Geometric Design Strategies for Speed Reduction and Traffic Calming: Survey of Practice

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Executive Summary

Background

Geometric design strategies may be the most viable solution for speed management along major routes on the state highway system and National Highway System (NHS). Strategies that lower speeds are needed at intersections, along bikeways and pedestrian corridors, and at other conflict points. The geometric design features of roads are directly related to the selected design speed. Self-enforcing roads, for example, use horizontal and vertical alignment and sight distance to encourage drivers to select operating speeds based on driving comfort.

California Department of Transportation (Caltrans) is seeking information about the use of geometric design strategies and self-enforcing roadways in various state highway and NHS road contexts—urban, suburban and rural—to lower speeds at conflict points. The agency is also interested in information about safety and operational issues, such as the impacts of large design vehicles and any trade-offs between decreased speed and geometric alternatives. Findings from this Preliminary Investigation will inform Caltrans' guidance and policy on traffic calming.

Summary of Findings

Survey of Practice

An online survey was distributed to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Design, which includes members of state departments of transportation (DOTs) in all 50 states and the District of Columbia.

Representatives from 13 state DOTs responded to the survey. Of these agencies, four states reported having experience with self-enforcing roadway and geometric design strategies or other traffic calming features:

- Connecticut.
- Florida.
- Oklahoma.
- Wyoming.

Speed Reduction Measures

Treatment Types

The four respondents provided information about their experience with four geometric treatments: horizontal alignment, raised cross sections, road narrowing and vertical alignment. Sight distance reduction measures have not been used for traffic calming by any of the four agencies. Connecticut DOT tries to meet all sight distance standards during the design stage; if standards can't be met, the agency obtains design exceptions.

Horizontal alignment and road narrowing treatments were most frequently described by survey respondents (see Table ES1), such as roundabouts, road diets, bulbouts and traffic islands. Florida DOT, which shifted to context-based design and context-based speed management about three years ago, describes the most diverse use of these treatments and strategies.

Table ES1. Use of Speed Reduction Measures in Highway Road Conflict Points

State	Horizontal Alignment	Raised Cross Section	Road Narrowing	Vertical Alignment	Other
Connecticut	Curvature on approaches to intersections (mainly to roundabouts, but also some town centers)	Speed tables (for multiuse trail crossings)	Traffic splitter islands on approaches to: • Roundabouts • Crosswalks in town centers.	Raised intersections (to help meet stopping sight distances)	N/R
Florida	Any technique, including: • Chicanes • Curves • Lane narrowing • Roundabouts • Splitter islands	• Raised crosswalks • Raised intersections	• Bulbouts • Lane narrowing • Road diets • Traffic islands	• Raised crosswalks • Raised intersections	Textured surface (C5 and C6 road segments with target speeds ≤30 mph)
Oklahoma	Roundabouts	Unknown	• Removal of 12-ft travel lane width • Road diets (currently developing at least one)	N/R	Revised design speed guidance to include FHWA rural/urban transect and functional classification
Wyoming	N/R	N/R	• Bulbouts • Road diets • Traffic islands (*Note*: Mainly used in low-speed urban areas.)	N/R	• Transverse rumble strips and lighting at rural intersections • Roundabouts • Changes to the type of intersection control • Variable speed limits

N/R No response.

Other treatments used by these agencies including textured surface (Florida) and transverse rumble strips (Wyoming). The Wyoming DOT respondent noted that sometimes changing the intersection type, such as installing a roundabout or changing the type of intersection control, can have a dramatic effect on speeds. Oklahoma DOT now includes Federal Highway Administration (FHWA) rural/urban transect and functional classification in its design speed guidance.

Selection Criteria and Other Design Guidance

Florida DOT provided speed ranges as criteria used to select treatments for various applications and road contexts:

- **Rural locations:** Speed management is only applied in rural towns (C2T). Speed range: 25 to 45 mph.
- **Suburban locations:** Speed range for suburban residential and commercial (C3): 35 to 55 mph.
- **Urban locations:** Speed range for urban settings:
  - General urban (C4): 30 to 45 mph.
  - Urban center (C5): 30 to 35 mph.
  - Urban core (C6): 25 to 30 mph.
- **Bicycle corridors:** All nonlimited-access state roads are considered bicycle corridors. Speed management is applied based on the desired target speed for the context.
- **Intersections:** Speed management is applied to all nonlimited-access state road intersections based on the desired target speed.
- **Pedestrian areas:** All nonlimited-access state roads are considered pedestrian areas. Speed management is applied based on the desired target speed of the following contexts, which are considered to have high levels of pedestrian use:
  - General urban (C4): 30 to 45 mph.
  - Urban center (C5): 30 to 35 mph.
  - Rural town (C2T): 25 to 30 mph.

The remaining three agencies have not developed agency-specific criteria or policy:

- Connecticut DOT uses guidance from the National Cooperative Highway Research Program (NCHRP), AASHTO and FHWA.
- Oklahoma DOT follows guidance from the National Association of City Transportation Officials (NACTO) and AASHTO's Policy on Geometric Design of Highways and Streets when selecting treatments. The agency is also developing an intersection control evaluation process for intersection applications.
- Wyoming DOT selects and installs treatments on a case-by-case basis that is usually driven by a documented safety concern. Traffic islands and bulbouts are typically only used in low-speed urban and suburban applications.

Applicable Speed Ranges

Florida DOT has established speed ranges to determine when specific geometric features are appropriate. Design speed ranges are assigned using road context classification and speed management techniques. The remaining three agencies have not established speed ranges for specific geometric features.

Safety and Operational Issues

Safety Criteria and Other Safety Issues

Safety criteria have been established in Florida for speed management techniques, bicycle facilities and pedestrian facilities. Additional criteria have been established for motor vehicle safety issues as well, such as countermeasures for lane departure crashes.

In terms of overall safety, Connecticut and Florida DOTs have not had any safety issues with speed management techniques, although use of these strategies is relatively new in Connecticut. In Wyoming, bulbouts are effective in a number of applications except in areas with heavy truck use where large vehicles may cut a corner and encroach on pedestrian space.

Operational Issues

Potential traffic and maintenance issues may occur in areas where geometric design strategies are implemented. Florida DOT has not experienced operational issues with traffic calming strategies, however, the agency expects that these treatments may increase traffic delays and create issues with large vehicles, particularly in areas using vertical deflection features.

Maintenance issues were reported by respondents from Connecticut and Wyoming DOTs. Curvature is an inconvenience to Connecticut's traveling public, and striping is worn from vehicles that travel outside their lanes. Maintaining vegetation in the state's splitter islands causes traffic delays. The Wyoming DOT respondent noted that raised features such as curbs, traffic islands or bulbouts may be damaged by the traveling public or snowplows, potentially increasing maintenance costs. Yet the safety benefits of these features may outweigh any maintenance concerns.

Impacts of Large Vehicles

Agencies reported on a range of potential impacts of traffic calming strategies on large vehicles. Connecticut DOT noted difficulties with curvature and large vehicles, particularly with roundabouts when larger trucks than anticipated use the designed corridor. In Florida, emergency services and transit vehicles may be impacted by vertical deflection features. The agency attempts to avoid turning movement impacts in the design phase, and aprons may be used to accommodate off-tracking of large vehicles, such as at a median nose or a curb radius. Oklahoma DOT also aims to prevent impacts on large vehicles by encouraging design vehicle selection on an individual movement basis rather than designing an entire intersection for an interstate semitrailer design vehicle. In Wyoming, right turns at bulbouts can be more difficult for larger trucks and buses, potentially putting pedestrians at risk.

Assessing Design Strategies

Effectiveness of Speed or Volume Reduction

Connecticut DOT is currently studying the effectiveness of speed reduction at a town center where splitter islands and curvature were added to both opposite approaches. The agency conducted a speed study before construction; the post-construction study has not been completed.

None of these agencies have evaluated the trade-off between decreased speed and geometric alternatives.

Successes With Geometric Design Strategies

The benefits of geometric design strategies were identified in two areas: safety (Wyoming) and speed management (Connecticut, Florida and Wyoming). Roundabouts in Connecticut have performed better than anticipated, resulting in speed reduction and operational improvements. The agency reported a 50% reduction in crashes and more than 80% reduction in severe injuries. Speed management techniques in Florida are considered “generally effective.” Although the strategies are very new and many have not been installed or evaluated in the state, they are based on national research and have been shown to positively impact speed management. While Wyoming DOT also reported successes with traffic calming treatments, the respondent noted that speed reduction is difficult without physically narrowing roads.

Challenges With Geometric Design Strategies

Four challenges were identified related to geometric design strategies: maintenance, post-installation modifications, public support and familiarity. In Connecticut, plowing is more difficult, and maintaining splitter islands, central islands and plantings contributes more work to maintenance staff. Gaining public support for these strategies has also been challenging. Some roads in suburban Florida DOT were designed at a higher speed than is now desired. Modifying treatments after construction can be extensive and very expensive. Florida DOT has also only been designing low-speed roadways since 2018, and while the concept of speed management has been well received, training is still underway to make staff more familiar with these strategies. Wyoming DOT noted that commonly used speed reduction strategies may become too familiar and lose their effectiveness with the traveling public over time.

Recommendations for Implementation

Florida DOT considers the self-enforcing approach as “a practical, sensible and cost-effective way” to provide better road safety for all modes of travel. In Connecticut, buy-in is key to successfully implementing geometric design strategies. Maintenance strategies should be developed during the design phase, and completed installations—including examples from other states or national resources if in-state examples don’t exist—should be shown to the public. Oklahoma DOT notes the importance of selecting a context-appropriate design speed.

<u>Agencies Not Using Geometric Design Strategies</u>

Nine agencies have not developed self-enforcing roadway and geometric design strategies or other traffic calming features:

- Indiana.
- Michigan.
- Minnesota.
- Missouri.
- Nevada.
- North Carolina.
- Oregon.
- Rhode Island.
- Virginia.

Indiana, Missouri, North Carolina and Virginia DOTs are implementing these features on a project-by-project basis:

- Indiana DOT is pursuing speed management on some corridors and has some guidance for using geometric design strategies (such as raised crosswalks and bulbouts at shared-use path intersections with roads) with other treatments.
- Missouri DOT works with local public agencies interested in installing these strategies but overall is focused on roadway asset management.

- North Carolina DOT has updated its Complete Streets policy and may consider developing traffic calming features as road designs increasingly incorporate multimodal accommodations.
- Virginia DOT has developed guidance for using traffic calming features.

Future plans within Minnesota, Nevada and Oregon DOTs include incorporating these strategies:

- Minnesota DOT is currently updating its Facility Design Guide to include speed management, safe systems, nonmotorized user safety, Complete Streets, performance-based practical design and context-sensitive solutions, which is expected to encourage the use of these strategies. Recommended strategies from the agency's Traffic division will also support the use of these strategies. Initially, these strategies would be implemented in urban or urbanizing corridors for speed management.
- Urban projects will also be the focus of Nevada DOT's initial implementation efforts although the state has many rural roads in small communities where these strategies could be installed. The agency may use design strategies based on functional classification only, relying on guidance from the 2018 AASHTO Policy on Geometric Design of Highways and Streets.
- Oregon DOT's Blueprint for Urban Design includes priorities to consider reducing vehicle operating speeds on highways and to identify strategies to achieve the desired speed. Rather than addressing a targeted location or providing context for a single treatment, the guide presents options to achieve target speeds that can be applied to any urban context and introduces performance-based design using urban context as the chief indicator for design treatments. Six urban contexts are presented: downtown, urban mix, commercial corridor, residential corridor, suburban fringe and rural community. Each context includes treatments that may be used for separated bike lanes and a target frequency for enhanced pedestrian crosswalk spacing.

  The agency's Highway Design Manual includes geometric conditions for roundabout design, including reversing curve alignments and other strategies to target self-enforcing speeds. Other projects frequently employ traffic calming geometric treatments, such as curb extensions and median refuge islands in pedestrian projects.

Supporting Documents

Publications and resources provided by survey respondents address speed management, road context classification and other design principles (beginning on page 24 in the **Detailed Findings** section of this report). The 2021 Florida DOT Design Manual describes strategies to achieve desired operating speeds across all context classifications, including intersections, bicycle corridors, pedestrian areas, and rural and urban locations. The agency's 2020 Context Classification Guide describes the measures used to determine the context classification of a roadway. Standard plans are also provided for raised crosswalks on two-lane, two-way facilities with target speeds of 30 mph or less. Minnesota DOT is currently updating its Facility Design Guide to include speed management, safe systems, nonmotorized user safety, Complete Streets, performance-based practical design and context-sensitive solutions. A preliminary chapter provides guidance for horizontal and vertical alignment features. Oregon DOT's 2020 Blueprint for Urban Design introduces performance-based design using urban context as the chief indicator for design treatments. The guide includes descriptions of the six urban contexts and the design approach for each context.

Related Research and Resources

A literature search of recent publicly available domestic and international resources and in-progress research identified a representative sampling of publications that are organized into the following topic areas:

- Background information.
- Research in progress.
- Bicycle presence.
- Intersection design.
- Large vehicles.
- Lower-speed roadways.
- Pedestrian presence.
- Rural roadways.
- Other design elements.

Tables summarizing these publications, research in progress and other resources are presented by topic area beginning on page 9. Each table provides the publication or project title, the year of publication if research is completed, and a brief description of the resource. Significantly more detail about the resource can be found in the **Detailed Findings** section of this report.

Gaps in Findings

Despite the national scope of the survey, response was limited and included only four agencies with varying levels of experience using geometric design strategies and self-enforcing roads. Of these four agencies, Florida DOT provided the most detailed information and guidance. Additional inquiries to nonresponding state transportation agencies could provide more experience and guidance for implementing these strategies.

Next Steps

Moving forward, Caltrans could consider:

- Contacting Florida DOT, which has been using these geometric design strategies and traffic calming features since 2018.
- Reaching out to other transportation agencies planning to incorporate these strategies in the future, including Minnesota and Oregon DOTs.
- Contacting nonresponding state DOTs to potentially uncover other agencies with experience using geometric design strategies and self-enforcing roadways.
- Examining the manuals and other resources provided by survey respondents for information related to speed management and road context classifications.
- Reviewing the findings of the literature search, which include practices and guidance from both domestic and international publications and resources.

Background Information

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Geometric Design, Speed and Safety (2012)	Domestic	Explores the idea of speed management through the use of roadway geometrics (i.e., geometric designs that influence driver selection of operating speed).
Geometric Design Guide for Canadian Roads (2017)	International	Describes the current design and human factors research and practices for roadway geometric design. Included are design guidelines for freeways, arterials, collectors and local roads in urban and rural locations, and guidance for integrated bicycle and pedestrian design.
Speed Reduction Treatments for High-Speed Environments (2016)	International	Examines the performance of different types of speed-reducing treatments (or combinations of treatments) in high-speed environments. Also considers how desired speed can be aligned with a safe, anticipated operating speed with the goal of making high-speed roads more self-explanatory.
Speed Adaptation Control By Self-Explaining Roads (SPACE) (2013)	International	Describes the European SPACE project (Speed Adaptation Control by Self-Explaining Roads) that looks at the most effective measures in achieving the objectives of self-explaining roads. Analyses indicated that combinations of treatments work more effectively than single treatments, and consistency of treatment is important for drivers.
Using Endemic Road Features to Create Self-Explaining Roads and Reduce Vehicle Speeds (2010)	International	Describes a project undertaken to establish a self-explaining roads design program on existing streets in an urban area. Researchers identified functional road categories and designs based on endemic road characteristics taken from examples in the study area.
Speed Change Management for New Zealand Roads (2006)	International	Presents a speed management approach intended to produce road designs that manipulate a constrained set of road features. These roadways are designed to elicit the correct speeds from drivers and allow drivers to readily recognize the road category and distinguish it from others.

Research in Progress

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
NCHRP Project 15-76: Designing for Target Speed	Domestic	Seeks to determine the effects of roadway, roadside and nonroadway elements on operating speeds on roadways with a target speed between 30 and 40 mph, and develop recommendations on how the findings can be incorporated into the roadway design process. Completion date: January 2023.

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
NCHRP Project 15-77: Aligning Geometric Design With Roadway Context	Domestic	Seeks to draft Part IV (Facility Design in Context) of the proposed eighth edition of AASHTO's A Policy on Geometric Design of Highways and Streets (often referred to as the Green Book). Completion date: December 2021.

Bicycle Presence

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Interaction Driver–Bicyclist on Rural Roads: Effects of Cross-Sections and Road Geometric Elements (2017)	International	Reports the results of a driving simulator study that provides suggestions for the most efficient cross-section reorganization of existing two-lane rural roads to improve road safety for drivers and bicyclists.
The Dutch Road to High Level of Cycling Safety (2017)	International	Explores how the Netherlands achieved an 80% reduction in the number of cyclists killed over a 30-year period. Separated bicycle paths and intersection treatments were found to decrease the likelihood of bicycle–motor vehicle crashes.

Intersection Design

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Use of Innovative Intersection Designs for Improving Mobility and Reducing Roadway Traffic Congestion (2018)	Domestic	Examines three widely implemented innovative intersections: displaced left turn (continuous-flow intersection), median U-turn (Michigan left) and restricted crossing U-turn (superstreet). (FHWA informational guides describing these intersection treatments are cited below.)
Displaced Left Turn Intersection Informational Guide (2014)	Domestic	Considers the displaced left turn intersection, also known as a continuous flow intersection or a crossover displaced left-turn intersection. The number of traffic signal phases and conflict points are reduced at a displaced left turn intersection, which can result in improvements in traffic operations and safety performance.

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Median U-Turn Intersection Informational Guide (2014)	Domestic	Considers the median U-turn intersection, which is also known as the median U-turn crossover and sometimes referred to as a boulevard turnaround, Michigan loon or thru-turn intersection. The median U-turn intersection eliminates left turns on both intersecting streets.
Restricted Crossing U-Turn Intersection Informational Guide (2014)	Domestic	Considers the restricted crossing U-turn intersection, also known as a superstreet intersection, J-turn intersection or synchronized street intersection. The restricted crossing U-turn intersection differs from a conventional intersection by eliminating the left-turn and through movements from cross street approaches.

Large Vehicles

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Effects of Geometric Design Features on Truck Crashes on Limited-Access Highways (2012)	Domestic	Describes the relationships between large truck crash probability, and traffic and geometric characteristics. Models indicated that highway design features such as horizontal curvature, vertical grade, lane width and shoulder width can be used to change the occurrence of large truck crashes.

Lower-Speed Roadways

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
NCHRP Report 880: Design Guide for Low-Speed Multimodal Roadways (2018)	Domestic	Provides best practice guidance to the designer by referencing a range of acceptable elements, criteria and values for critical dimensions in the design of low- to intermediate-speed (45 mph and lower design speed) roadways with a mix of users.

Pedestrian Presence

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Roadway and Infrastructure Design and Its Relation to Pedestrian and Bicyclist Safety: Basic Principles, Applications and Benefits (2013)	Domestic	Provides basic principles to guide roadway and infrastructure design for improved pedestrian and bicyclist safety, including reducing exposure, reducing the probability of a collision given exposure and reducing the probability of injury given a collision.

Rural Roadways

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Self-Enforcing Roadways: A Guidance Report (2018)	Domestic	Describes six self-enforcing road concepts and the processes needed to implement the concepts when designing or evaluating existing two-lane rural highways: speed feedback loop process, inferred design speed approach, design consistency methods, applying geometric design criteria, using a combination of signs and pavement markings, and setting rational speed limits.
SHRP 2—Roadway Information Database (2021)	Domestic	Describes the SHRP 2 Naturalistic Driving Study database, which provides data to support a comprehensive safety assessment of driver behavior and crash risk, especially the risk of lane departure and intersection collisions.
Roadway Information Database (RID): The Roadway Information Database Enables Safety Researchers to Explore the Relationships Between Driver, Vehicle and Roadway (2021)	Domestic	Offers access to the Roadway Information Database, which includes state metadata and supplemental data from Florida, Indiana, New York, North Carolina, Pennsylvania and Washington.
Speed Management ePrimer for Rural Transition Zones and Town Centers (2018)	Domestic	Reviews speeding-related safety issues facing rural communities, along with the basic elements required for data collection, information processing and countermeasure selection. Offers access to six online modules: introduction; speed management planning; collecting/analyzing speed and crash data; setting transition zones; countermeasures; and selected speed management case studies.
NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways (2012)	Domestic	Presents results of a study undertaken to develop improved design guidance for high-speed to low-speed transition zones on rural highways.

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
New Geometric Design Consistency Model Based on Operating Speed Profiles for Road Safety Evaluation (2013)	International	Describes a new methodology to evaluate road safety in the design and redesign stages of two-lane rural highways. The final consistency model takes into account the global dispersion of the operating speed and some indexes that consider both local speed decelerations and speeds over posted speeds.

Other Design Elements

Publication or Project (Date)	Domestic or International	Excerpt From Abstract or Description of Resource
Diverging Diamond Interchange Informational Guide (2014)	Domestic	Examines the diverging diamond interchange, one of four alternative intersections and interchanges evaluated by FHWA and deemed to "offer the potential to improve safety and reduce delay at a lower cost and with fewer impacts than traditional solutions."
Effect of Horizontal Curve Geometry on the Maximum Speed Reduction: A Driving Simulator-Based Study (2019)	International	Describes the development of a maximum speed reduction model for drivers "habituated in weak lane disciplined driving conditions" that addressed road geometric parameters such as radius, curvature, preceding tangent length, curve length, gradient, shoulder width and extra-widening.
Evaluating the Effects of Cross-Sectional Roadway Design Elements and the Impact on Driver Performance Using a Driving Simulator (2019)	International	Explores the relationship between cross-sectional design elements and the impact on selected driver attributes such as speed profiles and lateral positioning. Evidence suggests that the adaptation of narrow lanes, inclusion of bicycle lanes or addition of raised medians will have only a minimal influence on speed reduction.
Effect of Shoulder Width, Guardrail and Roadway Geometry on Driver Perception and Behavior (2011)	International	Tests the combined effects of three roadway design elements—shoulder width, guardrail existence and roadway geometry (curvature)—on objective driving measures (speed and lane position) and subjective measures (perceived safe driving speed and estimated road safety).

Detailed Findings

Background

Transportation agencies have made significant investments in countermeasures to reduce speed, yet nearly one-third of all roadway fatalities are the result of speeding. Many speed-reducing countermeasures, such as chicanes or speed tables, are not appropriate for major routes on the state highway system and National Highway System (NHS) because of design vehicle accommodation, roadway character, emergency response and other factors.

Geometric design strategies may be the most viable solution for long-term, consistent speed management along major routes, where simpler, less costly speed management strategies are unsustainable. Strategies that lower speeds are needed at conflict points such as at intersections or along bikeways and pedestrian corridors. The geometric design features of roads are directly related to the selected design speed. Self-enforcing roads, for example, use horizontal and vertical alignment and sight distance to encourage drivers to select operating speeds based on driving comfort. Other design elements such as pavement or shoulder width and horizontal clearances are generally not directly related to design speed.

California Department of Transportation (Caltrans) is seeking information from other state transportation agencies about the use of self-enforcing roadways and geometric design strategies in various state highway and NHS road contexts—urban, suburban and rural—that lower speed at conflict points. The agency is also interested in information about safety and operational issues, such as the impacts of large design vehicles and any trade-offs between decreased speed and geometric alternatives.

To assist Caltrans in this information-gathering effort, CTC & Associates conducted a national survey of state departments of transportation (DOTs) to inquire about agency experience using self-enforcing roadway and geometric design strategies that lower speeds at conflict points such as intersections and along bikeway and pedestrian corridors. Results of a literature search of publicly available domestic and international resources and in-progress research supplemented the findings from the national survey.

Survey of Practice

An online survey was distributed to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Design. This committee's membership is national in scope and includes representatives from state DOTs in all 50 states and the District of Columbia. Survey questions are provided in Appendix A. The full text of survey responses is presented in a supplement to this report.

Summary of Survey Results

Transportation agencies from 13 states responded to the survey; four reported on experience with self-enforcing roadway and geometric design strategies or other traffic calming features:

- Connecticut.
- Florida.
- Oklahoma.
- Wyoming.

Transportation agencies from the remaining nine states have not developed self-enforcing roadway and geometric design strategies or other traffic calming features in this road context:

- Indiana.
- Michigan.
- Minnesota.
- Missouri.
- Nevada.
- North Carolina.
- Oregon.
- Rhode Island.
- Virginia.

Three of these agencies—Minnesota, Nevada and Oregon DOTs—are considering self-enforcing strategies or traffic calming features. A summary of the information provided by agencies not currently using these strategies is presented in **Agencies Not Using Geometric Design Strategies**, beginning on page 22 of this report.

Below are survey results from the four state transportation agencies that reported on their experience developing self-enforcing roadway and geometric design strategies or other traffic calming features. Information is presented in the following categories:

- Speed reduction measures.
- Safety and operational issues.
- Assessing geometric design strategies.

Supplementary resources provided by these and other respondents are included as supporting documents.

Note that Wyoming DOT does not have a specific policy or plan for self-enforcing roads but has used a number of these strategies on a case-by-case basis.

Speed Reduction Measures

Agency experience with speed reduction measures in highway road conflict points is described below in the following categories:

- Treatment types.
- Selection criteria and other design guidance.
- Applicable speed ranges.

Treatment Types

Survey respondents described their agencies' experience using the following geometric treatments as speed reduction measures:

- Horizontal alignment (e.g., lateral shift, chicane).
- Raised cross sections (e.g., intersection, speed cushion, speed table, offset speed table).
- Road narrowing (e.g., pinch points, choker, traffic islands, bulbouts, road diet).
- Vertical alignment (e.g., speed hump, raised intersections).
- Other treatments.

Tables 1 through 5 summarize agency experience with these measures.

None of these agencies described sight distance reduction measures for traffic calming. The Connecticut DOT respondent noted that the agency tries to meet all sight distance standards and gets design exceptions whenever the standards can't be met.

Among the horizontal alignment treatments cited, roundabouts were mentioned most frequently, although the Florida DOT respondent noted that "any horizontal alignment techniques may be used." (See **Supporting Documents** for a reference to the Florida DOT (FDOT) Design Manual, which includes several treatments.) Florida DOT also described raised cross section treatments, including its recently released developmental standard plans for raised crosswalks on two-lane, two-way facilities with target speeds of 30 mph or less (see **Supporting Documents**). Road narrowing treatments in Oklahoma include removing 12-foot travel lane widths and road diets.

Respondents reported on other treatments used, including textured surface (Florida) and transverse rumble strips (Wyoming). Additionally, the Oklahoma DOT respondent reported that the agency has changed its design speed guidance to include Federal Highway Administration (FHWA) rural/urban transect and functional classification. The Wyoming DOT respondent noted that sometimes changing the intersection type, such as installing a roundabout or changing the type of intersection control, can have a dramatic effect on speeds.

Table 1. Horizontal Alignment Treatments

State	Treatment Description
Connecticut	*Curvature.* On approaches to intersections, primarily with roundabouts but also in town centers.

Florida	• Any horizontal alignment techniques may be used.
	• FDOT Design Manual 202 (see **Supporting Documents**) specifically describes:
	  ○ Chicanes
	  ○ Curves
	  ○ Lane narrowing
	  ○ Roundabouts
	  ○ Splitter islands

Oklahoma	Roundabouts

Table 2. Raised Cross Sections

State	Description
Connecticut	*Speed tables*: For multiuse trail crossings to make users who are crossing the roadway more visible to approaching traffic.
Florida	• *Raised crosswalks*: Developmental Standard Plans D520-030 for raised crosswalks on two-lane, two-way facilities with target speeds ≤ 30 mph (see **Supporting Documents**). • *Raised intersections*

Table 3. Road Narrowing

State	Description
Connecticut	*Traffic splitter islands*: • Provides reduced shy line and plantings for traffic calming. • Generally located on approaches to roundabouts, but have been used on approaches to crosswalks in town centers.
Florida	• Bulbouts • Lane narrowing • Road diets (lane repurposing) • Traffic islands
Oklahoma	• Removal of 12-foot travel lane width (see **Supporting Documents**) • Road diets (currently developing at least one)
Wyoming	• Bulbouts • Road diets (some) • Traffic islands *Note*: Treatments mainly used in low-speed urban areas.

Table 4. Vertical Alignment

State	Description
Connecticut	Raised intersections (generally only proposed to help meet stopping sight distances)
Florida	• Raised crosswalks • Raised intersections

Table 5. Additional Treatments and Practices

State	Description
Florida	Textured surface in road segments classified as C5 (urban center) and C6 (urban core) with desired target speeds ≤30 mph.
Oklahoma	Design speed guidance revised to include FHWA rural/urban transect and functional classification.
Wyoming	In some applications, the agency has used: • Transverse rumble strips and lighting at intersections in rural areas • Roundabouts • Changes to the type of intersection control • Variable speed limits

Selection Criteria and Other Design Guidance

Florida DOT provided speed ranges as criteria used when selecting a treatment for various applications. Speeds for specific road contexts are summarized below and available in Chapter 202, Speed Management, of the FDOT Design Manual (see **Supporting Documents**):

Bicycle Corridor	All nonlimited-access state roads are bicycle corridors and can have speed management applied in the appropriate context classifications, based on the desired target speed.
Intersection	All nonlimited access state road intersections can have speed management applied in the appropriate context classifications based on the desired target speed.
Pedestrian Area	All nonlimited access state roads are pedestrian areas and can have speed management applied in the appropriate context classifications based on the desired target speed. C4 (general urban), C5 (urban center), C6 (urban core) and C2T (rural town) are assumed to have high levels of pedestrian activity.
Rural Location	Rural towns (C2T) are the only places where speed management would be used within a rural area. The speed range for C2T is 25 to 45 mph.
Suburban Location	The speed range for C3 (suburban residential and commercial) is 35 to 55 mph.
Urban Location	The speed range for urban settings is: • C4: 30 to 45 mph. • C5: 30 to 35 mph. • C6: 25 to 30 mph.

Oklahoma DOT follows guidance from the National Association of City Transportation Officials (NACTO) (see *Related Resource* below) and AASHTO's Policy on Geometric Design of Highways and Streets (see **Related Research and Resources**, page 30) when selecting treatments. The respondent added that the agency is developing an intersection control evaluation process for intersection applications. Connecticut DOT has not developed agency-specific criteria. Instead, designers use national guidance from the National Cooperative Highway Research Program (NCHRP), AASHTO, FHWA and other sources that discuss these treatments. Wyoming DOT also has no set selection criteria or policy. Selection and installation are determined on a case-by-case basis and typically driven by a documented safety concern. The respondent added that traffic islands and bulbouts are typically only used in low-speed urban and suburban applications.

Related Resource:

National Association of City Transportation Officials (NACTO), undated.
https://nacto.org/
From the web site:

> NACTO's mission is to build cities as places for people, with safe, sustainable, accessible, and equitable transportation choices that support a strong economy and vibrant quality of life.

Design guides and other resources are available at this site.

Applicable Speed Ranges

Florida DOT has established speed ranges to determine when specific geometric features are appropriate. Design speed ranges are assigned using road context classification and speed management techniques (see **Supporting Documents**). The remaining three agencies have not established speed ranges for specific geometric features.

Safety and Operational Issues

Safety Criteria and Other Safety Issues

Florida DOT has established safety criteria for speed management techniques, bicycle facilities and pedestrian facilities that address safety problems. Additional criteria have been established for motor vehicle safety issues as well, such as countermeasures for lane departure crashes.

Examining safety issues in general, the Florida DOT respondent reported that the agency has not had safety issues with speed management techniques to date. Similarly, Connecticut DOT has had no safety issues with these strategies although using these treatments is a relatively new practice. The Wyoming DOT respondent noted that bulbouts are effective in a number of applications except in areas with heavy truck use where a bulbout may increase the frequency of large vehicles cutting a corner and encroaching on pedestrian space.

Operational Issues

To date, Florida DOT has not encountered operational issues with traffic calming strategies. The respondent noted that anticipated operational issues may include increased traffic delays and issues with large vehicles, particularly with vertical deflection interventions.

Maintenance issues were reported by respondents from Connecticut and Wyoming DOTs. The Connecticut DOT respondent reported that operationally, curvature is an inconvenience to the traveling public, striping is worn from vehicles that do not stay within their lane, and maintaining vegetation in the splitter islands causes traffic delays (maintenance is usually performed by municipalities).

The Wyoming DOT respondent cited potential increased maintenance costs. In general, as any raised feature (such as a curb, traffic island or bulbout) can be damaged by the traveling public or snowplows. The respondent added that the safety benefits of these features may outweigh any maintenance concern.

<u>Impacts of Large Vehicles</u>

Agencies noted potential impacts of traffic calming strategies on large vehicles and, in some cases, practices to prevent these impacts:

- *Connecticut*. The respondent noted that curvature “is tough for the large vehicle industry,” adding that the agency has had to rehabilitate one roundabout because larger trucks than anticipated use the designed corridor. The respondent also pointed to the “fine line” in designing roads that slow cars and accommodate large vehicles. Passenger car speed reduction is limited when large vehicles are also accommodated.
- *Florida*:
    - Vertical deflection can present issues for emergency services and transit vehicles. The agency is monitoring these situations as it introduces traffic calming interventions.

    - Turning movement impacts are addressed with AutoTURN in the design phase (see *Related Resource* below).
    - Aprons may be used to accommodate off-tracking of large vehicles, such as at a median nose or a curb radius.
- *Oklahoma*. The agency aims to prevent impacts on large vehicles by encouraging design vehicle selection on an individual movement basis rather than designing an entire intersection for a WB-67 design vehicle (an interstate semitrailer).
- *Wyoming*. Bulbouts can make right turns more difficult for larger trucks and buses, which can sometimes put pedestrians at risk (if the rear of the vehicle trails across the bulbout).

Related Resource:

AutoTURN, Transoft Solutions, undated.
https://www.transoftsolutions.com/vehicle-swept-path/autoturn-select/#learnmore
From the web site: AutoTURN is used to confidently analyze road and site design projects, including intersections, roundabouts, bus terminals, loading bays, parking lots or any on-/off-street assignments involving vehicle access checks, clearances and swept path maneuvers.

As the vehicle swept path analysis software of choice for transportation engineers, planners, drafters and architects, AutoTURN is used every day. In fact, almost every state DOT in the U.S. and provincial MOT [ministry of transportation] in Canada use AutoTURN, making it the defacto standard software of its kind for government agencies.

Assessing Geometric Design Strategies

Effectiveness of Speed or Volume Reduction

Connecticut DOT is currently studying the effectiveness of speed reduction at a town center where splitter islands and curvature were added to both opposite approaches. A speed study was conducted before construction; the post-construction study has not been completed.

None of these agencies has evaluated the trade-off between decreased speed and geometric alternatives.

Successes With Geometric Design Strategies

Three agencies described beneficial safety and speed management effects of geometric design strategies:

- **Safety**. The Wyoming DOT respondent reported success in general with some of the strategies from a safety perspective.
- **Speed management**:
    - Connecticut DOT has had success with the speed reduction and operational improvements at roundabouts. Operationally, the agency finds that roundabouts perform better than planned. Crashes have generally been reduced by 50%, according to the survey respondent, and severe injuries have been reduced by more than 80%.

- Florida DOT's speed management techniques are based on national research and incorporate tools shown to have positive impacts on speed management. The respondent noted that these strategies are very new and many have not been installed or evaluated. However, in the few instances where these interventions were found before they were introduced in the agency's Design Manual, they were considered "generally effective."
- Although the Wyoming DOT respondent reported successes in general with traffic calming treatments, he added that speed reduction is difficult without physically narrowing roads.

Challenges With Geometric Design Strategies

These agencies also recognized challenges with geometric design strategies in four areas:

- **Maintenance**. Maintaining these facilities is "a big challenge" within Connecticut DOT. Plowing is more difficult and maintaining the splitter islands, central islands and plantings adds more work responsibilities to the department's maintenance staff. (*Note*: Local municipalities maintain the landscaping.)
- **Post-installation modifications**. Florida DOT recognizes issues with the application of speed management in C3 (suburban) conditions where a road was designed at a higher speed than is now desirable (lower target speed). Interventions in these conditions can be very expensive and extensive.
- **Public support**. Connecticut DOT has had difficulty obtaining public buy-in for these strategies.
- **Unfamiliarity/Overfamiliarity:**
    - Florida DOT engineers have only been designing low-speed roadways since 2018. The respondent noted that while training and study of these techniques are still underway, the speed management concept has been well-received.
    - The Wyoming DOT respondent noted that commonly used strategies may become too familiar and lose their effectiveness over time, especially with respect to speed reduction.

Recommendations for Implementation

After using context-based design for three years, the Florida DOT respondent described the self-enforcing approach as "a practical, sensible and cost-effective way" to provide better road safety for all modes of travel. Making the shift to context-based design (and context-based speed management) is "a nontrivial endeavor," he reported, but "the payoffs are tremendous."

Connecticut DOT encouraged new users to obtain support from maintenance staff and the public:

- **Maintenance support**. Engage the maintenance staff early. When designing a traffic calming strategy, also develop a maintenance strategy that maintenance staff can support.
- **Public support**:
    - Involve the public early to gain support.
    - Use very similar examples that have worked and show the public that is what it will get.

- If in-state examples are not available, use information and examples from other states or from national resources.

Oklahoma DOT recommended selecting a context-appropriate design speed.

Agencies Not Using Geometric Design Strategies

Transportation agencies from nine states have not developed self-enforcing roadway and geometric design strategies or other traffic calming features in this road context:

- Indiana.
- Michigan.
- Minnesota.
- Missouri.
- Nevada.
- North Carolina.
- Oregon.
- Rhode Island.
- Virginia.

Four of these agencies—Indiana, Missouri, North Carolina and Virginia DOTs—do not currently have a formal policy or strategy, however, traffic calming features are implemented on a case-by-case basis:

- Indiana DOT is currently pursuing speed management on some corridors, but this work has not resulted in formal policy. The agency does have guidance that includes some self-enforcing geometric design strategies, such as raised crosswalks and bulbouts at shared-use path intersections with roads, but these features are included with other treatments.
- Missouri DOT is currently focused on roadway asset management. Although it does not have a statewide strategy, the agency assists local public agencies that may want to install these features.
- North Carolina DOT also does not have a statewide policy but the respondent noted that as road designs incorporate more and more multimodal accommodations as a result of its updated Complete Streets policy, the agency may consider developing traffic calming features in the future.
- Virginia DOT has developed guidance for using traffic calming features (see **Supporting Documents**).

Michigan DOT has not identified situations where these strategies are needed, and Rhode Island DOT is not familiar with these strategies.

Three agencies—Minnesota, Nevada and Oregon DOTs—are planning to incorporate self-enforcing strategies or traffic calming features:

- Minnesota DOT is currently compiling speed management, safe systems, nonmotorized user safety, Complete Streets, performance-based practical design and context-sensitive solutions into its update of the MnDOT Facility Design Guide (a two- to three-year effort). The update will incorporate elements that are expected to encourage designers to implement self-enforcing roadway and geometric design strategies. Although these strategies and treatments have not yet been determined, the agency's Traffic division has recommended strategies through scoping reports and geometric design reviews.

  Treatments would primarily be implemented in urban or urbanizing corridors and used for speed management. The agency has not established speed thresholds or volume limits.

- Nevada DOT expects the first chapter of the 2018 AASHTO Policy on Geometric Design of Highways and Streets (see page 30) may serve as the basis for design strategies for each type of functional classification. Agency staff is considering developing a typical cross section or strategy for each road type.

  Although no specific locations have been identified, the agency plans to focus initially on urban projects. But a lot of rural roads in the state pass through small towns where these design strategies could be implemented. The agency is considering using design strategies based on functional classification only with consideration for the five new context classifications. Volume limits, speed thresholds and geometry conditions have not yet been identified.
- An Oregon DOT directive requires that certain key priorities outlined in its Blueprint for Urban Design be considered for urban projects. Among the priorities are to consider reducing vehicle operating speeds on highways (target speed) and to identify strategies to achieve the desired speed.

  Rather than addressing a targeted location or providing context for a single treatment, the guide presents a menu of options to achieve target speeds that can be applied to any urban context and introduces performance-based design using urban context as the chief indicator for design treatments. The framework has six urban contexts: downtown, urban mix, commercial corridor, residential corridor, suburban fringe and rural community. Each context has a menu of treatments that may be used for separated bike lanes and a target frequency for enhanced pedestrian crosswalk spacing.

  Table 3-10 in Blueprint for Urban Design lists traffic calming options available to achieve target speeds in various contexts, including:
    - *Downtown* (target speed 20 to 25 mph): roundabouts, lane narrowing, speed feedback signs, on-street parking, street trees, median islands, curb extensions, chicanes, textured surface, coordinated signal timing, speed tables, road diets.
    - *Urban mix* (target speed 25 to 30 mph): roundabouts, lane narrowing, speed feedback signs, on-street parking, street trees, median islands, curb extensions, chicanes, textured surface, coordinated signal timing and road diets.
    - *Commercial or residential corridor* (target speed 30 to 35 mph): roundabouts, lane narrowing, speed feedback signs, landscaped median islands, coordinated signal timing and road diets.
    - *Suburban fringe* (target speed 35 to 40 mph): roundabouts, transverse pavement markings, lane narrowing, speed feedback signs, road diets and entry treatments.
    - *Rural community* (target speed 25 to 35 mph): roundabouts, lane narrowing, speed feedback signs, on-street parking, street trees, median islands, curb extensions, chicanes, speed tables, road diets and entry treatments.

  Geometric conditions for roundabout design are provided in the ODOT Highway Design Manual and include reversing curve alignments and other strategies to target self-enforcing speeds. Additionally, many traffic calming geometric treatments are often employed for other projects. For example, pedestrian projects often incorporate curb extensions and median refuge islands.

Note: Oregon statute (ORS 366.215) requires the agency to include freight mobility stakeholders in discussions related to any proposed reduction to existing state highway width.

Supporting Documents

Florida

Chapter 2, Speed Management, FDOT Design Manual (FDM), Florida Department of Transportation, January 2021.
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/2021/2021fdm202speedmgmt.pdf
FDOT Design Manual: https://www.fdot.gov/roadway/fdm/default.shtm
Chapter 1, Design Controls: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/2021/2021fdm201designcontrols.pdf
From the introduction:

> This chapter describes strategies that may be used to achieve desired operating speeds across all context classifications. The strategies described in this chapter are national best practices for low speed facilities and are allowable on arterials and collectors when consistent with the context classification of the roadway.
>
> The FDM recognizes a range of design speeds for each context classification. For very low speed conditions (35 mph or less) the context classification design speed range indicates the upper end of desirable operating speeds. For instance, the design speed range for C4 is 30-45 mph, but in conditions where on-street parking is present, a 35 mph or lower design speed should be used. Additionally, when the current design speed of a roadway exceeds the allowable range for the context classification, or exceeds the target speed for conditions within the roadway, the strategies described in this chapter can be used to achieve a lower operating speed.

Target speed and speed management strategies are discussed, including horizontal alignment, intersections, bicycle corridors, pedestrian areas, and rural and urban locations. Table 202.3.1 (page 13 of the PDF) summarizes strategies to achieve desired operating speeds by road context classification.

Design speed ranges are also discussed by context classification in Table 201.5.1 of Chapter 1, Design Controls (https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/2021/2021fdm201designcontrols.pdf, page 10 of the PDF).

FDOT Context Classification Guide, Florida Department of Transportation, July 2020.
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/completestreets/files/fdot-context-classification.pdf?sfvrsn=12be90da_2
From Chapter 1: FDOT has adopted a roadway classification system comprised of eight context classifications for all non-limited-access state roadways. … The context classification and transportation characteristics of a roadway will determine key design criteria for all non-limited-

access state roadways. This Context Classification Guide provides guidance on how context classification can be used, describes the measures used to determine the context classification of a roadway, and describes the relationship of context classification with the FDOT Design Manual (FDM) and other FDOT guidance.

Complete Streets Implementation, Florida Department of Transportation, undated.
http://www.flcompletestreets.com/
This web site provides access to design guides and resources, including the FDOT Design Manual and the FDOT Context Classification Guide.

"Raised Crosswalk," Developmental Standard Plans D520-030, Office of Design, Florida Department of Transportation, 2020.
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/dev/d520-030.pdf?sfvrsn=aefe800d_2
Citation at https://www.fdot.gov/design/standardplans/dev.shtm
These plans illustrate raised crosswalks on two-lane, two-way facilities with channel gutters and type D curb, and target speeds of 30 mph or less.

Minnesota

Facility Design Guide, Minnesota Department of Transportation, 2021.
https://roaddesign.dot.state.mn.us/facilitydesign.aspx
Minnesota DOT is updating its Facility Design Guide to include speed management, safe systems, nonmotorized user safety, Complete Streets, performance-based practical design and context-sensitive solutions. Current available chapters include Chapter 5, Alignment and Superelevation, which includes guidance for horizontal and vertical alignment.

Oklahoma

ODOT Roadway Design Manual, Oklahoma Department of Transportation, 1992.
https://www.odot.org/OK-GOV-DOCS/DOING-BUSINESS/Consultant-Contract-Info/1992%20Roadway%20Design%20Manual%20complete_both%20volumes%20comprest.pdf
The Roadway Design Manual addresses geometric and other design principles, including horizontal alignment (Chapter 6, beginning on page 155 of the PDF), vertical alignment (Chapter 7, beginning on page 274 of the PDF) and geometric design criteria for new construction and reconstruction (Chapter 12, beginning on page 684 of the PDF).

Oregon

Blueprint for Urban Design, Vol. 1, Oregon Department of Transportation, January 2020.
https://www.oregon.gov/odot/Engineering/Documents_RoadwayEng/Blueprint-for-Urban-Design_v1.pdf
This guide introduces performance-based design using urban context as the chief indicator for design treatments. Chapter 2, Refining Urban Contexts and Roadway Classifications (beginning on page 42 of the PDF), includes descriptions of the six urban contexts and the design approach for each context. Chapter 3 provides design guidance for target speed (beginning on page 102 of the PDF), including Table 3-10 (page 104 of the PDF), which recommends traffic calming treatments to achieve target speeds in various contexts.

Chapter 8, Intersections, ODOT Highway Design Manual, Oregon Department of Transportation, 2012.
https://www.oregon.gov/odot/Engineering/Documents_RoadwayEng/HDM_08-Intersections.pdf
Selection criteria and design considerations for roundabouts are discussed in this chapter, including reversing curve alignments and other strategies to target self-enforcing speeds (beginning on page 53 of the PDF).

ORS 366.215, Creation of State Highways: Reduction in Vehicle-Carrying Capacity, Oregon Revised Statutes, 2019.
https://www.oregonlaws.org/ors/366.215
According to the Oregon DOT respondent, this statute requires that freight mobility stakeholders be included in discussions whenever any reduction to existing state highway width is proposed.
From the statute:

> (1) The Oregon Transportation Commission may select, establish, adopt, lay out, locate, alter, relocate, change and realign primary and secondary state highways.
>
> (2) Except as provided in subsection (3) of this section, the commission may not permanently reduce the vehicle-carrying capacity of an identified freight route when altering, relocating, changing or realigning a state highway unless safety or access considerations require the reduction.
>
> (3) A local government … may apply to the commission for an exemption from the prohibition in subsection (2) of this section. The commission shall grant the exemption if it finds that the exemption is in the best interest of the state and that freight movement is not unreasonably impeded by the exemption.

Virginia

Traffic Calming Guide for Neighborhood Streets, Traffic Engineering Division, Virginia Department of Transportation, September 2018.
http://www.virginiadot.org/programs/resources/Traffic-Calming-Guide-For-Neighborhood-Streets.pdf
This educational resource for local communities provides an overview of traffic calming features along with “guidance and procedures for a local community to pursue traffic calming in their neighborhoods on streets maintained by [Virginia] DOT.” Horizontal, vertical and narrowing measures are discussed beginning on page 17 of the guide (page 20 of the PDF). Descriptions include the advantages and disadvantages of each treatment as well as estimated cost and effectiveness.

Related Research and Resources

A literature search of domestic and international in-progress and published research examined the use of self-enforcing roadways and geometric design strategies in various state highway and other road contexts—urban, suburban and rural—that lower speed at conflict points. The literature search also sought information about safety and operational issues, such as the impacts of large design vehicles and any trade-offs between decreased speed and geometric alternatives. Findings from this literature search are presented below in the following topic areas:

- Background information.
- Research in progress.
- Bicycle presence.
- Intersection design.
- Large vehicles.
- Lower-speed roadways.
- Pedestrian presence.
- Rural roadways.
- Other design elements.

Citations are further categorized as domestic and international resources. Summaries of the citations presented below begin on page 9.

Background Information

Domestic Resources

"Geometric Design, Speed and Safety," Richard J. Porter, Eric T. Donnell and John M. Mason, *Transportation Research Record 2309*, pages 39-47, 2012.
Citation at https://journals.sagepub.com/doi/10.3141/2309-05
From the abstract: A conservative approach to establishing design criteria, used to address the range of driver, vehicle and roadway conditions and capabilities that a designer must consider, is demonstrated. … The idea of speed management through the use of roadway geometrics (i.e., geometric designs that influence driver selection of operating speed)—one component of self-enforcing, self-explaining roadway design—is explored. Findings uncover possible challenges to implementing this idea. Five related questions are addressed: (a) What is known about the relationships between road geometry and operating speeds? (b) To what degree does road geometry influence operating speeds? (c) How are safety and security influenced by road geometry? (d) What are the potential impacts on large vehicles? and (e) What is the nature of the speed–safety trade-off?

International Resources

Geometric Design Guide for Canadian Roads, Transportation Association of Canada, 2017.
Guide description available at https://www.tac-atc.ca/en/publications-and-resources/geometric-design-guide-canadian-roads
Each chapter of this publication—including chapters on bicycle, pedestrian and intersection design—is available separately. *From the table of contents overview*:

> The Geometric Design Guide for Canadian Roads contains the current design and human factors research and practices for roadway geometric design. … Design guidelines for freeways, arterials, collectors and local roads, in both urban and rural locations are included as well as guidance for integrated bicycle and pedestrian design. The Guide is organized into ten chapters to cover the entire design process from design philosophy and roadway

classification to design parameters and specific guidelines for the safe accommodation of vehicles, cyclists and pedestrians on linear road elements and at intersections.

….

Chapter 5 - Bicycle Integrated Design identifies examples on how to integrate the design of bicycle facilities holistically into the design of roadways to provide a balanced solution for all modes and road users; and provides guidance on bicycle and in-line skater design needs, types of bicycle facilities, a framework for the selection of an appropriate type of facility, and specific design elements.

Chapter 6 - Pedestrian Integrated Design highlights examples on how to integrate the design of pedestrian facilities holistically into the design of roadways to provide a balanced solution for all modes and road users; provides guidance on pedestrian and wheelchair design needs, use of a framework approach to design which subdivides the roadside into frontage, pedestrian through and furnishing zones and specific design elements; and addresses integration with other design elements including adjacent roadway lane widths, roundabouts and bridges and other travel modes.

….

Chapter 9 - Intersections offers design guidance on intersections including roundabouts, innovative intersections and at-grade railroad crossings; summarizes relevant human factor aspects; identifies an intersection planning and design process for relevant inputs and possible constraints; summarizes guidelines on intersection spacing, layout and alignment and sight distance needs; and outlines guidelines and design details for simple intersections, channelization, tapers, auxiliary and turning lanes.

Speed Reduction Treatments for High-Speed Environments, Michael Levasseur, Austroads, February 2016.
Publication available at https://austroads.com.au/publications/road-design/ap-r508-16
From the overview and abstract: This report examines the performance of different types of speed-reducing treatments (or combinations of treatments) in high-speed environments. The project also considered how desired speed can be aligned with a safe, anticipated operating speed with the goal of making high-speed roads more self-explanatory.

Treatments reviewed included: treatments to support development of road hierarchies in line with the concept of self-explaining roads; perceptual countermeasures; transverse rumble strips; vehicle activated signs; gateway treatments; route-based curve treatments; wide median centrelines; and sight distance adjustments on intersection approaches.

"Speed Adaptation Control by Self-Explaining Roads (SPACE)," Carl Van Geem, Suzy Charman, Aoife Ahern, Anna Anund, Leif Sj gren, Andrea Pumberger, Graham Grayson and Shaun Helman, *Road Safety on Four Continents: 16th International Conference*, May 2013.
https://researchrepository.ucd.ie/rest/bitstreams/11338/retrieve
From the abstract: This paper describes the SPACE project (Speed Adaptation Control by Self-Explaining Roads). This is a European project, funded by ERANET Road initiative, looking at the meaning of self-explaining roads and what types of measures are most effective in achieving the objectives of self-explaining roads. A series of consultations with experts and driver simulation tests were conducted. From this analysis, it was clear that combinations of treatments work more effectively than single treatments and that consistency of treatment is important for drivers.

"Using Endemic Road Features to Create Self-Explaining Roads and Reduce Vehicle Speeds," Samuel G. Charlton, Hamish W. Mackie, Peter H. Baas, Karen Hay, Miguel Menezes and Clair Dixon, *Accident Analysis and Prevention*, Vol. 42, Issue 6, pages 1989-1998, November 2010.
Citation at https://doi.org/10.1016/j.aap.2010.06.006
From the abstract: This paper describes a project undertaken to establish a self-explaining roads (SER) design programme on existing streets in an urban area. The methodology focused on developing a process to identify functional road categories and designs based on endemic road characteristics taken from functional exemplars in the study area. ... Speed data collected [three] months after implementation showed a significant reduction in vehicle speeds on local roads and increased homogeneity of speeds on both local and collector roads. The objective speed data, combined with residents' speed choice ratings, indicated that the project was successful in creating two discriminably different road categories.

Speed Change Management for New Zealand Roads, S.G. Charlton and P.H. Baas, Land Transport New Zealand, 2006.
https://www.nzta.govt.nz/assets/resources/research/reports/300/docs/300.pdf
From the recommendations that begin on page 60: The goal of the present research was to identify and develop research findings that would enable the development of New Zealand speed management approaches akin to self-explaining and sustainably safe initiatives in other countries. The speed management approach adopted by this research programme was intended to produce road designs that:

- [M]anipulate a constrained set of road features,
- [A]re designed to elicit the correct speeds from drivers,
- [A]llow drivers to readily recognise the road category and distinguish it from others,
- [W]ill increase homogeneity of speeds (minimise individual differences),
- [W]ill resist habituation and behavioural adaptation.

Further to this goal, the present report identified some of the most promising speed management treatments as shown in the design recommendations in Chapter 5.

Research in Progress

Domestic Resources

NCHRP Project 15-76: Designing for Target Speed, start date: July 2020; expected completion date: January 2023.
Project description at https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4765
From the project description: Research is needed to gain a better understanding of how roadway, roadside and non-roadway elements influence the operating speed—the actual speed of the driver—in order to improve roadway designs and reliably achieve desired speed outcomes.
….

The objectives of this research are to (1) determine the effects of roadway, roadside and non-roadway elements on operating speeds on roadways with a target speed between 30 and 40 mph and (2) develop recommendations on how the findings can be incorporated into the roadway design process.

NCHRP Project 15-77: Aligning Geometric Design With Roadway Context, start date: June 2020; expected completion date: December 2021.
Project description at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4766
From the project description: The objective of this research is to draft Part IV (Facility Design in Context) of the proposed eighth edition of the Green Book (GB8), using a consistent structure for the context chapters and drawing content from the Green Book and research-based sources. ….

These chapters should present appropriate applications and ranges of design controls, criteria and elements that are considered appropriate for all modes of travel. The material should reflect a performance-based design process that considers a broad range of design choices and applies to all project types (i.e., new construction, reconstruction, projects on existing roads). The material will allow the identification of potential areas of concern and determination of the trade[-]offs required to best achieve the project's purpose and need statement.

Related Resource:

> **A Policy on Geometric Design of Highways and Streets**, 7th Edition, American Association of State Highway and Transportation Officials, 2018.
> Publication description at https://store.transportation.org/item/collectiondetail/180
> *From the description:* [This publication], commonly referred to as the Green Book, contains the current design research and practices for highway and street geometric design. This edition presents an updated framework for geometric design that is more flexible, multimodal and performance-based than in the past. The document provides guidance to engineers and designers who strive to make unique design solutions that meet the needs of all highway and street users on a project-by-project basis. Not only are the traditional functional classifications for roadways (local roads and streets, collectors, arterials and freeways) presented, but also an expanded set of context classifications (rural, rural town, suburban, urban and urban core) to guide geometric design.

Bicycle Presence

International Resources

"Interaction Driver–Bicyclist on Rural Roads: Effects of Cross-Sections and Road Geometric Elements," Francesco Bella and Manuel Silvestri, *Accident Analysis and Prevention*, Vol. 102, pages 191-201, February 2017.
Citation at https://doi.org/10.1016/j.aap.2017.03.008
From the abstract: The interaction of motorists and bicyclists, particularly during passing maneuvers, is cited as one of the primary causes of bicyclist fatalities. This paper reports the results of a driving simulator study, which sought to analyze the effects that three cross-section configurations of a two-lane rural road and four geometric elements of the road have on driver behavior, during the interaction with a cyclist. ... The obtained results provide suggestions for the most efficient cross-section reorganization of existing two-lane rural roads in order to improve the road safety.

"The Dutch Road to High Level of Cycling Safety," P. Schepers, D. Twisk, E. Fishman, A. Fyhri and A. Jenson, *Safety Science*, Vol. 92, pages 264-273, 2017.
Citation at https://doi.org/10.1016/j.ssci.2015.06.005
From the abstract: This paper explores how the Netherlands achieved an 80% reduction in the number of cyclists killed (predominantly bicycle–motor vehicle crashes) per billion bicycle

[kilometers] over a thirty-year period. Factors found to contribute to this improvement include the establishment of a road hierarchy with large traffic-calmed areas where through traffic is kept out. A heavily used freeway network shifts motor vehicles from streets with high cycling levels. This reduces exposure to high-speed motor vehicles. Separated bicycle paths and intersection treatments decrease the likelihood of bicycle–motor vehicle crashes. The high amount of bicycle use increases safety as a higher bicycle modal share corresponds with a lower share of driving and greater awareness of cyclists among drivers. Low cycling speed was also found to contribute to the high level of cycling safety in the Netherlands.

Intersection Design

Domestic Resources

Use of Innovative Intersection Designs for Improving Mobility and Reducing Roadway Traffic Congestion, Yi Qi, Qun Zhao, Mehdi Azimi, Qiao Sun, Juan Li, Shaojie Liu and Sahil Shah, Center for Advanced Multimodal Mobility Solutions and Education, 2018.
https://cammse.uncc.edu/sites/cammse.uncc.edu/files/media/CAMMSE-UNCC-2017-UTC-Project-Report-08-Qi-Final.pdf
From the abstract: Unlike conventional intersection designs, which usually accommodate traffic by improving signal systems or increasing rights of way by simply widening the road, innovative intersections are more comprehensive design measures, which are intended to utilize the roadway resources fully and to consider how best to benefit different roadway users. This research focuses on three widely implemented innovative intersections: the Displaced Left Turn (Continuous-flow Intersection), the Median U-turn (Michigan Left), and the Restricted Crossing U-turn (Superstreet). ... The objectives of this project are to (1) synthesize existing studies on these three representative innovative intersection designs regarding their aspects of mobility, safety and other performance; (2) examine the design guidelines on critical features of these three innovative intersection types; (3) conduct a simulation-based operational analysis of the displaced left turn intersection; (4) investigate the operational impacts of the left turn crossover distance; and (5) conduct case studies to investigate the safety impacts of implementing the displaced left turn intersection design.

Related Resources:

Cited below are FHWA guidance documents describing the three innovative intersection designs highlighted in the above publication:

> **Displaced Left Turn Intersection Informational Guide**, Hermanus Steyn, Zachary Bugg, Brian Ray, Andy Daleiden, Pete Jenior and Julia Knudsen, Office of Safety, Federal Highway Administration, August 2014.
> https://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasa14068_dlt_infoguide.pdf
> *From page 3 of the report (page 13 of the PDF)*: The displaced left turn (DLT) intersection is also known as a continuous flow intersection (CFI) and a crossover displaced left-turn intersection. For the purpose of this informational guide, DLT refers to any intersection form relocating one or more left-turn movements on an approach to the other side of the opposing traffic flow. This attribute consequently allows left-turn movements to proceed simultaneously with the through movements and eliminates the left-turn phase for this approach. The number of traffic signal phases and conflict points (locations where user paths cross) are reduced at a DLT intersection, which can result in improvements in traffic operations and safety performance. The green time formerly allocated for the left turn at a

conventional intersection could be reallocated, including being used to facilitate pedestrian crossings.

Median U-Turn Intersection Informational Guide, Jonathan Reid, Larry Sutherland, Brian Ray, Andy Daleiden, Pete Jenior and Julia Knudsen, Office of Safety, Federal Highway Administration, August 2014.
https://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasa14069_mut_infoguide.pdf
From page 3 of the report (page 11 of the PDF): The Median U-Turn (MUT) Intersection is also known as the Median U-turn Crossover and sometimes referred to as a boulevard turnaround, a Michigan loon, or Thru-Turn Intersection. For the purposes of this informational guide, MUT refers to any intersection replacing direct left turns at an intersection with indirect left turns using a U-turn movement in a wide median. The MUT intersection eliminates left turns on both intersecting streets and thus reduces the number of traffic signal phases and conflict points at the main crossing intersection, resulting in improved intersection operations and safety.

Restricted Crossing U-Turn Intersection Informational Guide, Joe Hummer, Brian Ray, Andy Daleiden, Pete Jenior and Julia Knudsen, Office of Safety, Federal Highway Administration, August 2014.
https://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasa14070_rcut_infoguide.pdf
From page 3 of the report (page 13 pf the PDF): The Restricted Crossing U-turn (RCUT) intersection is also known as a superstreet intersection, a J-turn intersection and synchronized street intersection. The RCUT intersection differs from a conventional intersection by eliminating the left-turn and through movements from cross street approaches. To accommodate these movements, the RCUT intersection requires drivers to turn right onto the main road and then make a U-turn maneuver at a one-way median opening at least 400 feet after the intersection. At the main street approaches, the left turns are typically accommodated similar to left turns at conventional intersections. In some cases, such as rural unsignalized RCUT intersection designs, left-turn movements from the main street could also be removed. RCUT intersections can have either three or four legs. In the case of a four-legged RCUT intersection, there are two U-turn crossovers, and minor street left-turn and through movements are not allowed to be made directly at the intersection.

Large Vehicles

Domestic Resources

Effects of Geometric Design Features on Truck Crashes on Limited-Access Highways, Sunanda Dissanayake and Niranga Amarasingha, Research and Innovative Technology Administration, June 2012.
https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1065&context=matcreports
From the abstract: The purpose of this study is to describe the relationships between large truck crash probability, and traffic and geometric characteristics. … According to the models [based on large truck crashes that occurred on Kansas limited-access highway sections], highway design features such as horizontal curvature, vertical grade, lane width and shoulder width are factors which can be used to change the occurrence of large truck crashes. Identifying the effect of traffic and geometric characteristics is important to promote safety treatments through engineering improvements.

Lower-Speed Roadways

Domestic Resources

NCHRP Report 880: Design Guide for Low-Speed Multimodal Roadways, Marshall Elizer, Jay Bockisch, Michael Sewell, Ingrid Potts, Darre Torbic and Joe Gilpin, 2018.
Report available at https://www.nap.edu/catalog/25248/design-guide-for-low-speed-multimodal-roadways
From the summary on page 1 of the report (page 10 of the PDF): The intent of this Guide is to provide best practice guidance to the designer by referencing a range of acceptable elements, criteria and values for critical dimensions in the design of low- to intermediate-speed (45 mph and lower design speed) roadways with a mix of users. Good design involves balancing safety, mobility, and preservation of scenic, aesthetic, historic, cultural, and environmental resources. The Guide provides extensive information and guidance for multimodal design, but it is not intended to be a detailed design manual that eliminates the need for the application of sound principles by a knowledgeable design professional.

Pedestrian Presence

Domestic Resources

"Roadway and Infrastructure Design and Its Relation to Pedestrian and Bicyclist Safety: Basic Principles, Applications and Benefits," David R. Ragland, Offer Grembek, Phyllis Orrick and Grace Felschundneff, *TRB 92nd Annual Meeting Compendium of Papers*, Paper #13-4820, January 2013.
Citation at https://trid.trb.org/view/1242828
From the abstract: Although a great deal of additional research is needed to determine the costs and benefits of various proposed solutions, some basic principles can be identified to guide roadway and infrastructure design for improved pedestrian and bicyclist safety. The three broad but separate strategies for reducing the probability of an injury or fatality are: (i) reducing exposure, (ii) reducing the probability of a collision given exposure, and (iii) reducing the probability of injury given a collision. The purpose of this paper is to describe and illustrate these principles, discuss issues related to each one, and discuss the benefits—indeed, imperativeness—of the application of these principles by planners and traffic engineers.

Rural Roadways

Domestic Resources

Self-Enforcing Roadways: A Guidance Report, Eric Donnell, Kristin Kersavage and Lisa Fontana Tierney, Federal Highway Administration, January 2018.
https://www.fhwa.dot.gov/publications/research/safety/17098/17098.pdf
From the abstract:

> Six self-enforcing road concepts and the processes needed to implement the concepts when designing or evaluating existing two-lane rural highways are identified and described in this document. It is anticipated that the concepts may be used to design roadways that produce operating speeds consistent with the desired operating speeds of the roadway. The six methods include: (1) the speed feedback loop process, (2) the inferred design speed approach, (3) design consistency methods, (4) applying geometric design criteria, (5) using a combination of signs and pavement markings, and (6) setting rational speed limits.

The authors note that these methods can be applied individually or in combination for planned or existing two-lane rural highways. Example implementation methods are offered in this report, including two case studies of existing two-lane rural highways. The SHRP 2 Roadway Information Database (RID) is recommended as a "potential source for identifying geometric design features of roadways. Research using this information would be valuable in furthering the self-enforcing or self-explaining road concepts described in this guidance report."

Related Resources:

> **SHRP 2—Roadway Information Database**, Center for Transportation Research and Education, Iowa State University, 2021.
> https://ctre.iastate.edu/shrp2-rid/
> *From the objective*: The overall focus of this research was based on providing good quality data that are linkable to the SHRP 2 Naturalistic Driving Study (NDS) database and stored in a secure, flexible database that is accessible utilizing geographic information system (GIS) tools. The RID will in essence provide the road element for safety research on the more than 5 million trips taken by the NDS participants. The data will support a comprehensive safety assessment of driver behavior and crash risk, especially the risk of lane departure and intersection collisions. The RID will enable safety researchers to look at data sets of selected road characteristics and study matching NDS trips to explore the relationships between driver, vehicle and roadway. This capability of the RID makes it a very useful tool for NDS users interested in roadway characteristics and features because it allows researchers to focus on only those NDS trips that traversed road segments containing the items of interest. In addition, the RID serves as a template on how transportation agencies can integrate data from disparate sources in an effort to improve decision[-]making beyond just safety; and the RID has the potential to serve as a template for a national integrated database to support decision making in a performance measurement environment.
>
> **Roadway Information Database (RID): The Roadway Information Database Enables Safety Researchers to Explore the Relationships Between Driver, Vehicle and Roadway**, Center for Transportation Research and Education, Iowa State University, 2021.
> https://ctre.iastate.edu/roadway-information-database-rid/
> The RID includes state metadata and supplemental data from Florida, Indiana, New York, North Carolina, Pennsylvania and Washington.

Speed Management ePrimer for Rural Transition Zones and Town Centers, Office of Safety Programs, Federal Highway Administration, page last modified January 25, 2018.
https://safety.fhwa.dot.gov/speedmgt/ref_mats/rural_transition_speed_zones.cfm
From the web page:

> This Speed Management ePrimer for Rural Transition Zones and Town Centers is a free, online resource openly available for public use. The ePrimer presents a review of speeding-related safety issues facing rural communities, along with the basic elements required for data collection, information processing and countermeasure selection by rural transportation professionals and community decision-makers. The ePrimer is presented in six distinct modules developed to allow the reader to move between each to find the desired information, without a cover-to-cover reading. The ePrimer presents:
>
> - [A] definition of speeding and speed management, its importance and its relationship to the goals and challenges (e.g., resource constraints) faced by many rural communities;

- Illustrations and photographs of 14 types of speed management countermeasures, particularly suited for rural transition zones and town centers;
- [C]onsiderations for their appropriate application, including effects and design and installation specifics;
- [R]esearch on the mobility and safety effects of speed management countermeasures for passenger cars and commercial trucks, pedestrians and bicyclists, and agricultural vehicles which frequent roadways in and around many rural communities;
- [C]ase studies that cover effective processes used to plan and define a rural community speed management program or project, and assessments of the effects of individual and series of speed management countermeasures.

The web page offers access to six modules: introduction; speed management planning; collecting/analyzing speed and crash data; setting transition zones; countermeasures; and selected speed management case studies.

NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways, Darren J. Torbic, David K. Gilmore, Karin M. Bauer, Courtney D. Bokenkroger, Douglas W. Harwood, Lindsay M. Lucas, Robert J. Frazier, Christopher S. Kinzel, David L. Petree and Michael D. Forsberg, 2012.
Report available at https://www.nap.edu/catalog/22670/design-guidance-for-high-speed-to-low-speed-transitions-zones-for-rural-highways
From the summary on page 1 of the report (page 9 of the PDF): This report presents the results of a study undertaken to develop improved design guidance for high-speed to low-speed transition zones on rural highways. The primary steps of the research included a literature review and state-of-practice review on speed reduction treatments utilized in transition zones (both domestically and internationally) and observational field studies of several key treatments that have been implemented in the United States.
….

The design guidance covers a wide range of issues to be considered in the design of high- to low-speed transition zones, including the following:

- Definitions and site characteristics to define the geographical limits or boundaries of the transition zone study area.
- A methodology for assessing whether a high- to low-speed transition zone has speed-limit compliance or safety issues to support the need for and the selection of an appropriate treatment to address the issue(s).
- Guiding principles and design concepts to be considered in the design of a transition zone.
- A catalog of potential transition zone treatments with a description and illustration of the treatments and information on effectiveness, cost, contraindications and installation location.
- The importance of evaluating the effectiveness of transition zone treatments after implementation.
- Legal/liability issues to be considered when evaluating and designing transition zones.

International Resources

"New Geometric Design Consistency Model Based on Operating Speed Profiles for Road Safety Evaluation," Francisco J. Camacho-Torregrosa, Ana M. Pérez-Zuriaga, J. Manuel Campoy-Ungría and Alfredo García-García, *Accident Analysis and Prevention*, Vol. 61, pages 33-42, December 2013.
Citation at https://doi.org/10.1016/j.aap.2012.10.001
From the abstract: To assist in the ongoing effort to reduce road fatalities as much as possible, this paper presents a new methodology to evaluate road safety in both the design and redesign stages of two-lane rural highways. This methodology is based on the analysis of road geometric design consistency, a value which will be a surrogate measure of the safety level of the two-lane rural road segment. The consistency model presented in this paper is based on the consideration of continuous operating speed profiles. The models used for their construction were obtained by using an innovative GPS-data collection method that is based on continuous operating speed profiles recorded from individual drivers. This new methodology allowed the researchers to observe the actual behavior of drivers and to develop more accurate operating speed models than was previously possible with spot-speed data collection, thereby enabling a more accurate approximation to the real phenomenon and thus a better consistency measurement.

Other Design Elements

Domestic Resources

Diverging Diamond Interchange Informational Guide, Bastian Schroeder, Chris Cunningham, Brian Ray, Andy Daleiden, Pete Jenior and Julia Knudsen, Office of Safety, Federal Highway Administration, August 2014.
https://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasa14067_ddi_infoguide.pdf
This publication is one of four FHWA guidance documents examining alternative intersections and interchanges that "offer the potential to improve safety and reduce delay at a lower cost and with fewer impacts than traditional solutions." Citations for the three alternative intersection guidance documents begin on page 31 of this Preliminary Investigation. *From page 3 of the report (page 13 of the PDF)*:

> The diverging diamond interchange (DDI) is also known as a double crossover diamond (DCD) and is an alternative to the conventional diamond interchange or other alternative interchange forms. The primary difference between a DDI and a conventional diamond interchange is the design of directional crossovers on either side of the interchange. This eliminates the need for left-turning vehicles to cross the paths of approaching through vehicles. By shifting cross street traffic to the left side of the street between the signalized crossover intersections, vehicles on the crossroad making a left turn on to or off of ramps do not conflict with vehicles approaching from other directions.
>
> The DDI design has shown to improve the operations of turning movements to and from the freeway facility and significantly reduces the number of vehicle-to-vehicle conflict points compared to a conventional diamond interchange.

Exhibit 2-8, Summary of DDI Advantages and Disadvantages, on page 27 of the report (page 37 of the PDF) provides a concise summary of this interchange treatment.

International Resources

“Effect of Horizontal Curve Geometry on the Maximum Speed Reduction: A Driving Simulator-Based Study,” Tushar Choudhari and Avijit Maji, *Transportation in Developing Economies,* Vol. 5, Issue 2, 2019.
Citation at https://doi.org/10.1007/s40890-019-0082-8
From the abstract: Operating speed reduction models can be used to evaluate the geometric design consistency. The proposed study developed a maximum speed reduction model for drivers habituated in weak lane disciplined driving conditions. ... A multiple regression model was developed for the obtained 85th percentile maximum speed reduction data and the road geometric parameters such as radius, curvature, preceding tangent length, curve length, gradient, shoulder width and extra-widening. The developed model identified curvature (i.e., the inverse of radius) and preceding tangent length as predictor variables.

“Evaluating the Effects of Cross-Sectional Roadway Design Elements and the Impact on Driver Performance Using a Driving Simulator,” F. Tainter, B. Gongalla, C. Fitzpatrick and M. Knodler Jr., *Advances in Transportation Studies*, Vol. 49, pages 103-116, 2019.
Citation at https://trid.trb.org/view/1672716
From the abstract: The combination between roadway design and driver performance has long been at the forefront of creating a safe driving environment. This research initiative explored the relationship between the cross-sectional design elements and the impact on selected driver attributes such as speed profiles and lateral positioning. ... Overall, there is evidence to suggest that the adaptation of narrow lanes, inclusion of bicycle lanes or addition of raised medians will have only a minimal influence on speed reduction in a controlled driving simulator environment.

“Effect of Shoulder Width, Guardrail and Roadway Geometry on Driver Perception and Behavior,” Tamar Ben-Bassat and David Shinar, *Accident Analysis and Prevention*, Vol. 43, Issue 6, pages 2142-2152, November 2011.
Citation at https://doi.org/10.1016/j.aap.2011.06.004
From the abstract: The current study tests the combined effects of three roadway design elements—shoulders width, guardrail existence and roadway geometry (curvature)—on objective driving measures (speed and lane position), and subjective measures (perceived safe driving speed and estimated road safety). A total of 22 drivers participated in an experiment with a driving simulation. ... The scenarios consisted of the various combinations of the three roadway design elements. The results showed a significant effect of roadway geometry on both objective and subjective measures. ... The results also demonstrate that roadway geometry can be used to reduce driving speeds, but at the same time it can have a negative effect on maintaining a stable lane position in sharp curves.

Contacts

CTC contacted the individuals below to gather information for this investigation.

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Appendix A: Survey Questions

The following survey was distributed to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Design.

Survey on Geometric Design Strategies for Speed Reduction and Traffic Calming

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Note: The response to the question below determined how a respondent was directed through the survey.

(Required) Has your agency developed self-enforcing roadway and geometric design strategies or other traffic calming features that lower speeds at conflict points such as at intersections or along pedestrian or bicycle corridors?

Response Options:

- No. Our agency has not developed self-enforcing roadway and geometric design strategies or other traffic calming features in this road context. (Directed the respondent to the **Agencies Not Implementing Geometric Design Strategies on State Roadways** section of the survey.)
- No. While our agency has not developed self-enforcing roadway and geometric design strategies or other traffic calming features in this road context, we are considering them. (Directed the respondent to the **Agencies Considering Implementing Geometric Design Strategies on State Roadways** section of the survey.)
- Yes. Our agency has developed self-enforcing roadway and geometric design strategies or other traffic calming features in this road context. (Directed the respondent to the "Speed Reduction Measures" of the **Agencies Implementing Geometric Design Strategies on State Roadways** section of the survey.)

Agencies Not Implementing Geometric Design Strategies on State Roadways

Please briefly explain why your agency is not using self-enforcing roadway and geometric design strategies or other traffic calming features that lower speeds at conflict points.

Note: After responding to the question above, the respondent was directed to the **Wrap-Up** section of the survey.

Agencies Considering Implementing Geometric Design Strategies on State Roadways

1. Please briefly describe your agency's discussion or plans to implement self-enforcing roadway and geometric design strategies or other traffic calming features.
2. Please briefly describe the location or application where the treatment will be implemented.
3. If available, please briefly describe the specific criteria for using this treatment:
   - Geometric conditions
   - Speed threshold
   - Volume limits
   - Other (Please describe.)

Note: After responding to the questions above, the respondent was directed to the **Wrap-Up** section of the survey.

Agencies Implementing Geometric Design Strategies on State Roadways

Speed Reduction Measures

1. Please identify the geometric treatments that your agency has installed as **speed reduction measures in highway road conflict points** such as at intersections or along pedestrian or bicycle corridors.
    - Horizontal alignment (lateral shift, chicane)
    - Raised cross sections (intersection, speed cushion, speed table, offset speed table)
    - Road narrowing (pinch points, choker, traffic islands, bulbouts, road diet)
    - Sight distance
    - Vertical alignment (speed hump, raised intersections)
    - Other (Please describe.)
2. Please describe the criteria used (such as speed thresholds, traffic volume limits, percent design vehicles and geometric conditions) when selecting a treatment for each of the following applications:
    - Bicycle corridor
    - Intersection
    - Pedestrian area
    - Rural location
    - Suburban location
    - Urban location
    - Other (Please describe.)
3. Has your agency established speed ranges to determine when specific geometric features are appropriate?
    - No
    - Yes (Please describe.)
4. What geometric design standards or guidance does your agency use to design these installations?

Safety and Operational Issues

1. Has your agency established safety criteria for using treatments in pedestrian or bicycle applications?
    - No
    - Yes (Please describe.)
2. What safety issues has your agency encountered with these strategies?
3. What operational issues has your agency encountered with these strategies?
4. What are the potential impacts of these strategies on large vehicles?

Assessment and Recommendations

1. Has your agency measured the effectiveness of speed reduction or volume reduction?
    - Yes (Please respond to Question 1A below.)
    - No (Please skip to Question 2.)

1A. Please describe how your agency determines the effectiveness of these strategies.

2. Has your agency evaluated the trade-off between decreased speed and geometric alternatives?
   - No
   - Yes (Please describe.)
3. What successes has your agency experienced with these strategies?
4. What challenges has your agency experienced with these strategies?
5. What recommendations does your agency have for using self-enforcing roadway and geometric design strategies?
6. Please provide links to documents associated with your agency's use of self-enforcing roadway and geometric design strategies. Send any files not available online to carol.rolland@ctcandassociates.com.

Wrap-Up

Please use this space to provide any comments or additional information about your previous responses.