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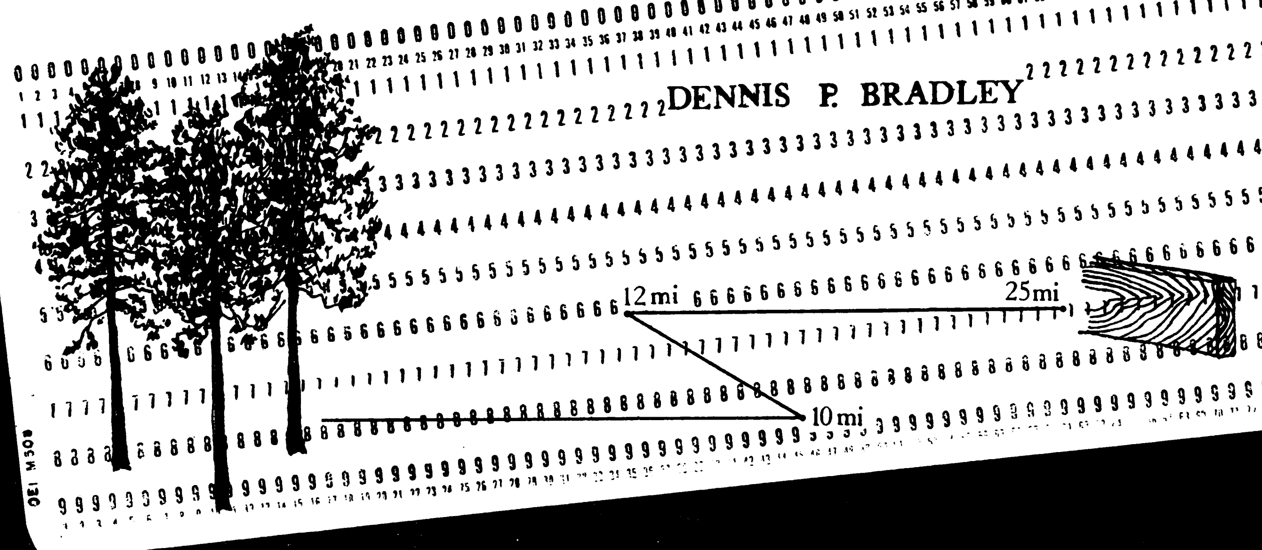
DENNIS P. BRADLEY



NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
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IMPROVE FOREST INVENTORY WITH ACCESS DATA—MEASURE TRANSPORT DISTANCE AND COST TO MARKET

Dennis P. Bradley

Forest inventories, through a lack of suitable methods, have typically been unable to provide the economic data essential to long-term forestry planning for both public and private decision-makers. Yet the efficient allocation of our forest resource demands that we know as much as possible about the factors affecting its value.

Because forests are generally dispersed over wide areas and at some distance from ultimate users, *forest access* is one of the principal determinants of value. Indeed, value can only be defined in relation to a specific time and place. In almost all inventories, however, forest access is either ignored completely or described only in the broadest terms.

Forest access refers to the distribution of the forest in relation to the transport system—highway, rail, and water. The objective in studying access is to determine the economic implications of present transport systems—how the systems affect the costs of harvesting, protecting, and otherwise using the forest—and to suggest ways to reduce forest-use costs.

Realizing the great practical significance of these questions, forest researchers in Sweden, Norway, and Finland have taken the lead in developing the necessary methods. We owe a great deal to their work.

This paper describes the adaptation of a method developed in Sweden at the Royal College of Forestry. The method is based on a fairly simple model relating transport distances to (1) length of the road net per unit land area, (2) the distribution of the road net, (3) the terrain, and (4) the location of specific delivery points. While the process has some novel features, *in principle it is a simple extension of any forest inventory;* and it is based on the location of the same sample points used for the conventional inventory. However, in addition to growing stock volume estimates provided by the inventory, the method makes it possible to summarize type areas and volumes by cross-country access, transport distances, and transport costs as well!

It must be emphasized that this method is a long-range planning tool to estimate the strategic impact of forest access. It is not an optimization procedure nor is it a route selector.

Forest investigators in Sweden have also pioneered in applying the results of access studies to many of the strategic questions that have plagued resource managers and planners for some time. For example, they have used the methods to answer questions such as: How much wood, in what sizes, species, and at what cost, can be brought to alternative mill sites? In areas with existing mills: If mill expansion takes place, will the delivered costs of additional supplies go up? If so, how much? The data are also useful in determining investment guidelines for silvicultural activities, road construction, and land purchase.

In summary, this study suggests a simple, inexpensive, and effective method for describing the effect of road systems and terrain on transport distances and costs to mill—problems inadequately treated in the past.

THE GENERAL METHOD

We will attempt to answer two complementary questions about forest access:

1. How far, on the average, is the nearest road from any given stand of timber?
2. How far, on the average, must a given volume of timber be transported to a mill?

In addition to averages, we would also like to describe the variation around the average and to answer all these questions in terms of transport costs.

To answer the first question, it is necessary to develop a model of forest access for ideal road nets and then to modify the model for more complex yet more realistic conditions. The answer to the second question requires only a simple extension of the answer to the first.

Forest access evaluation depends on the use of aerial photographs or a complete and accurate road map of the forest survey unit. Since most inventories already use aerial photos to locate plots, this is the ideal choice. Furthermore, photos generally show even the poorest roads, including those that are overgrown but still a part of the transport net. The photos can also be used to identify road quality and terrain characteristics. A road map rarely shows the complete road net in enough detail.

The same sample plots or points used in the conventional forest inventory are also used to obtain access data. These inventory plots have usually been located by some random process to give a representative and unbiased picture of cover types, species distribution, etc. This random feature is essential to the measurement of forest access as well.

Road Networks and the Estimation of Cross-Country Access Distance[1]

Ideal Road Nets

First, consider an ideal road network (fig. 1), a plane surface with all roads parallel and equidistant.[2] Moreover, the forest is uniformly distributed over the entire area. This type of road net can be described exhaustively by these parameters.

[1] *Cross-country access distance will not be defined precisely because it has several different definitions depending on the model used. Roughly, it is the distance between a certain volume of timber and the nearest existing road. The different kinds of access distances will be illustrated in the following description. However, the use of the term "cross-country" does not imply the use of any "cross-country vehicle" to transport the timber.*

[2] *Most of this explanation is based on a landmark publication from Sweden by Gustaf von Segebaden, Studies of cross-country transport distances and road net entension, Studia Forestalia Suecica, No. 18, 1964. Applications of these methods in Sweden are described in several later publications by von Segebaden and others; see bibliography.*

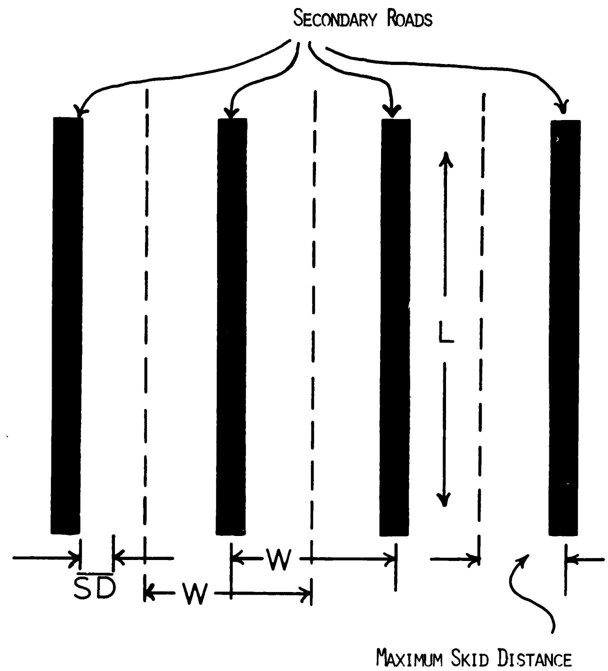

Figure 1.–An ideal road net.

W = *width* of area between roads. From figure 1, it also equals the width of the area from which all the timber is transported cross-country to a central road.

L = *length* of the road. It also equals the length of the area influenced by the road.

$\overline{SD}$ = *mean straight-line cross-country access distance* for the entire area.

Δ = road length per unit area or *road-net density.*

$$(1)\quad \overline{SD} = \frac{W}{4}.$$

Since area = length (L) x width (W), then

$$(2)\quad \Delta = \frac{L}{LxW} = \frac{1}{W}.$$

Taking the reciprocal of (2), we get

$$(3)\quad W = \frac{1}{\Delta},$$

substituting (3) in (1)

$$(4)\quad \overline{SD} = \frac{1}{4\Delta}.$$

Thus, by knowing either width (W), road-net density (Δ), or mean straight-line cross-country access distance ($\overline{SD}$), the complete characteristics of the ideal road net can be described.

Real Road Nets

While an ideal network provides an introduction to several important parameters of all road nets, it obviously has limited usefulness because:

1. Real road nets are not composed of straight, parallel and equidistant roads. Real nets have cross roads.

2. Cross-country access distances are seldom straight lines.

3. Timber is seldom skidded the shortest possible distance to the road but is usually brought to concentration points or landings along the road for efficient loading and sorting.

4. Timber is not uniformly distributed over the land.

Thus, the problem is to estimate a mean *practical* cross-country access distance for real road nets.

Consider first, an irregular road net on a perfectly flat surface (fig. 2). From equation 2,

$$\text{Road-net density, } \Delta = \frac{\text{road length}}{\text{area}}.$$

If in figure 2 road length[3] = 52 miles and area = 150 square miles,

$$\Delta = \frac{52 \text{ mi.}}{150 \text{ mi.}^2} = 0.347 \text{ miles of road/sq.mile.}$$

Presumably we can now calculate *mean straight-line cross-country access distance,* $\overline{SD}$, from equation 4,

$$\overline{SD} = \frac{1}{4\Delta} = \frac{1}{4(.347)} = 0.720 \text{ miles.}$$

This result is invalid, however, because equation 4 applies *only* if the road net is straight, parallel, and equidistant, as in figure 1. The use of equation 4 results in an underestimate of the mean cross-country access distance for this plane but irregular net.

Instead of using equation 4, consider another measure $\overline{sd}$ defined as the *mean straight-line cross-country access distance for irregular,* plane road nets.

$\overline{sd}$ always exceeds $\overline{SD}$.

[3] *A useful and interesting method for estimating road length where this information is not available is shown in Appendix A and discussed in the next section.*

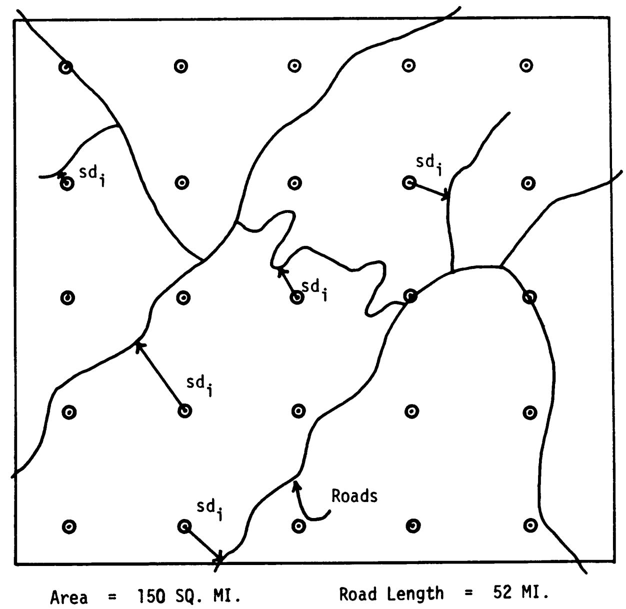

Figure 2.–Plane, irregular road net with dot grid overlay, and examples of sd_i.

While there is no analytical way to calculate $\overline{sd}$, it is possible to estimate $\overline{sd}$ in the following way. Using the dot grid overlay shown in figure 2 and a pair of dividers, measure the shortest straight-line distance from each dot to the nearest road. The arithmetic mean of these measures is $\overline{sd}$.

$$(5) \quad \overline{sd} = \frac{\Sigma sd_i}{n}$$

The number of dots required is a function of total area, the value of $\overline{SD}$ from equation 4 and the desired precision.[4]

Assume

$n = 25$ and that $\Sigma sd_i = 24.3$ miles;

then

$$\overline{sd} = \frac{24.3 \text{ miles}}{25} = 0.972 \text{ miles.}$$

Recall that $\overline{SD} = 0.720$ miles. There is a difference because $\overline{SD}$ assumes the 52 miles of road are distributed as in figure 1, while $\overline{sd} = 0.972$ is from the irregularly distributed road net with crossroads of figure 2.

[4] *Gustaf von Segebaden has prepared a formula and table for estimating the number of sample points. Appendix B.*

We can now define a ratio, R, called the *road net adjustment* by dividing $\overline{sd}$ by $\overline{SD}$.

$$(6)\quad R = \overline{sd}/\overline{SD} = \frac{0.972 \text{ miles}}{0.720 \text{ miles}} = 1.350.$$

Basically, this unitless factor means that this particular irregular net results in a *mean straight-line cross-country access distance,* $\overline{sd}$, 35 percent greater than an ideally distributed road net of the same length in the same area.

This ratio is a constant for road nets having the same kinds of geometry regardless of the absolute size of the net or the road-net density, Δ (Segebaden 1964).

Consider now, the same irregular road net superimposed on a topographic surface (fig. 3). Because we are now facing mountains, creeks, lakes, and various slopes, another measure must be introduced, $\overline{PD}$, the *mean practical cross-country access distance.* Returning to our overlay, the shortest *practical* distance from each point to a road, PD_i, is measured. The arithmetic mean of this measures is $\overline{PD}$.

$$(7)\quad \overline{PD} = \frac{\Sigma PD_i}{n}$$

What constitutes the shortest *practical* route must be determined from on-the-ground examination or from detailed topographic maps. Obviously, the shortest practical route equals or exceeds the shortest straight-line distance.

$$PD_i \geq sd_i$$

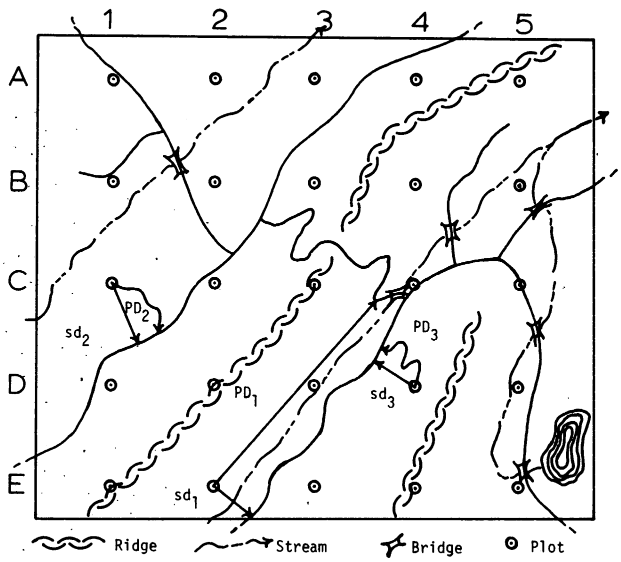

Figure 3.–Real road net, showing the difference between sd_i and PD_i. Numbers and letters at margins designate each sample point.

The transport technology greatly affects the route taken. In fact, the road used as the destination for the shortest straight-line route may change once topography is considered. For example, in sample point E-2 in figure 3, the *shortest straight-line distance* (sd) that ignores topography would be measured to the southeast. The *shortest practical cross-country access distance,* PD, would have to consider the stream lying between point E-2 and the closest road. Assuming the stream is impassable, PD would be measured to the northeast along the slope.

If

$$\Sigma PD_i = 29.0 \text{ miles}$$

then

$$\overline{PD} = \frac{29.0}{25} = 1.160 \text{ miles.}$$

Recall that $\overline{sd}$, the *mean straight-line cross-country access distance* for this plane, irregular road net, = 0.972 miles. $\overline{PD}$ is greater because a practical route would have to wind horizontally and vertically to its destination. We can now define another ratio, C, called the *cross-country transport adjustment,* by dividing $\overline{PD}$ by $\overline{sd}$.

$$(8)\quad C = \frac{\overline{PD}}{\overline{sd}} = \frac{1.160 \text{ miles}}{0.972 \text{ miles}} = 1.200.$$

This unitless factor accounts for the effect of terrain on cross-country transport distances. Thus, for these points and the given terrain, a practical distance exceeds the straight-line by 20 percent.

The cross-country adjustment factor C is a constant for similar terrain types, but it is not necessary to define the terrain type. It is sufficient to be able to classify an area as having the same general terrain, such as all glacial moraine, or all rolling piedmont.

This explanation has gone into more detail than necessary for practical application. The extra rigor was undertaken to make the process clearer. As the example described later will show, a practical answer to our first question–how far, on the average, is the nearest road from any given stand of timber? –requires: (1) The measurement of straight-line cross-country access distances sd_i for all plots, (2) the measurement of the practical distances PD_i from a subsample and the calculation of the cross-country adjustment $C = \frac{\overline{PD}}{\overline{sd}}$, and (3) the multiplication of the sd_i for all plots by C to obtain estimates of the practical cross-country access distances for all plots: i.e., $PD_i = Csd_i$. A summary of the derivation is given in Appendix C.

Estimating Transportation Distances and Costs to Market

Measuring Road Haul Distances

The answer to the second question—how far, on the average, must a given volume of timber be transported to market?—requires a simple extension of the answer to the first. Immediately after measuring the shortest straight-line distance (sd) for a sample plot, transport distances by road quality class to a specific delivery point are measured.

In figure 4 for example, in addition to sd (the distance AB), there are 7 miles of road from B to C whose quality permits a round-trip speed of 25 m.p.h. From C to D are 8 miles permitting 15 m.p.h. (the map shows a steep adverse grade). From D to E and on to the mill at F are 7 miles permitting a 45 m.p.h. round-trip speed.

These road haul distances can be stepped off on a map with a divider, but it is more convenient to use a small map measurer, a clockwork device with a graduated wheel.

Regardless of where the "delivery point" is located, there are usually several different ways of getting there. Thus, a criterion must be established to decide which route to measure; for this method, it will depend on how much the person doing the measuring knows about the locale.

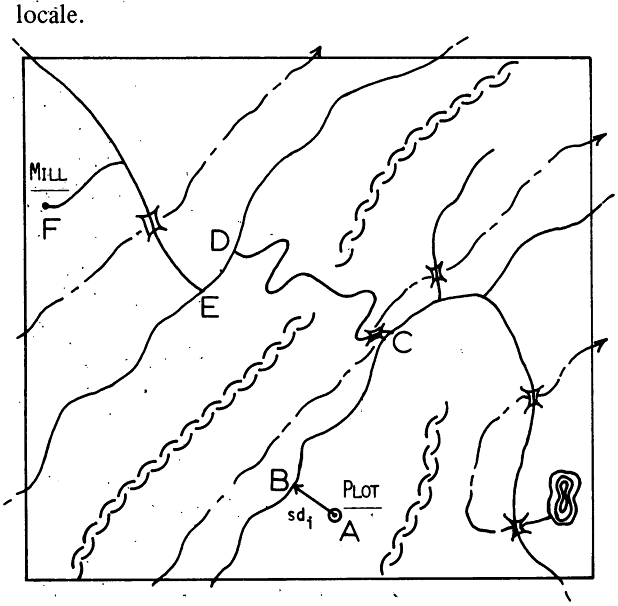

Figure 4.–Measuring cross-country access and road haul distances to delivery point.

For example, one might select the best route in terms of minimum distance as the criterion. However, this would probably not be realistic because transport cost is a function of distance *and* road quality. On the other hand, a true "least cost" criterion is impractical to apply because it requires an examination and cost calculation for every possible route.[5]

A more practical solution and the one used in the example is to get on successively higher quality roads as soon as possible. While this criterion is not without its ambiguities, the correct choice is usually obvious. If local knowledge of hauling routes and other relevant data are handy, these should be the guiding principle.

Choosing a Delivery Point

A principal feature of the method is that only one delivery point can be considered at any one time.

The selection of a specific "delivery point" is highly desirable in inventory units with little competition for the wood supply or if competition is concentrated at one location. It is under these conditions that the method is most useful to public or private planners. However, inventory units with overlapping competition pose a problem. In these cases "delivery point" can take a more general but less useful form. The "nearest all-weather road" or "nearest railroad landing" are alternatives. A final decision between specific or more general points will require a trade-off between the number of users and the value of the data. As the number of competing groups using the method in a given inventory unit increases, the less useful will be any choice of a specific delivery point.

However, because the process is so easy and cheap to apply, it can be repeated with alternative "delivery points." These different runs, while not easily com-

[5] *While this method, and more specifically the ACCESS computer program to be described later, do not have the power to calculate a least cost route, one could run comparisons of transport costs for different routes from a specific plot by hand. This so-called "best" route could then be used for the computer input. However, it is felt that this exercise would impute more accuracy to the estimates of road quality than warranted. If this is true, the exercise could be misleading as well as a waste of time. Refer again to the statement of objectives of this process, page 1, paragraph six.*

parable, offer advantages in mill feasibility studies where either there is no existing competition or where there is a clear surplus of harvestable timber offering a potential for new development. Alternative delivery points might also be considered for different species or products.

Transport Costs

To be really useful, the distributions of volume by distance to "delivery point" must be convertible to transport costs per cord. The principal factors determining these costs are: (1) road quality, (2) truck capacity, and (3) hauling distance.

We have already mentioned the requirement that road distances be measured by road quality to delivery point. Road quality affects costs two ways. First, it affects round-trip speed. Because trucks and drivers incur cost per unit time, transport costs per cord go up as speed declines. Second, and more difficult to judge, road quality affects vehicle wear and tear.

Haul cost information with respect to road quality is usually available from equipment manufacturers and contract haulers. Many companies and governmental agencies have constructed their own cost relationships. For example, the USDA Forest Service has prepared tables relating fixed and variable costs for various truck sizes and road qualities (see Appendix D). Given the distances from plot to "delivery point" by road classes, costs per cord mile are easily calculated for a variety of truck sizes.

Data Summary and Presentation of Results

When *straight-line access distance* and *road haul distances* have been collected from each plot and the *cross-country adjustment* C has been computed from the subsample, they are combined with the cover type and species volume data gathered from each plot in the conventional cruise.

At this point the computation of volumes in each cover type is changed slightly from the usual practice. Because cover type is the smallest summary unit in most surveys, the computations of volumes in each type are generally calculated in the following way:

1. Cover type areas are determined from the proportion of total plots in each cover type. If 50 percent of the plots is aspen, then 50 percent of the area is aspen.

2. Combining all plots in each type together, a total mean volume per acre (all species) and a mean volume per acre (ac.) by species are calculated. For example, the total mean volume per acre for the aspen cover type might be 11.0 cd. per ac.; and of this total, 6 cd. per ac. are aspen, 3 cd. per ac. are birch, and 2 cd. per ac. are balsam fir.

3. Total volumes by species within cover types are determined by multiplying cover type area by each of the mean species volumes for the type. For this example, if there are 10,000 acres of aspen cover type,

10,000 ac. x	6 cd./ac. aspen	=	60,000 cd. aspen
+10,000 ac. x	3 cd./ac. birch	=	30,000 cd. birch
+10,000 ac. x	2 cd./ac. balsam fir	=	20,000 cd. balsam fir
10,000 ac.	11 cd./ac. total	=	110,000 cd. all species

However, this procedure is unsuitable for summaries of volumes by access distances because the use of a mean volume for all plots within a type ignores the variation in plot volumes by access distance. For example, after measuring all aspen plots for access one might find some plots 10 miles from delivery point and some 100 miles. Using a mean volume per acre for all plots assumes equal volumes for plots at all distances. In fact, it is clear that plot volumes will vary by distance from delivery point. Thus volumes should not be calculated until plots have been separated into distance classes. Once this is done, conventional methods can be applied to the plots in each distance class. While both methods yield correct total volumes for each type, only the latter method realistically estimates the distribution of volumes by transport distances.

To avoid the tedium of hand tabulation as well as speed the widespread testing of the process by others, a computer program in Fortran IV was written to calculate and display the distribution of areas and volumes by transport distances and costs. Results are displayed in two forms. First, a series of tables, one for each cover type, shows the distribution of areas and species by 10 total distance classes, and for up to four transport options. Next, a series of tables, one for each species, summarizes the data from the first set of tables. Specific examples are illustrated in the Koochiching County example. Appendix E describes the program in detail.

Limitations in the Method

Most of the limitations of this method, including the consideration of only one "delivery point" at a time, arise out of restrictions imposed by the underlying forest inventory. A principal problem is the estimation of sampling error.

Most forest inventories are designed to yield answers with a specified accuracy for total volume based on estimates of population variation in type area and volume. Rarely is an attempt made to have an individual cover type meet a criterion for accuracy. Thus, sampling errors for individual cover type areas and volumes are usually large.

Yet, by using the same data to measure access, we unavoidably push the limits of reliability even farther. The resultant sampling errors are presently unknown, and should certainly be the subject of future study. As an approximate guide to the size of the sampling errors for the volumes in distance or cost classes, one might use error tables provided by most inventory summaries that estimate sampling error for various sized aggregates.

After following this process, what can we say about the accessibility of the resource? Briefly, we can say that given the restraints imposed by the underlying sample, this method describes the proportions of cover type areas and volumes lying at various distances from the "delivery point." However, we *cannot* say precisely where and in what size stands these areas and volumes are located. For example, if the cover type table for white pine says that 4,700 acres are within 11 to 20 miles of the "delivery point," these 4,700 acres may be in two stands of 2,000 and 2,700 acres or in 4,700 stands of 1 acre, etc. This follows from the basic inventory which cannot locate type areas either. However, general type maps are often available that may give a good idea of stand distribution.

EXAMPLE: FOREST ACCESS IN KOOCHICHING COUNTY, MINNESOTA

Because the objective of this paper is to describe procedures, a complete picture of forest access in Koochiching County will not be presented here. Only enough detail to clearly explain the practical problems and to illustrate typical output will be shown.

Cost data are especially susceptible to misinterpretation and transport cost data borrowed from the U.S. Forest Service do not necessarily describe actual transport cost conditions in Koochiching County.

Situation

Koochiching County, with an area exceeding 2,000,000 acres, is located on the Minnesota-Ontario border. Almost 80 percent of the county is classified as commercial forest, and as one might imagine, the forest resource dominates the economy of the county.

The 1,575,000 acres of commercial forest are distributed among the following ownerships (Iron Range Resources and Rehabilitation Commission 1962):

	Acres
State lands	792,200
County and municipal lands	292,600
Forest industry lands	204,000
Farmer and misc. private lands	194,000
Federal owned and trust lands	92,200
Total	1,575,000

Major forest types in the county are black spruce, 25 percent, and aspen, 21 percent of the area. Total output of forest products over the last 8 years has averaged around 200,000 cords annually (Iron Range Resources and Rehabilitation Commission 1962).

Why Koochiching County

A rationale for examining forest access in this county seems almost unnecessary, yet there were other less obvious reasons why Koochiching County was chosen. First, most of the harvested wood is processed in the largest town. This allowed us to realistically assume one delivery point. Second, Koochiching County and Boise Cascade, Inc., the largest industrial forest landowner in the county, had prepared a map that included all public roads, their own privately maintained system, and the seasonal logging roads as well. Third, the county contained an exceptionally large number of forest inventory plots, which permitted a detailed picture of forest access. Fourth, the small number of farms and resorts caused no problems in determining which roads would allow forest access and timber hauling.

Forest Survey Plot Record

The forest inventory plot records were obtained from all cooperators of the last survey: the Minnesota Department of Lands and Forests, Koochiching County, Bureau of Indian Affairs, North Central Forest Experiment Station, and Boise Cascade Corporation.

Measuring Forest Access

Road Network Quality

Although photos offer the best alternative for determining road quality, a photo-ground check of road quality should be made at the same time the plots are visited. This was beyond our resources and instead the detailed road map prepared by Koochiching County and Boise Cascade, Inc. was used. In contrast to most maps, it included the network of seasonal and privately maintained logging roads.

The five road types indicated by the map were assigned to cost-haul classes developed by the USDA Forest Service for timber appraisal purposes. Their table, relating round-trip speed in dollars per cord-mile to truck size and road quality, and the accompanying definitions, is presented in Appendix D.

The following tabulation shows how the roads in Koochiching County were classified according to the USDA Forest Service system.

As shown on the Koochiching county map	*USDA Forest Service quality class*
Paved, county, and State aid highways	High speed, permitting round-trip speed, 45 m.p.h.
Graveled township roads	Cost Haul Class I, permitting round-trip speed 35 m.p.h.
All-weather forest roads	Cost Haul Class II, round-trip speed 25 m.p.h.
Dry weather forest roads	Cost Haul Class III, round-trip speed 16 m.p.h.
Winter forest roads	Cost Haul Class IV, round-trip speed 8 m.p.h.
Cross-country access distances (assumed to be covered at a later date by a low-class road)	Cost Haul Class V, round-trip speed 4 m.p.h.

This classification is relatively accurate for road conditions in Koochiching County, but the assumption of a Cost-Haul Class V road for cross-country access distance was arbitrary. It cannot be known what road quality will eventually be used in any given situation. Certainly it depends on factors not foreseeable by this or any other study, such as total sale volume and the access distance itself. However, it is an easy matter to change this assumption if desired.

Estimating Road Lengths

Knowing the lengths of various road types is obviously essential to a complete understanding of the forest access picture. According to the various agencies responsible for road maintenance there are:

	Miles
County- and State-aid highways	250
County township roads	180
State forest roads	150
Privately maintained logging roads	150
Total	730

In addition, the detailed road map of the county shows an extensive network of seasonal woods roads. This network has been estimated to be 200 to 300 miles. If these figures are accepted for the moment, the total road length in the county approaches 1,000 miles of all types.

However, the application of Buffon's solution to a problem in geometrical probability (Appendix A, equation 11) allows us to estimate road lengths with surprising ease and accuracy:

$$L = \frac{\pi}{2} bn$$

where

L = road length in miles.
b = spacing in miles of a system of parallel, equidistant, randomly located, transect lines.
n = the number of intersections between the road net and the transect.
π = 3.1415.

To eliminate possible bias, two transects were used; the first was randomly located and the second was positioned perpendicular to the first (fig. 5).

Since it has been shown (Segebaden 1964) that the spacing of the transect system is related to the standard error of the road length estimate, it is possible to determine the spacing, b, in order to meet a desired level of confidence in the estimated length of the road net, L. An example of this calculation is shown in Appendix A. Setting b = 6 miles should permit an estimate of L to within ±5 percent of its true value 67 percent of the time (i.e., 1 standard error = 5 percent).

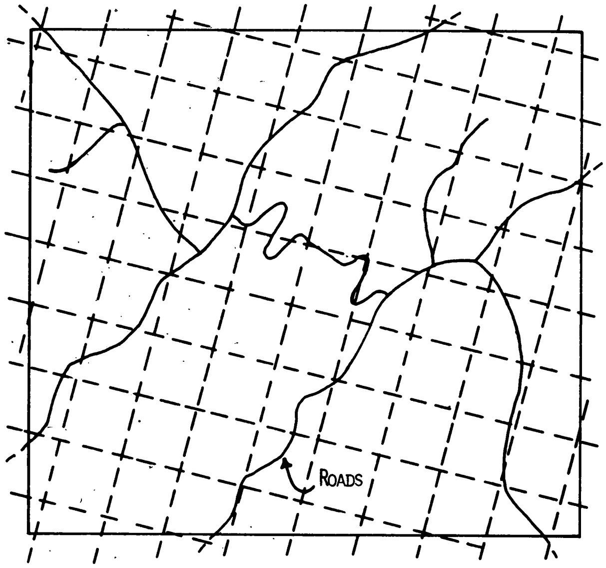

Figure 5.–Randomly located perpendicular line transect system on a road net.

After drawing the two transect systems on the map, the intersections between the road net and each transect were recorded by road quality as indicated on the map.

$$\text{Road length, L} = \frac{\pi \cdot 6 \cdot n}{2} = 3\pi n.$$

The method results in an estimated 2,700 miles of roads of all types (table 1).

Table 1.–Estimated road lengths in Koochiching County by a randomly located perpendicular transect

Road quality	Transect: NE-SW	Transect: NW-SE	Transect: Combined	Estimated relative error[1/]
		Miles		Percent
Paved	301.6	329.9	315.7	9.3
Gravel	75.4	75.4	75.4	19.0
All-weather woods road	829.4	820.0	824.7	5.7
Dry weather woods road	207.3	113.1	160.2	13.0
Winter woods road	1,131.0	1,460.8	1,295.9	4.6
Total	2,544.7	2,799.2	2,671.9	3.2
Railroads	84.8	94.2	89.5	17.4

1/ Where relative error (ε) = $76/\sqrt{n}$, from an empirical formula developed by von Segebaden (Segebaden 1964).

How accurate are these results? Certainly, they differ substantially from the initial estimate of 1,000 miles.

Comparing the NE-SW and the NW-SE transects shows little variation and their average is the final result. The last column estimates approximate error where relative error percent percent $= \frac{76}{\sqrt{n}}$, and where n = number of intersections with the transect and road system (Segebaden 1964). The estimated overall error is well within 5 percent.

To test the transect method another way, we measured the lengths of paved and graveled roads and railroads *on the map.* Mileage as determined by:

	Random transect	*Map measure*	*Percent error*
Paved roads	315.7	340.0	-7.1
Gravel roads	75.4	73.0	+3.0
Railroads	89.5	93.0	-3.8

Results from the two procedures agree closely, suggesting that available statistics grossly underestimate the extent of the seasonal woods road network in Koochiching County.

Straight-Line Cross-Country Access Distance

This is the "crow-fly" distance from plot center to the nearest road of any kind. Because the base map had a scale of 0.5 inch = 1 mile and we measured distances to 0.125 inch, cross-country access and road haul distances were actually measured to the nearest 0.25 mile. While it would have been possible to measure more precisely, we did not because the inherent error in the map was unknown.

Using a pair of dividers, the shortest straight-line distance was measured from each plot center to nearest road. For example, in figure 4 it is the distance $\overline{AB}$.

Road Haul Distances

Road haul distance is the distance from the "delivery point" to the spot where the straight-line cross-country access distance intersects the road. These distances were measured immediately after the straight-line access distance and entered on the same form.

Adjusting Straight-Line Access Distances for Actual Conditions

This study did not take a subsample of plots to estimate a cross-country access adjustment factor. Instead, Swedish studies in similar terrain (Segebaden 1964) and unpublished correspondence with Gustaf von Segebaden were used. He found that the cross-country access adjustment factor (C) equaled 1.25 in terrain much like northern Minnesota. This value of C was used for illustration.

Results

Cross-Country Access

Cross-country access varied considerably by ownership (table 2), but the results agree with expectations. For example, private lands, both miscellaneous private and forest industry, were more accessible on the average than public. This makes sense because access is a necessary condition for most private land ownership. The State of Minnesota holds the least accessible land, and this also agrees with their large holdings of bog and swampland in the county.

Table 2.–Straight-line (sd) and practical (PD) cross-country distances by owner–Koochiching County

Owner	Area	Sample points	$\overline{sd}$	$\overline{PD}$	Relative error, practical distances1/
	Acres	n	Miles	Miles	Percent
County	292,600	520	0.47	0.58	5.2
State	792,200	204	.69	.86	8.1
Federal	92,200	162	.48	.60	8.3
Misc. private	194,000	117	.30	.38	15.8
Forest industry	204,000	552	.30	.38	5.3
Total	1,575,000	1,555	--	--	--
Area weighted mean	--	--	.54	.67	5.7

1/ Relative error = $\frac{\frac{S_{PD}}{\sqrt{n}}}{\overline{PD}} \times 100$.

While the different bases for calculation may cast some doubt on the combination, the average point in Koochiching County is 0.54 "crow-fly" miles from the nearest road of any kind, or 0.67 "over the ground" miles.

As suggested in the previous section, the data from table 2 can be used to estimate the "unevenness" of the real road net as compared with an ideally distributed net of the same length. Earlier the entire road net was estimated to equal 2,762 miles. From equation 2,

$$\text{road net density } \Delta = \frac{\text{length}}{\text{area}} = \frac{2{,}672 \text{ miles}}{3{,}129 \text{ sq. mi.}}$$

$$= 0.85 \text{ miles/sq. mi.}$$

From equation (4) an ideal mean cross-country access distance $\overline{SD}$;

$$\overline{SD} = \frac{1}{4\Delta} = 0.29 \text{ miles.}$$

It has been pointed out that this calculation falsely assumes an equal areal distribution of the 2,672-mile road net. However, dividing $\overline{sd}$ from table 2 by $\overline{SD}$ yields the road net adjustment R.

$$R = \frac{\overline{sd}}{\overline{SD}} = \frac{0.54}{0.29} = 1.86.$$

Transport Distances and Costs by Cover Type and Species

A computer program (ACCESS) was developed that calculates volumes and cover type areas by total transport distance and cost to a specified "delivery point" from the following data:

1. Cover type areas up to 20 cover types.
2. Access measures for each plot up to 2,000 plots.
3. Cover type classification and species volumes per acre for each plot up to 20 species.
4. Cross-country adjustment factor, C.
5. Transport costs per cord mile for six road quality classes and up to four different truck sizes (referred to as Option 1, 2, 3, or 4).

Two sets of tables result; one set of cover type tables, and one set of species tables.

Table 3 is an example of the cover type output of the ACCESS program. There is another like it for each cover type. Briefly, it displays type areas, mean distances by road classes, transport costs for different truck sizes, and species volumes and volume-weighted transport costs for several "total distance to delivery point" classes. For a graphic look at these data, see figure 6.

Several species are usually present in a cover type in varying proportions; thus, table 4 shows the distribution of aspen volume from all cover types. These data may be useful to forest industries whose processes require only certain species. The distribution of aspen volume by distance to delivery point is shown in figure 7. This figure resembles figure 6 closely because most of the aspen volume comes from the aspen type. This is not always so, however. In some cases the volume distribution of a *species* may be quite different from the distribution of the corresponding *cover type.*

While the distributions of cover type and species volume by distance to delivery point are interesting,

Table 3. – Abbreviated example of ACCESS cover type output showing type areas and volumes by transport distances and costs (Type: aspen; area: 100,000 acres; number of plots: 100; acres per plot: 1,000)

Item	Distance to delivery point (miles) 0-20	21-40	41-60	61-80	81+	Totals
Number of plots	10	30	50	5	5	100
Percent of total	10.0	30.0	50.0	5.0	5.0	100.0
Type acreage	10,000	30,000	50,000	5,000	5,000	100,000
Class mean total distance (miles)	17.5	31.0	55.5	68.0	98.5	
Class mean distance by road quality (miles):						
1. Paved	15.0	20.0	50.5	60.0	85.0	
2. Gravel	2.0	10.7	2.5	5.1	13.0	
3. Woods	.0	.0	2.2	2.5	.3	
4. Cross country	.5	.3	.3	.4	.2	
Transport cost/cord not weighted by volume (dollars):						
Option 1	2.75	5.50	7.00	9.00	11.25	
Option 2	3.00	6.25	7.50	9.75	12.00	
Species volume (cords) followed by volume-weighted transport costs/cord (dollars):						
White pine:						
Volume	5,000	40,000	200,000	--	5,000	250,000
Option 1 cost	2.75	5.00	7.10		10.00	
Option 2 cost	3.10	6.00	8.00		12.00	
Paper birch:						
Volume	5,000	60,000	350,000	25,000	60,000	500,000
Option 1 cost	2.50	4.75	9.00	9.50	11.00	
Option 2 cost	2.90	6.00	9.50	10.00	11.50	
Aspen:						
Volume	90,000	200,000	1,250,000	150,000	60,000	1,750,000
Option 1 cost	3.25	5.60	7.25	10.00	12.00	
Option 2 cost	3.50	5.70	7.75	11.00	12.50	
Total volume	100,000	300,000	1,800,000	175,000	125,000	2,500,000

a picture of transport cost is of even greater value to a decision maker.

Figure 8 illustrates the transport *cost-volume* distribution of the data in table 4. Although it is similar to the *distance-volume* distribution (fig. 7), anomalies may exist because some volumes, while closer to "delivery point," require transport over poorer roads and thus are more costly to deliver.

The bottom graph in figure 8 is especially important. It is the cumulative transport cost-volume distribution of the upper portion. If the axes are reversed, placing volume on the x-axis and transport cost on the y-axis, the *marginal transport cost* curve for aspen results. For example, if mill management wishes 460,000 cords delivered, the cost of the last cord (assuming that the cheapest wood is harvested first) will be $5.40 for Option 1. This is not an average cost, however; only the last 340,000 cords would cost that much.

More to the point, mill management might ask: If we wish 460,000 cords delivered and a representative group of stands are harvested, what will our *average transport cost* be? An approximate answer can be found by dividing the sum of the transport costs of all volumes up to a specific total volume by that total volume. For example, from table 4, the first 120,000 cords cost $2.85 per cord and the next 340,000 cords cost $5.40 per cord to transport. *Average transport cost per cord* for 460,000 cords then equals:

$$\frac{(120{,}000 \text{ cds.} \times \$2.85/\text{cd.}) + (340{,}000 \text{ cds.} \times \$5.40/\text{cd.})}{460{,}000}$$

$$= \frac{\$2{,}178{,}000}{460{,}000 \text{ cds.}} = \$4.73/\text{cd.}$$

Figure 9 shows the average transport cost curve for the aspen growing stock from figure 8.

While the preceding table and discussion apply to the entire aspen growing stock, the marginal and average transport cost picture for aspen desirable cut can be estimated by assuming that desirable cut is distributed proportionately among the distance classes. This assumption may not be entirely correct, but it offers a useful starting point for reaching conclusions about desirable cut access. The last row of table 4 from the ACCESS program uses this assumption to calculate the distribution of desirable cut by distance and transport cost class.

Table 4. – Abbreviated examples of ACCESS species output showing species growing stock and desirable cut volumes by transport distances and costs (Specie: aspen; annual desirable cut: 30,000 cords)

Item	Distance to delivery point: 0-20	21-40	41-60	61-80	81+	Total
Type:						
White pine	--	20,000	10,000	5,000	5,000	40,000
Paper birch	30,000	120,000	175,000	100,000	75,000	500,000
Aspen	90,000	200,000	1,250,000	150,000	60,000	1,750,000
Total volume	120,000	340,000	1,435,000	255,000	140,000	2,290,000
Overall-volume weighted transport costs (dollars/cord):						
Option 1	2.85	5.40	7.00	8.95	11.00	
Option 2	3.15	6.35	7.45	9.70	12.50	
Percent of growing stock	5.2	14.8	62.7	11.2	6.1	100.0
Distribution of desirable cut (cords)	1,560	4,440	18,810	3,360	1,830	30,000

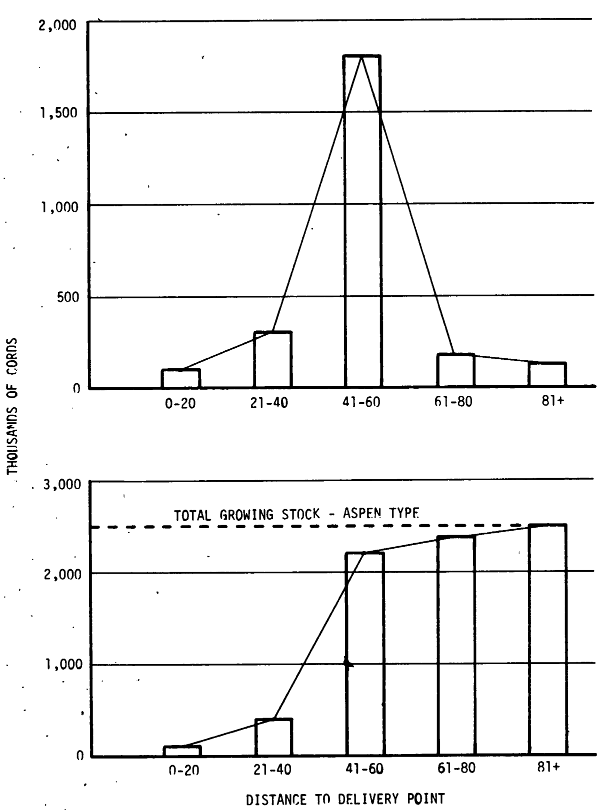

Figure 6.–Distribution of volume by distance from International Falls for all species within the aspen cover type. The top graph shows volumes at class mean distance; the bottom graph shows cumulative volumes at class upper limit.

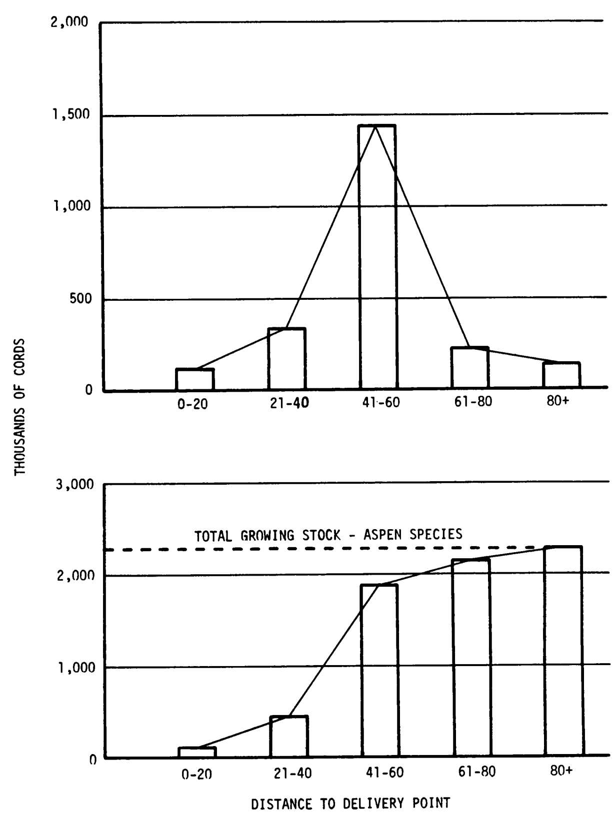

Figure 7.–Distribution of volume by distance from International Falls, aspen growing stock from all cover types. The top graph shows volumes; the bottom graph shows cumulative volumes.

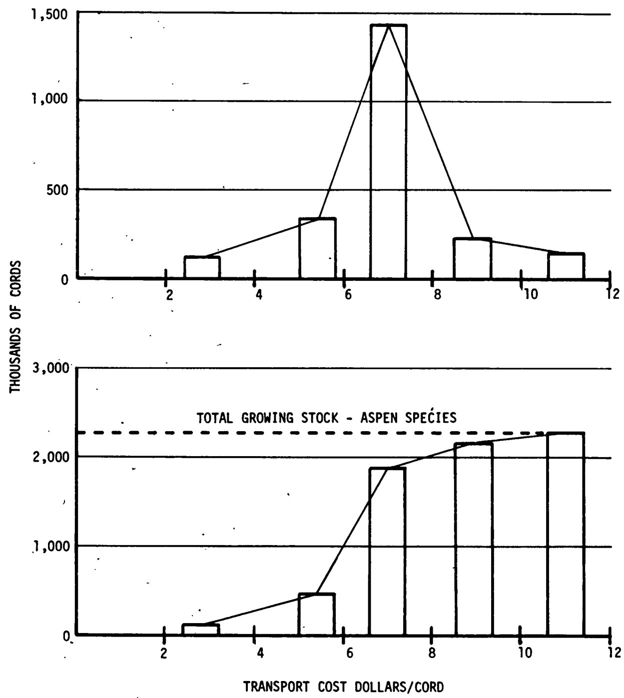

Figure 8.–Distribution of volume by Option 1 transport costs to International Falls, aspen growing stock from all types. The top graph shows volumes; the bottom graph shows cumulative volumes.

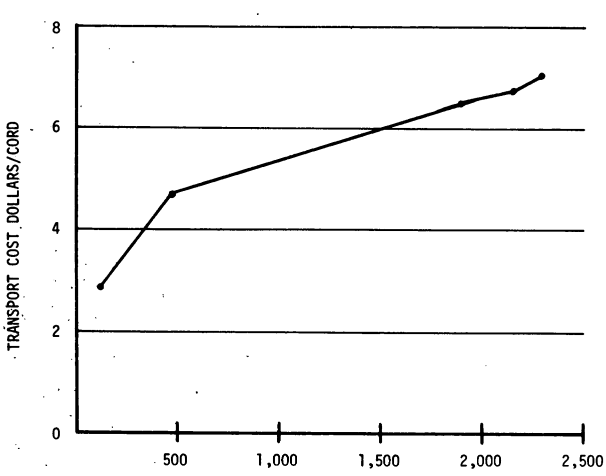

Figure 9.–Average transport cost per cord for option No. 1 to International Falls, aspen growing stock from all types.

Applications

There are three general areas in which forest access data have been of value (Segebaden 1969). First, the most common problem is to reduce a gross estimate of growing stock (or desirable cut) to that portion which is economically accessible (accessible in terms of the effects of terrain and distance on transport costs, and with a specific transport technology).

Second, the problem is to identify how location affects the desirability–i.e., profitability–of forest investments such as planting, release, or even fire protection.

Finally, the problem is to identify how the answers to the first and second questions affect the purchase, sale, or exchange of forest lands.

The average transport cost curve, figure 9, furnishes a brief example. For any mill with a fixed capacity in the short run, this average transport cost curve is the relevant one because it indicates how much wood is deliverable within a cost restraint. Given the mill's technology and the price its output demands in the market, this kind of graph should allow the mill to estimate what price it can afford to pay, on the average, for its pulpwood. Generally, the harvest-cost portion of a cord's total delivered price is relatively constant. Transport cost is the variable factor.

Therefore, if it is possible for a mill to estimate how its supply of wood is distributed by transport costs, it may be possible to predict short-run profits.

And for the long run, this process makes it possible (using a computer, for example) to examine the economic impact of changes in the extent, distribution, and quality of a road network, on land purchase policies, and forest investments (Segebaden 1969).

RECOMMENDATIONS

Forest inventory data are fundamentally incomplete if one cannot judge the impact of location upon value. This brief look at the methodology and the potential of forest access data is intended to whet the appetite of all public agencies and private corporations that have had to answer the most difficult kinds of resource analysis questions with insufficient data. While these procedures have been developed and tested in Sweden for almost 5 years, there has been almost no parallel development in North America. This lamentable situation is all the more remarkable because of the method's basic simplicity. Although it has limitations, arising primarily from sample size, it offers a rich potential.

This resource information deficiency can be improved in several ways. First, inventories of public lands should seriously consider the collection and presentation of access data. This could range from only a determination of the extent of the transport system up to a complete application of the process described here. The actual level of additional effort should be a function of anticipated benefits.

At the present time we are conducting a cooperative test of the process for a corporation undergoing a major expansion of wood requirements. This test should give us a clearer picture of costs and benefits.

One of the results of this work to date is the realization that present forest inventory systems lack flexibility, making the data difficult to geographically rearrange or retabulate. For the very reason that forest inventories cannot anticipate every future request, the entire data handling process should be made more flexible.

On the other hand, the tremendous increase in the demand for all kinds of resource data from timber development groups, recreationists, and wildlife managers precludes a system flexible enough to satisfy everyone. Some middle ground exists, however, and survey procedures at the North Central Forest Experiment Station are moving in this direction.

Hopefully, this paper heralds a more intensive and widespread investigation of the practical problems posed by location on the economics of forest resource use.

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Appendix A

Estimating Road Lengths Using a Randomly Located Rectangular Transect System[6]

As the previous section indicates, the length of the present road network is an important statistic. Except for the better classes of public roads, these data are often not available. This is especially true for seasonal and private logging roads. However, a rather simple method to determine road length is available, and it can easily be adapted to any inventory system.

The method is derived from the "Needle Problem," a classical exercise in geometrical probabilities, as follows: A system of parallel equidistant lines is drawn on a sheet of paper with (b) the distance between the lines. A needle with length (a) is placed at random on the paper. What is the probability that the needle intersects the lines?

The probability according to the 18th century French naturalist Buffon is:

$$(9) \quad P = \frac{2}{\pi}\frac{a}{b}$$

For example, if the needle is 2 inches long and the lines are 4 inches apart, the probability that the randomly dropped needle will touch or cross a line is:

$$P = \frac{2}{\pi} \quad \frac{2}{4} = 0.3183$$

If the needle is dropped on the paper a great number of times, this probability can be used to calculate the expected number of contacts or intersections of the needle with a line. In the example given, the needle would touch or contact a line about P times the number of attempts, or 32 percent of the time.

Consider now a chain of N links, each link with length a, and total length L = Na. Conversely $a = \frac{L}{N}$. If the chain is placed at random on the line system, the probability of an intersection between any link and the system is given by equation (9). But if the probability of one intersection is $\frac{2}{\pi}\frac{a}{b}$ and there are N links, what is the expected number of intersections between the chain and the system? Since

$$P = \frac{2}{\pi}\frac{a}{b} \text{ and } a = \frac{L}{N},$$

$$\text{then } P = \frac{2}{\pi}\frac{L}{Nb};$$

$$(10) \quad \therefore \; E(I) = PN = \frac{2}{\pi} \quad \frac{L}{b}.$$

The term "expected number" refers to a mean value that would be approached if this chain were dropped a large number of times. Thus, while a specific trial may yield no intersections (if all the links fell between the line system) or an infinite number of intersections (if all the links coincided exactly with the line system), the average number of intersections with many trials will equal $\frac{2}{\pi}\frac{L}{b}$.

Obviously the same result is obtained if the process is reversed by first placing the chain on the paper and then locating the parallel equidistant line system by random translation and rotation of the system in relation to fixed coordinate axes.

Consider next an area with a road network of length L. If a parallel equidistant line system is now placed at random over the network, the expected number of intersections is from equation 10:

$$E(I) = \frac{2}{\pi}\frac{L}{b}.$$

Assume for the moment that a specific test of this procedure results in n intersections. Substituting n for E (I) in the above and solving for L:

$$n = \frac{2}{\pi}\frac{L}{b},$$

$$L = \frac{\pi \, b \, n}{2}.$$

While this is only one trial, the expected value of this expression is L. That is,

$$(11) \quad E\left\{\frac{\pi \, b \, n}{2}\right\} = L.$$

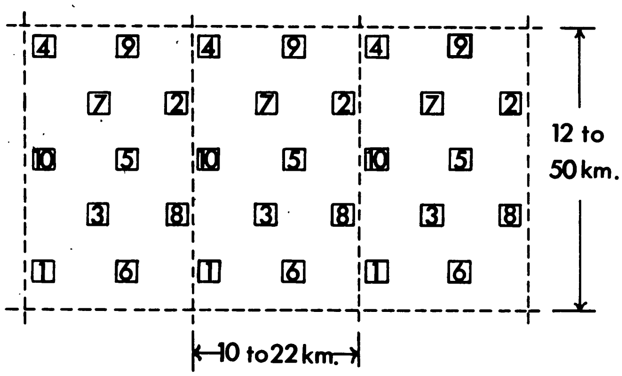
Thus, if the length of a road net is unknown, one may estimate its length by: (1) randomly locating a parallel,

[6] *The outline for this description is taken from an appendix by Bertil Matérn which appears in a publication by Gustaf von Segebaden: Studies of cross-country transport distances and road net extension: Studia Forestalia Suecica, 18, 70 p. 1964.*

equidistant line system with spacing b, over a road net or its map equivalent; (2) counting the number of intersections n; and (3) substituting the value of n in equation 11.

As mentioned before, individual estimates of L will vary from the expected value. Only the average of many trials will equal L. In fact, the variation may be great even if the equidistant lines are close together. This may happen, for example, if the roads are approximately parallel. However, the possibility of serious bias is greatly reduced if two line systems, perpendicular to each other, are used.

Other modifications of the line system to avoid bias are also possible using the basic principle of perpendicular systems. For example, the Swedish Forest Service uses closed rectangular transects located regularly throughout Sweden, figure 10. The four sides of the transect represent fragments of two perpendicular line systems.



--- Boundary of "survey area" with one tract surveyed each year.

☐ Tract boundary; perimeter varies from 4.8 to 8.8 km. in different provinces.

[1] Tract surveyed the first year, etc.

[4] Tract surveyed the fourth year, etc.

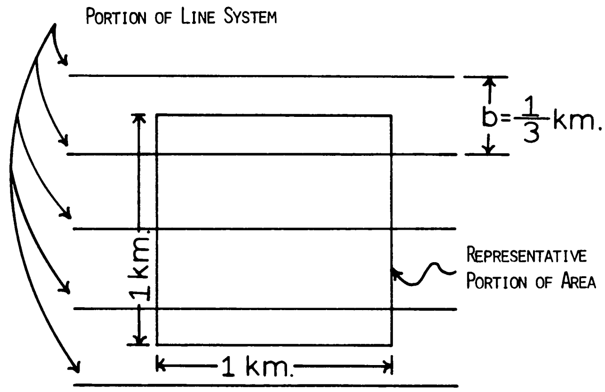
Figure 10.–Approximate layout of the Swedish national forest survey tracts. The dimension of the survey area varies between provinces.

Note from equation 11 that the estimate of length L is independent of the size of the area covered by the road net, the only parameter being the spacing of the transect lines, b. The parameter b works fine as long as one parallel equidistant line system is used. However, the spacing b is a meaningless term when applied to perpendicular systems such as the one used in Sweden. Instead, the length of the line system per unit area, t, is used. To calculate t for any shape of transect, divide the total length of the transect system by the total area in the survey unit.

$$t = \frac{1}{b} \quad \frac{\text{miles of road}}{\text{square mile of area}}.$$

This relationship is proved by the following, figure 11. Say, for example, that

$$b = \frac{1}{3} \text{ km.}$$



$$t = \frac{1}{b} = \frac{3\,\text{km.}}{\text{km.}^2}$$

Figure 11.–The relationship between transect spacing (b) and transect length per unit area (t).

Multiply numerator and denominator by 1 kilometer to get the area per unit length,

$$b = \frac{1\text{ km x km}}{3\text{ km}} = \frac{1\text{ km}^2}{3\text{ km}}.$$

Taking the reciprocal of b we have

$$t = \frac{1}{b} = \frac{1}{\frac{1\text{ km}^2}{3\text{ km}}} = \frac{3\text{ km}}{\text{km}^2}.$$

Determining the Spacing (b) of a Randomly Located Perpendicular Transect System

Segebaden (1964) has shown that the spacing of the transect system b is related to the standard error of the road length estimate according to the following approximate formula:

$$\text{Standard error percent} = \frac{76}{\sqrt{n}}$$

where n = number of intersections and standard error percent is for a confidence coefficient of 0.67.

This formula can be combined with a preliminary estimate of road length, L, to estimate an appropriate spacing, b, in the following manner.

First, choose a desired relative error. That is, a desired upper limit on the relative error in L to be estimated from the transect. For example, you may wish to estimate L from the transect to within ± 5 percent of its true value.

Next substitute the 5 percent in the approximate formula above and solve for n:

$$5 = \frac{76}{\sqrt{n}},$$

$$n = 231.$$

Next substitute a preliminary estimate of L (1,000 miles) and n (231) in the formula:

$$L = \frac{\pi b n}{2},$$

and solving for b,

$$b = \frac{2\ L}{\pi\ n} = \frac{(2)\ (1000)}{(3.14)(231)} = 2.75.$$

Thus, the spacing b of the line transect $\simeq$ 3 miles.

Appendix B

Determining the Proper Number of Point Samples to Accurately Estimate the Cross-Country Access Distances (sd) for Real Road Nets

Segebaden (1964) has designed an approximate formula to estimate the number of sample points from which to estimate the mean straight-line cross-country access distances for real road nets, $\overline{sd}$ (table 5).

While the formula was designed for rectangular arrays of sample points, it is also thought to be applicable to triangular arrays of points and other regular arrays as well. The approximate formula is as follows:

$$(12)\quad \log\sigma = 1.42 + \log\left\{\frac{A}{n\overline{SD}^2}\right\} \frac{6}{20 + \left[\log\left\{\frac{A}{n\overline{SD}^2}\right\}\right]^2},$$

and where the relative standard error of $\overline{sd}$ can be obtained from the formula:

$$(13)\quad \epsilon = \frac{\sigma}{\sqrt{n}}.$$

To use table 5, determine total area A, road length L, and calculate $\overline{SD}$ as if the road net was ideally distributed.

For example, if area A = 2,500 sq. miles and road length L = 833 miles,

Table 5. – Approximate number of points in a regular square spacing required to obtain a desired standard error of estimate of a mean straight-line cross-country access distance for a real net, $\overline{sd}$

Area (mi.^{2})	Desired limit of relative error, ε - percent[1/]														
	2.5 percent $\overline{SD}$, miles					5 percent $\overline{SD}$, miles					10 percent $\overline{SD}$, miles				
	0.25	0.50	0.75	1.0	1.25	0.25	0.50	0.75	1.0	1.25	0.25	0.50	0.75	1.0	1.25
5	95	60	45	35	30	40	25	20	15	15	15	10	10	5	5
10	125	75	55	45	40	55	30	25	20	15	20	15	10	10	5
15	145	90	65	55	45	60	35	25	20	20	25	15	10	10	10
20	160	95	70	60	50	65	40	30	25	20	30	15	15	10	10
25	175	105	75	65	55	75	45	35	25	20	30	20	15	10	10
50	230	135	100	80	70	95	55	40	35	30	40	25	20	15	15
75	265	160	115	95	80	110	65	50	40	35	40	25	20	15	15
100	290	175	130	105	90	120	75	55	45	40	45	30	25	20	15
250	405	245	185	150	125	160	105	75	60	55	60	40	30	25	20
500	510	320	240	195	160	195	130	100	80	65	70	50	40	30	30
1,000	640	405	305	245	215	240	160	125	105	85	85	60	50	40	35
2,500	840	550	425	345	295	300	210	165	135	120	100	75	60	55	45
5,000	1,010	670	530	440	370	350	255	205	170	150	110	90	75	65	55

1/ Relative standard error of the estimate at one standard deviation.

That is, $P\left[\hat{\overline{sd}} - \varepsilon(\hat{\overline{sd}}) \le \overline{sd} \le \hat{\overline{sd}} + \varepsilon(\hat{\overline{sd}})\right] = 0.67$

$$\Delta = \frac{833 \text{ mi.}}{2{,}500 \text{ sq.mi.}} = 0.333 \text{ mi./mi.}^2,$$

$$\overline{SD} = \frac{1}{4\Delta} = 0.75 \text{ mi.}$$

Choose an acceptable standard error; i.e., 5 percent. Now look in the table for an area of 2,500 square miles, a desired error of 5 percent, and an $\overline{SD}$ of 0.75 miles. The result is 165, the number of sample points that should provide an estimate of $\overline{sd}$, the mean straight-line cross-country access distance for a real road net, with an error equal to or less than 5 percent.

Table 5 was prepared by solving equation 13 for σ,

$$(14) \quad \sigma = \epsilon \sqrt{n},$$

substituting the right-hand portion in equation 12,

$$(15) \log(\epsilon\sqrt{n}) = 1.42 + \log\left\{\frac{A}{n\overline{SD}^2}\right\} \frac{6}{20 + \left[\log\left\{\frac{A}{n\overline{SD}^2}\right\}\right]^2},$$

and solving equation (15) for n by iteration.

Appendix C

Summary of Terms Relating Road Net Length and Distribution to Cross-Country Access

For ideally distributed road nets (fig. 1):

W = width of area between roads.
L = length of road or area influenced by road.
SD = straight-line cross-country access distance.
Δ = road net density, road length per unit area.

For irregularly distributed roads (fig. 2):

sd_i = straight-line cross-country access distance for the i *th* sample point.
R = road net adjustment.

For real road nets, both irregular and topographic (fig. 3):

PD_i = practical cross-country access distance for the i *th* sample plot.
C = cross-country transport adjustment.

These parameters are related in the following way:

$$(16) \overline{SD} = \frac{W}{4},$$

$$(17) \quad \Delta = \frac{L}{L x W} = \frac{1}{W}.$$

Taking the reciprocal of (17),

$$(18) \quad W = \frac{1}{\Delta}.$$

Substituting (18) in (1),

$$(19) \overline{SD} = \frac{1}{4\Delta}.$$

From an irregular road net,

$$(20) \quad \overline{sd} = \frac{\Sigma sd_i}{n}.$$

Tying ideal road nets to irregular nets is the equation:

$$(21) \quad R = \frac{\overline{sd}}{\overline{SD}} \geqq 1.0,$$

where R is a measure of road net irregularity. Rearranging (21),

$$(22) \quad \overline{sd} = R\ \overline{SD}$$

From a real road net,

$$(23) \overline{PD} = \frac{\Sigma PD_i}{n}.$$

Tying irregular road nets to real road nets is the equation:

$$(24) \quad C = \frac{\overline{PD}}{\overline{sd}} \geqq 1.0$$

Rearranging (24),

$$(25) \overline{PD} = C\ \overline{sd}.$$

Substituting (22) in (25),

$$(26) \overline{PD} = CR\ \overline{SD}.$$

Substituting 19 in 26, ideal, irregular, and real road nets are tied together by:

$$(27) \overline{PD} = \frac{C\ R}{4\Delta}.$$

This last result means that an overall practical cross-country access distance for a real road net ($\overline{PD}$) can be estimated from a knowledge of the existing road net geometry (R), the terrain (C), and the road net density (Δ).

Appendix D

Forest Service's Road Classification System[7] and Transport Costs for Minnesota Pulpwood

Hauling rates are based on drivers' wages, including compensation insurance and other payroll taxes, cost of equipment, depreciation insurance, and all operating costs (table 6). The costs were based on 1968 data for wages, truck, trailer, and loader selling prices, insurance rates, and tire and fuel costs. Current depreciation rates of straight-line 6-year life and 6 percent interest rates were used. All adjustments were made on a comparison basis with the 1957 R-7 truck hauling cost study and the Byrnes-Nelson-Coogin report on log hauling costs.

Table 6.—Hauling costs for Minnesota pulpwood by road quality and truck size (In dollars per cord-mile)

Road class	Truck size--mean load (cords)1/			
	4	6	8	10
High speed, 45 m.p.h.	0.09	0.08	0.08	0.06
Class I, 35 m.p.h.	.13	.12	.11	.08
Class II, 25 m.p.h.	.18	.17	.16	.12
Class III, 16 m.p.h.	.26	.24	.24	.18
Class IV, 8 m.p.h.	.47	.43	.46	.34
Class V, 4 m.p.h.	.85	.78	.86	.65
Fixed costs (standby, delay, load, unload)	1.78	1.65	1.41	1.81

1/ Truck description--all are equipped with loader: 4 cords, flat bed, 4 by 2, single axle, GVW 28,000 lbs.; 6 cords, flat bed, 6 by 4, tandem axle, GVW 37,000 lbs.; 8 cords, truck tractor, 4 by 2, single axle, with 28-30 ft. platform bed, GVW 59,000 lbs.; 10 cords, truck tractor, 4 x 6, tandem axle, with 30-35 ft. platform trailer, GVW 72,000 lbs.

262—Road Capacity and Service Class Description

High speed highways, average running speed 45 m.p.h.— This class of road includes the best highways where trucks are able to maintain a high average speed. However, consideration should be given to delays through towns, etc.

Cost haul Class I, average running speed 35 m.p.h.— This class includes Federal, State, and primary county highways with concrete or bituminous pavement of well stabilized gravel surfacing. The design speeds for highways in this group will fall within the range of 40 to 60 miles per hour. Truck running speed for this group will range from 30 to 40 miles per hour, with an average of 35 miles per hour. If a section of a highway in this class has a 1/4 mile or more of sustained adverse grades of 6 percent or greater, that portion should be considered as a Class II road.

Cost haul Class II, average running speed 25 m.p.h.— This class includes county secondary, township, and forest roads with a design speed of 30 miles per hour and truck running speed averaging 25 miles per hour. Roads in this class will be two-lane width or single-lane with intervisible passing sections. The roadway surface may have bituminous, compacted gravel, or stabilized soil wearing course well maintained. Horizontal alignment is limited to minimum radius curves of 300 feet and maximum grades of 7 percent. If a section of a road within this group has a 1/4 mile or more of sustained adverse grades exceeding 7 percent, that portion should be considered as a Class III road.

Cost haul Class III, average running speed 16 m.p.h.— This class includes county, local, township, and one-lane forest roads with a design speed of 20 miles per hour, and truck running speed of 16 miles per hour. One-lane roads will have passing sections, but not always located at intervisible points. The roadway will usually have fair gravel or soil wearing surface with intermittent blade maintenance. Horizontal alignment is limited to minimum radius curves of 200 feet and maximum grades not exceeding 10 percent. If a section of a road within this group has a 1/4 mile or more of sustained adverse grades exceeding 10 percent, that portion should be considered as a Class IV road.

Cost haul Class IV, average running speed 8 m.p.h.— This class includes roads, regardless of jurisdiction, that are single-lane in width and lacking adequate passing sections. These roads will classify as low service facilities with little or no consideration given to design speed during route selection or construction. They will usually have winding alignment with numerous sharp curves. The vertical alignment closely follows the rolling natural ground line with hidden dips and undulating grades. Maximum grades may be up to 12 percent. Roads in this class are usually unsurfaced with

[7] *Source: Handbook of timber appraisal. USDA For. Serv. Reg. 9. Chap. 260, June 1968, Amend. 36; Oct. 1968, Amend. 39.*

limited spot graveling on unstable sections. Drainage is usually limited to natural drainage channels where they cross the roadway. Truck running speeds may range from 6 to 11 miles per hour with an average of 8 miles per hour.

Cost haul Class V, average running speed 4 m.p.h. – This class includes the poorest service roads within the sale area. They are usually narrow and undrained with winding alignment and rolling grades. They are average one-lane dozer-constructed roads with low protruding rocks and stumps in the driving surface and with limited or no passing sections. Truck running speeds may range from 3 to 5 miles per hour with an average speed of 4 miles per hour. Do not allow for short sections (up to 400 feet) out of landings as this cost is taken care of in standby time.

Appendix E

ACCESS, a Fortran IV Program[8]

This program was written to conform to an algorithm supplied by Dennis P. Bradley. It takes as partial input the plot record from a forest survey. This record can consist of the following data for each plot: (1) cover type, size, and density up to 20 cover types and (2) species volumes per acre–up to 20 species. At present, size and density are not used in the summary tables but the program can be easily modified to provide this feature.

In addition, the cross-country access distances and the hauling distances for up to six road quality classes for each plot are required. Finally, if transport costs are desired, up to four different truck or other transport options are permissible. Program output by cover type and species is illustrated in tables 3 and 4, respectively, in the text.

Program Statistics.–Size: main 110,048 bytes, subprogram 1,584 bytes, total 111,632 bytes of core. Disk requirements: 108 bytes per plot. Typical run time (compilation and execution) with approximately 1,000 plots: 8 minutes.

Equipment used.–At Michigan Technological University, Houghton, Michigan: (1) IBM/360, Model 44–(a) 256,000 bytes of core, (b) HASP operating system, (c) Fortran IV: FORGO–and (2) 2314 Disk Drive.

To obtain this program for study or use, send inquiry to D.P. Bradley, North Central Forest Experiment Station, 118 Old Main Building, Duluth, Minnesota 55812.

The following flow chart (fig. 12) is a simplified description of the program.

[8] *Written by Donald Moore, Forest Engineering Laboratory, North Central Forest Experiment Station, USDA Forest Service, Houghton, Michigan.*

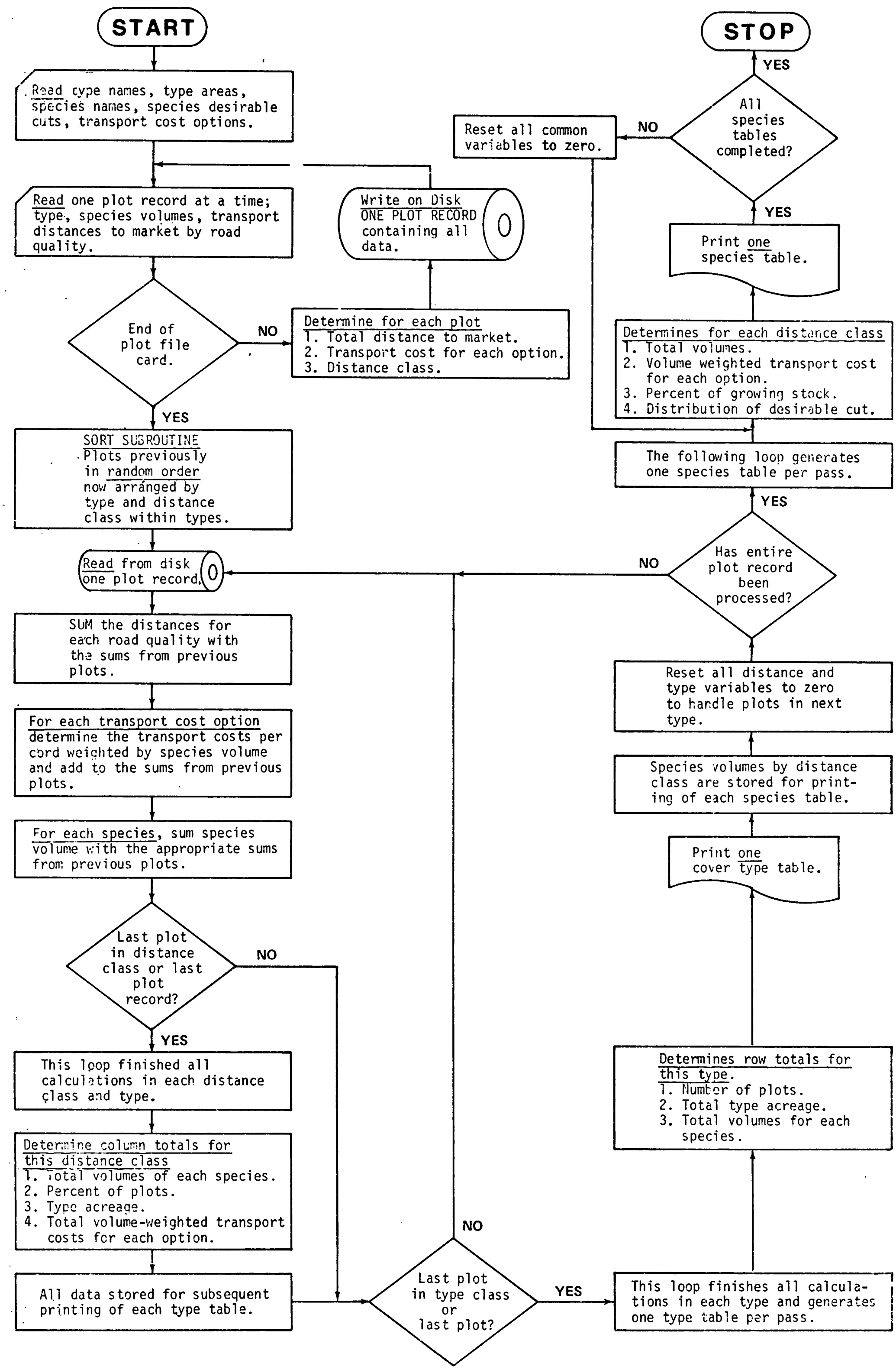


Figure 12.–Flow chart for ACCESS program.

SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

Crosscut Shearing of Roundwood Bolts, by Rodger A. Arola. USDA For. Serv. Res. Pap. NC-68, 21 p., illus. 1971.

Storm Flow from Dual-Use Watersheds in Southwestern Wisconsin, by Richard S. Sartz. USDA For. Serv. Res. Pap. NC-69, 7 p., illus. 1971.

Annotated Bibliography of Walnut—Supplement No. 1, by Martha K. Dillow and Norman L. Hawker. USDA For. Serv. Res. Pap. NC-70, 23 p. 1971.

Fire Whirlwind Formation Over Flat Terrain, by Donald A. Haines and Gerald H. Updike. USDA For. Serv. Res. Pap. NC-71, 12 p., illus. 1971.

The Changing Hardwood Veneer and Plywood Industry of Michigan and Wisconsin, by Gary R. Lindell and Lewis T. Hendricks. USDA For. Serv. Res. Pap. NC-72, 8 p., illus. 1972.

Estimating Force and Power Requirements for Crosscut Shearing of Roundwood, by Rodger A. Arola. USDA For. Serv. Res. Pap. NC-73, 8 p., illus. 1972.

Effect of Topography on Microclimate in Southwestern Wisconsin, by Richard S. Sartz. USDA For. Serv. Res. Pap. NC-74, 6 p., illus. 1972.

Weights and Centers of Gravity for Red Pine, White Spruce, and Balsam Fir, by H.M. Steinhilb and John R. Erickson, USDA For. Serv. Res. Pap. NC-75, 7 p., illus. 1972.

Fire Weather and Behavior of the Little Sioux Fire, by Rodney W. Sando and Donald A. Haines. USDA For. Serv. Res. Pap. NC-76, 6 p., illus. 1972.

Canoeist Suggestions for Stream Management in the Manistee National Forest of Michigan, by Michael J. Solomon and Edward A. Hansen. USDA For. Serv. Res. Pap. NC-77, 10 p., illus. 1972.

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As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

For more than 60 years, the Forest Service has been serving the Nation as a leading natural resource conservation agency.