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CONFIGURATION OF APPALACHIAN LOGGING ROADS

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CONFIGURATION OF APPALACHIAN LOGGING ROADS

THE CONFIGURATION — the curvature and grade — of logging roads in southern Appalachia is seldom severe, according to a recent Forest Service study. To improve the efficiency of logging roads, we must first define the characteristics of these roads; and in this report we provide a quantitative description of the configuration of over 200 miles of logging roads.

This information will enable future work in equipment development and forest road design to be related to woods-road conditions as they actually exist. In addition, the configuration of today's forest truck roads can be compared to the requirements of future trucking equipment. This comparison will facilitate a critical review of present road-building practices in light of future demands upon logging roads.

Trucking logs to the sawmill often represents the largest single cost in Appalachian logging operations *(Appalachian Hardwood Manufacturers 1969)*. A disproportionate amount of this cost is incurred trucking over woods roads. A study in the Tennessee Valley *(Jiles and Lehman 1960)*, found the cost per mile to truck over logging roads to be twice the cost over gravel roads and three times the cost over paved roads. Thus, the cost of trucking logs over woods roads is a key element in the economics of Appalachian logging.

The physical characteristics of logging roads — grade, curvature, length, width, and surface conditions — are all determinants of trucking efficiency. When road characteristics become adverse to trucking, production delays increase; truck size and thus payloads are limited; truck wear accelerates; and travel time increases. Each of these events either increases costs or decreases production.

The influence of logging road engineering has been documented for West Coast conditions *(Byrne, Nelson, and Googins 1960)*, but the same criteria may not apply to Appalachia.

THE STUDY

Objectives.—The prime objective of this study was to describe the configuration of logging roads constructed in southern Appalachia. Supplemental objectives were to assess the influence of three types of mountain topography upon road curvature and grade and to study the relationship between road length and its grade and profile. Logically, trucking efficiency increases as severity of grade and curvature decreases. Thus the type of terrain and length of road may influence trucking costs.

This paper does not give any data on the effects of road configuration upon trucking cost, nor does it compare road configuration with the most severe curves and grades negotiable by different truck types.

Study Area.—The study was conducted in three physiographic regions of the Appalachian system. We studied these three areas because each has distinct topographical characteristics that might influence logging road configuration (fig. 1).

Region A consists of long ridges oriented northeast-southwest with relatively flat to rolling terrain between the ridges. It has a regular drainage pattern.

Region B, defined as the unglaciated Allegheny plateau, has less distinct topography. Base elevations generally exceed 2,000 feet, and mountains rise to 4,000 feet above sea level. This highland plateau is laced with deep ravines and precipitous slopes and is spotted with rounded to sharp knobs and short ridges.

The third study area, region C, represents the exceptionally rough topography characteristic of the coal-field region in Kentucky and southern West Virginia. The steep hills and ridges have no recognizable orientation — thus the drainage pattern is very irregular. Elevations are lower than in region B, rising

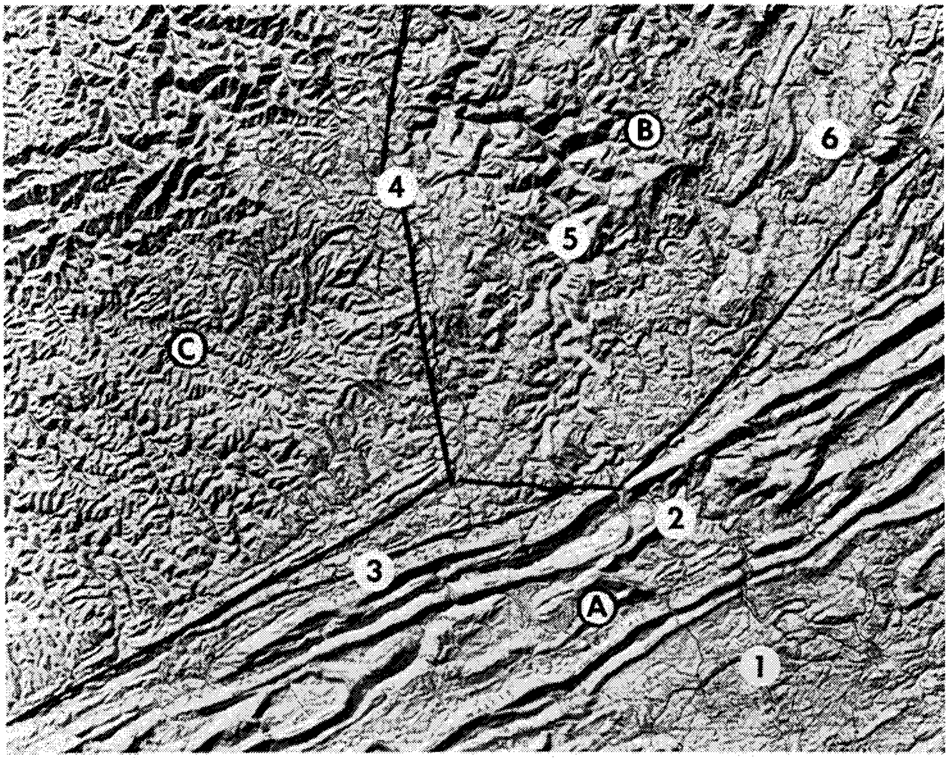


Figure 1.—Map of study area showing differences in terrain between sample regions A, B, and C. The towns indicated are (1) Radford, Va.; (2) Pearisburg, Va.; (3) Bluefield, W. Va.; (4) Beckley, W. Va.; (5) Hinton, W. Va.; and (6) Lewisburg, W. Va.

sharply from 800 feet in the coves to about 2,300 feet on the somewhat flattened ridges.

Sampling Method

To study the relationship of configuration to gross topography or road length, we stratified the roads sampled into 12 groups by using four road-length classes in each of three physiographic regions.

The logging roads surveyed were located at random from interviews with sawmill operators and loggers. We tried to locate and survey 10 roads in each sampling strata for a total of

Table 1.—*Frequency and length of sample roads used in study of logging road configuration.*

Road-length class		Number and length of roads by physiographic region					
Class	Length	(A) Ridge and valley		(B) Mountain plateau		(C) Coalfields region	
Code	*Miles*	*No.*	*Miles*	*No.*	*Miles*	*No.*	*Miles*
1	0.3 to 0.9	12	7.54	13	8.14	15	9.04
2	1.0 to 1.9	12	17.09	13	18.67	20	25.28
3	2.0 to 2.9	9	22.68	5	12.21	5	11.64
4	3.0 and longer	6	21.90	6	25.94	7	26.64
Total all classes		39	69.21	37	64.96	47	72.60

120 roads. Due to the relative scarcity of logging roads longer than 2 miles, we avoided the costly effort required to locate the prescribed number of class 3 roads (2.0 to 2.9 miles long) and class 4 roads (3 miles and longer) (table 1).

Only roads longer than 0.3 miles were sampled in this study. Furthermore, we surveyed only one road built by any given logger. These roads were located on National Forest as well as on private land.

Road Survey Technique

A new method of measuring configuration was used to provide a rapid means of adequately assessing road alignment and profile. Although less accurate than standard road survey techniques, the method described here provides accuracy adequate for assessment purposes at reduced time and cost.

Alignment Survey.—The survey consists of rolling a measuring wheel in a straight line between alignment stations and recording the cumulative distance at successive stations (fig. 2). The location of each alignment station was the intersection of the road centerline and the longest possible straight line that could be sighted down the road, keeping within the truck wheel tracks.

In figure 2, the surveyor has proceeded from station 1 to station 2 by sighting along line 1-2, stopping at 2 where the line of sight intersects the road centerline. The surveyor always measured the straight line distance between stations, thus road curvature is measured in straight line segments.

Profile Survey.—For measurements of road profile, segment length is not controlled by the line of sight, but by a prearranged difference in elevation. We selected a contour interval of 20 feet and measured the change in elevation with a sensitive surveying altimeter. We recorded the cumulative distance between successive 20-foot changes in elevation during the course of the alignment survey.

Rarely did we find that profile stations coincided with alignment stations. Usually the road segment lengths representing a 20-foot difference in elevation were much longer than the segment lengths representing curvature.

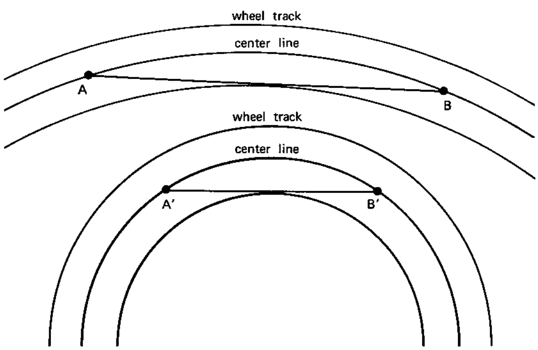
Figure 2.—Technique of measuring alignment segment lengths. Line of sight follows dotted line.

Survey Geometry

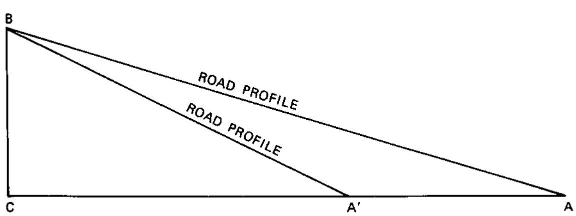
The geometry supporting this survey technique is fully explained in the appendix. Briefly, the chord length-arc radius relationship is held constant by keeping the line of sight within the wheel tracks and locating each alignment station on the road centerline. The sharper the curve, the shorter the alignment segment (fig. 3).

Profile segment lengths can be used when measuring road grade, because the segments constitute the hypotenuse of a right triangle with a constant height of 20 feet (fig. 3). Trigonometric solution of the triangle provides the base distance from which

Figure 3.—Effect of changing radius of curvature on alignment-segment lengths; and effect of changing segment length on percent of grade.



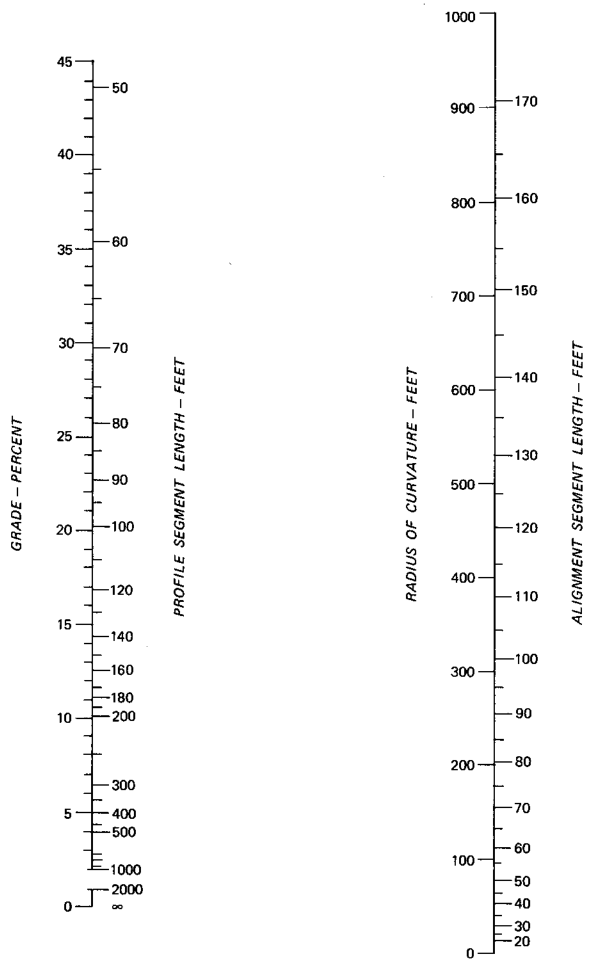
DECREASING THE RADIUS OF CURVATURE DECREASES THE ALIGNMENT – SEGMENT LENGTH FROM AB TO A'B'.



KEEPING BC CONSTANT AT 20' AND DECREASING AC TO A'C INCREASES THE GRADE OF SLOPE percent of grade is derived. Again, segment length and severity are directly related: as profile segment length increases, steepness of grade decreases.

Alignment and profile were measured and recorded in feet of segment length. For normal engineering purposes, alignment is expressed in radius of curvature, and profile is measured in percent of grade. The charts in figure 4 convert segment length to

Figure 4.—Charts for converting segment lengths to percent grade or radius of curvature.



the standard units — radius of curvature and percent of grade. The relationships expressed by these charts are derived in the appendix.

Evaluation of Findings

The proportionate road distance associated with different levels of curvature and grade is the basis of our assessment of logging road configuration. Plots of summarized field observations as cumulative frequency distributions illustrate relative severity of curvature and grade and provide comparisons of alignment and profile between the physiographic regions and road-length classes (figs. 5 to 8).

On figures 5 to 8, cumulative frequency represents that portion of a group of roads that is equal to or less than the corresponding value on the horizontal axis. For example, in figure 5, about 25 percent of the road distance sampled in length-class 1 is in curves with a radius of 450 feet or less.

Alignment

Radius of curvature derived from alignment segments ranged from 20 to 20,000 feet. For all practical purposes, a curve with a radius exceeding 1,000 feet is negligible, almost a straight line.

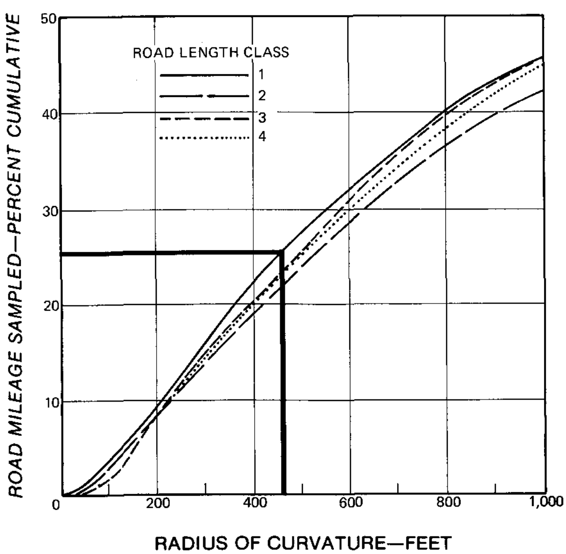
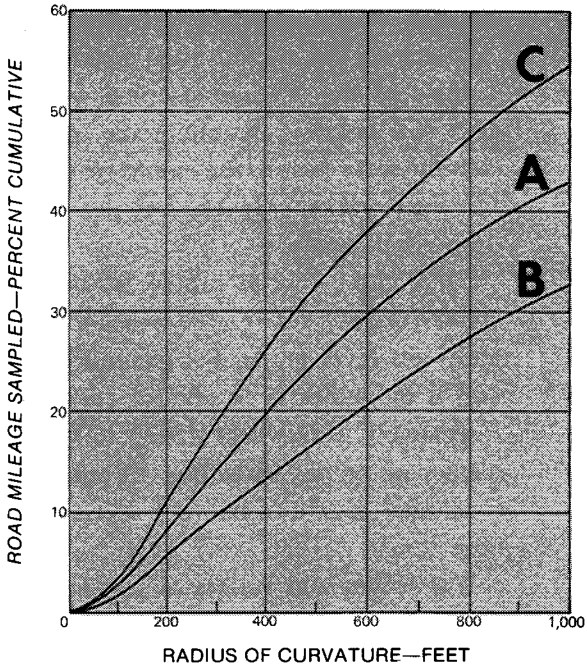


Figure 5. — Proportionate distribution of logging road mileage by radius of curvature and road length class.

Figure 6. — Proportionate distribution of logging road mileage by radius of curvature and physiographic region.



Thus, the frequency distributions in figures 5 and 6 apply only to curves with a radius less than 1,000 feet.

Very sharp curves occurred infrequently. In fact, road curvature with a radius less than 100 feet occurred at a rate of only 160 feet per mile of road surveyed. Curves with a radius as low as 300 feet are gradual, yet 85 percent of the sampled distance exceeded this measure.

Total length of individual roads has little relation to severity of curvature (fig. 5).

As you would logically expect, physiography affected alignment (fig. 6). Roads were straightest in the mountain plateau region where 67 percent of surveyed road length had a radius of curvature exceeding 1,000 feet. The rugged and irregular topography of region C had the most severe influence upon road alignment. However, regional differences were small where alignment becomes critical; in curves with a radius less than 200 feet, the maximum difference between regions is only 6 percent.

Profile

Much of the logging road profile sampled was relatively level; a third of the mileage sampled was below 3-percent grade, and half was below 5-percent grade. Although grades as high as 25 percent were found, the extent of severe profile was very limited. On the average, only 240 feet per mile of logging road exceeded 15-percent grade.

Differences in the profile between roads of different length classes do occur (fig. 7). Short logging roads have proportionately less level grade. For example, the portion of length-class 1 and 4 in grades of 2 percent and below are 8 and 30 percent, respectively. Roads less than 1 mile long also have a higher frequency of grades exceeding 10 percent. From this data, we have concluded profile to be most severe on logging roads less than 1 mile long.

The ridges and valleys of region A and the mountain plateau topography in region B are distinctly different, yet roads in these two regions have much the same distribution of profile (fig. 8). The rugged coal field terrain had an extremely variable effect on road profile. Roads in this region had the highest proportion of

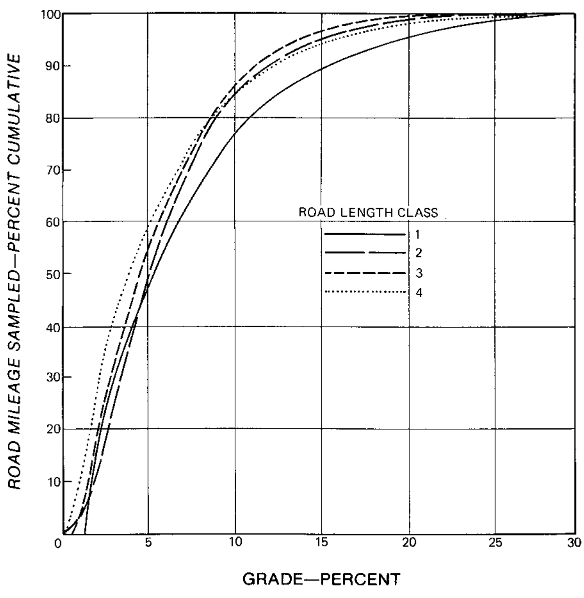
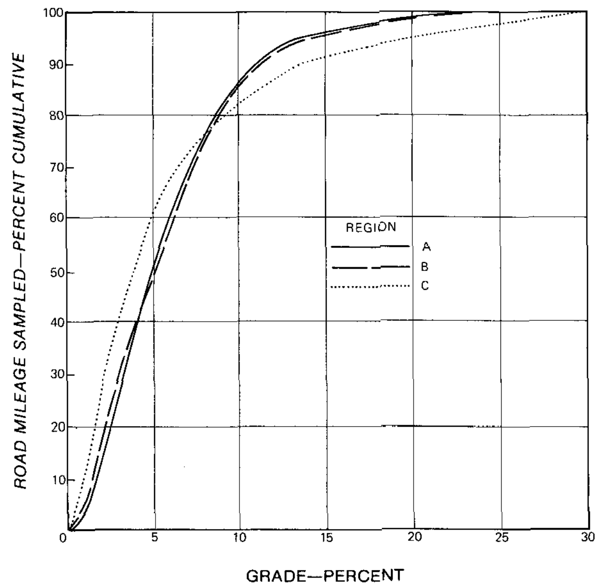


Figure 7. — Proportionate distribution of logging road mileage by percent of grade and road length class.

Figure 8. — Proportionate distribution of logging road mileage by percent of grade and physiographic region.



relatively level profile, yet had more grade in excess of 10 percent than did roads in regions A or B. The greatest difference in profile among the physiographic regions is in the range below 10 percent grade, which is least likely to hinder trucking.

Configuration

Thus far we have evaluated logging road alignment and profile as separate entities. However, configuration is defined as the interaction of alignment and profile. To assess configuration, we have measured this interaction as radius of curvature coincident with percent grade.

To simplify this analysis, we have reduced the infinite number of potential combinations of alignment and profile to three groups. Here are the quantitative descriptions of each group:

- *Favorable.*—Sections of a woods road where radius of curvature greater than 300 feet is mutually associated with grades less than 10 percent; in brief, neither curves nor grades are severe.

- *Moderate.*—Sections of a woods road where favorable alignment is coupled with grades steeper than 10 percent or where favorable profile is linked to curves with radii less than 300 feet; in brief, a sharp curve coupled with a relatively flat slope or vice versa.

- *Adverse.*—Sections of woods roads where curves with radii sharper than 300 feet are associated with grades steeper than 10 percent; in brief, a combination of sharp curves and steep grades.

Illustrated in figure 9 is the percent of each road's length that meets the criteria specified for favorable, moderate, and adverse configuration. The 123 roads are arranged in order of increasing proportions of favorable configuration.

The effects of physiography and road length upon alignment and profile are reflected in configuration of individual logging roads. Roads less than 1 mile long have the poorest configuration of all roads sampled. Nine of the 10 poorest roads are class-1 roads. In addition, 9 of the 12 roads with more than 5 percent adverse configuration are also less than 1-mile long. Of the three physiographic regions, region A—ridge and valley topography—had the lowest frequency of relatively poor configuration. Only 5 roads from region A were among the 30 poorest roads; furthermore, no road in this region has more than 2-percent adverse configuration.

The following three points summarize the broad view of logging road configuration in this study:

- The shape of individual woods roads, like the rugged mountain terrain, is extremely variable. Roads range from 0- to 100-percent favorable.
- Although grades in excess of 10 percent and curves with a radius of curvature less than 200 feet frequently occur separately (described as roads of moderate configuration), they seldom occur simultaneously. Very few roads had more than 5 percent of their length in adverse configuration; the average being less than 2 percent.
- Configuration characterized by grades less than 10 percent and a radius of curvature exceeding 200 feet predominated. In fact, three out of four roads had more than 70 percent of their

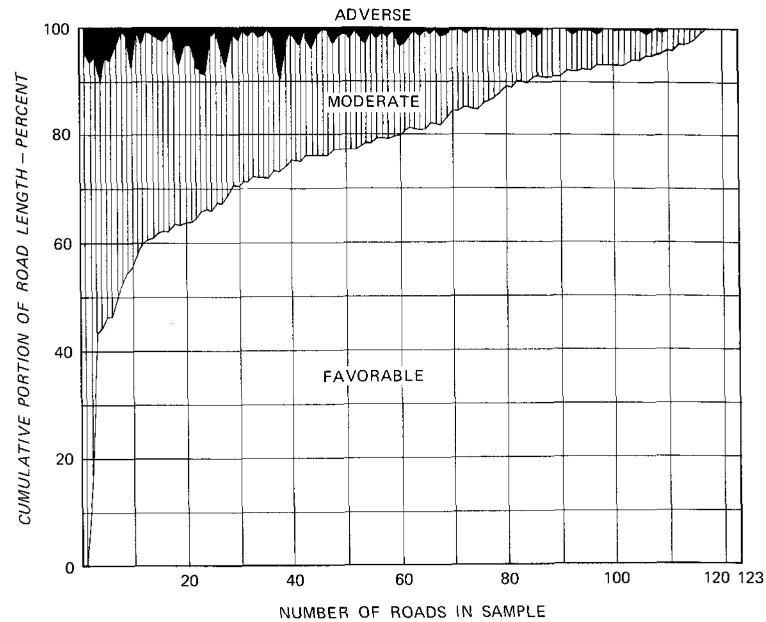


Figure 9.—Configuration of each of the 123 logging roads sampled.

length in favorable configuration; half the roads surveyed were better than 80-percent favorable.

DISCUSSION AND RECOMMENDATIONS

Because logging road configuration is the product of many factors that are seldom constant from one logging operation to another, the configuration of individual roads differs greatly. Two factors influencing configuration are road length and topography. Both influence the variation and severity of road alignment and profile. In our opinion, this influence can be attributed to road building cost. Loggers cannot afford to lengthen potentially short roads to rectify severe configuration; nor can they invest enough money in logging roads to cancel the effects of rugged terrain.

Not having a quantified relationship between logging road configuration and roundwood hauling costs, the quality of configuration cannot be assessed relative to hauling cost. However, configuration has been measured in feet of segment length and assessed in terms of degrees of curvature and percent of grade. This assessment indicates configuration is predominately favorable in light of limited road building funds and rugged terrain. Since 75 percent of the total road length sampled was below 8 percent grade, and 80 percent of the curvature exceeded a radius of 300 feet; logging road configuration should not be the principal obstacle to efficient transportation of logs from landing to mill.

Although the shape of logging roads may be ruled out as the principal cause of high cost incurred when trucking over these roads, it may well be a contributing factor. Configuration of woods roads is favorable, but not optimal. The effect of sharp curves and steep grades upon hauling costs should be assessed. Then this cost can be compared to the investment required to eliminate adverse configuration. This would determine the economic feasibility of improving existing road configuration.

This appraisal suggests that researchers look elsewhere for factors that might affect roundwood transport costs. Logging road surface condition is one such factor, trucking equipment is another. It is possible that high costs are inevitable using the present trucking system, and a new concept of extracting logs is in order. Here are our specific recommendations for future research:

- Determine the influence of adverse configuration on hauling time and cost.
- Compare the costs of improving configuration with the costs of hauling where severe curves and grades have not been eliminated.
- Establish the link between road surface conditions and hauling costs.
- Compare the costs of improving woods-road surface with the benefits derived from operating on the better surface.
- Compare costs of operating the present system, trucking logs over woods roads, to that of alternate systems such as forwarding logs to surfaced roads.

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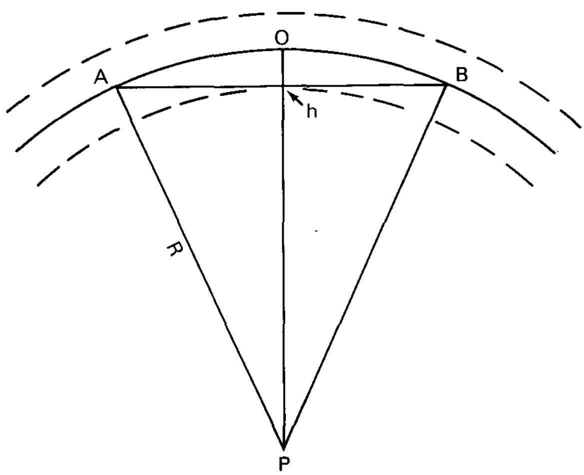
APPENDIX

Deriving Radius of Curvature from Alignment Segment Length



AP = OP = BP = radius of curvature, R

AB = line of sight, segment length, chord of arc AOB

AOB = arc of road center line

Oh = constant middle ordinate, 4 feet from center line to inside wheel track

hP = radius minus middle ordinate = OP — Oh

By definition $AB = 2\sqrt{R^2 - hP^2}$

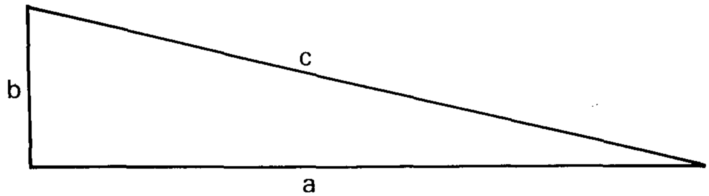
substituting (R—4) for hP, $AB = 2\sqrt{R^2 - (R-4)^2}$

deriving R $AB = 2\sqrt{8R - 16}$

$$R = \frac{AB^2}{32} + 2$$

$$\text{Radius of curvature} = \frac{(\text{segment length})^2}{32} + 2$$

Deriving Percent of Grade from Profile Segment Length



a = horizontal distance—feet

b = vertical distance, a constant 20 feet

c = profile segment length—measured distance in feet

Grade in percent is defined as $\frac{\text{vertical distance}}{\text{horizontal distance}} \times 100$

The profile survey measures the length of c, b is a constant of 20 feet. Using the Pythagorean theory, $a = \sqrt{c^2 - b^2}$. By substitution, percent

$$\text{grade} = \frac{b}{\sqrt{c^2 - b^2}} \times 100$$

$$\text{Percent grade} = \frac{20}{\sqrt{(\text{segment length})^2 - 400}} \times 100$$