Alabama Department of Transportation

Performance-Based, Practical Design Guide

Alabama Department of Transportation
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PREFACE

The concepts of practical design and performance- based design may be new in one sense, but they are the concepts most designers have realized should be the goal. However, many have believed the standards did not allow their use. One aspect of performance-based design has been commonly practiced for years by using the Highway Capacity Manual to analyze the anticipated operational performance of a facility. Auxiliary lanes have been added, weave types changed and merges adjusted to meet an established performance level. With the advent of the Highway Safety Manual, another tool is available to determine the predicted safety performance of a facility so that the decision of what will be included (and just as important, what is not included) in a project is data-driven. Practical design brings a proper balance of economic realities and project needs. Its formation and development have been provoked by two main realizations:

1. The road building industry must do business in a more financially sustainable, results-oriented, and context sensitive way.
2. A more flexible and data-driven design approach is necessary to realize this objective.

These recognitions have prompted the compilation of data, and development of tools based on that data, intended to ascertain the connections between actual performance and roadway features. This allows for greater understanding of what improvements or physical features are likely to produce desired outcomes and allows design decisions to be made based on defensible and reproducible analyses.

In general, the research that has analyzed safety and other data has found that some long-standing practices and long-held assumptions did not in fact reflect reality. In some cases, current design standards have been found to be outdated or lacking in scientific basis. The Federal revision of the Controlling Criteria for Geometric Design implemented in May 2016 eliminated three of the criteria and greatly reduced their applicability to low-speed facilities. This was due to research findings that found little or no safety sensitivity for some design elements that had been assumed in the past to be crucial to safety. Even for elements known to have sizable effects on performance, rigid adherence to dimensional guidance without understanding the nuance of how small variations affect performance can lead to large expenditures with little benefit. An increased knowledge base allows a more flexible, confident and cost-effective design approach.

The matter of the Controlling Criteria is one of several efforts that will take place in the coming years to further investigate the performance effects of roadway features. A great deal of data and empirical relationships are already available, most notably in the AASHTO *Highway Safety Manual* (HSM). The increasing body of knowledge will inform not just project design decisions but also nominal road design criteria, i.e. design standards. The 2018, 7th edition of AASHTO's *A Policy on Geometric Design of Highways and Streets* (the "Green Book") features new content on performance-based design. An even more comprehensive re-envisioning of the Green Book in the image of performance-based design is proposed for its subsequent edition. This is an inevitable and irrevocable trend.

As is occurring on the national level, this document applies newly available data and knowledge to recommend ranges of flexibility in dimensional guidance that have proven to be acceptable practices, oriented toward solving problems and achieving project goals more reliably and efficiently. On reconstruction and preservation type projects the dimensional ranges provided in this Guide are not intended to become required minimums to achieve if an existing element is functioning satisfactorily with lesser values and is determined to not need revision.

For those elements requiring a design exception, compliance with dimensional ranges in this Guide that are less than the AASHTO Green Book values does not negate the need for a documented design exception. However, this Guide will aid in engineering justification supporting the decision.

Documenting decisions is an important component of a successful performance-based design.

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Part I

Definitions and Process

DEFINITIONS

Practical design is an approach to road and street engineering that prioritizes economy and seeks to optimize return on capital investment across the entire highway program and system. Its goal is a use of public funds that results in the best possible highway system. “Right sizing” is a term often used to describe the physical manifestation of practical design on projects.

Performance-based design involves determining design features in order to achieve desired outcomes and solve identified problems, based on known direct effects of physical roadway features on actual performance.

Combining these two concepts, **Performance-Based Practical Design (PBPD)** is simply the use of performance-based methods and processes to solve problems and produce outcomes, all the while recognizing our limited financial resources and the need to spend public funds wisely and with a long-term, system-wide outlook. Expressed another way, every scoping and design decision should be made based on whether the proposed feature will address the project’s stated desired outcomes as well as whether it represents a use of funds that makes good sense considering other needs on the system as a whole. It tends to rely on the use of a **flexible design** approach to choose appropriate dimensions and parameters within and sometimes outside the ranges of standard nominal values.

Many recommendations in this guide will reference **low speed** or **high speed**. For the purposes of this Guide 45 mph is the upper limit for low speed consideration and 50 mph is the lower limit for high speed consideration.

THE PRACTICAL DESIGN APPROACH

In 2005, the Missouri Department of Transportation (MoDOT) stated their new strategic objective, to “build good projects everywhere – rather than perfect projects somewhere.” So began the newly coined **Practical Design** movement in the United States. Its implementation in Missouri was prompted by persistent fiscal challenges as well as deteriorating infrastructure condition and low public approval. Within five years of adoption, 87 percent of the state’s major road pavements were in good condition, and customer satisfaction with MoDOT had risen to 83 percent. They had proven to the citizens of their state that they could be good stewards of public funds.

Practical Design is not a new or unique concept, as attention to economy and balancing provision with investment are traditional components of public works engineering. Instead, this movement is a rediscovering of and refocusing on these principles, made more critical by downward trends in revenue. It aims to reverse the culture of reflexive design conservatism and immoderate spending that have been prevalent for some time.

As suggested by MoDOT’s stated objective, Practical Design goes beyond saving money on an individual project in a vacuum; it aspires to build the best-performing transportation system affordable with the money available. It accepts funding levels as a given and makes the best use of them. This economical, system-wide perspective naturally encourages:

1. **Value:** optimizing return on investment and quality of life for users and neighbors of facilities
2. **Flexibility:** considering a variety of scopes and design values, inside and outside the customary range of practice
3. **Analysis:** being reasonably sure, using evidence-based techniques, that a design approach will yield the desired outcome
4. **Financial sustainability:** taking a design approach that can be repeated in all similar circumstances, across the entire system, indefinitely, within the long-term fiscal outlook

The Alabama DOT adopts the concept of practical design. There is no flowcharted process for the application of Practical Design nor is there a methodology to determine what scope and cost of a project will yield an optimized system over the course of time. However, when combined with the performance-based design thought process explained in the following section, designers will, over time and with experience, develop a feel for right-sized projects and design features. Most simply, though, merely foregoing features and expenditures that return little or no benefit is an obvious initial action. The many small cost efficiencies from a systematic attention to economy and value will add up to a significant amount of available capital funds – funds that can be used to build more projects addressing the many needs on Alabama’s road and street system.

The Practical Design approach is not optional or elective. Its application is necessary on every project in order to have even a minimally functional transportation system in the long term. Every project that does not incorporate its principles steals from concurrent needs elsewhere on the system as well as from other needs and projects in the future.

THE PERFORMANCE-BASED DESIGN PROCESS

National Cooperative Highway Research Program (NCHRP) Reports 785 (*Performance-Based Analysis of Geometric Design of Highways and Streets*) and 839 (*A Performance-Based Highway Geometric Design Process*) are recent publications that seek to guide project managers and practitioners through performance-based design processes. They are recommended reading for all designers and project managers. Report 785 "establishes an approach that practitioners can use to evaluate the performance tradeoffs of different project development and design decisions." Report 839 presents a revised geometric design process providing guidelines based on the project type and the problem or need being addressed. These products, although authored by different researchers and published at different times, are based in the same philosophies and are intended to be complementary.

Expanding on the definition of performance-based design earlier in this document, Report 785 "presents an approach for understanding the desired outcomes of a project, selecting performance measures that align with those outcomes, evaluating the impact of alternative geometric design decisions on those performance measures, and arriving at solutions that achieve the overall desired project outcomes." Boiled down, the process is to **identify problems** and **solve problems**, all from the standpoint of actual **functional performance**. These basic process elements are explored below.

The 7th Edition of the Green Book makes several statements that give the performance-based design intent. "Noncompliance with geometric design criteria is not sufficient to be identified as an issue in a project purpose and need statement; such noncompliance with geometric design criteria only becomes an issue to be addressed in the project purpose and need if that noncompliance has resulted in (or is forecast to result in) poor performance that is correctable by a geometric design improvement and that the agency chooses to address." "Noncompliance with geometric design criteria should be addressed in projects on existing roads only where it is established that the current design is performing poorly or that a geometric design improvement would be cost-effective." "This approach is intended to avoid expenditures that have no impact on performance."

A primary focus of performance-based design is design decision making. Through history, the guidance for design decisions has been largely dimension-based, i.e. specified design values for physical dimensions often derived from physical and mathematical models. It has been common to presume that applying these criteria will automatically provide good performance, but this has not been reliably true. Per Report 839, "During the past 75 years, transportation needs have changed and much has been learned about the relationships among geometric design, vehicle fleet, human factors, safety, and operations." Performance-based design brings this knowledge to bear on projects, allowing us to better understand and estimate the effect of alternative design decisions on actual performance.

Design development and decision making will most likely evolve to utilize a blend of traditional design criteria and performance-based methods. Dimensional guides like the AASHTO Green Book will remain, but their guidance and criteria will become more evidence based, and they may recommend analysis rather than specific treatments.

Intended Project Outcomes

The foundational process step is determining project purpose, need and problems followed by establishing desired outcomes and goals. This step is represented by the "project initialization" stage in Chapter 5 of NCHRP Report 785. Crucial to this is an understanding of the nature of performance characteristics.

Performance Characteristics

As basic as the concept of performance might seem, its definition in the context of PBPD represents much of the difference between the traditional dimension-based design approach and the emerging PBPD approach. For example, whereas achieving a standard dimension might have once been thought of as a performance goal, PBPD focuses on actual functional performance. Prominent broad performance characteristics include the following:

- Quality of service
- Safety
- Reliability
- Accessibility
- Infrastructure integrity
- Ease of use
- Ease of maintenance
- Visual quality
- Fit to context and community

As evident from this list, many performance attributes are subjective or difficult to quantify or define. Even the more tangible items are subject to variables and uncertainty, reflecting the imprecise nature of public works engineering. Nevertheless, focusing on these and other outcome-based measures is the most reliable way to achieve real improvements for users, stewards and communities.

Project Objective

Defining a corridor's needs, purpose and problems is an obvious initial step toward project scoping and design. Consistent with the foregoing discussion, this must be done in the context of actual functional performance. The fundamental questions to be considered on every project are:

- What are we trying to achieve?
- What is the project context?

Addressing the former question is fundamental to properly establishing the project purpose and need. But the second question will affect the nature of improvements that are appropriate to be incorporated. Who are the stakeholders and users and what needs should the project address? An urban bridge replacement very likely will incorporate different design elements than a rural bridge. As obvious as that may sound, many projects suffer from the lack of that consideration or an inaccurate or incomplete assessment of needs, problems and potential opportunities, often as part of a rush to a solution. As often as a misplaced focus on dimensional standards can lead to solving problems that don't exist, overlooking problems or needs can result in projects that fail to address or even worsen them.

Desired Outcomes and Goals

A clear statement of what we are trying to achieve with a project is essential in order to develop a design that will achieve it. PBPD is an outcome-oriented process, with the outcomes defined in terms of functional performance (in contrast to an out*put*-based process – the output being a product built to standard dimensions).

Specific, detailed goal definition may not be possible until the concept development and scoping / preliminary design phases, when cost and feasibility can be determined and expected performance outcomes estimated for various alternatives. However, a certain degree of goal setting is necessary early in project development in order to begin conceptualizing proposed features and general scope.

Designing to Achieve Intended Outcomes

The "concept development" and "evaluation & selection" phases of the application framework presented in Chapter 5 of NCHRP Report 785 largely lie within ALDOT's scoping and preliminary design phases of project development. Both Chapters 4 and 5 should be considered an essential reference for practitioners of performance- based design. In general, the procedure involves utilizing performance-based methodologies and data to determine the expected performance associated with scope elements, design features, configurations, concept alternatives, etc. This includes iteration as necessary to select an alternative and refine the design. The goal is a cost-effective solution that achieves performance improvement and solves problems within the bounds of practicality and context sensitivity. The most prevalent resource for performance-based methodology and data is the AASHTO *Highway Safety Manual* (HSM), which presents empirical formulae and factors based on a vast volume of known safety data, allowing practitioners to compute and compare expected safety performance for various design options. Other performance-based design resources have been developed and continue to be developed through applied research, including a growing database of supplemental HSM material. Such resources include:

- *Highway Safety Manual* – American Association of State Highway and Transportation Officials (AASHTO), 2010
- *Interactive Highway Safety Design Model* – Federal Highway Administration (FHWA)
- *Highway Capacity Manual* – Transportation Research Board (TRB), 2016
- NCHRP Report 687 *Guidelines for Ramp and Interchange Spacing*, 2011
- NCHRP Report 783 *Evaluation of the 13 Controlling Criteria for Geometric Design*, 2014
- NCHRP Report 839 *A Performance-Based Highway Geometric Design Process*, 2017

As alluded to above, evaluation of more than one design option is inherent in the performance-based approach. Doing so is necessary in order to compare the costs and expected performance of design alternatives. This has always been a preferred approach, but it is more essential in this regimen, especially considering diminishing resources and expanding needs. When comparing alternatives and their costs, a point of diminishing or no added return on investment often becomes clear, suggesting a logical limit of practicality and prudent expenditure. Furthermore, evaluating proposed spending against other potential uses of the same funds in another location or manner from the standpoint of performance improvement (e.g. crash reduction, vehicular delay) will be a useful thought exercise in seeking to optimize the overall return on investment statewide.

The transition to performance-based design involves moving away from defining project success strictly on attaining dimensional metrics, which is so ingrained in the practice that it is difficult to stop thinking in those terms. As discussed previously, much dimensional guidance will continue to be useful and relevant, even within a framework of a performance-based approach. It is almost certain that some mixture of standards-based and direct-performance methods will be the future state of road design process in the United States.

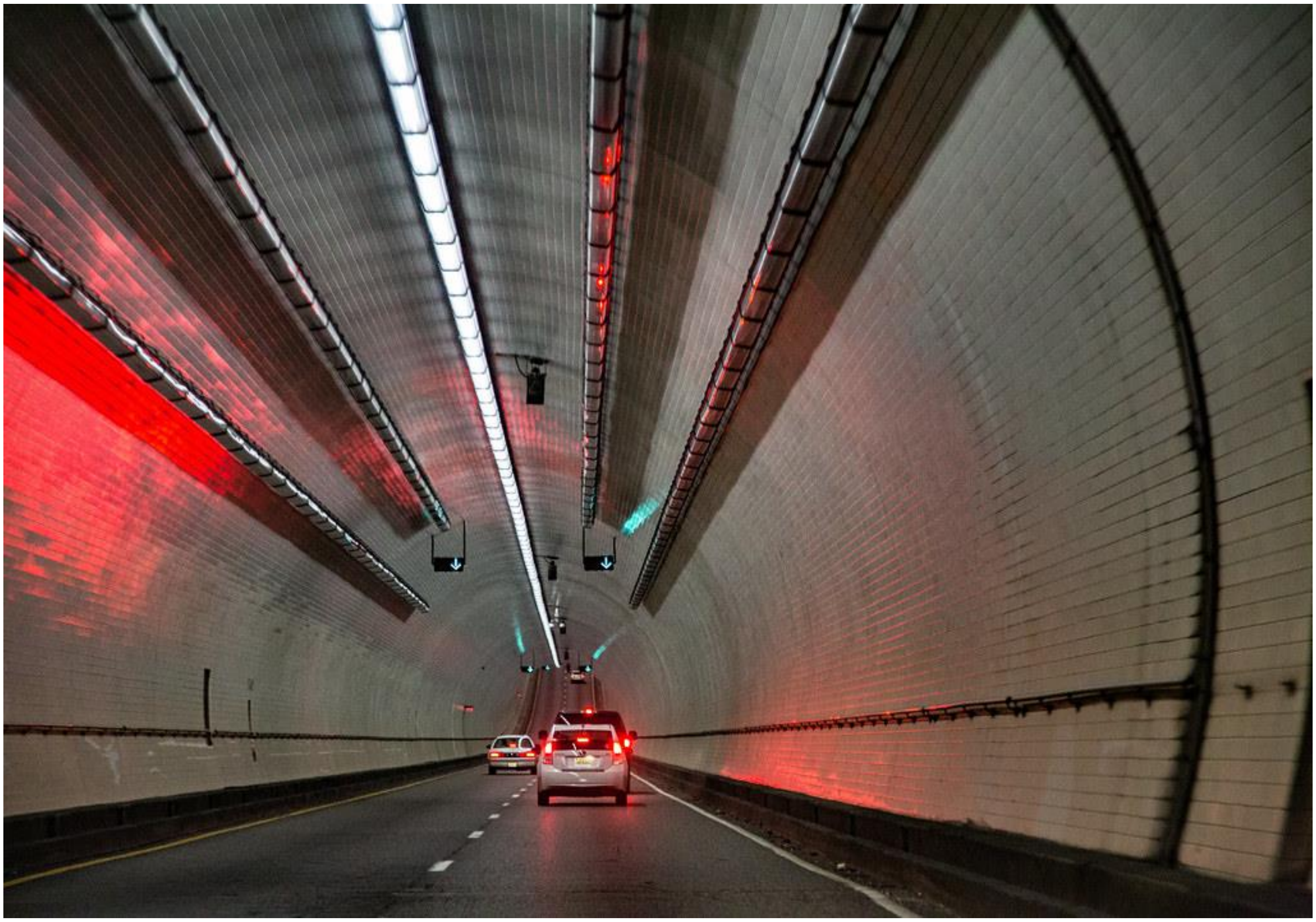
Part II

Design Controls and Elements

INTRODUCTION

The guidance that follows is intended to foster a performance-based, economical design approach and provide useful background information and practical advice. Some design criteria presented are new or modified from pre-existing ALDOT policy, either to provide additional design flexibility or establish a desirable design value short of the nominal minimum or maximum.

FUNDAMENTAL DESIGN CONTROLS



LEVEL OF SERVICE

Level of service (LOS) is a qualitative measure of operational performance and, as such, is a quality of service indicator for transportation facilities and networks. It was originally developed as a means of describing uninterrupted-flow traffic conditions and has since been expanded to encompass intersection operation and multimodal quality of service.

LOS is often expressed as a design parameter or criterion but is better thought of as a performance metric for use in evaluating design alternatives. It should not be considered a design standard on which to singularly base design decisions; rather, it should be one of several factors to take into consideration in fashioning a practical, multimodal and context sensitive solution.

Both ALDOT and AASHTO have advocated providing the highest level of service feasible/practical; however, that principle has been called into question in recent years. The Green Book guidelines for design LOS (Chapter 2) were revised downward in the 2011 edition, mostly due to concerns related to urban streets. Prior to this change, a motor vehicle Level of Service C was the recommended design value for urban arterials. Streets that achieve this LOS in the design-year peak hour, however, will be underpopulated under most conditions in the intervening years, a condition known to be associated with excessive operating speed and reduced safety. This helps illustrate the difficulty of balancing capacity with safety, especially since congestion itself is a contributing factor to crashes (albeit relatively low-severity crashes).

For rural highways, LOS on particular segments is often secondary to what has come to be known as trip quality: a quotient based on user perceptions that includes factors such as travel time reliability, intersection efficiency, and density of heavy vehicles. The traditional design condition of the 30th highest hour volume is valid, but using it along with a target LOS as a sole basis for facility design is questionable and often impractical.

Guidance and Criteria

- Consider Level of Service a performance measure rather than a design standard or criterion. LOS should describe an expected operational outcome of a design option rather than be a minimum parameter to be achieved.
- Rather than providing the highest LOS feasible, consider it one of many attributes to right size. As with other performance measures, it can be appropriate to target a desired outcome; however, such objectives must be contextually appropriate and balanced with other, sometimes conflicting, considerations.
- Focus on corridor-length travel time rather than future-year micro-level LOS calculations.
- On urban and suburban streets, congestion in the design year must be balanced against the facility's safety and operation in the intervening years, as underpopulated streets are known to exhibit higher crash rates and severities than those nearer capacity.
- A design vehicular level of service of D or lower is suggested for urban streets as an appropriate balance between design-year peak-hour operation and off-peak safety.
- For rural highways, consider several factors in addition to LOS on particular segments. A user-focused approach informed by the public involvement process can identify trip quality indicators.
- Consider designing for an interim-year traffic volume short of the ultimate design year. A project that can feasibly provide several years of benefit, but is short of a 20-year LOS goal, should be considered if the alternative is a project that is not practical.

Design Standards / Administrative Control

- Interstate projects should be based on a 20-year traffic projection. However, capacity improvements in constrained areas may only be able to practically achieve a LOS less than the goal for the full 20-year design.

DESIGN SPEED

Discussion

The design speed of a facility, perhaps more so than any other design control, will have a major impact on all facets of its geometric design. The design speed concept was originally developed as a mechanism to allow drivers to operate at a uniform speed on a rural highway. Design speed fosters consistency along a highway segment as well as harmony among design elements. It also serves to characterize a facility in terms of class and context. A well- chosen design speed will put a right-sized and practical solution easily within reach, while an ill-fitting design speed selection will tend to cause difficulties throughout the design process. On complex or sensitive projects, an iterative process is sometimes necessary to determine a proper design speed that supports project goals, economy/practicality, and environmental and social sensitivity.

Until recent years, AASHTO encouraged making every effort to use as high a design speed as practical. A conventional approach to determining design speed has been to select a speed in excess of the existing or anticipated posted speed, ostensibly to accommodate drivers who exceed the speed limit. These practices reflect the premise of a higher design speed being inherently superior to a lower value. They also perpetuate a past AASHTO definition of design speed as being the maximum safe speed of travel. The latter notion was dismissed by NCHRP Report 400 (*Determination of Stopping Sight Distances*), which evaluated design speed as a component of stopping sight distance. It found that exceeding the design speed was not necessarily unsafe and recommended that the AASHTO Green Book definition be revised from the maximum safe speed to “a selected speed.” This was incorporated with the publication of the Green Book’s 4th Edition (2001). It is echoed in NCHRP Report 783, which states, “There is no research that demonstrates that vehicle operations at the design speed are safe or that vehicle operations above the design speed are unsafe.” Notably, there are anecdotal examples of *increasing* crash frequency resulting from highway reconstruction that increased the design speed, suggesting the consequence of excessive speeds or speed differentials. The 6th edition of the Green Book (2011) removed the direction to provide a maximum practicable design speed.

NCHRP Report 839 states, “Besides being a critical component to design criteria, speed must be acknowledged as having conflicting contributions to transportation performance. Historically, speed has been a surrogate measure of quality in that the prevailing transportation value was travel time (i.e. its minimization). However, the adverse effects of speed on safety performance must also be considered.” This recognizes that speed affects drivers’ ability to avoid crashes and directly influences the severity of conflicts and crashes. Also, well known is that the survivability of vulnerable users (e.g. pedestrians) decreases dramatically with increased vehicular speed.

NCHRP Project 15-25 (Alternatives to Design Speed for Selection of Roadway Design Criteria) had previously examined the concept of design speed and suggested that, instead of speed being an input into the design process, it could be understood as an output of the design process – in other words, a desired speed outcome. Because of the conflicting performance effects of speed noted in Report 839, a right-sized speed outcome should be a design objective whenever practicable.

Considering the preceding discussion, flexibility to choose within and outside the standard ranges given in the Green Book is appropriate. Rather than the highest practicable design speed or one based strictly on posted speed, the selection should be based on practicality, context and intended outcome. A design speed should not be chosen to ensure all proposed criterion can be met without a design exception.

Rural Highways

Typically design speed is subject to functional classification, context classification, terrain and traffic volume. Its selection should also consider driver desires and expectation, which are themselves influenced by context, terrain and functional class. There is generally a weak correlation between design speed and operating speed on rural highways, especially where there are few restrictive horizontal and vertical curves. For that reason, it may be unrealistic to expect a speed outcome as a result of design speed selection.

On preservation and reconstruction projects there may be locations where the design speed of a portion of a route is less than the posted speed due to changes in design criteria for an element or due to the previous conversion of the facility such as when a 4-lane divided facility is created by retaining the existing older lanes. This differential in speed does not in itself indicate that portion of the facility is unsafe, but if elements of the lower design speed portion are determined in the scoping process to need correction due to performance history, the element should be increased as close to the posted speed value as is practical. Other elements designed to a lower speed without a known performance problem may be retained.

Above all, the final selection must be made in recognition of the need to engineer balanced, practical, affordable and context sensitive projects. On preservation and reconstruction projects as well as spot-location projects, the design speed at the time of original construction should typically be adopted unless there is a known performance problem that can be attributed to design speed-associated factors. It has been common practice to increase a design speed in order to match or exceed the posted speed. Doing so, however, has no known benefit and often considerable cost and should therefore be avoided.

Urban and Suburban Streets

Considering the effect of operating speed on crash rate and severity, streets should be engineered to achieve a desired speed outcome to the extent practicable. Reflecting this premise, the term "target speed" has come into use to express speed outcome goals and to guide design speed practice. Unlike rural highways, design features of urban and suburban streets are known to influence operating speed. For this reason, selection of design speed and incorporation of geometric features consistent with that speed is a realistic and desirable means to achieving a speed outcome. Designing a street toward a speed outcome conducive to the safety of all travel modes is the best-known way to achieve optimal safety performance in an urban or suburban right of way.

As with rural highways, adopting the original design speed on preservation and reconstruction projects is often appropriate, but the nature of urban and suburban areas is a constantly-changing context. For that reason, downward revisions to design speed as part of corridor reconstructions may be appropriate to reflect changes in land use, density and modal usage on a route that no longer functions as the original higher design speed.

Guidance and Criteria

- Design speed is a choice – a selection. Base design speed selection on context and practicality.
- In some cases, a design speed less than the posted speed can be used. This is more applicable for urban and suburban streets.
- In general, the design speed should be equal to or greater than the posted speed. Rather than lower the design speed to keep all elements within the design speed, it is appropriate to obtain a design exception for the element(s) that cannot meet.
- On rural two-lane arterial highways, base design speed selection on context, terrain, functional class and economy. A 55 mph design speed is typically appropriate. Rural multilane facilities with a depressed median are typically 65 mph, but 55 mph is appropriate for hilly terrain with numerous curves.
- On urban routes be aware that design features such as curvature and clear zone may be based on an appropriate design speed for rush hour characteristics, but off-peak traffic unimpeded by congestion will operate at higher speeds.
- On urban streets, base design speed selection on context, practicality, driveway access frequency, and the presence of non-motorized users.
- Rural freeways and expressways should have a 70 mph design speed except in recreational or environmentally sensitive areas.
- For urban and suburban freeways, choose a design speed of either 50 or 60 mph depending on development density, context and practicability.

Design Standards / Administrative Control

- Design Speed is one of the 10 Controlling Criteria for Geometric Design as well as a controlling criterion for ramp design.
- The AASHTO Green Book presents the applicable standard for design speed in each functional, contextual classification. Any design speed value outside the indicated range requires design exception documentation

DESIGN VEHICLE

Discussion

Selection of design vehicle(s) and assumptions made about their operating behavior are a major determining factor in geometric design, particularly intersection design. To achieve optimal intersection performance, the accommodation of large and oversized vehicles must be balanced with providing a safe, usable and functional environment for small vehicles and pedestrians. In pursuit of this balance, the useful concept of “control vehicle” has been coined in recent years. Whereas “design vehicle” is defined as a frequent user of a facility, a “control vehicle” is an infrequent large user.

There are five vehicles as primary design vehicles for typical highway design. They are the passenger car (P), city transit bus (CITY- BUS), single-unit truck (SU), and 62-foot wheelbase semi- tractor trailer (WB-62), and 67-foot wheelbase semi- tractor trailer (WB-67) for use at interchanges. Since the time these were established, there have been significant changes in the vehicular fleet. NCHRP Report 505 (*Review of Truck Characteristics as Factors in Roadway Design*) examined the range of dimensions and performance characteristics of trucks currently used on U.S. highways. That data in combination with the current legal limits on truck dimensions in Alabama establishes the vehicles and recommended practice provided in *Specific Design Guidance*, below. Refer to the AASHTO Green Book for dimensions of the vehicles discussed.

Guidelines on the designation and application of design vehicles and control vehicles area as follows:

- Tractor-trailers and large emergency vehicles should generally be considered control vehicles except in rare cases where they are predominant users. For turning movements by control vehicles, some encroachment into adjacent or opposing lanes is usually necessary to keep intersection size and geometry within reasonable limits. An exception to this is left turns onto wide-median rural divided highways, where a turning path into the nearest lane typically does not impair intersection geometry.

- Many vehicles can be considered design vehicles, but only those that frequently use the facility or particular intersections should be designated as such. Passenger cars and school buses can be expected on most urban streets and rural roads. It is sound practice to assume a passenger car turning path into the nearest available lane without encroachment, although there can be exceptions in constrained cases. School buses and single-unit trucks should be given greater allowances, including using most of the width of unstriped residential streets to turn onto where necessary; otherwise, undesirably wide corner radii may result.

- The minimum outside turning radii (OTR) presented in the Green Book are conservative in nature, as are the commercially available computer software that model vehicle movements. The given minimum OTR’s can be used for intersection design where constraints exist, but the radius leaving the higher speed roadway should be selected keeping in mind the safety need to have the decelerating vehicle leave the higher speed lanes quickly.

- Intersections should provide for movement of the design vehicle, but overemphasis on control vehicle movements can affect the safety and ease of use for other users. The goal of intersection design is to keep its size and footprint to a practical and functional minimum in order to optimize safety and usability for all modes, especially in urban and suburban settings. An iterative design approach is often necessary to achieve a proper balance between these factors.

Guidance and Criteria

- The passenger car (P) and school bus (S-BUS-36) should be assumed to use any roadway and intersection unless prohibited, thereby serving as universal design vehicles.
- Generally, assume passenger car turns to be done from near edge to near edge of traveled way. For curbed streets, such a movement translates to a corner radius of roughly 15 feet based on its minimum outside turning radius (OTR) of 24 feet.
- School bus turns do not need to be near edge to near edge, but their turning path should not cross a center stripe on either end of the turn. They may, however, be assumed to cross un-striped centerlines of local residential streets.
- The two-axle single unit truck (SU-30) is representative of delivery-type vehicles and can be expected most anywhere on the system. They may serve as either design vehicle or control vehicle depending on frequency of usage and context.
- The three-axle single unit truck (SU-40) represents the larger end of the single-unit fleet. Their population is small compared with that of two-axle trucks but large when compared with the population of combination trucks (i.e. tractor-semitrailers). Their minimum OTR of 51+ feet is larger than even semi-truck tractors, so this vehicle is useful where turning radius controls the geometric design. Because of their wide turning radius, they will almost exclusively be control vehicles.
- Interstate WB-67 semitrailer vehicles should be used as control vehicles where such combination trucks can realistically be expected. It should be used as the design vehicle for freeway ramp terminals with crossroads, rest areas and other routes that are high volume truck facilities connected to a freeway. The dimensions of the WB-67 exceed the legal allowance for kingpin-to-center-rear-tandem (KCRT) dimension in Alabama. Most haulers use the 53’ trailer but adjust the rear tandem all the way forward to give it the same wheel base as a WB-62.
- The WB-62 represents a vehicle size limit specified in Federal law to operate anywhere on the National Highway System and satisfies the legal allowance in Alabama. Except as noted above for the WB-67, it should be used as a control vehicle in areas where tractor-trailers can be expected, as well as generally for roundabout design.
- Various recreational vehicles are available in the AASHTO Green Book, to be used at the discretion of the designer at recreational sites or other special circumstances.
- A wide variety of oversize vehicles including agricultural vehicles use the highway system. Consult the ALDOT Permit Office for general and project-specific guidance.

CROSS SECTIONAL ELEMENTS

CROSS SECTION COMPOSITION

Discussion

Design the usable surface of the cross section as a whole, rather than each element or travel mode individually. The cross section should consider the longitudinal and cross movements of all users, with the elements balanced to optimize functionality and safety within constraints and practicality. The overall width must accommodate expected freight users in a safe and reasonable way without presenting a barrier to movement but also avoiding excessive costs or unduly degrading safety or operation for other users. On rural undivided highways, tradeoffs between lane and shoulder widths within an existing roadbed may be considered on projects, using predictive tools for safety and capacity and considering bicycle demand and routing. The Traffic and Safety Operations Office in the Traffic Design Division in the Design Bureau can advise and assist in such analyses.

There is no definitive minimum standard governing total or one-way roadway width. On urban arterials, sufficient unobstructed width must be provided for the occasional oversize loads that are known to use the facility. Exactly how this is done should consider the frequency of transport and must be weighed against the cost, speed, and safety disadvantages of wide cross sections. In general, urban and suburban roadway widths should be kept to a practical minimum necessary to accommodate the modes and volumes expected. This approach will commonly require truck turns and oversize loads to encroach on adjacent and/or opposing lanes.

Guidance and Criteria

- For reconstruction and preservation on rural highways, begin with the existing total section width as a starting point for design consideration. Reallocation of lateral space among lane and shoulder width should be investigated using the AASHTO *Highway Safety Manual* to identify beneficial tradeoffs and potential performance improvement.
- Use locally calibrated HSM data, as available, when considering tradeoffs between lane and shoulder widths on rural highways.
- On urban and suburban streets, allocate space to balance the functionality and safety of all modes of travel demand.

TRAVEL LANE WIDTH

Discussion

Lane width has known operational and safety effects on roads and streets. Operational effects differ between uninterrupted-flow and interrupted-flow conditions. In the uninterrupted-flow condition, lane width affects operating speed which in turn marginally affects travel time and capacity. In interrupted flow (e.g. traffic signal-controlled operation), there is no known difference in capacity between lane widths down to 10 feet. For more detailed information, consult the TRB *Highway Capacity Manual* (HCM). Safety performance effects of lane width differ profoundly between rural and urban/suburban settings and are discussed separately below.

Rural Highways

Potential crash effects of lane width on rural two-lane and multilane non freeways are presented in Section 13.4.2.1 and Figures 13-1 through 13-3 in the AASHTO *Highway Safety Manual*. Crash expectancy generally increases with a decrease in lane width below the default value of 12 feet, but safety differences between 11 feet and 12 feet are relatively small, even at moderate to high volumes. For this reason, NCHRP Report 783 concludes, "It appears reasonable that designers should be provided with great flexibility to choose between 11- and 12-ft lanes for rural two-lane and multilane highways (non-freeways)…" Considering that there are similarly small differences in expected crash frequency between and 9- and 12-foot lanes on very low volume roads (AADT < 500), it is logical to apply the same flexibility to choose within that wider range of lane widths on those facilities.

Urban and Suburban Streets

Unlike rural highways, there is no general indication that the use of lanes narrower than 12 feet on urban and suburban arterials and collectors is associated with increased crash frequencies. In fact, *Relationship of Lane Width to Safety on Urban and Suburban Arterials* (Harwood, Potts, Richard, 2007) found that, where its results were statistically significant, narrower lanes were generally associated with lower crash frequencies. NCHRP Report 783 states, "Using narrower lanes on urban and suburban arterials can provide space for incorporation of other features that are positive for operations and safety including medians, turn lanes, bicycle lanes, parking lanes, and shorter pedestrian crossings. It appears reasonable that designers should be provided with substantial flexibility to choose among 10-, 11-, and 12-ft lanes on urban and suburban arterials…"

Lane width flexibility between 10 and 12 feet for urban streets has been longstanding in the AASHTO Green Book, dating from its first edition (1984). Bearing in mind the general advantages of narrower lanes cited above and the obvious economic and environmental advantages of narrower cross sections, designers should favor narrower lane dimensions unless wider dimensions can be justified based on expected performance. Consideration should originate at 10 feet for design speeds of 20 to 35 mph and 11 feet for 40 mph design speeds and greater, with flexibility either wider or narrower depending on circumstances. In general, 12-foot lanes are appropriate on high-speed facilities; they're generally less suitable for low-speed streets due to their probable speed and safety disadvantages. There is limited experience with 9-foot lanes on the street system, so their expected performance cannot be reliably predicted. Potts, et al found inconsistent lane width effects of 9-foot and narrower lanes, varying with study site. As a result, they recommend "that [9-foot and narrower] lane widths be used cautiously…unless local experience indicates otherwise." In this spirit and subject to judgment, they may be appropriate for lower volumes and/or in constrained circumstances.

Urban Freeways

Lane widths narrower than the 12-foot standard dimension have been employed occasionally to allow fitting additional lanes in constrained corridors. As the predominant crash type in metropolitan areas is the congestion-related crash, this is usually a beneficial tradeoff in cities. Experience indicates that 11-foot lanes typically perform adequately with lower freeway design speeds (i.e. 50 mph) and/or where the horizontal alignment is favorable. 11.5-foot lanes are nearly indistinguishable from 12-foot lanes from the standpoint of driver perception and may be suitable for many circumstances where deemed necessary.

Guidance and Criteria

- On rural highways, 12-foot lanes exhibit optimal safety, but, depending on traffic volume, the expected safety differences between alternate lane widths can be small. Take a flexible design approach that considers the costs and benefits of various lane widths.
- For new construction of rural highways, 12-foot lane widths should typically be used. In high cost areas (e.g. rock excavation areas) or environmentally sensitive areas 11-foot lane widths may be appropriate through the constricted area.
- For reconstruction or preservation projects on rural highways, consider a range of lane widths and explore tradeoffs between lane and shoulder widths using the *Highway Safety Manual* and locally-specific data.
- On urban and suburban streets, narrower lanes are associated with lower crash frequencies and should therefore be favored.
- 10-foot lane widths are generally acceptable for the design of urban streets up to a design speed of 35 mph.
- For streets with design speeds of 40 mph and above, 11-foot lanes are normally suitable, although lesser widths can be considered.
- 12-foot lanes should be used on urban and suburban streets where design speed is high (i.e. 50 mph and greater) or non-motorized traffic is absent.
- Lanes narrower than 12 feet may be considered on urban freeways with 50 mph design speeds or favorable alignment. This flexibility is most appropriate when needed to add a travel lane within constraints or where cost differences are extraordinarily high.

Design Standards / Administrative Control

- The AASHTO Green Book remains as the source for ALDOT's lane width standard. Although designers are encouraged to find the best design options for the project, even if it is below the standard values, certain design decisions may entail design exception documentation.
- Lane Width has been eliminated as a controlling criterion for low-speed design speeds. It remains a general design element in those circumstances, requiring a design variance for non-standard dimensions.

SHOULDER WIDTH

Discussion

Highway shoulders have various functions ranging from safety to providing lateral support for the roadway, and thus exhibit various performance characteristics. As with travel lanes, those characteristics differ greatly between rural and urban settings.

Rural Highways

NCHRP Report 783 states, "Shoulder width has the largest effect on crash frequency of any of the controlling criteria for rural highways." When analyzing crash types associated with shoulder width effects on two lane rural roads, consider single-vehicle run-off-road and also multiple vehicle head-on, opposite direction sideswipe and same-direction sideswipe. These potential crash effects are presented in Section 13.4.2.4 and Figure 13-5 in the AASHTO *Highway Safety Manual*, which may also be applied to undivided rural multilane highways. HSM Table 13-8 applies to right shoulders on divided highways. For those road types, no data is presented for shoulders wider than 8 feet. The text states, "Shoulders greater than 8 ft wide can be assigned a CMF equal to 8-ft wide shoulders" suggesting little or no benefit of additional width. The Interstate shoulder dimensions given in the AASHTO "A Policy on Design Standards – Interstate System" still should be provided.

ALDOT shoulder width standards are from the AASHTO Green Book criteria. They originally predate the Highway Safety Manual and so do not consider the data and insights available in that resource. For that reason, a design approach relying on engineering judgment and predictive data such as the HSM is generally superior to an exclusively standards-based approach. Although the standard dimension represents a sound initial point for consideration for projects on new alignment, designers should consider a range of options above and/or below that value. For reconstruction on existing alignment or preservation, the existing condition should serve as the base of consideration. Consistent with the performance- based design approach, decisions on shoulder width should be grounded on solving known problems and achieving stated performance goals within the bounds of practicality and cost effectiveness. As with lane width, there are likely to be suitable solutions that do not meet the current nominal standard and thus require design exception documentation.

Urban and Suburban Streets

NCHRP Report 783 states, "There are no documented effects of shoulder width on traffic speed or crash frequency for urban and suburban arterials." AASHTO encourages to routinely incorporate shoulders into urban and suburban cross sections but acknowledges the constraints typically present and does not require them. They should be provided on high-speed facilities. Again, on urban interstates, the shoulder dimensions of the AASHTO Interstate Policy apply.

Due to their cost and evident lack of performance effect, shoulders are not needed on low speed streets except where they serve as parking or for bicycle travel. Since a bicycle lane adds to the pedestrian crossing distance, the design decision of whether to include one entails seeking a balance between those modes.

The AASHTO *Highway Safety Manual* describes crash effects associated with on-street parking in its Section 13.11.2.1, which apply for AADTs of 30,000 and greater. The HSM does caution that crash migration (rather than elimination) is a possible result of the prohibition of on-street parking.

Parking lanes should be right-sized, subject to functional needs and site constraints. They should be made no wider than needed but should allow safe and adequate egress/ingress, which depends largely on the adjacent vehicular use and traffic density.

Guidance and Criteria

- For new construction of two-lane rural roads, begin with the nominal AASHTO Green Book dimensions and evaluate values above and below that dimension, using the *Highway Safety Manual* and site-specific data, for comparison of costs and expected performance benefits.
- For multilane divided highways, choose within the 8-to-10-foot paved width range, considering both overall and heavy commercial traffic volumes.
- For preservation or reconstruction of rural roads, begin with the existing condition and investigate options including reallocating existing space and road bed widening. Because of the cost of grading, widening will typically be justified only to correct an existing safety problem or non-motorized travel deficiency.
- Shoulders should be provided for high speed urban routes. For low speed urban and suburban streets they have no documented effect on safety, and they add crossing distance for pedestrians. For these reasons, shoulders should be included on low-speed streets only as parking lanes or bicycle facilities.
- The right size of parking lanes depends largely on the traffic density of the adjacent use. Most designs should incorporate the middle values of the standard range (8 and 9 feet), with 7 feet reserved for constrained and/or low-traffic conditions and 10 feet appropriate only with extremely high traffic density. Greater-than- standard dimensions should be restricted to rare circumstances with unusual parking needs.

Design Standards

- The Green Book remains in effect as ALDOT's shoulder width standard. Although designers are encouraged to explore design options above and below the standard values, certain design decisions may entail design exception documentation.
- Shoulder Width has been eliminated as a controlling criterion for low-speed design speeds. It remains a general design element in those circumstances, requiring a design variance for non-standard dimensions.

SHOULDER SURFACE

Discussion

The safety effects of shoulder surface on rural two-lane highways are presented in Highway Safety Manual Table 13-9. For the most part, the differences in crash modification factor (CMF) can be characterized as relatively small and generally do not by themselves justify the expense of full width paving shoulders for safety benefit alone. The benefit is the shoulder itself, not necessarily the surface type. However, the ALDOT practice of 2’ safety widening to move the drop-off away from the through lane and provide room for the rumble strip has proven very effective. Shoulder paving can give other performance benefits, however, including ease of maintenance and space for bicycling – which may by itself warrant a paved surface if demand is high or the facility is designated as a bicycle route. Design decisions should be made based on these and any other potential performance effects as well as corridor consistency.

Guidance and Criteria

- Paved shoulders and gravel shoulders exhibit very similar safety performance, though more significant differences are noted in wide shoulders (8 to 10 feet).
- Ease of maintenance is the principal factor to consider in determining shoulder pavement width. There are also secondary benefits of bicycle accommodation.
- Provide a minimum paved shoulder width of 2 feet on rural arterials.
- On the inside of sharp curvature, continuous or intermittent shoulder paving may be necessary to accommodate off-tracking of trucks.

Design Standards

- The criteria in the AASHTO Green Book express both usable and paved shoulder widths. For rural two-lane highways, the operative standard dimension is usable shoulder width; paved widths are given but do not have the force of controlling criterion. For all other facilities, multilane rural arterials and freeways, the paved dimension is the nominal standard.

BRIDGE WIDTH

Discussion

AASHTO policy (*A Policy on Geometric Design of Highways and Streets*, *A Policy on Design Standards Interstate System*) states that the full width of roadways including shoulders is normally provided across new structures. Long bridges (defined by AASHTO as greater than 200 feet in length) or long-span structures with high cost per square foot may have a lesser width. Minimum shoulder widths are specified therein for each respective functional classification.

ALDOT practice has generally been to consider functional requirements, performance characteristics, risk, and cost to determine a right-sized structure width for all bridges, regardless of length. Because many ordinary highway overpasses in Alabama have lengths greater than 200 feet, ALDOT has not typically reduced bridge width based on the AASHTO definition of a long bridge. Instead, the width of long-span and complex bridges as well as major river crossings should be evaluated to address emergency use, safety and capacity impacts of reduced shoulder and other facility user needs.

Regarding bridge preservation and improvement on two-lane rural highways, NCHRP Report 783 concluded, "Research conducted in this project found no relationship between bridge width and crash frequency on rural two-lane highways." These findings are based on statistically significant but geographically limited data and appear to provide a basis for bridge width flexibility on preservation and improvement projects. The report recommends "that if an existing bridge on a rural two-lane highway has a roadway narrower than the approach roadway, is in good structural condition, and has no accompanying pattern of crashes indicating a concern related to bridge width, the existing bridge may remain in place." ALDOT guidelines parallel these findings.

Guidance and Criteria

- For bridges less than 250 feet in overall length and having no single span greater than 200 feet, match the existing approach roadway width. Per AASHTO criteria, the operative width dimension for rural 2-lane highways is usable shoulder (paved plus unpaved width) with a minimum of 6'. For rural freeways, expressways, ramps, loops, and freeway auxiliary lanes, paved shoulder width is the operative dimension.
- For complex bridges, major river crossings, bridges with a single span greater than 200 feet, or bridges exceeding 250 feet in overall length, conduct a risk assessment of non-standard width options that weighs the various modal, cost and performance factors. Consult with the Region Engineer, Bridge Bureau and Design Bureau, and others as needed. A minimum bridge shoulder width of 4 feet applies to arterials.
- Minimum bridge shoulder widths for collectors are per Table 6-6 in the AASHTO Green Book, 7th Edition (2018).
- For structure types of any length where future bridge widening is virtually impossible or exceptionally costly, consideration should be given to future needs, even beyond long-range plans, up to the functional life span.

Design Standards

- Bridge width was formerly one of the thirteen Controlling Criteria for Geometric Design but was not retained as such in the Federal revision that reduced the number of controlling criteria to ten. Consequently, bridge width is now a general design element, for which no formal design exception documentation or approval is required. A design variance should be documented when a design value is less than the standard dimension.
- The risk assessment process for complex/long bridges will be administered and facilitated by the project manager and documented in the approved design criteria.

ROADSIDE DESIGN

GENERAL

Roadside safety is a sizable component of overall highway safety, as nearly a quarter of roadway fatalities are single-vehicle road-departure crashes. Meanwhile, grading represents one of the more costly components of highway construction, particularly for projects on new alignment. As with other aspects of road engineering, the practical design approach seeks to balance provision with economy so that more road miles can benefit from limited funds and system-wide safety is optimized. To this end, designers should pursue a practical minimum of excavation and borrow while still providing a product that is conducive to safety and maintenance. Much of this goal can be accomplished by judicious selection of design speed and economical design of horizontal and vertical alignments, but roadside geometry is also crucial to controlling costs and impacts.

The most common items involved in severe road departure crashes are crossroad embankments and trees. Attention should be given to both. Trees represent an asset as well as a hazard, therefore necessitating a balanced design approach.

The definitive design guidance for roadside geometry and clear zone criteria is Chapter 3 of the AASHTO *Roadside Design Guide* (RDG). Its content is principles-based and does not constitute design "policy" in the sense that other AASHTO publications do. It recognizes the need for practical solutions when it states, "Engineering judgment will have to play a part in determining the extent to which improvements reasonably can be made with the limited resources available."

ROADSIDE GEOMETRY

Discussion

The *Highway Safety Manual* provides data on the safety effects of roadside treatments in its Section 13.5.

Front slopes

ALDOT GN-2 Notes 106 through 108 specify maximum front slope rates for various highway types. Construction cost and feasibility, erosion and sediment control and long-term maintenance are factors to consider in side slope design. The criteria which follow should be applied with judgment and practicality.

The *Roadside Design Guide* discusses front slopes in Section 3.2.1. It distinguishes between recoverable, non-recoverable and critical slopes. Where unshielded non-recoverable front slopes are used, a clear runout area at the base of the embankment is recommended.

"Umbrella" cross sections are typically used in high fill sections with a 6:1 side slope out to the clear zone distance. This provides a measure of recoverability in addition to the RDG guidance, which merely recommends a clear runout area at the bottom of the slope if a portion of a non-recoverable slope is within the clear zone. In very high fills with high grading costs and drainage structure costs, evaluate the elimination of the umbrella slope and provision of barrier protection at the full shoulder width.

Ditches

ALDOT typically uses a roadside ditch depth of 3' to 3.5'. This has pavement subgrade benefits as well as roadway drainage benefits. Consider ditch traversability within the clear zone based on slope geometry and ditch bottom width as provided in Chapter 3 of the RDG.

Backslopes steeper than 3:1 are typically discouraged due to erosion and sediment control during construction and long-term maintenance. When necessary on a project, it should be noted the *Roadside Design Guide* does not discuss a safety deficit with backslopes steeper than 3:1, however, except to say that "a steep, rough-sided rock cut normally should begin outside the clear zone or be shielded."

Guidance and Criteria

- Be open to considering various combinations of front slope and back slope rates in order to keep grading limits within the right of way and earthmoving to a reasonable limit.
- Use GN-2 106 through 108 front slopes; however, consider 3:1 front slopes where a steeper slope allows a grading limit to fall within the typical right of way.
- 3:1 typical front slopes should be considered for low-volume roads, especially in rolling terrain.
- On umbrella side slopes, the recoverable portion may – but does not need to – extend to the edge of the clear zone.
- Where non-recoverable slopes exist within the clear zone, provide a clear runout area at the bottom of the embankment.
- 2:1 backslopes and cut slopes behind curbs are undesirable but sometimes necessary in constrained circumstances.
- Observe the ditch traversability guidance (Roadside Design Guide, Chapter 3) if the ditch is inside the suggested clear zone. Ditch slopes outside the preferred channel section may be practical for low-volume or low-speed roads.
- Due to the cost of rock excavation, bedrock does not need to be removed to the edge of the computed clear zone. Where it is not, evaluate the need for shielding if there is not a smooth face.
- 6:1 or flatter longitudinal slopes at cross roads and drive entrances are greatly beneficial and entail a relatively low cost.

CLEAR ZONE

Discussion

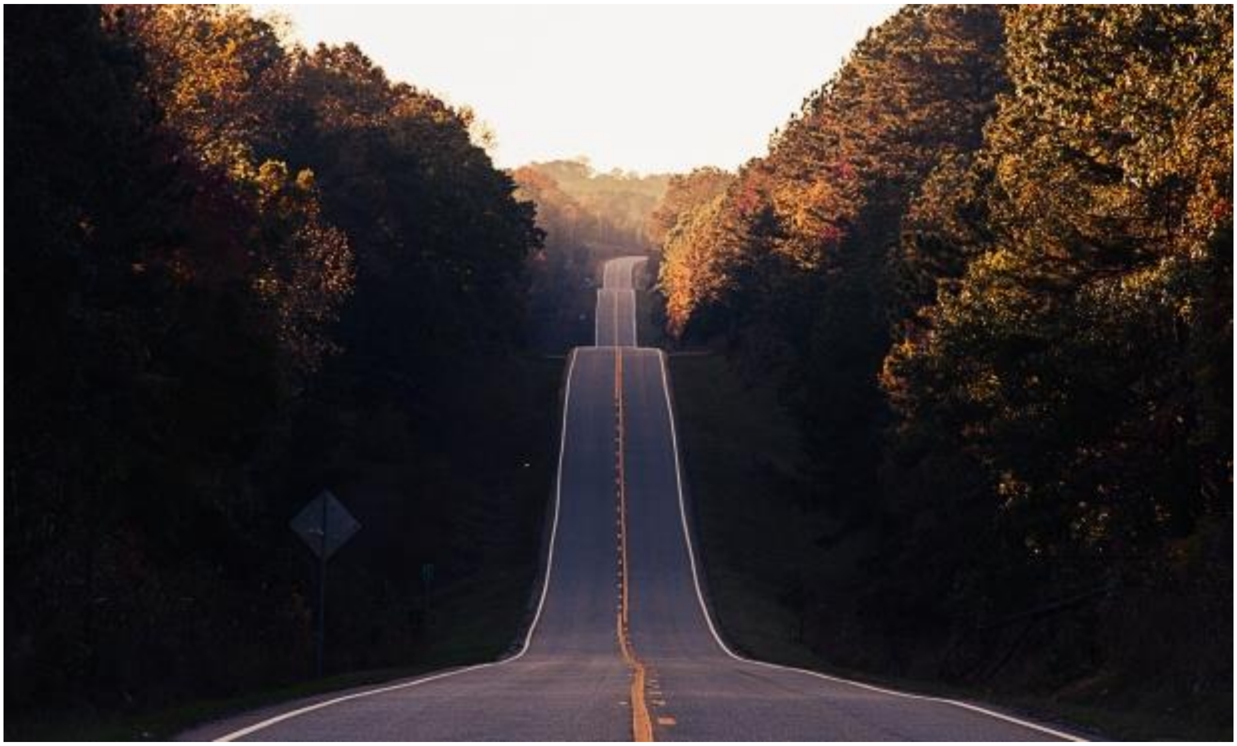
Clear zone criteria are commonly misunderstood to be a design standard but instead represent a guideline for best practice on rural highways where feasible and practical. They are approximate in nature and should be considered the center of a range to be considered at each location along the highway. Design flexibility exists both above and below the published design values depending on site specifics and crash history.

Clear zone application on urban and suburban streets is less clear cut. *Roadside Design Guide* Chapter 10 is devoted to urban and restricted environments. It acknowledges that "the principles and guidelines for roadside design presented in the previous chapters of this guide discuss roadside safety considerations for rural highways, Interstates, and freeways where speeds are generally higher…" For non-freeway arterials in urban environments, "…in many cases, establishing a clear zone using the guidance in Chapter 3 is not practical." It is generally agreed that, for high-speed urban facilities, the clear roadside concept is applicable, subject to practicality and judgment as with rural highways. It is also generally accepted that streets of the type having design speeds of 20 to 35 mph do not require the clear roadside approach, rather a 1.5-foot lateral operational offset from an unyielding object to face of curb. The class of streets for which judgments are more difficult is the so-called transitional-speed facilities – those with design speeds of 40 to 45 mph. They commonly exist in environments where providing clear zones and high-speed roadside hardware would be inconsistent with or disruptive to the community context. The RDG suggests a so-called "enhanced lateral offset" of 4 to 6 feet be provided in these circumstances as an alternative to a typical rural clear zone.

Guidance and Criteria

- Clear zone application is appropriate – subject to engineering judgment – on rural highways, urban and suburban freeways, and high-speed urban and suburban non freeways.
- For low-speed urban and suburban streets, follow the guidance in the AASHTO *Roadside Design Guide*, Chapter 10. A lateral offset to obstruction of 1.5 feet should normally be provided along all curbed streets. The "enhanced lateral offset" of 4 to 6 feet discussed therein should be considered where contextually appropriate for design speeds of 40 mph or greater.

SIGHT DISTANCES



GENERAL

The various aspects of sight distance each have their respective performance characteristics and are discussed separately below. One of the arts of highway design is judging where and how often to provide sight distances to balance functionality with economy and feasibility. This is most often true in rolling terrain, where the grading costs of providing sight distances are considerable. A holistic and sometimes iterative design approach is necessary to achieve this balance.

STOPPING SIGHT DISTANCE

Discussion

It has long been considered crucial to safety and operational efficiency to provide stopping sight distance (SSD) at every point along a road. Research results in recent decades have raised questions about the safety effects of SSD provision, however, suggesting that crash rates increase only when sight distance is severely restricted. NCHRP Report 400 (*Determination of Stopping Sight Distances*) cited these studies and recognized the uncertain performance effects of SSD but nevertheless proposed only a modification of the pre-existing mechanistic model – which does not consider empirical performance – and perpetuated the direction to provide SSD universally. More recently, however, NCHRP Report 783 analyzed available performance data and concluded, "These results indicate that stopping sight distance has no effect on safety at crest vertical curves except when the presence of a crest curve hides a horizontal curve, intersection, or driveway from the view of approaching drivers…There is no reason to suppose that this research finding for vertical sight restrictions would not also apply to horizontal sight restrictions caused by sight obstructions on the inside of horizontal curves."

NCHRP Report 783 recommends, "New construction projects generally can and should be designed to provide the full stopping sight distances presented in the AASHTO Green Book. However, in improvement projects on existing roadways, where stopping sight distances less than (especially just less than) AASHTO criteria are present, consideration should be given to any history of sight-distance-related crashes at the site and to the presence of hidden features that might lead to future crashes as part of any decision to invest in sight distance improvements." In keeping with this recommendation, projects on existing alignment should generally not correct stopping sight distances to meet the nominal standard unless there is a horizontal curve or intersection hidden by the restriction or a sight distance-related crash pattern.

Because of the high cost of bridge construction and the questionable benefit of stopping sight distance discussed above, it is not normally justified for bridges to have wider-than-typical dimensions expressly to provide additional sight distance on the inside of curves unless an intersection or horizontal curve is hidden by the restriction. In light, however, of the aforementioned findings suggesting higher crash rates with severely restricted sight distance, a wider bridge shoulder may be justified in order to provide sight distance of at least 300 feet.

Where SSD provision is desired but standard design values are impractical, somewhat lesser provision can be considered adequate in many cases. As discussed in NCHRP Report 400, the SSD model is comprised of individual components for which conservative values are assumed. These components in combination account for all but a tiny fraction of real-world occurrences, rendering those circumstances practically nonexistent. This may partly explain the relative insensitivity of safety to standard SSD adherence. Consequently, there is considerable flexibility available in stopping sight distance design.

Guidance and Criteria

- For new construction, generally provide the standard stopping sight distance wherever practical – both vertically and horizontally. This includes widening of inside shoulders on curves where median barrier is present, as practical.
- Due to the high cost of bridge construction, do not provide bridge shoulders wider than the typical standard width for the express purpose of sight distance provision. An exception to this is where SSD is limited to less than 300 feet; in these cases, additional width may be provided at the designer's discretion.
- For reconstruction and preservation projects, do not correct substandard SSD conditions unless there is a crash history attributable to sight distance deficiency or there is an intersection or horizontal curve hidden by the obstruction. In these cases, study should be undertaken to assess whether additional sight distance would yield a performance improvement.
- Design with the awareness that the stopping sight distance criteria are very conservative in nature and, as a result, have considerable flexibility built into them.

Design Standards

- Stopping sight distance remains a controlling criterion for design. Applying the guidance herein will sometimes entail design exception documentation.
- Successful design exception justification for non-standard SSD can entail citation of NCHRP Report 783 findings cited above; statement that no hazards, curves or intersections are hidden by the restriction; and affirmation that site-specific history does not indicate a pattern of existing sight distance-related safety problems.

INTERSECTION SIGHT DISTANCE

Discussion

For new and reconstruction projects that substantially alter the grade, it is desirable to provide the AASHTO Green Book intersection sight distance (ISD) design criteria. As with stopping sight distance, the criteria for ISD are based on a mechanistic model designed to allow potentially conflicting vehicles to perceive each other and act accordingly with minimal operational effect. The model was first published in NCHRP Report 383 and is founded in the same principles as stopping sight distance but incorporates modified assumptions based on observed driver behavior at intersections.

Quantitative relationships between available sight distance at intersections and expected safety performance are published in NCHRP Report 875 and will be included in future editions of the AASHTO *Highway Safety Manual*. Guidelines and analytical steps for applying this information on road and street projects are provided in the report.

As previously noted, NCHRP Report 783 found that stopping sight distance (SSD) is associated with increased crash frequency where an intersection is hidden by an SSD restriction. For that reason, SSD should be considered the minimum sight distance design in the vicinity of intersections. Intersection sight distance (ISD) provision is highly encouraged at public road intersections and higher-volume driveway entrances where practical. Because intersections are the most prevalent crash location on the road system, well above minimum sight distance provision is sometimes justifiable, especially in addressing crash problem locations or where site specifics complicate the driving task. The data and guidance in NCHRP Report 875 should be used to assess expected safety outcomes in these situations as well as where standard sight distances are difficult or costly to achieve.

Guidance and Criteria

- For new construction, provide at least stopping sight distance at intersections and driveways. Intersection sight distance provision should be provided, if practical, at public road intersections and higher-volume driveways wherever practical.
- Use the information and guidance in NCHRP Report 875 to assess expected safety outcomes in cases where standard sight distances are not available or practical or where additional sight distance provision is being considered to address existing safety issues or unusual site specifics.
- Intersection safety is a multifaceted, complex, and not well understood system, of which sight distance is only one component. Although deficient sight distance is associated with higher crash rates, an existing crash problem will not automatically be solved by increasing sight distance. At high-crash locations, conduct a Road Safety Audit or similar activity to fully analyze and diagnose the situation. Lower-cost solutions than sight distance improvement may be available.

PASSING SIGHT DISTANCE

Discussion

Standard passing sight distance (PSD) criteria have a clear direct-performance characteristic, at least in that provision of the adopted values is known to be associated with two-lane highways that experience very few crashes related to passing maneuvers. NCHRP Report 605 (*Passing Sight Distance Criteria*) cited research strongly suggesting that two-lane highways with passing zones based on MUTCD striping criteria operate safely. Report 605 established revised PSD design criteria based on the longstanding MUTCD values and the 2011 Green Book incorporated those values.

The AASHTO Green Book recommends "frequently" providing sight distance adequate for passing and that each passing section be as long as practical. This tends to be easily attainable in level terrain, but balancing PSD provision with economy in rolling terrain is one of the most challenging judgments in road design. In some locations it may be more economical to construct passing lanes than to provide passing sight distance.

Guidance and Criteria

- Performance characteristics related to passing provision are generally travel time and travel time consistency. Traffic operational analyses of corridors from these standpoints provide insight into desired frequency of passing sections. Investigate both passing sight distance and passing lane provision to compare costs and benefits.

DECISION SIGHT DISTANCE

Discussion

Decision sight distance (DSD) is useful where a driver must detect an unusual or unexpected roadway element, decide on a required maneuver, and complete it. It is based on criterion using the rule of thumb of approximately 10 seconds for detection, recognition and maneuver performance in an unusual situation. This parameter is experience based and valid, but its approximate nature must be considered in application. Use of values more than or less than 10 seconds may be judged appropriate as circumstances dictate.

Guidance and Criteria

- There are no known data linking crash rate with decision sight distance, but its provision is highly desirable for ease of use as well as to avoid potential erratic driving behavior when DSD is severely restricted.
- Application of DSD is at the discretion of the designer, but it is customarily provided where practical at ramp exit terminals, especially in a lane drop situation.
- Although 10 seconds is the nominal standard, that value should be considered an ideal. Lesser provision – down to 6 or 7 seconds – has been known to perform adequately.
- Mitigation measures should be considered where DSD is desired but cannot be fully provided.

ALIGNMENT ELEMENTS

HORIZONTAL ALIGNMENT

Discussion

Section 13.6.2.1 of the AASHTO *Highway Safety Manual* states, “The probability of a crash generally decreases with longer curve radii, longer horizontal curve length, and the presence of spiral transitions.” These factors also tend to be beneficial for operational and aesthetic performance. For these reasons, attention to these components should be a primary focus of alignment design.

Curve Radius/Degree

Designers should not be averse to employing minimum and even below-minimum radii wherever necessary to achieve feasible and practical solutions. However, minimum radii should be used infrequently along road segments – especially on rural highways – unless restrictive conditions are numerous, as frequent sharp curves place cumulative strain on drivers. For this reason, with projects on new alignments it is useful to establish a desirable minimum radius that can be applied in most circumstances, especially in unconstrained rural locations and across bridges. Recommended desirable maximum curvatures in the table below are based on an incurred side friction value of roughly 60 percent of the standard maximum friction factor. They also encompass the great majority of curves on the existing highway system.

Design Speed, mph	Maximum Desirable D_c or Minimum Desirable Radius
30	400-ft radius
40	8° 00’
50	5° 00’
60	3° 00’
70	2° 00’

Desirable Maximum Curvatures – Rural and High-Speed Urban Highways

Curve Length

Length of horizontal curve has historically been an underemphasized parameter in road design but has gained prominence with the *Highway Safety Manual*’s (Chapter 10) publication. Drivers tend to track poorly through short curves, which may account for some of their safety deficit. As with curve radius, it is difficult to establish minimum desirable values, and there are few applicable design criteria in current literature. One of note is the AASHTO (Green Book, Chapter3) criterion for minimum length of curve ($L_{c\ min}$) of 15 times the design speed expressed in mph. This is generally attainable on most rural highways and thus represents a reasonable guideline for rural design. This criterion will be less easily achievable on urban highways and streets but should be applied to the extent practical. For minor long- radius curves – such as reverse curves used to transition centerline spacing on a divided highway – curves of 8 times the design speed (mph) are known to perform adequately; however, this reduced criterion should generally be limited to curves not requiring superelevation.

It must be noted that the preceding curve length criteria are intended as design guidelines and not standards to be applied at all costs. Where these lengths are not easily attainable, curves should be made as long as practical in the interest of safety performance.

Tangent Length Between Curves

Although tangent length is not known to be safety sensitive, it is often closely interrelated to curve length (above) and so serves as a companion element.

Reverse Curves

There is no known evidence that continuous superelevation transition through a reverse curve is associated with diminished performance. Therefore, the minimum tangent length between simple reverse curves should be provided that allows the reversal of the respective superelevations using a continuous transition. Where there is no superelevation or where it does not control the design, the minimum tangent length should be approximately 3 times the design speed in mph. This is based on observed lengths of maneuvers performed by drivers entering and exiting simple curves.

Longer tangents than the minimums are considered aesthetically superior and are arguably more comfortable to drive. For these reasons, greater-than- minimum lengths should normally be provided.

Broken-Back Curves

Broken-back curves (a short tangent between two curves in the same direction) should be avoided, as they violate driver expectation and are unpleasant in appearance. There is no universal definition of a broken-back-curve in terms of tangent length, however. On new alignments designing broken back curves should be avoided. Where flexibility is needed, a minimum tangent length of 10 times the design speed (mph) can be used. This criterion is presented as an approximation and not a precise design value.

Guidance and Criteria

- Apply a minimum horizontal curve length of 15 times the design speed (mph) where practical for safety and ease of use. For minor long-radius curves not requiring superelevation, a curve length of 8 times the design speed is adequate. These criteria are less crucial but still desirable on low-speed urban streets.
- The minimum tangent length between reverse curves is that required to continuously transition the superelevation, with a desirable minimum of 3 times the design speed (mph).
- On new alignment projects avoid broken-back curves on mainline roads and streets, maintaining a minimum tangent length of roughly 10 times the design speed (mph) between curves in the same direction. On projects with minor alterations to the existing alignment, provide as much tangent length as is practical.

VERTICAL ALIGNMENT

Discussion

Grade has a documented effect on crash frequency on rural highways and well-documented operational effects on all facilities. However, current AASHTO criteria on maximum grade, critical length of grade, and climbing lane warrants are sufficient to guide designers, so no additional guidance is presented herein.

Vertical curve criteria are interrelated with the sight distance elements discussed elsewhere in this document and are addressed respectively for crest and sag conditions below. Absolute Minimum curve length should be 3 times the design speed in mph, however they should be made as long as practicable to avoid the appearance of a kink from the driver's perspective.

Crest Vertical Curves

Crest vertical curves should generally meet the criteria associated with the sight distance design controls selected for each segment or location along a project. As discussed previously, for new construction or reconstruction on new alignment, vertical alignment meeting standard stopping sight distance should typically be provided along the entire length of the project. For preservation or reconstruction on existing alignment, profiles should generally be corrected only in the case of a known performance problem that can be attributed to a sight distance deficiency.

Sag Vertical Curves

NCHRP Report 783 states, "Sag vertical curves by their nature appear to be less related to crash frequency than crest vertical curves…The recent change in design criteria for crest vertical curves to use a 2-ft object height indicates that the small objects implied by the headlight sight distance model for sag vertical curve design may not represent an appropriate design approach." This refers to NCHRP Report 400, which found that small objects in the road are the cause of an exceedingly small percentage of total crashes. For this reason, the sag vertical curve length criterion will initially be the K Values in the Green Book but may be reduced to the comfort criterion where meeting the K Value criterion is not practical or feasible or where comfort controls the design. The design standard below which a design exception must be documented will be the comfort criterion.