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Engineering Field Notes

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Reader's Notes

The Forest Service Planning Process & Its Implications on Transportation Issues

Jerry Knaebel, Chief Engineer, Transportation System Planning & Analysis, Washington Office

(This information was used to prepare a presentation for the AASHTO Standing Committee on Planning, Phoenix, Arizona, May 27, 1982)

The Forest Service is now engaged in one of the most complex and comprehensive efforts ever undertaken by a land managing agency. Decisions that will result from this effort may have significant implications on local, State, and Regional transportation issues. Transportation modes of all types, including highways, railroads, pipelines, powerlines, as well as air and water routes, may be affected. State transportation agencies and their planning officials must be informed about the Forest Service planning process; we must point out how decisions resulting from that process might affect transportation issues; and we should suggest means by which State agencies can participate in and provide needed input for those planning efforts.

Public participation is an important feature of Forest Service planning activities. The success of those activities, and the quality of resulting decisions, depends upon our ability to identify and address pertinent issues and concerns, including resource use and development opportunities. Since transportation is a very important and visible instrument for economic and social change, assistance and advice of transportation agencies or those who are concerned with State or Regional transportation needs is important to ensure that these issues are raised in their proper perspective. Frequently, these consequences occur beyond the National Forest boundaries and are difficult for our planners to identify and assess.

A principal objective of the Forest Service planning effort is to make some very specific decisions regarding how National Forest System lands are to be managed, and for what purposes. Decisions on land allocation and resource schedules will directly affect the use of existing transportation facilities and will strongly influence the location of new corridors. For this reason, transportation officials responsible for developing State-wide or Regional transportation policies must help the Forest Service planners to ensure that land use decisions are consistent with those policies and with the needs of their individual States. This is particularly

important in many of the western States, where the Federal Government controls a significant portion of the land area.

ABOUT the FOREST SERVICE

The Forest Service, an agency of the Department of Agriculture, is dedicated to the principle of multiple-use management of the Nation's forest resources. Through forestry research, cooperation with State and private forest owners, and management of the various National Forests and National Grasslands, this Service strives, as directed by Congress, to provide increasingly greater service to the Nation. Of particular importance to this concept are the National Forests and National Grasslands (the National Forest System), which collectively comprise nearly 190,000,000 acres of land in 44 States, Puerto Rico, and the Virgin Islands. In some States, the Forest Service presence is particularly significant from an economic and social standpoint. For example, 38 percent of the entire State of Idaho is in National Forest ownership. With an annual budget of nearly \$2,000,000,000 and a network of over 280,000 miles of road, it is apparent that the Forest Service is no small, obscure Federal Agency; indeed, it represents a large and influential business.

Administratively, the Forest Service is organized into nine Regions, with headquarters in Atlanta, Milwaukee, Missoula, Ogden, Denver, Albuquerque, San Francisco, Portland, and Juneau. These Regions are further organized into the 155 National Forests and National Grasslands. Our planning efforts are tiered along this same hierarchy; that is, we have separate--though linked--planning functions at each of these organizational levels. Since planning at each of the three levels is approached differently, a basic understanding of each is needed. It should be kept in mind, however, that the entire process is characterized by a continuous cycle that must be viewed with a time perspective. Each plan has a special relationship to other plans prepared both before and after it.

NATIONAL PLANNING

The National Planning effort is mandated by the Renewable Resources Planning Act of 1974, usually referred to as RPA. RPA results in a goal-oriented, programmatic type of plan, rather than one dealing with specific land allocation decisions. Its primary purpose is to provide broad policy level direction and emphasis to all Forest Service programs. It covers a 50-year planning period and has two main features, the Assessment and the Program.

The Assessment is prepared every 10 years; the first was developed in 1979. The assessment has three purposes:

1. To measure the Nation's ability to produce renewable resources from all lands, including all Federal, State, and private lands;
2. To forecast the national demand for renewable resources; and
3. To determine what share of the national demand must be produced by the National Forests.

The assessment is based on information gathered from a number of sources, including:

1. The production capability of National Forests, as determined by National Forest Land and Resource Management Plans;
2. The production capability of State and privately owned lands, as determined by State Resource Plans that are prepared by individual State Foresters;
3. Assessments of other Federal Agencies; and
4. Information from individuals or groups and organizations.

Once the capability and demand information has been assessed, alternative levels of outputs and associated costs are examined in the Program, which, unlike the Assessment, is prepared every 5 years. Based upon an analysis of these alternatives along with consideration of public views, the Secretary of Agriculture decides upon a Recommended Program for the Forest Service. This Program, along with a Presidential Statement of Policy, is then transmitted to Congress; Congress may accept or revise the Statement of Policy, depending upon how it views the national need. The final Policy Statement and Program then serve as the guiding document to direct Forest Service activities and subsequent renewable resource output levels. These directions and production levels are then assigned to the individual Regions based upon Regional ability to produce. This brings us to the next planning level: Regional Planning.

REGIONAL PLANNING

The Regional planning effort is directed by the National Forest Management Act of 1976, commonly referred to as NFMA; it is, actually, an amendment to RPA. The Regional Plan has four purposes:

1. To define major issues that must be resolved on a Regional basis;
2. To establish standards for management of each National Forest in a Region;

3. To consolidate information developed in the individual Forest land management plans, and to make that information available for development of the RPA Assessment and Program; and

4. To distribute Regional shares of the RPA Program Goals to each of the National Forests.

Since many major transportation issues are State-wide, or multi-State in scope, they are difficult to address in particular National Forest plans. For this reason, major transportation issues should be raised at the Regional planning level. Regional plans may address critical transportation issues or corridor designation; however, most will not deal with specific land allocation decisions. Instead, the Regional plan will develop specific criteria and instructions for those National Forests involved to ensure that each issue is addressed in their respective planning efforts. For example, the need for a major transportation corridor may be identified at the Regional planning level. Instead of actually allocating affected lands for that purpose, however, the details of how the land may be used and possible developmental constraints will be left to the concerned Forests. The Regional plan merely provides the direction and guidance to the Forests for making those decisions.

NATIONAL FOREST PLANNING

For many years, the Forest Service has been preparing what we referred to as "multiple-use" plans -- not because we were required to, but because it was good business to do so. Now, these plans are required under the National Forest Management Act of 1976, and are known as National Forest Land and Resource Management Plans. Within them, decisions are made about how National Forest land will be allocated, managed, used, and protected.

All National Forests are required to complete integrated-resource plans by 1985. To meet review and approval requirements by this date, the Forest Service has set an administrative target for completion in 1983, by which all functional resource plans are to be integrated into one plan. This requirement is significant because prior planning efforts were single-resource in scope; hence, there was no effective way to evaluate the management of one resource in relation to any others. NFMA now requires that kind of analysis. The plan must be prepared by an interdisciplinary team consistent with policies established by the National Environmental Policy Act and NFMA.

Forest plans are particularly significant because they will determine the level, kind, and timing of

activities that will take place in each National Forest, including the quantity of goods and services that each National Forest will provide in both the short term and long term.

Regulations promulgated under NFMA prescribe a standard 10-step procedure common to the development of all Forest plans:

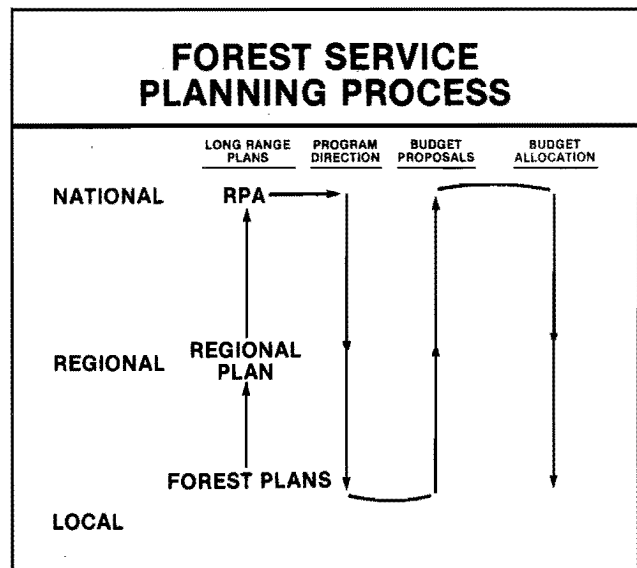
1. Identify the issues and management concerns to be resolved in the planning effort, and the opportunities for resource use and development. This is the key point at which the public is involved, and is the critical time when transportation issues should be identified in the planning process. Under NEPA, this process is referred to as "scoping."
2. Set the criteria to be used in preparing the plan; that is, define how public issues will be used, how inventory data will be used, how alternatives will be evaluated, and how the plans and programs of other agencies will be coordinated.
3. Gather data and take inventory; that is, collect all the biological, physical, social, and economic information to be used in the planning effort.
4. Analyze the management situation. At this stage, a determination is made of a Forest's ability to produce goods and services; for example, a Forest's biological capability to produce timber. In this analysis, the Forest Service examines a number of scenarios for resource production to provide a basis for formulating a range of reasonable alternatives.
5. Formulate alternatives. After assessing the possible scenarios developed in the previous step, alternatives are developed to provide different ways to address and respond to the major public issues, management concerns, and resource opportunities that are identified during the early stages of the planning process.
6. Estimate the physical, biological, economic, and social effects of implementing each feasible alternative. This is one activity with which we have some difficulty, particularly because some effects, transportation effects, for example, may occur well beyond National Forest boundaries.
7. Evaluate the significant physical, biological, economic, and social effects of each alternative. This includes a comparison of the costs and benefits of the alternatives. This comparison helps us

recognize those alternatives that provide the greatest public benefit.

At the conclusion of this step, the Forest Service prepares a Draft Environmental Impact Statement and Plan, and publishes them for public review. The Draft EIS identifies the Forest Service preferred alternative upon which the Plan is based. At this point State transportation agencies should conduct an in-depth review to determine what effects, if any, the proposed actions will have on transportation issues.

Steps 8, 9, and 10 involve approval of the Plan recommended as the preferred alternative in the Final Environmental Impact Statement, implementing it, and monitoring it.

In summary, the Forest Service planning process involves National, Regional, and Forest planning levels, and occurs independently at each level; but the whole process is interactive (see Figure). Forest planning feeds information to the Regional level; in turn, the Regional plan feeds information to the National level. Through the assessment and program activities, RPA gives national program direction (including goals and output objectives) to the Regions, which pass them on to the Forests. Budget proposals are made through the same process; and when appropriations are made, allocations flow back down.



The SIGNIFI-
CANCE of
FOREST SERVICE
PLANNING

Why is Forest Service planning important from a transportation standpoint? At present, National Forests--particularly in the West--make up large areas for which planning is being done. If National Forest land is combined with other Federal lands, the areas involved are even more significant; for example, the State of Nevada is 86 percent federally owned, of which 6 percent is National Forest. Although other Federal agencies are not yet engaged in the same kind of comprehensive planning effort as the Forest Service, all are planning to some extent; their planning principles, if not their procedures, are basically the same.

With this amount of land under continuous review for land use decisions, transportation concerns of all kinds are affected. Some specific examples may help to illustrate the point.

The overthrust belt that runs through the Intermountain West has been identified as having one of the Nation's greatest potentials for development of energy and minerals. Much of these resources lie on National Forest land. Development of these resources will require transportation of raw materials and generated power to the population and industrial centers in the East and West. Since Federal lands are so extensive in the West, land management decisions will influence the location of possible corridors. As suitable corridor locations on Federal lands become more limited, the flexibility of States to regulate siting of power plants also becomes reduced. By the same token, decisions of State and local governments for power plant siting also influence corridor requirements. Land speculation is more active adjacent to acceptable corridors and increases as locations become more limited. As a result, the economies and the social stability of local communities may be affected. Frequent and continuous coordination among all agencies is required to ensure that decisions being made are consistent and compatible.

Mineral and energy development will also have a direct impact upon existing transportation networks and public services. State and local transportation officials must recognize the need for the relocation of workers to areas that are now lightly populated, as well as new transportation routes to serve mine sites, growing communities (and in some cases, whole new communities), and milling or processing facilities. Although the development of these resources is not totally under the control of the Forest Service, their existence and potential are recognized and displayed in the planning process.

Grain shipment from the agricultural Regions of Montana to the inland seaport of Lewiston, Idaho, is affected by Forest Service land management decisions. Approximately 10 percent of Montana's wheat that is destined for west coast export flows over U.S. 12 across northern Idaho. This grain haul has had a severe impact on the highway, and more efficient transportation facilities are needed. Since the route is flanked by a classified Wilderness and a Recreation River (classified under the provisions of the Wild and Scenic Rivers Act), the opportunity for major improvements is severely limited. The availability of corridors for alternate routes is constrained by difficult and sensitive topography; land-use decisions that affect any remaining alternatives could impose further constraints.

Because the social and economic effects of National Forest planning in these cases will be felt far beyond the boundaries of those Forests involved, it is difficult for the Forest Service to assess them in proper perspective. State transportation officials must be in a position to draw our attention to the possible consequences of which we are not aware, and to provide us with realistic cause and effect data, so that we will be able to choose rationally among the available management decisions.

Probably, the above examples are self-evident; yet, how do these issues pertain to the three Forest Service planning levels? Since the National level plan deals with broad program policy, emphasis, and goals, it will be difficult for transportation officials to identify specific issues. However, there are a number of things to keep in mind. A major policy shift emphasizing higher levels of commodity production can be looked upon as creating the potential for impact on existing networks. For example, major increases in timber production--whether for providing raw material for housing or for bio-mass energy production--can only be achieved in those localities having significant growth potential. Increases will not be distributed evenly throughout the Nation, as that potential does not exist everywhere. The impact, in terms of increased truck or rail haul, will be felt in more localized areas. Transportation officials can be alert to identify the problems, and should be in a strong position to help formulate both the RPA Assessment and the Program.

A major shift toward increased Wilderness classification will have a different effect, because opportunities for additional corridors may be foreclosed. Again, new Wilderness designation will only occur

where the potential exists, and transportation officials need to be aware of those opportunities and the consequent impact on transportation needs.

As mentioned earlier, the Regional planning level provides the opportunity to surface more specific transportation issues that are multi-Forest, State-wide, or multi-State in nature. Particular attention should be paid to Regional emphasis and to the assignment of production levels to each of the National Forests.

National Forest planning is most site specific. Land is allocated for various uses and activities, and production levels over defined time periods are determined. Thus, Forest level planning has the greatest potential for resolving issues concerning transportation facility use or location.

The STRATEGY for INVOLVEMENT

Since the ultimate viability of our planning process is dependent to varying degrees upon the active participation of other Governmental agencies, various organizations, and the general public, the process has been designed to solicit the involvement of those groups at strategic points. This applies at all three levels of planning; the two principal points are at the very beginning (during scoping efforts when issues, concerns, and opportunities are identified), and during the review of draft plans and draft EIS's. Prior to each of these points, public notification is provided by direct mailing to those we know have an interest, by publication in the Federal Register, and by formal notification to State Governors and State Clearinghouses.

Transportation planners and others who are concerned with transportation issues are invited and encouraged to participate directly at these structured points in the planning process. In addition, they are strongly encouraged to become actively involved through their respective Governors' Offices. The Governor's position is sought on matters concerning planning at all three levels. His position, however, is strongly influenced by those who advise him and who are most knowledgeable about National Forest related issues. Because the activities and concerns of most State resource agencies are similar to those of the Forest Service, the State planners are often in the best position to provide advice and counsel to the Governor and his staff. Our experience has shown that the Governor's position or response to Forest Service planning activities frequently reflects the advice of these agencies. To ensure that State or local transportation concerns are equally reflected, agencies with those responsibilities must be in an equally influential position. In this way, the Governor will

be better prepared to offer a position that reflects a balance of resource activities that accommodate transportation or commerce issues.

National organizations, such as the American Association of State Highway and Transportation Officials (AASHTO), Standing Committee on Planning, and its companion WASHTO Committee, can also play an important role. Through subcommittees, Regional or multi-State issues can be identified. These same groups are in a position to provide valuable advice and assistance to individual member States on such matters as current and pending legislation governing the activities of all land management agencies, and to feed information concerning major issues to the National umbrella organizations.

SUMMARY

The planning activities of land management agencies, such as the Forest Service, will have a significant effect on transportation issues of all kinds. State and local planners, and those concerned with transportation matters need to be aware of these activities, and be in a position to ensure that land use decisions are consistent with transportation needs. This can be achieved only through direct and active involvement in those planning efforts, and by working with other State agencies, their Governors' Offices, and national organizations.

Improving Road Location & Network Design with Digital Terrain Models

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The Forest Service annually locates, designs, and constructs hundreds of miles of roads of varying standards. These roads provide access to timber and other resources; most are in rugged, mountainous terrain, often traversing fragile soils and environmentally sensitive areas.

The siting of locations for these roads is a significant management problem, and FS characteristically relies on judgments of experts in several disciplines to make location decisions. Geologists, biologists, hydrologists, foresters, engineers, and others commonly provide guidance for selecting the most favorable location by assessing impacts and costs of various roading proposals.

Usually because of manpower and time limitations, only a few locations for each road are analyzed; in fact, in the majority of cases, only one route is given an intensive study and cost analysis. Often, during engineering design, localized problems are dealt with by making design modifications, but the quality of the end result suffers because of our inability to make more than superficial reviews of possible alternatives. Meaningful cost or impact assessments are seldom made of all alternatives, thus weakening the justification of the management decision.

DIGITAL TERRAIN MODELING

For many years it has been possible to model large areas of terrain, with thousands of salient terrain points stored as X, Y, and Z coordinates. Computer programs have been developed to manipulate these data so that plots can be drawn that enable us to identify terrain features which are significant from a road construction and impact standpoint. Moreover, these same data can be processed to extract measurements needed for preliminary road design.

Thus, terrain modeling offers a way to qualitatively and quantitatively compare costs and impacts among several road locations, whereby the most favorable can be selected. Once the terrain is modeled to a suitable level of fidelity, the comparison can be made in the office, in a reasonably short time, without expensive field surveys.

The key to the validity of impact analyses and cost estimates of road locations lies in the fidelity of the terrain model. There are numerous ways to acquire digital models of terrain. The most widely available are the so-called DMA tapes, which were used years ago to manufacture the molds for raised relief maps of mountainous areas in the United States; the resolution of this data is too coarse, however, for the purposes under discussion.

Another source of terrain data is the USGS DEM tapes, which are a by-product of the orthophoto production process. These tapes generally have an r.m.s. of 7 meters, which approaches the level of fidelity necessary for some types of analysis; however, they are available presently in only a few areas of the United States.

The contour lines of existing topo maps can be digitized to create terrain models. This source may or may not be suitable, depending on the map scale and contour interval, and the amount of generalization of the terrain introduced through "topographic license."

The most reliable terrain data for road analysis purposes is obtained by directly digitizing a photogrammetric terrain model of suitable scale. By selecting critical points of sufficient number and proper location, the terrain can be modeled efficiently and accurately, and the products derived from the model can be used with confidence. The terrain data file should contain a sufficient number of strategically placed and properly coded points, so that the terrain can be accurately described; too many points result in wasted operator and computer time; too few points, or a lack of points defining critical changes in terrain, result in an inaccurate representation of the terrain.

In addition to the number and distribution of data points, other factors that contribute to the vertical and horizontal fidelity of derived graphical and numerical products are (1) photogrammetric measurements; (2) vegetative cover; and (3) terrain characteristics.

Two factors govern the reliability of photogrammetric measurements: (1) reliability of ground control, with accurate fit of the model to it; and (2) density and spacing of points that define the terrain in the stereo model.

The accuracy of the photogrammetric measurements related to the ground dictate the expected level of

accuracy of the data file. The best precision attainable in high-order analog optical stereo plotters is generally conceded to be not less than 1/10,000 of the flight height, for 6-inch cameras with 60 percent overlap; in practice, we seldom meet this level of precision, more often achieving a value of about 1/6,000, both vertically and horizontally (r.m.s.)

Internal validity of the data file is assessed by comparing a number of measured elevations with elevations of the same points computed from the data file. The discrepancy in these values is analyzed statistically. In practice, the r.m.s. of this discrepancy ranges from 1/1,000 to 1/3,000 of the flight height, with the average about 1/2,000. To meet map accuracy standards, the contour interval for a map derived from the data file should not be less than about $2 \frac{1}{2} (\sqrt{E^2 + I^2} + |M|)$, where "E" is the external r.m.s. (vertical), "I" is the internal r.m.s., and "M" is the average internal discrepancy.

In order to model the terrain, one must be able to see either it or a reasonable representation of it. The smaller the scale and the larger the derived contour interval, the less critical tree canopy becomes. At photo scales of 1:50,000 and smaller, the vegetative cover constraint becomes insignificant. For large-scale photogrammetric projects (e.g., photo scales of 1:30,000 and larger), tree cover should not obscure more than about 50 percent of the ground surface. Areas of the model where tree cover exceeds about 50 percent should be excluded, or identified as not meeting basic accuracy, or field-completed.

Geomorphological characteristics of the terrain have a significant influence on the data file size. Relief, steepness of slope, predominant shape of slopes, and dissection of terrain--each has to be considered when designing the data file.

Terrain with large relief amplitude and steep slopes requires more contour lines for a given contour interval than does terrain with lesser slopes and amplitude. Since the manner in which computer programs produce contour plots is related to the number of points per contour, more contours will require more data points.

Slopes that are predominantly flat should yield an average internal discrepancy (M) near zero, as will terrain containing a mixture of slope shapes. Convex slopes should yield a negative average M, while concave slopes, a positive. Increasing the number

of data points on concave or convex slopes should tend to make the average M approach zero.

For poorly dissected terrain that contains a large number of slope-reversals, a large number of data points are required to model the terrain with fidelity. This criterion, however, should be assessed in conjunction with slope amplitude versus contour interval, i.e., only the significant terrain changes need be modeled.

For some applications and in some terrain (e.g., uniform slopes) data collected by raster scanning are satisfactory. However, random digitizing is generally the most efficient technique, requiring fewer numbers of strategically placed points to define the terrain.

This technique provides for separately digitizing critical terrain features (e.g., ridges, drains, and breaks), and supplementing these points with general terrain points to complete the model. When digitizing, it is helpful for the operator to visualize a triangular "facet," the three vertices of which are at digitized points, and the plane of which "rests" on the ground. Areas in which the plane of the facet do not appear to hit the ground should be supplemented with additional points. The facet shape should be kept nearly equilateral.

While digitizing, the elevation of a number (at least 30) of well-separated points is measured and recorded in a separate file. The elevations of the same points are then computed and compared to the measured values. These data provide a means of statistically testing the model fidelity. The data should be used for analysis of map accuracy and bias according to the ASP "Proposed Accuracy Specification for Large Scale Maps."

In addition, these data should be used to compute the limiting contour interval and to identify areas of the map that fall outside the accuracy standard.

The final map produced from the digital file should contain a statement revealing compliance of the scale and contour interval with the proposed ASP standard.

In mountainous terrain, a data file which can produce a map with contour interval of about 25 feet or less is satisfactory for reconnaissance level road analysis.

GRAPHIC PRODUCTS
for ROAD NETWORK
DESIGN

The traditional large-scale contour map is the basic graphical tool used by transportation system designers. This map, produced from the digital data file, will continue to be used by engineers to lay out road locations. Because the map is referenced to the terrain data file, likewise, proposed features can be oriented to the same reference frame. The terrain data is used to produce plots of terrain parameters, such as slope and aspect, that are of interest to the road locator. Plots of slope or aspect zones enable the engineer to avoid locations through areas that are critical because of slope or aspect.

Perspective plots, or the terrain as visualized by an observer from key points, can be made with the proposed road shown. Areas visually or esthetically sensitive to construction can be identified and the potential impacts assessed. Means to mitigate them can then be developed.

Proposed construction can also be shown in correct location on vertical or oblique aerial photos, by photo resection. This will also allow a more complete analysis of impacts and identification of problem areas by photo interpretation.

ROAD SYSTEM
ALTERNATIVES

It's always possible to "get there from here" by several ways. Unroaded terrain in which access is required for resource utilization can be made for a thorough analysis of several road system networks.

Networks should be generalized at first, then very carefully laid out on the large-scale topographic map, using whatever controls are appropriate (e.g., road grade, avoidance of problem areas, alinement, etc.)

Individual routes then can be digitized from the topographic map. The coordinates of the proposed alinement define the alinement in the same coordinate reference system as the Digital Terrain Model, and then are converted to stations, bearings, and curve radii.

Terrain information is used to compute and plot the center-line profile, and slope cross-sections at uniform intervals, resulting in engineering data used for preliminary design of the roadway and computation of comparison quantities such as earthwork volumes, clearing acreage, and drainage. Comparative construction cost estimates are then made.

It should be noted that these estimates of quantities and costs are for comparison purposes only, to identify the apparent, most economical route;

but the estimates will not generally be accurate enough for contract estimates or planning purposes. Development of cost data accurate enough for these purposes will depend on more refined terrain measurements, which may be made with conventional ground surveys or by photogrammetry from project photography especially planned, flown, and controlled.

By analysis of environmental and esthetic impacts of the proposed route, the most favorable selection (considering these criteria) can be identified. Use of perspective plots and photo resections will aid in this analysis, and approximate costs of route selections made for environmental reasons can be determined.

FINAL GROUND LOCATION

Inevitably, the route(s) selected must be located on the ground before construction. Additional investigations as to suitability may be made on closely competing options. Certainly, Engineering surveys must be made for final design and control of construction, at least for the route finally selected.

The usual procedure for route location is to make a preliminary recon on the best available map. A single feasible route is identified; occasionally, this may be approximately sketched on an aerial photo. A route locator takes these materials to the field and, by trial and error, flags the location on the ground. Because of imperfect mapping, the recon route is usually only an approximate method, requiring many false starts and trial grades to be run. This procedure is time consuming and inefficient.

By use of the DTM, an accurately studied and analyzed route can be precisely placed on large-scale aerial photos. Using the photos as the main location tool, the locator can rapidly and efficiently flag the location, without the need to run trial grades and other data. The advantages in time and cost savings are obvious.

The route can be field revised, as needed, to make localized refinements and improvements in the flagged line. Once a final line is flagged, standard route surveying techniques are used to make the necessary measurements for engineering design and construction.

OTHER CONSIDERATIONS

Once the significant features of terrain are recorded in a digital model, the data can be used for a variety of other purposes.

Almost any proposal requiring terrain parameters for design or analysis can be studied by use of the DTM, for once digitized, always digitized.

Cable logging systems, for example, require the analysis of terrain profiles under the proposed cable span. These profiles can easily be generated from the terrain model. Profiles for pipelines and power transmission lines can likewise be developed.

The visual impacts of terrain modification schemes such as clearcuts can be previewed and assessed.

Any "imaginary" line can be projected with precision onto aerial photos for study or field layout. Such lines as sale-area boundaries and wilderness boundaries can be located easily in the field by reference to the air photo.

Transportation system networks can be analyzed by computer processing. Input parameters such as grade, curve radii, and length can be computed for either proposed or existing systems by use of the terrain model, thus reducing expensive collection of this information by field methods.

CONCLUSION

In road construction alone, the potential exists for great savings by use of DTM for analysis and selection of the best option. One good way to save road costs is to build only roads that are needed, for example, 20 miles instead of 22 miles. The cost saved in not constructing the extra 2 miles could more than pay for the analysis of hundreds of miles of road!

Analysis of several options can also reduce construction and continuing maintenance costs by enabling the intelligent selection of the option with the most favorable life-cycle costs.

Costs can also be saved by improvements in the efficiency of layout of the route selected.

Although cost savings are important, perhaps of even greater importance is the opportunity to improve the quality of decisions by managers. Environmental impacts can be quantitatively compared and assessed. No longer must we totally rely on changeable and subjective judgments, which are well known for weakness to attack by others. Use of DTM will enable documentation of analysis and decision as perhaps no other means now in use allows. The support this offers when decisions are criticized should be obvious.

Use of DTM has future, as well as current, benefits. With experience, these techniques can be refined and improved so that final designs and estimates of cost can be developed. These advances portend additional savings in reducing the amount of time and energy to be spent in the collection of field measurements.

DTM's can be used today at little cost and with limited training. The Forest Service should aggressively pursue this technology.

A Guide for Determining Minimum Road Width on Curves for Single-Lane Forest Roads

*Carl Cain, Civil Engineer, Region 1
and*

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Several methods have been devised to determine the offtracking of the rear wheels of log trucks and lowboys. Each method has had various degrees of acceptance. There are several questions or criteria one may consider in evaluating a method:

1. Is it easy to use?
2. Is it reasonably accurate, so that land impact and road costs are minimized, yet safe, negotiable curves will result?
3. Is the central angle (Δ) of the curve considered?
4. Is the method easily adaptable for various vehicle configurations?
5. Does the method give total vehicle offtracking (considering the path of both the front tires of the tractor, and the rear tires of the trailer), rather than only the offtracking of the trailer as a single unit?

These criteria were used to review several papers published previously; the steps were (1) review and evaluate existing methods; (2) show how data were extracted from two existing methods to form a new method; (3) display values obtained from this new method with values from a tractrix integrator and field tests; and (4) graphically display the minimum traveled way for a standardized lowboy and log truck.

A common method of establishing the offtracking is $400/R$ for lowboys, and $200/R$ for trucks. This meets criterion number 1, but not numbers 2 or 3. Further, it results in excessive road width on curves with small central angles and inadequate width on curves with central angles over 50 degrees.

In October 1976, Leonard Della-Maretta and Michael Cisneros of the FS San Dimas Equipment Development

Center (SDEDC) published "Trailer Tractrix Equations and Computer Program for Curve Widening"; that information was revised in September 1978. Their described procedure is precise, but fails to meet criteria numbers 1 and 5. From the equations presented in the SDEDC publication, Rick Nelson, FS Civil Engineer, made charts for a 40-foot and a 55-foot trailer, and developed an equation to calculate the offtracking of a tractor. (The charts were published in the August 1978 issue of Engineering Field Notes.) This procedure meets criteria numbers 1, 2, 3, and 5, but does not meet number 4.

Two other papers were reviewed: "Transport of Logging Equipment and the Effect on Geometric Roadway Design Standards," by James R. Smith, FS Civil Engineer (April 1972); and "A Graphical Method for Determining Log Truck Tracking Patterns," by John Sessions, FS Civil Engineer (August 1976). These methods meet criteria numbers 2, 4, and 5; James Smith's procedure meets criterion number 1, but neither procedure meets criterion number 3.

Jim Langdon, FS Civil Engineer, took Nelson's charts and derived a reduction equation by using a regression analysis; this was combined with Smith's equation to give the following:

$$C = \left(R - \sqrt{R^2 - L^2} \right) \left[1 - e \left(-.015 \Delta \frac{R}{L} + .216 \right) \right]$$

Where:

C = Total vehicle offtracking

R = Radius at the centerline of the roadway

e = Base for natural logarithms

Δ = Central angle

$$L = \sqrt{\sum_{i=1}^n L_i^2} \quad , \text{ or the square root of the sums of the wheel bases}$$

For a lowboy or standard tractor-trailer:

$$L = \sqrt{L_1^2 + L_2^2 + L_3^2}$$

Where:

L_1 = Wheel base of the tractor (feet)

L_2 = Distance from the fifth wheel to the middle of the rear duals for the first trailer (feet)

L_3 = Distance from the fifth wheel to the middle of the rear duals for the second trailer (feet)

For a log truck or any vehicle with a stinger, L is calculated in the following manner:

$$L = \sqrt{L_1^2 + L_3^2 + L_2^2}$$

Where:

L_1 is the wheel base of the tractor (feet)

L_2 is the length of the stinger (feet)

L_3 is the distance from bunk to bunk (feet)
minus the length of the stinger

Note that as the central angle (Δ) becomes large, the reduction portion of Langdon's equation (the portion in brackets) goes to 1. Thus, for large central angles, the values obtained are identical to those from Smith's procedure.

This equation was tested twice. First, it was compared with results obtained in a report entitled "Truck Paths on Short Radius Turns" (May 1972), prepared by the State of California, Division of Highways (Caltrans) in cooperation with the Federal Highway Administration, for a tractor-lowboy combination.

Caltrans devised a tractrix integrator model to simulate offtracking, and compared its results with field measurements of the offtracking for a combination of four radii and six central angles. The maximum discrepancy was 3.1 percent.

The tractrix integrator model was adjusted for a tractor-lowboy with dimensions of 18 feet for the tractor wheel base, and 36 feet from the "fifth wheel" to the center of the rear duals.

Table 1 is a comparison of values obtained from Langdon's formula with those from Caltrans' adjusted tractrix model.

Table 1.--Offtracking (feet), central angle (Δ).

Radius at		30°	60°	90°	180°	400/R
44'	Langdon	6.3	13.6	18.8	24.5	9.1
	Caltrans	6.8	11.7	15.4	21.5	
54'	Langdon	5.8	11.3	14.3	17.4	7.4
	Caltrans	6.3	10.3	13.2	16.7	
69'	Langdon	5.5	9.5	11.4	12.8	5.8
	Caltrans	6.0	9.2	11.1	12.4	
94'	Langdon	5.1	7.7	8.6	9.0	4.3
	Caltrans	5.3	7.5	8.3	8.8	

The second comparison was of values obtained by the new formula with field measurements of offtracking made by a stinger-type vehicle (log truck).

In cooperation with Champion International's office at Bonner, Montana, four members of Region 1's Engineering Staff conducted the field test. A loaded log truck was used with dimensions slightly different from those for the log truck used to form Charts B and D. The test was run with a combination of five radii and seven central angles, on a dirt-surfaced empty log yard. The measurements made are given in Table 1, which also shows values obtained from the formula and 200 over R. Field measurements could be off up to 0.5 feet, because measurements were made from visual observations of tire tracks to a line marked with lime, which the driver did his best to track with his left front tire. Figures 1 through 5 show this test being conducted, and illustrate the procedure and conditions.

Recommended use and limitations of the formula are

1. Minimum lane width (MLW) should be 10 feet plus C (value obtained from the formula); however, the MLW should not be less than 12 feet, thereby allowing 2 feet to compensate for formula and driver's errors, grade of road, and road superelevation.

2. Disregard extra width for offtracking when C is less than 2 feet; this happens

a. when the central angle is less than 12° ;

b. for a tractor-lowboy when the radius exceeds 400 feet; and

c. for a standard log truck when the radius exceeds 175 feet.

3. Charts A through D show the MLW for a standardized truck-lowboy combination and log truck. The



Figure 1.--Offtracking being measured by members of R-1's Engineering Staff. (Left to right: George Tuxbury, Ted Zealley, and Bill Schnelle.)



Figure 2.--Offtracking of the log truck as it leaves a curve on a tangent.

dimensions of the equipment were discussed with Engineers in Regions 5, 6, and 10.

Tapers were observed during the field test of the log truck and from Caltrans' report on their integrator model (table 2). Most of the widening is necessary when the vehicle leaves the curve; however, the vehicle travels both directions. Therefore, the full amount of widening should occur at the point of curvature (P.C.) and point of tangent (P.T.).

Recommended length of tapers before the P.C. and after the P.T. are as follows:

<u>Radius (feet)</u>	<u>Length of Taper (feet)</u>
under 70	60
70 to 85	50
85 to 100	40
over 100	30

The National Forest Management Act requires roads to be designed appropriately for their intended use; consideration should be given to safety, cost, and impact on land and resources. This curve widening procedure provides the accuracy necessary for designing safe negotiable curves; road cost and land impact are reduced by constructing no more road width than is necessary.

A simpler equation was desired, but because of the accuracy required, none was developed. Langdon's equation may be programed easily on most small programmable calculators.

Table 2.--Loaded log truck offtracking.

Central Angle (Δ)	50 Ft. Radius at $\mathcal{C}$									
	Field Measurements								Max. C by	
	P.C.	Central Angle Ahead of P.C.							New	200/
		19°	30°	46°	64°	90°	116°	180°	Formula	R
19°	1.8	2.1	--	--	--	--	--	--	2.0	4.0
30°	2.2	3.7	3.5	--	--	--	--	--	3.3	4.0
46°	2.2	4.6	5.0	3.7	--	--	--	--	4.5	4.0
64°	2.2	4.6	5.7	5.7	4.4	--	--	--	5.4	4.0
90°	2.2	4.6	5.7	5.8	6.3	4.8	--	--	6.0	4.0
116°	2.2	4.6	5.7	5.8	6.4	6.0	4.8	--	6.3	4.0
180°	2.2	4.6	5.7	5.8	6.4	6.0	6.8	4.7	6.5	4.0
Central Angle (Δ)	60 Ft. Radius at $\mathcal{C}$									
	Field Measurements								Max. C by	
	P.C.	Central Angle Ahead of P.C.							New	200/
		19°	30°	46°	64°	90°	116°	180°	Formula	R
19°	1.5	2.4	--	--	--	--	--	--	2.0	3.3
30°	1.5	3.6	2.9	--	--	--	--	--	3.1	3.3
46°	1.5	4.0	4.3	3.5	--	--	--	--	4.1	3.3
64°	1.5	4.0	4.3	5.2	3.9	--	--	--	4.7	3.3
90°	1.5	4.0	4.3	5.2	5.6	3.9	--	--	5.1	3.3
116°	1.5	4.0	4.3	5.2	5.6	5.7	4.0	--	5.2	3.3
180°	1.5	4.0	4.3	5.2	5.6	5.7	5.8	3.9	5.3	3.3

Note: The log truck used in this field test had the following dimensions: $L_1 = 19^0$, $L_2 = 9^0$, $L_3 = 18^2$.

*Probable measurement error.

Table 2. (continued)--Loaded log truck offtracking.

Central Angle (Δ)	75 Ft. Radius at $\mathcal{C}$									
	Field Measurements								Max. C by	
	P.C.	Central Angle Ahead of P.C.							New	200/
		19°	30°	46°	64°	90°	116°	180°	Formula	R
19°	1.6	1.7	--	--	--	--	--	--	2.0	2.7
30°	1.6	2.8	2.3	--	--	--	--	--	2.9	2.7
46°	1.6	2.8	4.7*	2.6	--	--	--	--	3.6	2.7
64°	1.6	2.8	3.8	4.3	3.1	--	--	--	3.9	2.7
90°	1.6	2.8	3.8	4.3	4.4	2.7	--	--	4.1	2.7
116°	1.6	2.8	3.8	4.3	4.4	4.2	3.2	--	4.2	2.7
180°	1.6	2.8	3.8	4.3	4.4	4.2	4.5	3.1	4.2	2.7
Central Angle (Δ)	100 Ft. Radius at $\mathcal{C}$									
	Field Measurements								Max. C by	
	P.C.	Central Angle Ahead of P.C.							New	200/
		19°	30°	46°	64°	90°	116°	180°	Formula	R
19°	1.0	2.1	--	--	--	--	--	--	1.9	2.0
30°	1.1	2.8	2.2	--	--	--	--	--	2.5	2.0
46°	1.1	2.8	3.4	1.8	--	--	--	--	2.9	2.0
64°	1.1	2.8	3.4	3.5	2.4	--	--	--	3.0	2.0
90°	1.1	2.8	3.4	3.5	3.3	2.6	--	--	3.1	2.0
116°	2.2	2.8	3.4	3.5	3.3	3.4	2.1	--	3.1	2.0
180°	1.1	2.8	3.4	3.5	3.3	3.4	2.8	2.2	3.1	2.0

Table 2. (continued)--Loaded log truck offtracking.

Central Angle (Δ)	125 Ft. Radius at $\mathcal{C}$								
	Field Measurements								Max. C by
	Central Angle Ahead of P.C.								New 200 /
	P.C.	19°	30°	46°	64°	90°	116°	180°	Formula R
19°	1.0	1.5	--	--	--	--	--	--	1.7 1.6
30°	1.0	1.9	1.9	--	--	--	--	--	2.2 1.6
46°	1.0	1.9	2.9	1.8	--	--	--	--	2.4 1.6
64°	1.0	2.4	3.3*	2.6	1.3	--	--	--	2.4 1.6
90°	1.0	2.5	3.0	2.9	2.7	1.6	--	--	2.5 1.6
116°	1.0	2.6	2.3	3.0	2.0	2.1	0.5	--	2.5 1.6
180°	1.0	2.6	2.7	2.7	2.4	2.4	2.4	1.2	2.5 1.6

Figure 3.--Measurement of the log truck.



Figure 4.--View of course showing various radii and central angles. The test was run on the outer radii first. The truck obliterated the lime lines as it tracked on them.



Figure 5.--Log truck returns after leaving the course on a tangent. To avoid confusion, the tangent lines were marked for one radius at a time during the test.



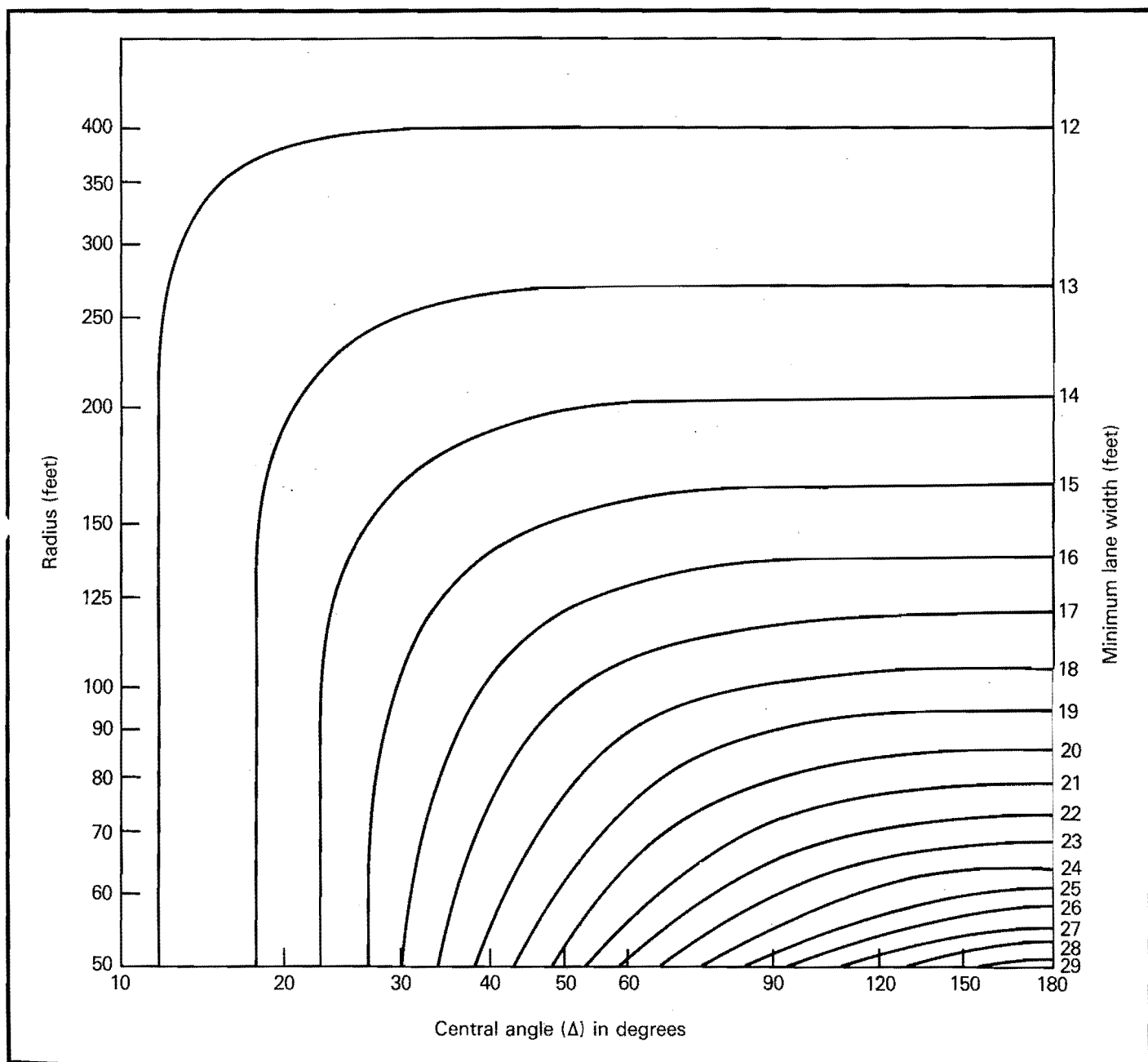


Chart A.--Minimum lane width for lowboy with a 18-foot tractor and a 36-foot trailer.

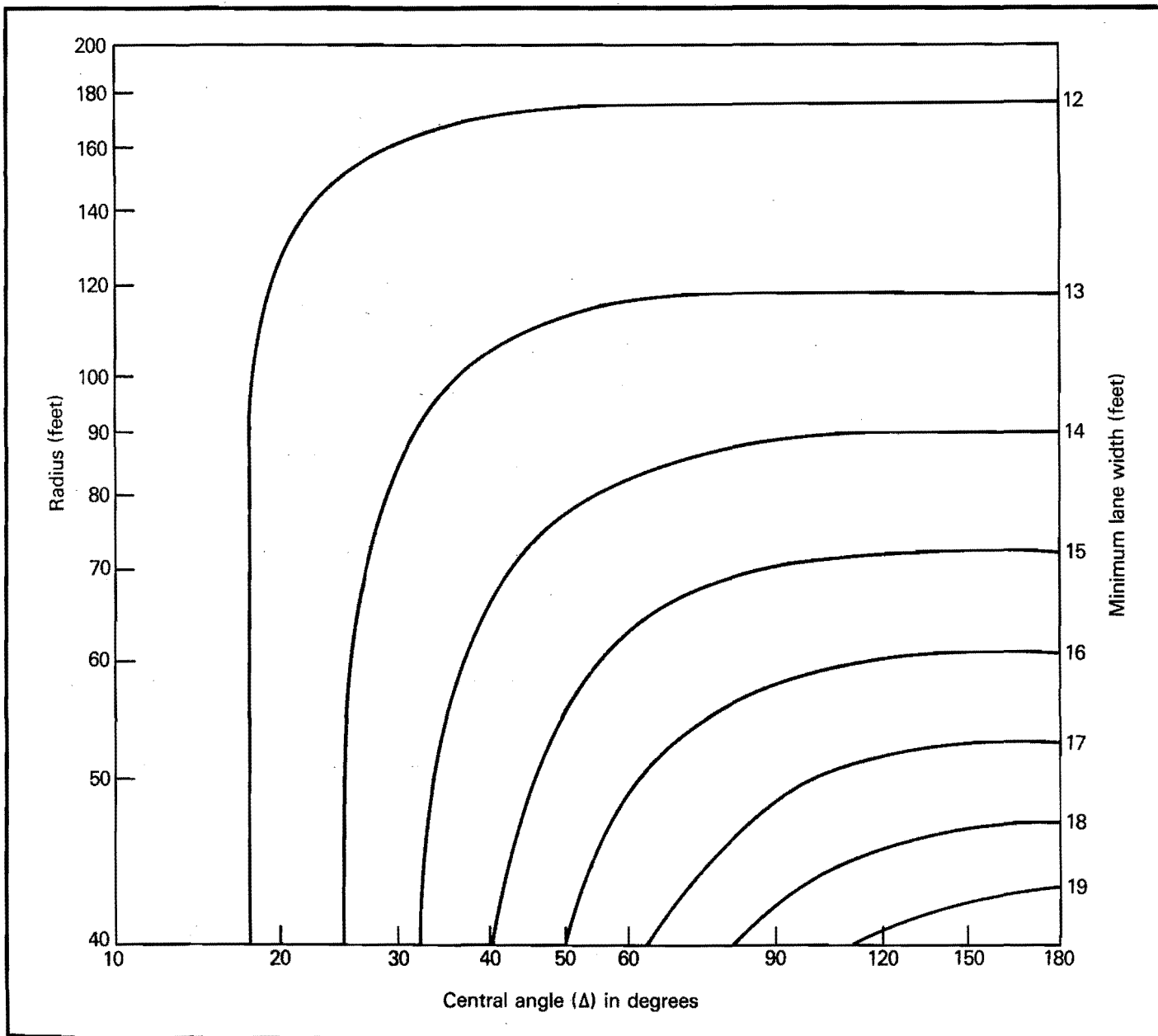


Chart B.--Minimum lane width for log truck with a 20-foot tractor, 10-foot stinger, and 30-foot bunk to bunk.

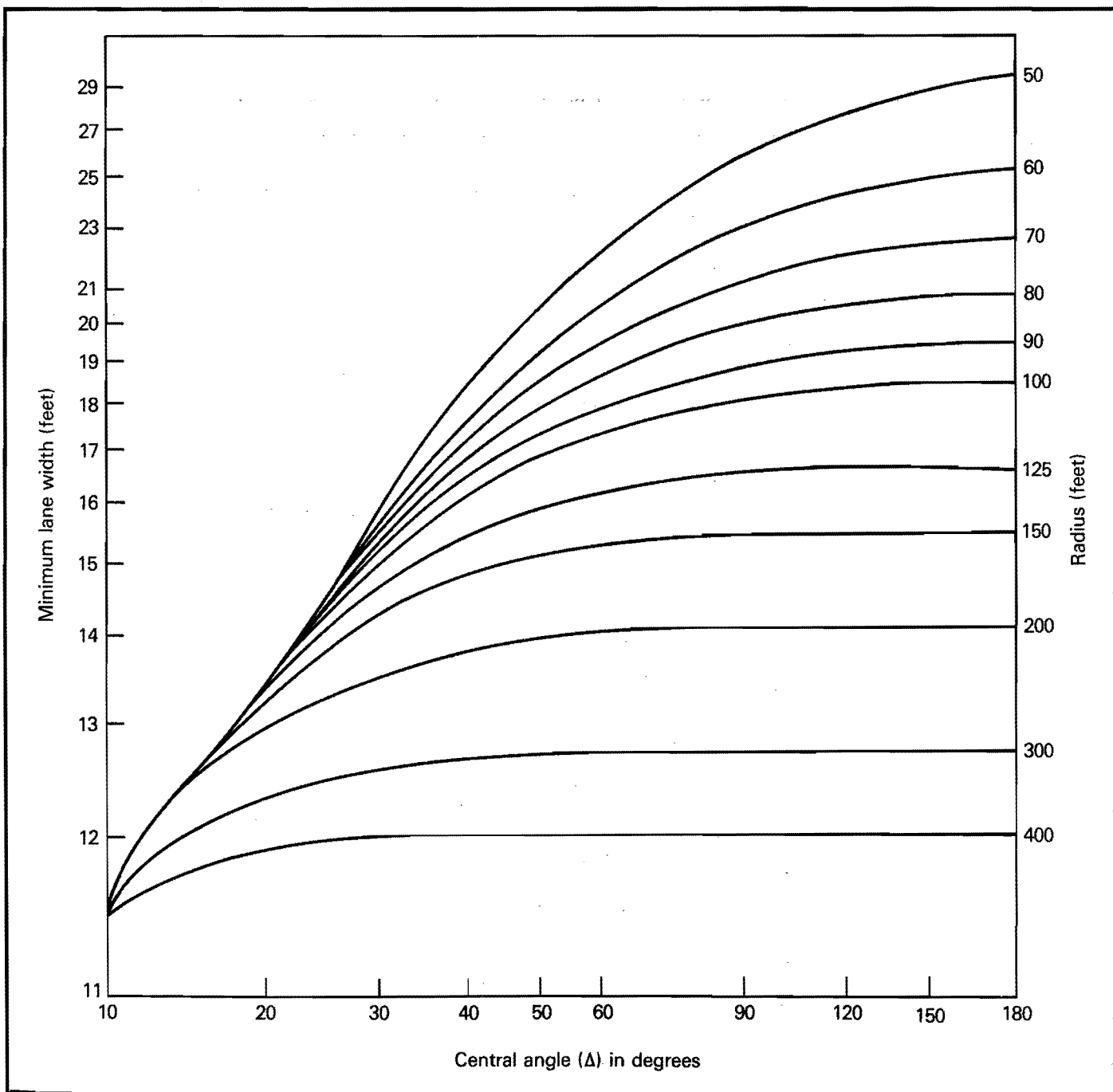


Chart C.--Minimum lane width for lowboy with a 18-foot tractor and a 36-foot trailer.

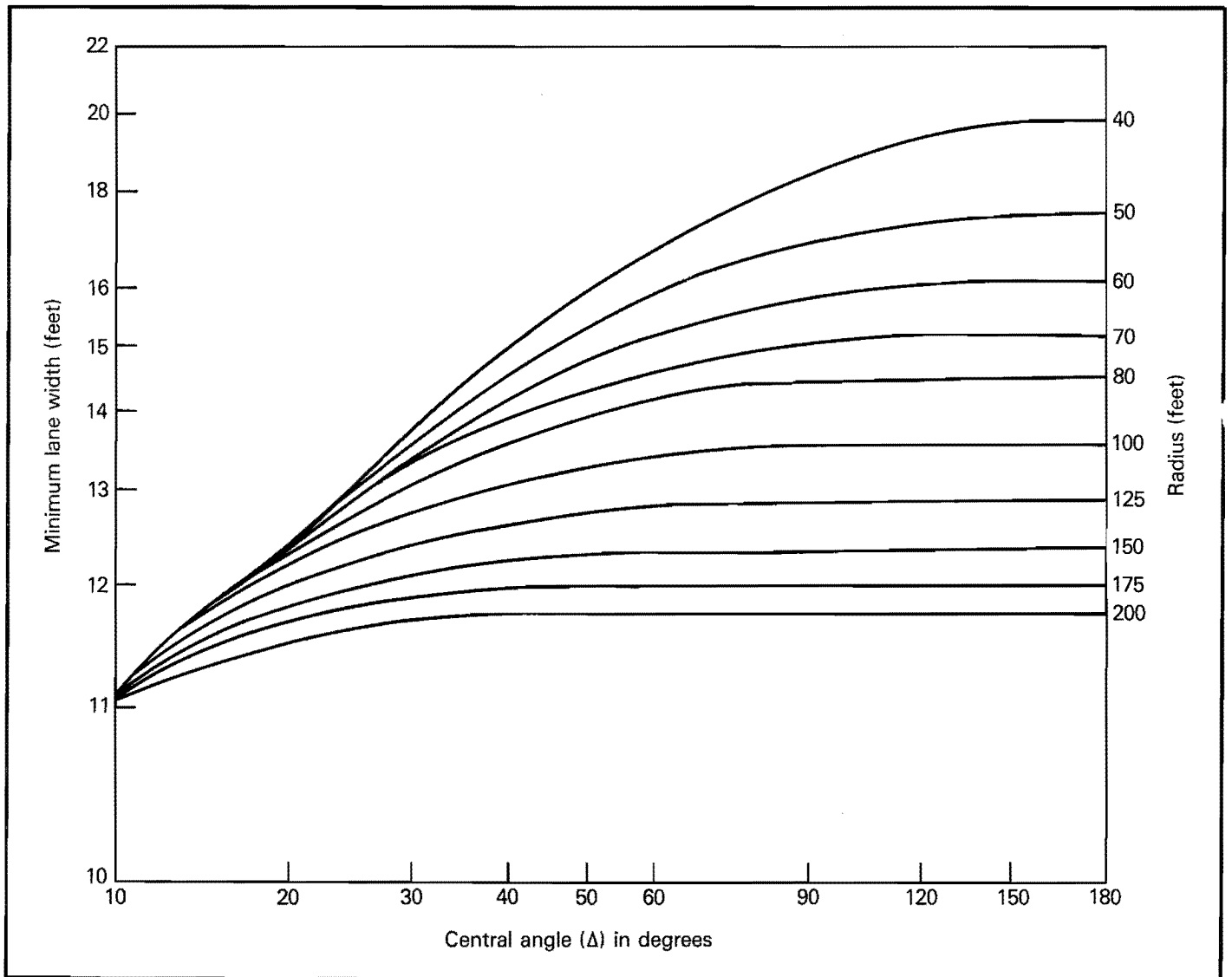


Chart D.--Minimum lane width for log truck with a 20-foot tractor, 10-foot stinger, and 30-foot bunk to bunk.



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