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Operational and Safety Effects of Highway Geometrics at the Turn of the Millennium and Beyond

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The arrival of the new millennium is a time for taking stock: it reminds us how far we have come in transportation research and how much there is still to be done. Looking forward from the year 2000, it is possible to anticipate the changes we will see in our transportation system and the role that the operational effects of geometrics will play in those changes. This paper considers key issues in operational effects of geometrics at the turn of the millennium and emerging issues that will become increasingly important.

History tells us that at some times and in some modes of transportation less than 100 years is needed for a revolution to occur. It was only 65 years from Lewis and Clark's laborious crossing of the continent by boat and horseback to the opening of the transcontinental railroad. It was also only about 65 years from the Wright brothers' first flight to the landing on the moon. Looking back, the changes in the highway system over the past 100 years have been revolutionary, whereas the changes in the highway system in the past 50 years have been more evolutionary. Although an observer in 1900 would have had great difficulty in picturing the highway system of today, an astute observer in 1950 could have foreseen much of what has happened since. Indeed, many of the broad principles of highway geometric design were formulated in the 1930s and 1940s and have changed today only in their details. The members of the Committee on Operational Effects of Geometrics consider it likely that such evolutionary changes in highway transportation will continue. In this paper, we will look at some key anticipated changes and trends and their relation to traffic operational and safety effects of highway geometrics.

A LOOK FORWARD

In the foreseeable future, we expect the changes in highway transportation to be evolutionary rather than revolutionary. Although we may experience some catastrophe or technological breakthrough that makes automobile and truck travel on roads obsolete, the most likely scenario is a continuation of the evolution that has been occurring for the past 100 years. Our vision of six of the important changes in the operational and safety effects of roadway geometry that will occur over the next 50 to 60 years follows.

First, we expect that highway traffic volumes will continue to increase for at least the next 60 years in North America and throughout the next century in the developing world. Thus, there will more congestion and more accidents of all types. In particular, traffic operations and safety will be a persistent concern on old substandard country roads pressed into service as suburban arterials. Good intersection designs and access controls will be more important than ever in mitigating an increase in multivehicle collisions.

Second, the information revolution will continue as computers, communications, and sensors become increasingly fast and cheap. Highway agencies will have access to complete data sets on vehicle positions and speeds and road conditions. From these data, agencies will generate better traffic management tools, better accident prediction models, and more realistic simulations of proposed improvements. The information available to the driver will improve tremendously as well. Night vision, collision warning, and impairment warning will be among the innovations routinely available to make drivers safer.

Third, new vehicle technology, including advanced materials, will affect road safety in several important ways. Collisions will be less severe because of wraparound airbags in vehicles, stronger helmets and "body armor" for motorcyclists, and tougher and cheaper guardrails on roads. New methods will make snow and ice control easier. Structures will be lighter and cheaper, and tunnels will be easier and cheaper to dig.

Fourth, the trend toward private ownership of the transportation infrastructure, including roads, will accelerate worldwide. Current trends toward managed lanes and high-occupancy-vehicle lanes will continue. Strategies for building and operating highways that are used on only a limited basis today may become commonplace, including tolling of existing roadways, design-build and design-build-operate agreements, public-private partnerships, and, ultimately, private ownership. Design-build agreements may require safety performance guarantees from the private owner of the road, and owners may advertise the safety, as well as the operational efficiency, of their road to attract traffic.

Fifth, community and public involvement programs together with environmental restrictions and much higher real estate costs will make new right-of-way nearly impossible to obtain for many highway projects. As a result, many new roads will be elevated or in tunnels, and safety under these conditions will be important.

Finally, major changes in the demographics of the U.S. population and the makeup of the vehicle fleet are under way, including more older drivers, more drivers in their teens and twenties, and larger vehicles.

In sum, we expect increasingly private road systems to face higher traffic volumes without much ability to add new roads. Fortunately, for agencies that can afford them, better information and materials will help operational efficiency to improve and accident rates to fall. However, for those that cannot afford these advances, unsafe roadway geometrics will contribute to a substantial increase in the number of collisions.

Automated highways, with computer control of vehicles, have long been expected to take control from the driver and thus make operational and safety effects of highway geometrics less critical. Although some highways, such as major urban freeways, may be automated to some extent, we envision that the majority of driving will be done on conventional roadways with the driver in control. A more complete understanding of the operational and safety effects of geometric design features will thus remain important to safe and efficient operation of the road system.

KEY ISSUES

The Committee on Operational Effects of Geometrics has identified five issues that we see as the focus for advances in highway geometric design in the coming years:

- Traffic operational effects of geometric design elements,
- Safety effects of geometric design elements,
- Impact of technology on geometric design,
- Impact of demographic trends, and
- Flexibility in geometric design.

Each of these issues is discussed below with an emphasis on the needs for continuing research.

TRAFFIC OPERATIONAL EFFECTS OF GEOMETRIC DESIGN ELEMENTS

Geometric design elements play an important role in defining the traffic operational efficiency of any roadway. Key geometric design elements that influence traffic operations include the number and width of lanes, the presence and widths of shoulders and highway medians, and the horizontal and vertical alignment of the highway. The key reference source in documenting the traffic operational effects of geometric design elements is the *Highway Capacity Manual* (HCM) (*1*), which is the responsibility of the Committee on Highway Capacity and Quality of Service. The publication of a new edition of the HCM, incorporating the latest knowledge on traffic operational effects of geometrics, is anticipated for the year 2000. This new HCM edition will, for the first time, be more than just a printed manual. A CD-ROM version will integrate the manual, example problems, and multimedia presentations on a single disk.

Although the technology of presenting the HCM to users is being improved, there is a continuing need for research to develop better understanding of traffic operational effects of geometric design elements, an understanding that is broad, but not too deep. For many highway types, we are only just beginning to develop methods to predict the effects of individual geometric design elements on traffic speeds and other operational performance measures. For example, the Federal Highway Administration (FHWA) is developing a speed prediction algorithm for two-lane highways that can serve as the basis for identifying inconsistent features of a proposed design that may represent potential safety problems.

Beyond the operational analysis procedures of the HCM, there is a wide variety of computerized traffic models, both deterministic and stochastic, that are used to evaluate the traffic operational performance of specific roadways. These include the TWOPAS and TRARR models for two-lane highways, the CORFLO model for freeways, the NETSIM model for urban road networks, and a broad variety of models for signalized intersections. These models vary widely in the detail and accuracy with which the operational effects of geometric design features, as opposed to traffic volumes and traffic control devices, are represented. There is a clear need to fully incorporate the results of existing research into all of these models and to encourage new research to fill the gaps in knowledge. Environmental models that derive air quality estimates from predicted traffic speeds also lack a detailed representation of the effects of geometric design elements on traffic speeds.

SAFETY EFFECTS OF GEOMETRIC DESIGN ELEMENTS

Although there has been a great deal of research on the safety effects of geometric design elements, much of this research has focused on specific issues in isolation, to the exclusion of other related issues. Thus, we have a good sense of the safety effects of many geometric design elements but not much definitive knowledge of the effect on safety of the interactions between geometric features. Our qualitative understanding of safety is excellent, but we lack tools to develop quantitative assessments of the anticipated safety effects of proposed highway improvements. This is a concern because in the development of geometric designs for new projects, we typically quantify every anticipated effect of the project, including, but not limited to, traffic operations, air quality, noise, runoff, and construction cost, but not safety. Even where safety estimates are made, they typically rely on the judgments of individual analysts about the available safety research rather than on established and widely accepted procedures.

We see a need to codify safety knowledge and provide analytical tools to predict the safety performance of existing roadways and the anticipated safety performance of proposed projects. This could potentially be accomplished through development of a highway safety manual, equivalent in stature to the HCM, that would provide a standardized method of making safety estimates. A first effort in this direction is currently under way in an FHWA project to develop a general-purpose accident prediction algorithm for rural two-lane highways. This approach could be expanded to other roadway types.

The accuracy of any safety prediction tools that are developed depends on the reliability of research results concerning the safety effects of geometric features. Major advances in research techniques have recently been made and more are expected. In developing statistical relationships between geometric features and safety, researchers have begun to use regression techniques, such as Poisson and negative binomial regression, which are far better suited to the nature of accident data than traditional multiple regression. Furthermore, there has been a key recognition that the results of well-designed before-and-after evaluations provide better measures of safety effectiveness than regression relationships, which, by their nature, do not necessarily represent cause-and-effect relationships. Techniques for conducting well-designed before-and-after evaluations have improved. In particular, the empirical Bayes approach to before-and-after studies has the potential to eliminate many of the limitations of past evaluations. Procedures for applying the empirical Bayes approach have recently been formalized by Hauer (*2*).

Finally, to have a maximum impact on geometric design safety, safety research results must be incorporated into national design policy, such as the *Policy on Geometric Design of Streets and Highways* published by the American Association of State Highway and Transportation Officials (AASHTO) (*3*) (also known as the Green Book), and into the policies of individual highway agencies. This has been happening effectively in recent years through AASHTO's sponsorship of the National Cooperative Highway Research Program (NCHRP) administered by the Transportation Research Board (TRB). Recent NCHRP research on key geometric design issues, such as stopping sight distance and intersection sight distance, has been requested by AASHTO and is now being considered for implementation in the AASHTO Green Book. AASHTO policy sets an example that influences the design policies of individual highway agencies in the United States and around the world. It is vital that this cooperative approach to direct implementation of safety research results in geometric design policy continue.

IMPACT OF TECHNOLOGY ON GEOMETRIC DESIGN

Technology has been having an important effect on geometric design of highways. During the past 20 years, highway design has moved from the drafting board to the computer as computer-aided design (CAD) systems have been implemented by most highway agencies and design consultants. CAD systems have brought about a revolution in the efficiency of the design process, but they have not as yet brought about better and safer highway designs.

The nearly universal use of CAD systems for highway design provides an opportunity to ensure better consideration of the operational and safety effects of geometric elements in the proposed designs for highway projects. To accomplish this, computer tools are needed that work interactively with CAD systems and allow users to evaluate operational and safety effects of geometrics. FHWA is currently developing a first-generation system of this type known as the Interactive Highway Safety Design Model (IHSDM) (*4*). IHSDM will be a suite of computer tools, fully integrable with a range of CAD systems, that allows users to improve the safety and operational efficiency of their designs. Components of the IHSDM will include

- Design policy review module,
- Design consistency analysis tool,
- Crash prediction algorithm,
- Diagnostic review package for intersection designs,
- Driver-vehicle performance module, and
- Traffic analysis module.

The initial IHSDM development is for rural two-lane highways, but its scope is expected to be expanded to other roadway types.

IHSDM is merely an initial example of the types of technology-driven improvements that are needed to increase the consideration of safety in the design process. The accident prediction algorithm and other tools like the design consistency analysis methodology are key to changing the consideration of safety in design from a qualitative to a quantitative issue. A highway safety manual like that mentioned earlier is one method by which quantitative safety procedures could be established and publicized. In the future, it will be vital to keep these tools updated as new safety knowledge becomes available. Furthermore, as computer technology evolves, new approaches to safety design that we cannot even envision now will become possible. We do not foresee that highway designs can or should be developed by a computer without intervention by a human designer, but we see that, increasingly, computer software will call designers' attention to safety-related issues that might not have been detected until later in the design process or until after the road was built. The highway design and research community must be alert for these technologies as they develop and must see that they are applied effectively to producing better and safer highway designs.

IMPACT OF DEMOGRAPHIC TRENDS

Demographic trends are already having a marked impact on the U.S. highway system, making operational and safety effects of geometrics ever more important. The key demographic trend is an increase in older drivers using the highway system. At the turn of the millennium, approximately 13 percent of the American population is over age 65. As much as 20 percent of the population may be over that age by 2030.

Research indicates that accident rates for drivers increase markedly after age 55 and that specific types of violations (those involving traffic signs, right-of-way, and turning left) occur. In addition, most accidents involving older drivers take place under ideal conditions, since the elderly drive much less at night and less in heavy traffic (*5,6*).

Given the anticipated change in the age distribution of the driving population, it will become increasingly important to design highways to accommodate drivers whose perception-reaction time and motor skills may be less than the performance levels of the driving population as a whole. FHWA has developed the *Older Driver Highway Design Handbook* (*7*) to present recommended practices for highway designs that better accommodate older drivers. The recommendations of the handbook include changes to design and traffic control criteria for at-grade intersections, grade-separated interchanges, roadway curvature and passing zones, and construction work zones.

Not only the driving population, but also the pedestrian population can be expected to be older in the future. There may well be an increase in the proportion of pedestrians with disabilities, making compliance of facilities with the requirements of the Americans With Disabilities Act more critical.

The trend toward an older population also means that the population includes more retired persons and more persons approaching retirement, who have increased time to spend on leisure activities, including travel. This trend is expected to result in an increase in the number of recreational vehicles (RVs) on the highway. A recent survey found that RV ownership among 45- to 54-year-olds has grown 25 percent since 1993, faster than for any other age group (*8*). Larger vehicles, including pickups, vans, and sport-utility vehicles, already constitute about one-third of new passenger vehicle sales, and the anticipated increase in RV sales will add to this trend.

Younger drivers, especially drivers in their teens and early twenties, experience higher accident rates, just as do drivers over age 55. The anticipated “echo” or “rebound” of the baby boom generation is likely to increase the proportion of younger drivers. Well-designed roadway geometrics can play an important role in minimizing both the rate and the severity of accidents involving younger drivers.

FLEXIBILITY IN GEOMETRIC DESIGN

An emerging trend is the encouragement of flexibility in geometric design for highway improvement projects. Highway design has historically been conducted in compliance with the geometric design policies established by AASHTO at the national level and by individual highway agencies. Exceptions to these policies can be made where necessary, but exceptions must typically be extensively justified. Established highway agency procedures discourage design exceptions. The current philosophy of design is based on the implicit assumption that any design developed in accordance with established geometric design policies is safe and that any design that does not meet key aspects of established policies is unsafe. Many engineers take this for granted, and the courts appear to base decisions in tort liability cases on this philosophy.

The need for flexibility in design arises because many factors other than safety must be considered in the design of a highway improvement project. Critical factors in many design decisions include impacts on existing neighborhoods and communities, air quality, noise, water quality and wetlands, historic preservation, and construction cost. The priority or weight given to each of these factors must reflect community priorities and established laws and regulations. Furthermore, in many cases, geometric design can depart from established policies without compromising safety. Many elements of geometric design policies have purposely been made very conservative to make up for the lack of explicit knowledge of safety relationships for particular geometric features.

A session at the 1998 TRB Annual Meeting cosponsored by the Committee on Operational Effects of Geometrics and two recent workshops entitled “Thinking Beyond the Pavement” and “Context Sensitive Design” have been convened to assist highway agencies in formulating improved strategies for considering a broad variety of factors in making geometric design decisions. Consideration of community values is likely to grow as an issue, and the momentum established by recent conferences should be continued.

Research on traffic operational and safety effects of geometrics is essential to introducing more flexibility into the future geometric design process because it will be much more important for engineers and planners to know which geometric design criteria can be relaxed without compromising safety and without creating undesirable levels of congestion. Better computer tools like those discussed earlier will be of increasing importance in the analysis of proposed alternative designs. Accident prediction algorithms, like the two-lane highway algorithm being developed for the IHSDM, can have an important role in comparing the safety performance of alternative designs. Expert systems, like the diagnostic review model for at-grade intersections of rural two-lane highways currently being developed for the IHSDM, can consider whether relaxation of established geometric design policies will lead to potential safety problems. The more our knowledge of safety relationships for geometric design elements is increased through future research, the more flexibility can be introduced into the design process without risk of compromising safety.

CONCLUSION

In closing, the Committee on Operational Effects of Geometrics expects evolutionary changes in our highway transportation system over the foreseeable future. These changes will include continued growth of traffic volumes, computer technology, and vehicle technology. More and more roads may be privately owned, operated, or both. Environmental restrictions and real estate costs will make building new roads less feasible and will make more efficient operation of the current highway system vital.

Key issues related to operational effects of highway geometrics in the foreseeable future include traffic operational effects of geometrics, safety effects of geometrics, impact of technology on geometric design, impact of driver demographic trends, and flexibility of geometric design. Research related to all of these areas will be needed to keep our highway transportation system operating efficiently and safely as we move into the next millennium.

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