y = -7.635964 + 1.162656X_1$

Where for the above three equations:

Y = Seconds to load 10 cubic feet. (With Drott Loader it was seconds to load 100 cubic feet.)

X_1 = Number of 100-inch bolts (Number logs for self-loading truck).

X_2 = Number of hand piled ricks per truckload.

Averages and Other Statistics

	Slashersaw Chain lift	Drott Skid Loader	Self-loading truck
$\bar{Y}$	47.584429	145.784200	87.120500
$\bar{X}_1$	189.000000	125.466667	81.500000
$\bar{X}_2$	---	8.733333	---
s 1/	6.413991	37.577816	32.396839
r_{y1}	.780756	-.061916	.392425
r_{y2}	---	.122674	---
R^2	.609580	.015062	.153997
$\bar{R}^2$	.577045	-.149094 2/	.012997
3/	X_1	None	None

1/ Seconds per 10 cubic feet (seconds per 100 cubic feet for Drott Skid Loading.

2/ R^2 so small the adjustment more than wipes it out.

3/ Significant variables at 5 percent level.

APPENDIX 11

Effect of Adding Additional Variables to Regression Equation Predicting Hauling Time for Lodgepole Pine Logs with 2-Ton, Dual-axle Trucks. Basis: 6 Trucks and Drivers, 22 Roundtrips Montana and Colorado, Summer, 1957

Y = Roundtrip minutes per mile.	$\bar{Y}$ =	2.625545
X_1 = Percent of rise in direction of loaded haul.	$\bar{X}_1$ =	19.473636
X_2 = Roundtrip rate of rise and fall in percent.	$\bar{X}_2$ =	2.361818
X_3 = Weight-power ratio, adjusted for elevation.	$\bar{X}_3$ =	3.167318
X_4 = Speed index dependent upon road surface.	$\bar{X}_4$ =	11.896364

Coefficient of Correlation Matrix

1.000000	+.406280	+.507955	+.207572	-.393319
	1.000000	-.308637	-.467457	-.339626
		1.000000	+.881031	-.138468
			1.000000	+.120987
				1.000000

$Y = 2.108871 + 0.026532X_1$

$R^2 = .165063$

$Y = 0.973074 + 0.040641X_1 + 0.364568X_2$

$R^2 = .608426$

$Y \quad 1.809660 + 0.031446X_1 + 0.640863X_2 - 0.413626X_3$

$R^2 = .685473$

$Y = 1.775823 + 0.031880X_1 + 0.655626X_2 - 0.429713X_3 + 0.003486X_4$

t =	2.992	3.722	1.932*	0.014*

$S = 0.252854$ *Not significant at 5 percent level

$\bar{R}^2 \quad .612156$

Note: Sign of regression coefficients for X_3 and X_4 do not agree with sign of correlation coefficients r_{y3} and r_{y4}. Perhaps this is explained by the high intercorrelation shown in r_{23}, which seems to be spurious.

APPENDIX 12

Machine Cost Per Time Unit and Running Expense Per Mile for 2-ton Trucks[1/]

	Dollars
Investment	
Truck, complete	2551.00
Minus tires[2/]	- 627.28
Net investment	1923.72
Minus truck trade-in value	- 600.00
Amount to be depreciated	1323.72
Fixed expenses	
Interest on investment at 7 per cent[3/]	111.50
License and taxes per year	57.00
Insurance or risk	91.00
Total fixed expenses per year	259.50
Fixed expenses per day (200 days per year)	1.30
Depreciation of truck per day[4/]	3.31
Total fixed expenses per day	4.61
Fixed expenses per hour (8-hour day), truck only	.58
Running expense per mile--woods or low-quality road	
Tires--life = 6,000 miles	.105
Gasoline--5 miles per gallon	,056
Oil and grease	.006
Repair labor	.020
Repair supplies	.020
Total	.207
Running expenses per mile--graded dirt or better road	
Tires--life = 10,000 miles	.063
Gasoline--9 miles per gallon	.031
Oil and grease	.003
Repair labor	.012
Repair supplies	.012
Total	.121

1/ R. R. Reynolds, Pulpwood Production Costs in Southeast Arkansas, 1950, Southern Forest Experiment Station, New Orleans, La. June, 1951, p. 15. The figures are specifically for a 2-ton, 105 h.p., 161-inch wheelbase, single-axle truck.

2/ Cost of tires charged against running expense.
Front tires 7:50 x 20 = $ 93.54 each
Rear tires 8:25 x 20 = 110.05 each

3/ Average investment = $1,592.79

4/ Life = 400 days

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