INTERACTIVE HIGHWAY SAFETY DESIGN MODEL (IHSDM): DESIGNING HIGHWAYS WITH SAFETY IN MIND

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The Federal Highway Administration (FHWA) has designated Highway Safety Design Practices and Criteria as a high-priority research and development area. The objective of this program is to develop an integrated design process that systematically considers safety in developing and evaluating cost-effective highway design alternatives. Conceptually, the idea behind this research program is to develop a system that can be used to evaluate the safety of alternative highway designs in a Computer-Aided Design (CAD) environment. This evaluation would include an examination of the entire roadway design including both the roadway alignment and cross-section and the roadside design (sideslopes, ditches, guardrails, utility poles, etc.). Work in this area has been underway for several years and this initial objective has grown from a rough concept into a well-defined research program that is aimed at developing a fully functional system called the Interactive Highway Safety Design Model (IHSDM).

This paper will provide a status report on the IHSDM research program and present the current vision of how a fully-functional IHSDM can improve the consideration of safety in the design process.

BACKGROUND

The goal of the IHSDM research program is to develop a systematic approach that will allow the highway designer to explicitly consider the safety implications of design decisions. In the past, "safe" design has meant satisfying a set of minimum design criteria. There has been no effective way for a designer to compare the safety of various alternatives or to optimize the safety of a particular design. Failure to explicitly address safety issues during the design process can result in inconsistent or inappropriate design decisions that manifest themselves in the form of "accident black spots" once the project is constructed. Limited funds and staff time must then be spent trying to remedy problems through the safety improvement program.

In the early planning stages for the IHSDM it was recognized that achieving the goal of explicit consideration of safety would require that the IHSDM operate from within the design process and not as a separate outside activity. Operating within the design process required the adoption of several basic principles to be followed in the development of IHSDM:

- IHSDM must be applicable for both new construction and reconstruction projects. While the general design principles are similar for both types of projects they also differ in some important respects. New construction projects are initiated by planning for transportation access and traffic growth. Reconstruction projects are generally initiated because of capacity problems or to preserve the structural integrity of the roadway. Reconstruction projects are typically constrained by the available right-of-way and/or funding availability.
- IHSDM must facilitate decision-making from the planning through the final design stages. While the highway design process varies considerably among the 50 states, it can be generally divided into two phases: (1) preliminary design often associated with the preparation of environmental impact statements (EIS); and (2) detailed design associated with the preparation of plans, specifications, and estimates (PS&E). At the preliminary design stage only limited information on the alignment, design speed, ADT, traffic mix, and crosssection, and intersections is available. In developing the detailed design final decisions on the alignment, crosssection, intersection and median layout, roadside hardware, signing and markings, etc. are made. The IHSDM will be primarily focused on the detailed design stage, however parts of the model must also be appropriate for the preliminary design stage when important safety-related decisions are made.
- IHSDM must be a computer-based system that can be integrated into the CAD environment. With the advances in computer technology, the designer now has the ability to view, analyze, and change designs electronically. Clearly, if IHSDM is to be an integrated part of the design process then it must operate in this environment. The IHSDM is envisioned as a series of modules that could be integrated into and accessed from the commercially-available CAD packages that are now being used by State Departments of Transportation and

their consultants. The designer would be able to work in an interactive process to evaluate a potential design and correct problems that are identified by IHSDM.

The FHWA plans to conduct the research and development necessary to develop the IHSDM modules and demonstrate their application. Full implementation would occur as these modules are integrated into the CAD packages by the software vendors. The FHWA plans to enter into cooperative agreements with all interested vendors in 1995. These cooperative agreements will provide for sharing of information between the FHWA and the vendors during the research process to facilitate implementation.

- IHSDM must integrate safety research into a form usable by the designer. Considerable research has been conducted into the relationships between geometric design elements and highway safety. However, much of this research was not conducted with the designer in mind and cannot be directly used by highway designers to make decisions. IHSDM will seek to utilized existing research that is of acceptable quality and to supplement that research with well-designed, statistically-valid studies where necessary.

User-input will be heavily relied upon in developing the user interfaces, identifying appropriate operational and safety measures, and in selecting effective ways to display results from the model. To facilitate this process the FHWA, through its Office of Technology Applications, will be developing a prototype demonstration of the IHSDM. This prototype demonstration will allow a user group (consisting of representatives from several DOTs and design consultants) to review and provide input into the development of the IHSDM. This activity will be initiated in 1995.

- IHSDM must be developed in a modular process that allows the system to be tested and implemented in stages. Development of a fully operational IHSDM will be a 10-year, multi-million dollar effort. Interim results from this program must be developed and implemented if the program is to improve highway design in the near-term, be responsive to changes in user needs, and maintain support for this long-term commitment. As is described below, the research program has been designed around a number of stand-alone modules which are interrelated, but can also operate independently. Implementation of prototype modules is planned to provide for user input. In addition, initial IHSDM development efforts have been directed at two-lane rural roads. This area was selected because of the wide variety of geometric design conditions on these roadways and the potential to make significant improvement in their safety.

It is believed that by following these basic principles, the IHSDM can be developed in was way that allows it to become an integral part of the highway design process.

IHSDM PROGRAM STATUS

The IHSDM program is currently focused on six major areas of research (as shown in Figure 1): Consistency, Vehicle Dynamics, Driver, Accident Analysis, Policy Review, and Traffic. From an end user standpoint these six major research areas are likely to result in four basic tools for the designer: Driver/Vehicle Performance, Accident Analysis, Traffic Assessment and Policy Review. A description of each of these tools is provided below along with a summary of ongoing research.

DRIVER/VEHICLE PERFORMANCE TOOL

It is believed that many safety-related problems that occur in the highway design process are due to the inability of a designer to view the design from a driver's perspective. The designer is limited to working in a two-dimensional environment that does not lend itself to a visualization of how the final product will look or how it will operate with real vehicles and drivers. The designer has to rely on design policies such as the AASHTO document *A Policy on Geometric Design of Highways and Streets* which are based on the concept of design speed. Research has shown that the use of design speed in selecting geometric elements can result in designs that violate driver expectancy.

The IHSDM Driver/Vehicle Performance Tool will provide the designer with the ability to assess the consistency of the design. Initially, this will be done using consistency models that generate a speed profile and/or a driver workload profile for a design, and vehicle dynamics models that allow the designer to select a vehicle type and speed and obtain feedback on lateral acceleration and rollover potential. Plots of vertical sight distance as a function of station will also be provided to the designer. These tools will allow the designer to locate inconsistencies and identify potential problem areas for specific vehicle types (such as ramps with high rollover potential or acceleration or deceleration lanes of insufficient length).

When completed, the IHSDM will also include a driver module that contains profiles of a range of driver types (e.g. aggressive, impaired, young, elderly) that can be combined with various design vehicles. Using a virtual-reality approach the designer will be able to

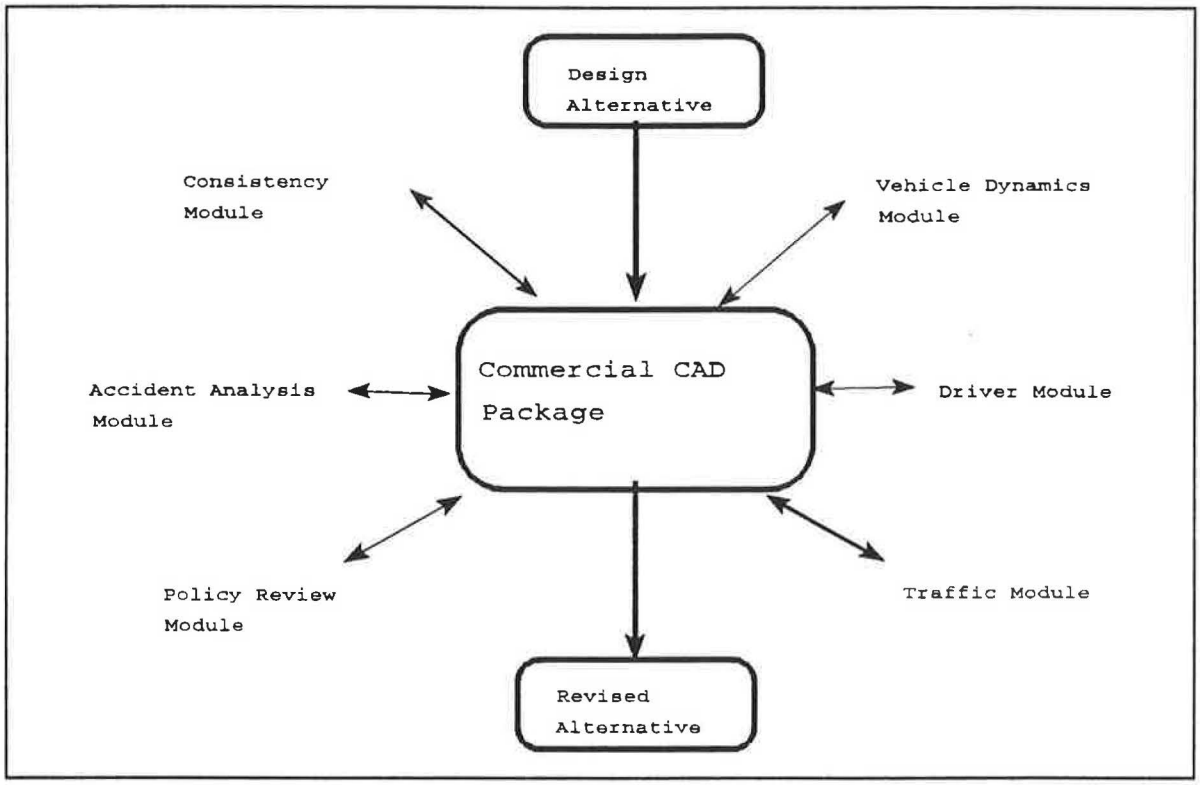

FIGURE 1 Interactive highway safety design model.

"drive" through a three-dimensional image of the design. This will give the designer a visual method of spotting "busts" in the design or inconsistencies that could affect driver performance. This visual review combined with data generated by selected driver/vehicle combinations will provide the designer with a much clearer understanding of the impacts of design decisions on driver performance.

Research is underway in each of the major areas necessary to develop the driver/vehicle performance tool:

- *Design Consistency* — As noted above, it is envisioned that the design consistency model will serve as a core component of the Driver/Vehicle Performance Tool until longer range research into the driver model can be completed. An initial research effort on design consistency, "Horizontal Alignment Design Consistency for Rural Two-Lane Highways" has been completed. This study developed a preliminary model for generating the speed profiles of passenger cars on two-lane rural highways. A preliminary driver workload model based on test track conditions was also developed. A follow-on effort is expected to begin in the fall of 1995. This study will validate the previously developed speed profile model under real-world conditions and expand the model to consider other vehicle types and environmental conditions. Additional work on the driver workload model and in the area of driver eye movement will also be performed.

- *Vehicle Dynamics* — Two efforts were initiated in September 1993 to develop the IHSDM vehicle dynamics module. The vehicle dynamics module will provide a realistic simulation of vehicle performance characteristics for the design vehicles listed in the AASHTO "Green Book." These vehicles can operate at a constant speed using a driver path-following model using a driver look ahead algorithm which incorporates a delay in steering wheel response to account for reaction time. Driver control capabilities will be expanded as work progresses on the driver module. Prototype vehicle dynamics models have been completed and are in the process of being integrated into a CAD environment. This work is expected to be completed by the fall of 1995. Selected State Departments of Transportation will beta test these models beginning in 1996.

- *Driver* — Development of a driver module will be a complex and long-range effort. The interactions between the driver, vehicle and roadway are not well-understood and will require a significant research effort. Two initial development efforts were initiated in March 1995. These studies are developing the functional

requirements and design specifications for the driver module. These requirements and specifications are expected to be available in early 1996. They will guide follow-on behavioral research that will be initiated to collect the data necessary to represent the driver in an IHSDM environment.

- *Visualization* — Three-dimensional rendering of major highway design projects has become commonplace among highway agencies for use at public meetings. However, these images are created off-line and not available in real time. The IHSDM will provide the designer with the ability to obtain a three-dimensional view of the actual design, identify problem areas, and interactively correct the problems. Pilot research efforts in the area of virtual-reality have shown promise and work to determine the amount of detail, visual quality, and realism needed to make "design decisions" is schedule to begin in the fall of 1995.

ACCIDENT ANALYSIS TOOL

The second tool that will be available to the designer will be an accident analysis tool. The purpose of this tool will be to allow the designer to both quantitatively and qualitatively assess the safety impacts of design decisions. In the preliminary design stage this tool is envisioned as a stand-alone computer program that would allow the planner/engineer to input information on the basic design characteristics (alignment, crosssection, intersections, design speed, ADT, etc.) and obtain an estimate of the expected number of accidents. This general information will then be available to the decision-maker as trade-offs between social, economic, and environmental effects are made.

Separate roadway and roadside accident modules are envisioned, along with a diagnostic review module. In the final design process the designer will use a combination of quantitative and diagnostic approaches to assess the safety impacts of the design. Work is underway in the following areas:

- *Roadway Accident Prediction* — The development of accident prediction models has been an area of considerable research in the highway safety field. Unfortunately, many earlier efforts have been constrained by data availability and/or flawed by the use of inappropriate statistical procedures.

The creation of the FHWA Highway Safety Information System (HSIS) provides much better data access. The HSIS contains traffic, geometric design, roadway inventory, and traffic volume data from eight states: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington. These data bases supplemented by additional laboratory (from videodisc photologs) and field data collection will form the basis for the development of the IHSDM models for evaluating preliminary designs. When combined with advances in the application of statistical techniques for highway safety analysis these data bases offer the potential to developed improved accident prediction models.

To provide a framework for development of these models, research in this area has been subdivided by roadway type (rural, urban), roadway class (freeway, multi-lane divided, multi-lane undivided, two-lane), and level of interaction type (roadway segment, intersections, interchanges). Preliminary research into the development of urban intersection models and rural multi-lane segment models has been completed. Development of operational rural, two-lane segment and intersection models is now underway.

- *Roadside Accident Prediction* — The encroachment model now under development under National Cooperative Highway Research Program (NCHRP) Project 22-9, "Improved Procedures for Cost-Effectiveness Analysis of Roadside Features" will be adapted for use in the IHSDM. It will form the basis of the roadside accident prediction module. Evaluation of roadside safety and the impacts of decisions such as the placement of guardrails, luminaire supports, and other appurtenances will be conducted using this module. Encroachments occur when the driver unintentionally leaves the roadway. Given information on the roadway design and the location of roadside obstacles the encroachment models will use a series of conditional probabilities to estimate the ran-off-road crash costs associated with a given design. The designer can use this information to evaluate alternative designs while seeking to minimize the potential crash costs.

Research to improve the trajectory data used in the encroachment model is included in NCHRP Project 17-11 "Recovery-Area Distance Relationships for Highway Roadsides," with supplemental funding being provided by the FHWA. This effort will develop relationships between recovery-area distance and sideslopes and other factors for various highway functional classes and design speeds. The Oak Ridge National Laboratory is modeling horizontal curvature and vertical grade and adjustment factors for rural 2-lane road encroachment rates using State data developed by FHWA.

- *Diagnostic Review* — The third component of the safety analysis tool will be a diagnostic review module. This module is a recent addition to the IHSDM and is

still in a conceptual stage. Exploratory research in the accident predictive and vehicle encroachment area pointed out the difficulties of fully assessing the safety of a design in a quantitative model. Even with improved data bases and advanced statistical analysis techniques, quantitative models will not be able to provide the desired level of safety assessment. The diagnostic review module will serve as a storehouse of information that cannot be captured in a modelling context. As currently conceived, the diagnostic review model would be developed as an expert system that could automatically review a potential design and compare it to a knowledge base to identify potential safety problems. These problems would be raised as "flags" to the designer. In many instances, other constraints (cost, environmental, etc.) may preclude the designer from making a change to the design, but these decisions will then be made and documented explicitly.

The key to the diagnostic review module will be the knowledge base. This knowledge base could be developed through a combination of sources, including

- Expert knowledge from experienced designers,
- Utilization of existing research,
- In-depth accident investigation,
- Review of common problems identified by the Highway Safety Improvement Program, and
- Conduct of well-designed before-after studies.

Safety audit procedures developed in other countries may also be instructive in the development of the knowledge base. It is expected that the knowledge base will include both qualitative and quantitative guidance to the designer as available and appropriate. Work on a design for the diagnostic review module will be initiated in the fall of 1995.

TRAFFIC ASSESSMENT TOOL

The third major tool that will be developed as part of the IHSDM will be a traffic assessment tool. The core of this tool will be traffic simulation models that have been developed by the FHWA for use in traffic engineering. These models will allow the planner/ designer to examine the design under full traffic conditions (as opposed to the driver/vehicle performance tool which will examine individual driver/vehicle combinations). The impact of design decisions on traffic flow can be assessed and insights into the safety impacts of these decisions can be obtained. For example, use of a traffic simulation model on a two-lane rural road design could be useful in identifying areas with large numbers of platooned vehicles and/or aborted passing attempts. This could point out the need for the addition of a short passing section. At intersections, traffic simulation models could identify inadequate turn lane storage lengths which may create traffic flow and safety problems.

It is expected that the models would be designed to operate in a stand-alone manner for use in preliminary design and as part of IHSDM for use in the detailed design process. The integration of the simulation models into the CAD environment will simplify their application. It will provide a direct link to the roadway data (alignment,grades and crosssection) data that is necessary as input to the simulation model. It is also anticipated that the driver model will serve as a source for the driver characteristics used in the simulation models.

Considerable research and development of urban network (NETSIM) and freeway simulation (FRESIM) models has been conducted. These simulation models are now routinely used as evaluation tools in many facets of transportation planning and engineering. Rural road simulation models are not as well developed. Research to improve the quality of existing two-lane simulation models will be initiated in 1995 as part of an NCHRP effort, "Capacity and Quality of Service for Two-lane Highways (NCHRP 3-55(3))." This effort is being jointly funded by NCHRP and FHWA and will develop improved methods and procedures for capacity and quality-of-service analysis of two-lane highways. The resulting model will be incorporated into IHSDM.

POLICY REVIEW TOOL

This tool will insure that the proposed design complies with established design criteria. This module would identify design elements that are not in compliance and "flag" these elements for review by the designer. In many cases there may be valid reasons for a "design exception." This module will provide a means for explicitly documenting such decisions.

Existing CAD-based highway design packages handle the policy issue in different ways. This effort would review the existing packages and identify opportunities to improve their operation. For example, are there checks for adequate intersection sight distance or decision sight distance? Are there procedures available for ensuring the curvature and grades are in proper balance? Does the program discourage sharp horizontal curves from being introduced at or near the top a crest vertical curve?

The development of the policy review tool is believed to be a straight-forward effort that will require no new research. The major work to be accomplished will be performed in conjunction with the CAD software vendors.

When the IHSDM becomes fully-operational it may be that other modules such as the design consistency, driver/vehicle or diagnostic review make a separate policy module unnecessary.

CONCLUSION

The IHSDM is an ambitious research program that seeks to enhance the consideration of safety in the highway design process. If successful, the IHSDM will become a standard part of CAD-based highway design packages and will routinely be applied by the State DOTs and their consultants. Explicitly considering safety in the design process will improve the quality of new designs, minimize the number of "black spots" due to highway design problems, and reduce the need to redesign these facilities in the future.

The IHSDM is envisioned as a fluid system that can be improved and updated as new safety research is completed. It can set a standard for the design of future research efforts and serve as the vehicle for translating new highway safety research into practice.