LOW-VOLUME ROAD GEOMETRIC DESIGN PRACTICES IN THE NATIONAL FORESTS OF THE UNITED STATES

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ABSTRACT

The United States has over 4 million kilometers (2.5 million miles) of low-volume roads. Many do not incorporate the standards of current highway policies. The application of these standards to road improvements would be extremely expensive and in many cases, unnecessary. Low-volume roads present unique design situations that require unique design solutions. Too often though, design standards for major highways are arbitrarily applied to low-volume roads, resulting in significant environmental impacts and costs. The USDA-Forest Service (FS) manages over 480,000 kilometers (300,000 miles) of low-volume roads. Many have a daily traffic of less than 50. FS roads are often located in sensitive environmental situations. As a result, geometric practices associated with high-volume roads have to be modified. To ensure consistency in the application of geometric design standards, the FS developed a National Preconstruction Handbook. This Handbook is consistent with the policies of the American Association of State Highway and Transportation Officials (AASHTO), while still providing flexibility for the design of low-volume roads. The FS recognized that low-volume roads function differently than major highways and that greater design flexibility and engineering judgement are needed. Traffic convenience often assumes a secondary role to the environmental and economic concerns. The FS design philosophy places a high level of responsibility for safety on the road user. By implementing a national low-volume road design practice, the FS has been able to defend against litigation even though some standards vary significantly from the more common highway policies. The FS practices can be successfully adopted by other local road agencies, if the special needs of low-volume roads are recognized and if increased engineering judgement is allowed in the selection of geometric design standards.

INTRODUCTION

The mission of the United States Department of Agriculture - Forest Service (FS) is to manage the land and resources of the National Forests. This is an extensive undertaking that occurs on over 77,000,000 hectares (190,000,000 acres) of land. The major resource activities involve the management of timber, watersheds, wildlife habitat, and recreation. All of these activities depend on road access in order to maintain a healthy and productive forest that benefits the needs of the country. Ecosystem management on the National Forests is a tremendous challenge, a challenge whose success depends on the availability of adequate land access.

The FS manages about 480,000 kilometers (300,000 miles) of road. Most of these roads are recognized as local and rural when compared with common highway classifications. Traffic volumes are quite low, most with less than 100 average daily traffic (ADT). Roads with an ADT of 50 or less are common. FS roads with very low traffic volumes are often single-lane with a two-way flow, having periodic turnouts for the safety and convenience of opposing traffic. Design speeds are usually less than 50 km/h (30 mi/h). The low traffic volume and design speed are consistent and suitable for the often severe environmental conditions.

FS roads are located in many different topographic situations, from the high mountains of the west to the low-lying lands of the southeastern coastal plains.

Climatic conditions vary from desert to rain forest. Although conditions vary significantly, most FS road locations have two common characteristics; they are located in remote areas and in very complex and sensitive ecosystems. The protection of fragile soils, water quality, and wildlife and fish habitat is usually emphasized over the efficient movement of traffic. This road design decision is acceptable because of the low traffic volumes.

Although FS roads have very little traffic in comparison to State and County highways, the FS roads do provide service to the same variety of vehicles as the major highways. Light traffic includes passenger cars, pickups, four-wheel drives, and recreational vehicles such as campers and trailers. Where timber or mineral production is managed, heavy log- and ore-hauling trucks are also accommodated. In many cases, this mix of traffic is served by the same road.

The design of the FS road presents an unusual challenge because of the application of common highway engineering practices to a facility that serves only a small number of vehicles but is located in an area with sensitive environmental conditions. The design has to provide a road over which the largest of trucks can maneuver. The design also has to recognize the safety of the users and has to protect the adjacent natural resources. All of these objectives are to be accomplished at a minimum cost.

This complex road design situation requires a unique approach, not by overturning the principles of highway engineering, but by CHANGING THE EMPHASIS of the highway engineering components. An example is design speed. Design speed is very important to high traffic volume roads; it is often ignored on FS roads. Accepted geometric design policies and guidelines, such as provided by the American Association of State Highway and Transportation Officials (AASHTO) (1), are modified when necessary to serve unique traffic needs and to accomplish the FS mission for land and resource management in the National Forests.

The success of the FS road program is highly dependent on engineering flexibility and judgement. The FS fully supports this concept, and readily accepts the need to consider variances from established geometric design practices. However, the FS also wants to ensure that these concepts are applied consistently throughout the National Forests. To accomplish this objective, the FS developed a national design handbook, the "Road Preconstruction Handbook" (2). This handbook provides guidance that is consistent with the AASHTO "green book" (1), while still allowing the design flexibility that is needed for low-volume rural roads. This national guidance establishes the Agency position on road geometrics, which is very useful in defending against tort claims.

This paper will present an overview of the FS geometric design practices, with an emphasis on the items that have the most flexibility. This presentation will also discuss the opportunities for local road agencies, such as a County, to adopt similar design practices.

DESIGN CONCEPTS

The FS geometric design considerations are the same as for any highway project. The geometrics are governed by the function of the road. Safety, traffic volume, vehicle size, and environmental issues are evaluated for the design. If effectively accomplished, a well-coordinated cross section and horizontal and vertical alignment result, and the users can expect a reasonably safe facility that provides adequate service (3).

The primary difference between the FS design philosophy and the design of high-volume highways is the increased flexibility that is available to the FS designer to vary a geometric element in order to resolve a problem with another element. For example, if a section of road is located in an area that must have minimum earthwork, an alternative will be considered to reduce design speed, narrow the roadway, and locate an alignment that conforms with the terrain. This design alternative will be considered even if other road sections have different characteristics. Traffic speed and convenience are reduced for the benefit of the soil resource. Similar evaluations are made between other elements. Even some safety related items may be reduced to assist the resolution of environmental problems. It must be remembered, of course, that this design flexibility is applied to low-volume roads, where efficient traffic movement is not as important as on major highways.

Each road design project is unique. Each project has road management objectives, design criteria and priorities that have to be evaluated. The goal is to obtain a balanced design that incorporates the environmental requirements and that provides an adequate facility for the movement of the expected traffic (3).

The influence of design speed on road geometrics is a significant difference between the high traffic volume road and the FS low-volume road. The FS handbook recognizes design speed as an important safety consideration, with less importance given to its effect on geometrics. Design speeds do not have to be the same throughout the total length of a facility, as long as variations can be implemented with a reasonable transition. The driver must be able to adjust speeds safely. Long tangents are a special problem on FS roads because of the preponderance of low-speed curves (4). The FS guidance is to refrain from using tangents, and instead design a series of curves to keep the speed lowered. Traffic control devices are not a good option to warn of speed changes because of vandalism in the remote road locations.

Most FS roads have low design speeds, primarily because of constraints with terrain. With a design speed of about 40 km/h (25 mi/h) or less, the speed factor can be ignored and the terrain dictates the alignment. A horizontal curve with a 15 km/h (10 mi/h) speed can easily be justified to co-exist with a 40 km/h (25 mi/h) curve. To the other extreme, a 60 km/h (35 mi/h) curve could be included in the design, as long as it is isolated and does not create a higher consistent speed. Consistency of alignment has to be recognized in order to minimize the safety problems associated with a few slow curves on an otherwise fast road. With overall slow speeds, consistency is not as great a concern.

The major point of the FS design speed philosophy is that environmental concerns and economics are more important than traffic speed and convenience on low-volume rural roads.

Safety is another design element that has flexibility. While the objective of any road design is to provide a reasonably safe facility, some latitude can be allowed on low-volume, low-speed roads. Some common features on a major highway, such as clear zone, may be dispensed with on a low-speed route. Driver responsibility is also an important aspect of the low-volume rural road. A greater degree of driver alertness is expected.

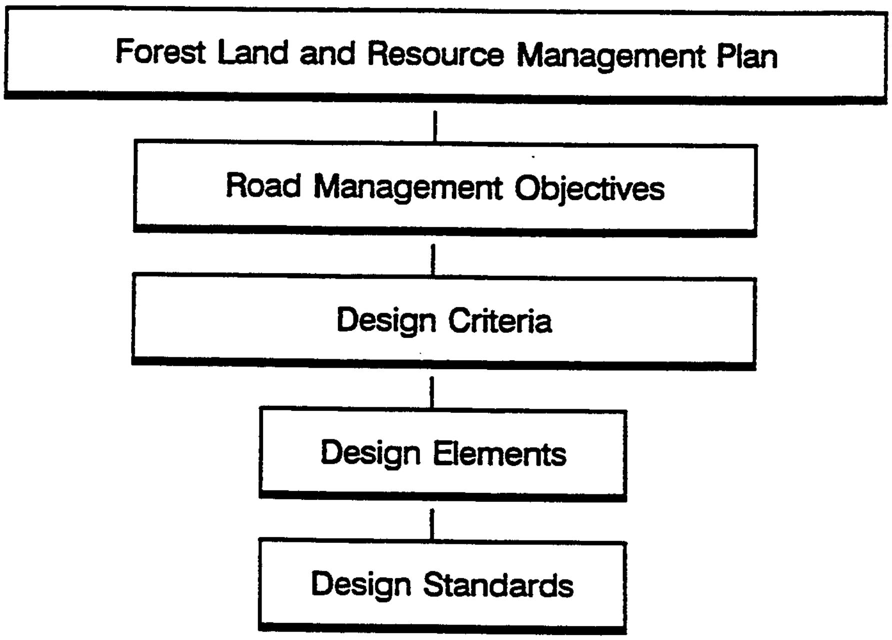
Driving in the rugged terrain of the National Forests requires an extensive amount of attention to the ever changing conditions. Some roads are often difficult to travel because of slow alignment and rough surfaces. Intersections may not have traffic control devices. However, these conditions are acceptable for low-volume roads, especially when the geometrics are consistent with other roads in the same area. Maintaining reasonable consistency in the road geometrics is an important design feature that can improve the safety of travel (5).

Since most geometric design practices have evolved from experience with interstates and major highways, an expectation often exists that the same practices will apply to low-volume roads. Anything else may be considered as inappropriate engineering. This expectation needs to be dispelled for all low-volume roads, as it is on FS roads. Such an expectation places a higher value on standard practices than on the environmental situation, traffic needs, and cost. Flexibility in the selection of design standards for low-volume roads is vital to achieving an economical facility with minimum impact on the ground.

ROAD MANAGEMENT OBJECTIVES

The flexibility that FS designers enjoy is not practiced in an arbitrary manner. Considerable thought goes into developing road design criteria. Land use objectives play a major role in determining which forest resources are served, the type of access needed, the traffic volume and composition, and ultimately, the road characteristics that will accomplish the land use objectives.

The access planning process has the following form (2):



Forest Land and Resource Management Plan

This plan provides direction on how the land and its resources are managed. The results of the planning decisions affect the access needs. For example, a designated wilderness area has no roads. A designated primitive area may have limited roads. A developed recreation area will need considerable access. The land and resource management plan also provides direction concerning the resource conditions and environmental issues. The plan is the foundation for developing the type of access needed, and the conditions with which the access has to comply.

Road Management Objectives

The road management objectives define the intended purpose of the road. This is a critical step in the planning process because it translates the land uses into access needs. Information to calculate traffic volumes and types is described. Environmental requirements are developed such as for soil and water protection and fisheries habitat protection. This step in the planning process establishes the objectives for the road design.

Design Criteria

The design criteria describe the users of the road, the type of service to be provided, the traffic types and volumes, the environmental considerations, and the economic constraints.

Design Elements

The design elements describe the physical characteristics that are needed on the road, such as the traveled way, shoulders, slopes, and pavement structure.

Design Standards

The design standards are the definitive lengths and widths of the individual elements, such as a 3.6 meter (12 foot) traveled way.

This access planning process provides the opportunity to fully document the relationship between the land uses and the design standards. It is a dynamic process where road management objectives influence the design and where the design can point out a need to change a road management objective. Design flexibility: this is the key to the success of FS low-volume roads.

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DESIGN CRITERIA

The criteria are developed from the road management objectives. For example, an objective may detail the need to protect an aquatic species in a stream adjacent to the road location. The criteria will utilize this information and develop methods by which this protection can be achieved, such as by constructing sediment basins, paving the road surface, and lining all ditches.

The road management objectives will also discuss the anticipated volumes and types of traffic. For example, traffic is expected to consist of camping vehicles and passenger cars. Some small logging operations will also use the road facility. From the description of the land uses and the generated traffic, criteria are developed to specifically identify traffic composition and the level of service to be provided. The service criteria may, for example, state that the recreation traffic is a priority and must experience only minor delays. The log-hauling traffic will be controlled and may be restricted to specific time periods.

The design criteria that are most commonly applied are:

Environmental and Resource Considerations:

Identifies issues related to soils, wildlife, fish, endangered species, water quality, visual quality, and other resource-oriented factors. Coordination with other modes of travel, such as trail hiking, is also a common criterion.

Safety:

Identifies special hazards, such as a pedestrian crossing.

Traffic:

Identifies the volume, type, and composition of traffic. The possibility of restricting certain forms of traffic are discussed.

Traffic Service Level:

Identifies the level of service that is expected, such as speed, convenience, and comfort.

Special Vehicle Characteristics:

Identifies critical vehicles that may use the road. These are vehicles, generally large trucks, whose characteristics will significantly influence road width and alignment.

Economics:

Identifies cost constraints that will influence design options.

The traffic service levels provide a good description of the FS road design alternatives. There are four levels that reflect design options involving speed, travel time, traffic interruptions, safety, driver comfort, convenience of travel, and cost. The majority of FS roads are in traffic service levels C and D.

Level A:

The highest level of service. Traffic is free flowing, with the volumes and types of traffic easily accommodated. Safety is a high priority. Design speed is very important and takes precedence over topographic constraints.

Level B:

Traffic may not flow smoothly in all situations. Safety is a high priority, but some controls may be enforced. Design speed is important, but topography may dictate some changes and controls.

Level C:

The efficiency of traffic movement is not a concern. Convenience is not important. Traffic will be accommodated, but some controls may be applied. Safety provisions may be relaxed. The topography dictates alignment and the design speed.

Level D:

The lowest level of service. Generally these roads have only a single use. Roads may be impassable at times. Some roads are even closed. Low speeds and rough conditions allow significant flexibility in the implementation of traffic safety requirements.

Each of the design criteria is evaluated in regards to the selection of design elements and standards. For example, the roadside clear zone is an important consideration in service level A, but is ignored in service level D. Alternative design standards are prepared to test the impacts of the design on the road management objectives and the design criteria. Cost is an important factor in all design alternatives. A design standard may result in an unacceptable cost, forcing a reevaluation of the design criteria. This flexibility in selecting design standards is the key to the FS success in minimizing road costs while still providing a reasonable service.

DESIGN ELEMENTS AND STANDARDS

This is the design stage where actual dimensions are applied to the roadway section and the ground location. This is also where the alternative designs are developed and where the coordination begins to respond to the design criteria.

The reason for giving such strong emphasis to road management objectives and design criteria is because they establish very specific guidance for the limitations of the design standards. Each project has its own geometric design. Precise standards do not dictate what the road will look like; the objectives and criteria dictate the design.

Although the FS handbook (2) does not specify dimensions for every situation, some general guidelines are provided for the road elements.

Number of Lanes:

Only single- and double-lane roads are discussed. Many FS roads are single lane, with turnouts. The dividing point between single and double lanes is not precise. If possible, an ADT of 100 or more should initiate the consideration of a double lane.

Turnouts:

Turnouts are provided on single-lane roads to allow for the safe passage of opposing traffic and for convenience. Turnout spacing depends primarily on traffic volume. The higher the volume, the closer the turnouts. A maximum spacing of about 300 m (1,000 ft) is recommended. Turnouts should be intervisible, especially on the higher-volume roads.

Traveled Way:

For single-lane roads, the width should be at least 3 m (10 ft). In unusual resource protection situations, the width can be reduced, even to 2.4 m (8 ft). For double-lane roads, the lane width should be at least 2.7 m (9 ft). The influence of large truck traffic may necessitate an increase in the lane width to at least 3 m (10 ft). On the other hand, if a two-lane road has very little truck traffic, then 2.4 m (8 ft) lanes can be used if significant environmental problems exist.

Higher design speeds should be reflected in an increased lane width. However, most FS roads have design speeds less than 65 km/h (40 mi/h), so speed is not a significant factor in lane width.

Shoulders:

On gravel roads, shoulders are not readily evident. As a result, shoulders have little need to be considered. The total width of the gravel surface is the important design feature. On paved roads, shoulders vary depending on need. Dispensing with a shoulder is acceptable for low-speed roads. When a shoulder is designated, the width will depend on the need for the shoulder. A shoulder is considered to have less influence on safe travel than selecting the proper traveled way width (6).

Clear Zone:

A clear zone is not a necessity for most FS roads. The road locations are generally in mountainous, forested terrain, where it is difficult to obtain any recovery area. A clear zone of at least 1.2 m (4 ft) is desirable for two-lane roads. However, the clear zone can range from zero to 1.2 m (4 feet).

Horizontal Alignment:

There are no specific requirements. A 15 m (50 ft) radius curve is generally considered to be a minimum. However, this can be reduced if the anticipated vehicle types can still be served.

Vertical Alignment:

The maximum allowable grade is dictated by the vehicle types using the road and the volume of traffic. The design of the vertical alignment also has to recognize the quality of the surfacing material and the potential for surface erosion on steep grades.

Suggested maximum grades are:
Recreation traffic: 12%
Trucks and trailers: 12%
High clearance, light vehicles: 18%

Steeper grades may be acceptable for short pitches.

The theoretical relationships of geometric elements for horizontal and vertical alignment are the same as prescribed by AASHTO (1). Normally, the minimum values are used. For design speeds below 30 km/h (20 mi/h), it is acceptable to use an alignment that approximates the geometric requirements.

LIABILITY

Lawsuits for personal injury and property damage resulting from road incidents are of great concern. These lawsuits have been increasing recently. The most common complaint is that the road authority is not following policies for design geometrics and safety requirements. As a result, there is a tendency for road agencies to avoid design flexibility and substitute very rigid geometric standards.

The FS has not taken this position. Flexibility in design is considered to be appropriate and defensible. It is also the policy of the Agency, and receives full Agency support.

The FS has been challenged on some design decisions. In most of the cases, the FS design has been compared with other national guidelines, such as the AASHTO "green book" (1). Where the design decisions have been clearly documented and have followed Agency policies and guidelines, the FS has prevailed against the legal challenges. The Agency support of design flexibility and engineering judgement has been quite worthwhile. To date, there is no reason to believe that this position results in greater liability problems.

GEOMETRIC PRACTICES ON RURAL ROADS

Studies of the nation's road system have estimated that there are over 4.0 million kilometers (2.4 million miles) of two-lane rural roads. Of these roads, over 80% have ADT's of 400 or less and over 38% have ADT's of 50 or less (7).

Many of these roads are old and need major repairs. However, the repairs will be very difficult to accomplish and will be costly. Many of these rural roads were built with geometrics that are significantly less than what is currently suggested. These roads are vital to the rural communities, so they cannot be ignored. But at the same time, funds are insufficient for even minor improvements. The choices become: do nothing to change, or try to find a way to minimize the cost of the improvements so more work can be accomplished.

The geometric practices of the FS could be very helpful to the nation's rural roads. Establishing objectives unique to each road, and then developing design criteria and standards for the road, could help to reduce the improvement costs.

The AASHTO "green book" provides guidance for local rural roads (1). This guideline is used by many road authorities. Although guide values are established for rural roads, AASHTO also suggests that some reductions may be needed to be consistent with the terrain, safety, and available funds. This flexibility is very similar to the FS objectives for road design, although the procedures for implementing flexibility are not provided by AASHTO. A well-documented procedure is important to gaining acceptance of the desired flexibility and to reduce the liability for implementing variations in design geometrics.

The AASHTO "green book" includes a very brief section on "Local Service Roads" (1). The definition for these roads covers most FS roads; low-volume, serves isolated areas, and has repeat type traffic. The definition also covers over 2.0 million kilometers (1.2 million miles) of the nation's rural roads. The FS geometric design practices would be a valuable addition to the flexibility and guidance provided by AASHTO for local service roads.

CONCLUSIONS

The FS geometric road design practices have been successfully implemented on over 480,000 km (300,000 mi) of low-volume roads. This success is based on the premise that flexibility can be used for the selection of design elements and standards. The FS National Preconstruction Handbook provides guidance on how to implement flexibility and engineering judgement.

The FS has recognized that low-volume roads function differently than major highways. For low-volume, low-speed roads, the design for traffic convenience and speed often assumes a secondary role to the environmental and economic concerns. Road design flexibility and engineering judgement have been successfully implemented to accommodate traffic uses, protect natural resources, and minimize costs. These same practices could be adopted by other local road agencies.

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