A2A02: Committee on Geometric Design
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Geometric Design: Past, Present, and Future

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The Committee on Geometric Design addresses the design of highway and street geometric elements that affect efficient traffic operations and safety. This paper provides a brief review of the past and present and a look into the future.

STATE OF THE PRACTICE

Geometric design, which is the name given to the surface design of highways and streets, is at the end of a century of significant change and achievement. It has been almost 80 years since the transformation from roadways for animal-drawn vehicles to roadways for automatically powered vehicles. During those 80 years, most countries developed geometric design guidelines and then designed and built an extensive network of highways and streets. Most, if not all, of these facilities were designed so that small cars and large trucks could operate safely and efficiently at speeds of 50 to 120 kilometers per hour.

The fundamental principles of geometric design were discussed in engineering textbooks as early as 1912; however, it was not until 1940 that the American Association of State Highway Officials (AASHO), later the American Association of State Highway and Transportation Officials (AASHTO), published seven documents, formally recognizing policies on certain aspects of geometric design. The 1940 AASHO policies were revised and amended in 1954, 1965, and 1971. They also were revised and amended by AASHTO in 1984, 1990, and 1994. AASHTO geometric design policies are based on the laws of physics and conservative assumptions in regard to the driver, vehicle, and roadway. Although some assumptions have changed, most of the basic models are the same as those in the 1940s.

The design process consists of the four steps. Conceptual design is done at scales of 1:20,000 to 1:5,000 to identify broad design constraints and overall cost estimates. Functional design is done at scales of 1:5,000 to 1:2,000 to identify property and utility impacts and to refine the cost estimates. Preliminary design is done at scales of 1:1,000 to 1:200 to provide an enhanced graphical representation of the road. Final design is done at a similar scale and provides the coordinate geometry of the alignment and cross section and the final cost estimate and construction layouts. Generally, designers hold meetings and involve the public in the first three of these steps.

CURRENT TRENDS

The current AASHTO policy on geometric design considers functional classification, alignment, cross section, intersections, interchanges, and freeways. These and other design-related topics have been the focus of several research projects in the 1990s. Recommendations from this research have not yet been adopted; however, AASHTO is considering several of them for future editions of their geometric design policies.

Functional Classification

Conceptually, roadways are designed according to the function they are intended to serve. Once the function has been established, the subsequent design criteria should result in driver behavior that is consistent with that function. Problems arise when a roadway's function changes over time or driver behavior is not consistent with the roadway's intended function. These problems have led to increased interest in the relationship between design speed and operating speed. NCHRP Project 15-18 is addressing these issues.

Alignment

The committee sponsored several conference sessions on sight distance and alignment issues in the 1990s. These conference sessions led to research on stopping sight distance, horizontal alignment, and superelevation methods. Generally, researchers are recommending geometric design models based on driver behavior rather than on the laws of physics. For example, NCHRP Report 400 recommends a stopping sight distance model based on driver capabilities rather than vehicle and roadway capabilities.

Cross Section

A conference session on cross section issues was held in the 1990s, which led to research on roadway and shoulder widths (NCHRP Reports 362 and 369), median intersection design (NCHRP Report 375), and mid-block left-turn lanes (NCHRP Report 395). Additional studies have focused on urban, suburban, and rural clear-zone requirements and roadside safety design. Much of this research centered on the relationship between cross-sectional elements and safety; however, few safety-effectiveness models have been developed.

Intersections

A conference session in the 1990s on intersection design issues led to research on intersection sight distance requirements (NCHRP Report 383). This report recommends several intersection sight distance models based on driver behavior rather than vehicle and roadway capabilities. Additional research focused on innovative designs for high-volume intersections.

Interchanges

Research has been done on single-point urban interchanges (NCHRP Report 345) and capacity of interchange ramp terminals (NCHRP Project 3-47). These studies focused on the interrelationships among geometric design, signal timing, and highway capacity.

Freeways
Although there has been little research on freeway design in the 1990s, several recent studies have focused on design of certain aspects of urban freeways: acceleration lanes, high-occupancy-vehicle (HOV) lanes, entrance and exit ramps, and incident detection sites. Much of this research is in response to increased emphasis on freeway traffic management centers and changing technology and strategies for managing traffic during congested time periods.

Design Consistency
FHWA and NCHRP sponsored several studies on design consistency in the 1990s. These studies have developed models for predicting operating speeds in response to alignment changes on two-lane highways. These models can then be used to check the design consistency of a proposed or existing alignment. The models have been developed; however, they have not yet been incorporated into the design process.

Design Standards and Safety
NCHRP sponsored a study on design standards and safety in the 1990s (NCHRP Report 374). This study synthesized information relating the effects of design features on highway safety under varying conditions. The effort revealed that significant gaps exist in basic knowledge, making it impossible to make recommendations for revisions or additions to AASHTO design policies. A research program to address these deficiencies was prepared as part of this study.

Older Drivers
FHWA sponsored research to develop the *Older Driver Highway Design Handbook* in 1997. This handbook supplements existing standards and guidelines in the areas of highway geometry, operations, and traffic control devices. Specific roadway features singled out for attention are at-grade intersections, interchanges, roadway alignment and passing zones, and highway maintenance and construction zones.

Pedestrians and Bicycles
FHWA sponsored several studies on pedestrian and bicycle design issues in the 1990s. These studies identified pedestrian and bicycle design issues and in some cases recommended design guidelines. AASHTO published a bicycle design guide in 1999.

Roundabouts
FHWA sponsored research to develop a roundabout design guide in the late 1990s. This research addresses design issues and guidelines for modern roundabouts. Although not the answer to all intersection-related problems, the guidelines provide effective solutions for a number of operational and safety problems. It is anticipated that more and more roundabouts will be constructed over the next 20 years.

Toll Plazas
NCHRP sponsored a project to synthesize the state of the practice in regard to toll plaza design. The results of this project were published in NCHRP Synthesis 240. Although much

good information was assembled, changing technology and increasing numbers of toll roads may necessitate a follow-on project.

Information Needs

Several areas in which additional research is needed to fill in gaps in the state of the practice are the following:

- Clear-zone design guidelines for modern landscaping practices,
- Geometric design of at-grade intersections near railroad grade crossings,
- Innovative designs for congested intersections,
- Impacts of geometric design on traffic calming,
- Implications of intelligent transportation systems (ITS) technology on geometric design,
- Improved design of freeway on-ramps and acceleration lanes,
- Reevaluation of horizontal curve design for comfort and safety, and
- Safety consequences of flexible design standards.

THE FUTURE

Several critical transportation issues will affect geometric design policies and practices as we move into the 21st century. These issues include mobility and accessibility, sustainable development, safety and security, technological innovation, and institutional roles. Specific impacts are not known; however, it is likely that geometric design will be more technologically complex and more tightly coupled with environmental and cultural values. What follows is a discussion of some of the most important issues and initiatives that fall within the committee's scope.

Context-Sensitive Design

Context-sensitive design, or flexible design, is a commitment to safety and mobility and at the same time a commitment to preserve and protect the environmental and cultural values affected by transportation facilities. Thus, the objectives of context-sensitive design are to simultaneously advance safety, mobility, enhancement of the natural environment, and preservation of community values. Designers can and should take advantage of the flexibility in the current design guidelines; however, the unknowns are the safety and liability effects of this flexibility. Research programs in the new millennium must provide answers to these questions.

Training and education programs must reemphasize three critical areas. First, planners and designers must actively seek public involvement at the earliest possible time and throughout the process. Second, they must develop designs that meet the needs of specific sites rather than attempt to use centralized standardized solutions. Third, to meet specific needs, they must consider the flexibility in the current design guidelines instead of automatically opting for the high-end solution that gives priority to capacity over environmental, historic preservation, and neighborhood-protection concerns.

Design Visualization

Advances in computer technology are facilitating the increased use of three-dimensional (3D) and four-dimensional (4D) tools in highway design. Although not for every project, these tools will become more important in the next century as design projects become more complex and public involvement and acceptance become even more important. Some examples include photo rendering, 3D visualization, 4D simulation, and virtual reality. Most departments of transportation are building facilities and hiring specialists to support these activities.

Highway Safety Manual

TRB's *Highway Capacity Manual* provides guidance for assessing capacity and level of service (i.e., operational efficiency) of highways and streets. There is no similar document for assessing the safety of alternative designs; however, TRB and FHWA are sponsoring a workshop to discuss such a document. The workshop's objectives are to develop a consensus on the objectives, scope of content, and organization as well as an oversight or coordinating body, development process, and funding mechanism.

The objectives of a Highway Safety Manual would be to assemble the best available methods for estimating the safety impacts of highway design and operations and raise the credibility of safety impact analysis through the peer-review and consensus-building process by which it is being developed.

Interactive Highway Safety Design Model

FHWA is developing the Interactive Highway Safety Design Model (IHSDM) to provide what is known about safety in a form useful to highway designers. IHSDM is envisioned as a computer-based tool that facilitates evaluation of the safety implications of design decisions throughout the planning, design, and review phases of highway construction and reconstruction projects. It is being developed to operate in the computer-aided design (CAD) environment, in which most design work is currently performed.

IHSDM consists of five modules. The accident analysis module estimates number and severity of accidents, analyzes the benefits versus the cost of alternative roadside designs, and identifies geometric deficiencies and suggests countermeasures. The design consistency module provides information on the extent to which a roadway design conforms to driver expectations. The driver-vehicle module estimates driver speed and path choice along a roadway as well as lateral acceleration, friction demand, and rolling moment. The traffic analysis module estimates the operational effects of road designs under current and projected traffic demands. The policy review module verifies highway design policies at various steps in the design process.

ITS Technology

Several ITS technologies have the potential to significantly affect geometric design of highways and streets. The use of infrared (or halogen) headlights and automatic braking systems could have a significant effect on stopping sight distance and vertical curve length.

The use of automated vehicle guidance systems could affect horizontal curve design. For example, transition sections at the beginning and ending of a horizontal curve may need to be redesigned to ensure safe and efficient operations. Automated highways may reduce right-of-way requirements.

Road Safety Audits

Road safety audits are formal procedures for assessing the accident potential and safety performance of new and existing highways and streets. Although the safety audit concept was developed in Australia, it is similar to diagnostic studies and driver expectancy checklists used in the United States. The objective of the road safety audit is to ensure that all new highways operate as safely as practicable. This objective means that safety should be considered throughout the design process. The outcome of the audit is the identification of any potential problems, together with recommendations on how to rectify the problems.

Two basic principles underlie road safety audits: (*a*) prevention is better than the cure and (*b*) drive, ride, and walk in safety. Prevention seeks to minimize the risk of crashes occurring as a result of future changes to the highway. Drive, ride, and walk in safety highlights the needs of the most venerable road user; that is, the road scene should be visualized through the eyes of all types of road users.

Simultaneous Vehicle and Infrastructure Design

Simultaneous Vehicle and Infrastructure Design (SVID) is a systems approach to vehicle and infrastructure design. It brings together vehicle and infrastructure designers to assess and select alternatives that improve the performance of both the vehicle and the infrastructure. The SVID concept involves the vehicle, the environment in which the vehicle operates (i.e., the infrastructure), the vehicle operator, and the affected community. SVID concepts are being strengthened by the emergence of more capable science-based system decision support methods and tools.

SVID is an evolving and maturing concept. The domain for its applicability has broadened from only highway vehicles and infrastructure to the entire transportation system. Because of the continuing evolution of the SVID process, a proof-of-principle project could be a valuable means to further its maturity. For highway vehicle and infrastructure design, both passenger cars and commercial vehicles should be considered.

Special Use Highways

Special use highways are transportation facilities not available to the general public, for example, bus and HOV lanes. In the next century, we may see separate facilities for large trucks and automated highways in congested corridors.

Traffic Calming

More communities are demanding that more attention be paid to sustainability and livability. Thus transportation professionals must plan, design, and operate transportation facilities that contribute to this objective. To meet this challenge, planners, designers, and decision makers need a firm knowledge of what traffic calming measures can and cannot do to enhance livability while at the same time providing safe and efficient movement of people and goods. The basic question is how can geometric design be used to control speed volume without compromising safety.

SUMMARY

In summary, geometric design for streets and highways has come a long way in the 20th century—from roadways for animal-drawn vehicles to roadways for automatically powered vehicles and from a network of relatively few unpaved roads to a magnificent National Highway System. Research in the 1990s focused on the driver as the design control and safety as the performance measure for assessing effectiveness. Technological innovation, sustainability and livability, and safety and security will play a much larger role in the 21st century.