TECH**BRIEF**

These expert systems were developed under the Safety Management focus area. This focus area's activities are improving the quality, uniformity, completeness, and accessibility of safety data; improving the process of identifying and addressing safety problems; and providing critical training to safety specialists.

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

www.tfhrc.gov

Evaluation of Design Consistency Methods for Two-Lane Rural Highways

FHWA Contact: Ann Do, HRDS-20, (202) 493-3319, ann.do@fhwa.dot.gov

The information contained herein and in the three reports referenced below pertains in particular to new data concerning the Design Consistency Module, one of seven modules being developed as part of the Interactive Highway Safety Design Model (IHSDM).

For further information on IHSDM and the IHSDM Design Consistency Module, click on "Safety" and then "Interactive Highway Safety Design Model" at www.tfhrc.gov to view IHSDM's comprehensive Web site and to examine in full the new Design Consistency Module studies, as well as an online version of this technical summary.

This technical summary announces the completion of an FHWA study that is fully documented for online viewing in three separate reports:

- *Evaluation of Design Consistency Methods for Two-Lane Rural Highways, Executive Summary* (FHWA-RD-99-173)
- *Speed Prediction for Two-Lane Rural Highways, Final Report* (FHWA-RD-99-171)
- *Alternative Design Consistency Rating Methods for Two-Lane Rural Highways, Final Report* (FHWA-RD-99-172)

(See report ordering information on the last page of this summary.)

Background

The goal of transportation is generally stated as the safe and efficient movement of people and goods. To achieve this goal, designers use many tools and techniques. One technique used to improve safety on roadways is to examine the consistency of the design. Design consistency refers to highway geometry's conformance with driver expectancy. Generally, drivers make fewer errors at geometric features that conform with their expectations. An inconsistency in design can be described as a geometric feature or combination of features that has such a high driver workload requirement that drivers may drive in an unsafe manner. This situation could lead to inappropriate driving maneuvers and/or an undesirable level of accidents.

A design consistency method will be incorporated into the Interactive Highway Safety Design Model (IHSDM). IHSDM is being developed by the Federal Highway Administration (FHWA) as a suite of evaluation tools for assessing the safety impacts of geometric design decisions. IHSDM focuses on the safety effects of design alternatives. The Design Consistency Module will be one of seven modules which are to be integrated with commercial CAD/roadway design software. The other modules include: crash prediction, intersection diagnostic review, roadside safety, traffic analysis, driver/vehicle and policy review.

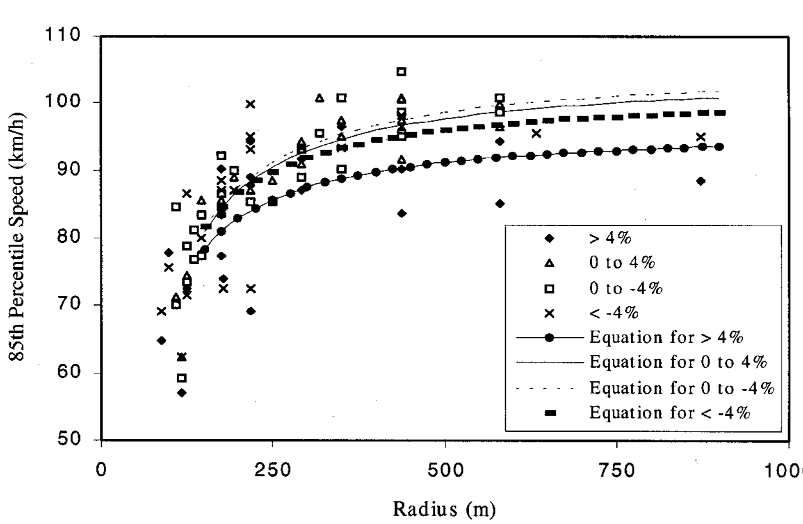
Objective

An earlier FHWA study, *Horizontal Alignment Design Consistency for Rural Two-Lane Highways* (FHWA-RD-94-034), developed a design consistency evaluation procedure that used a speed-profile model based on horizontal alignment. The objective of the present study, *Evaluation of Design Consistency Methods for Two-Lane Rural Highways* (FHWA-RD-99-173), was to expand the research conducted under the previous FHWA study in two directions. These directions were (1) to expand the speed-profile model and (2) to investigate three promising design consistency rating methods. In addition, the research objective was to identify the relationship between accident frequency and the proposed design consistency methods. The following is a summary of the efforts from this research project.

Speed-Profile Model

Several different studies were undertaken to predict operating speed for different conditions such as horizontal curves, vertical curves, and combinations of horizontal and vertical curves; tangent sections; and prior to or after horizontal curves. Speed data were collected at over 200 two-lane rural highway sites for use in the project. Regression equations were developed for 85th percentile, free-flow passenger vehicle speeds for the different combinations of horizontal and vertical alignment. Additionally, acceleration and deceleration rates were developed to consider the effects of horizontal curve radius.

Figure 1. Horizontal Curves on Grades: V_{85} versus R



For passenger vehicles, the best forms of the independent variable in the regression equations were 1/R for horizontal curves and 1/K for vertical curves. An example of the collected data and the developed regression equations for horizontal curves on grades is shown in Figure 1.

Operating speeds on horizontal curves are very similar to speeds on long tangents when the radius is approximately 800 m or more. When this condition occurs, the grade of the section controls and the contribution of the horizontal radius is negligible. Operating speeds on horizontal curves drop sharply when the radius is less than 250 m.

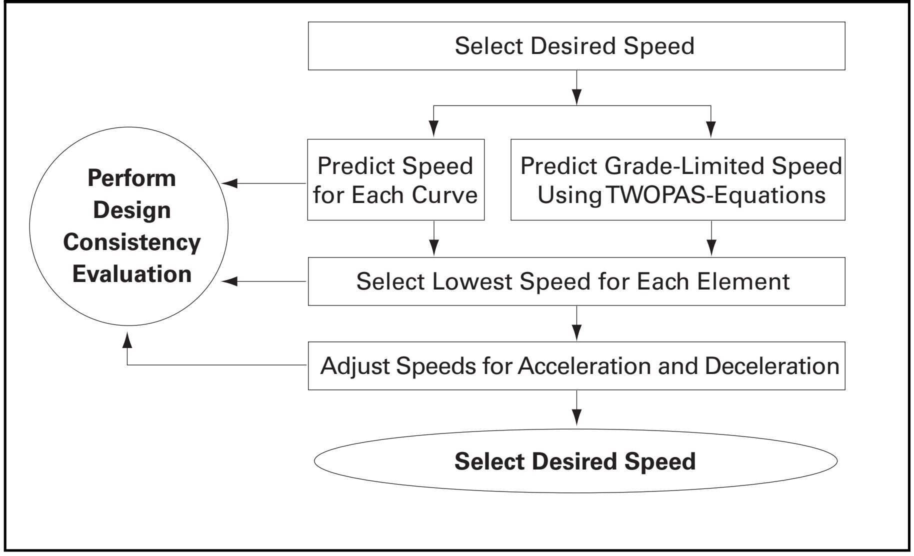
Using the regression equations and other data, a speed-profile model was developed. The model can be used to evaluate the design consistency of a facility or to generate a speed profile along an alignment. The steps to follow in the model are shown in Figure 2. The initial step is to select the desired V_{85} speed along the roadway. Based upon the findings from the research, the average 85th percentile speeds on long tangents range between 93 and 104 km/h for the States in this study. Therefore, a speed of 100 km/h is a good estimate of the desired speed along a two-lane rural roadway when seeking a representative, rounded speed.

The speeds predicted from developed speed prediction equations represent the speeds throughout the horizontal or vertical curves.

The equations included in the TWOPAS model can be used to check the performance-limited speed at every point on the roadway (upgrade, downgrade, or level). If, at any point, the grade-limited speed is less than the tangent or curve speed predicted using the speed prediction equations or the assumed desired speed, then the grade-limited speed will govern. The speeds predicted from the previous three methods (the assumed desired speed, the speeds predicted using the speed prediction equations, and the speeds from the TWOPAS equations) are compared, and the lowest speed is selected. If a continuous speed profile for the alignment is needed, these speeds would then be adjusted for deceleration and acceleration.

The speeds for the different alignment features could be compared at any step in the speed profile model to identify unacceptable changes in speed between alignment features. For example, a flag could be raised if the speed change from one curve to another is greater than a preset value, such as 15 km/h. In addition, a flag could be raised if the deceleration is greater than desired.

Figure 2. Speed-Profile Model Flowchart



Speed Distribution Measures

Speed distribution measures—including variance, standard deviation, coefficient of variation, and coefficient of skewness—are logical candidates for a consistency rating method to complement speed reduction estimates from the 85th percentile speed models. The rationale for using spot speed variability measures is that inconsistent features are expected to cause more spot speed variability than would consistent features and could result in more driver errors and accidents. The results from the analysis showed a low correlation between geometric alignment features and speed variance. Given this finding, it is not appropriate to consider speed variance as a design consistency measure for horizontal curvature.

Alignment Indices

Alignment indices are quantitative measures of the general character of a roadway segment's alignment. Geometric inconsistencies can arise when the general character of alignment changes between segments of roadway. None of the alignment indices studied in this project, however, were statistically significant predictors of the desired speeds of motorists on long tangents of two-lane rural highways.

Driver Workload/Visual Demand

A consistent roadway geometry allows a driver to accurately predict the correct path while using little visual information processing capacity, thus allowing attention or capacity to be dedicated to obstacle avoidance and navigation. A way of measuring the amount of workload or visual information needed is to use visual demand. Visual demand reflects the percentage of time that a driver is observing the roadway and is measured using a vision occlusion procedure. During the procedure, drivers wore an LCD visor that was opaque except when the driver requested a 0.5-second glimpse through the use of a floor-mounted switch.

Visual demand was determined at 3 types of facilities: test track environment (24 subjects driving 6 single curves and 4 paired curves for 6 runs), on-road (6 subjects driving 5 curves for 4 runs), and simulation (24 subjects driving 12 curves for 6 runs). When comparing the findings among the different studies, statistical analysis showed that no significant difference in slope (with respect to the inverse of radius) existed among all but one of the comparisons. This finding provides a level of confidence that workload differences between features can reliably be predicted. The comparisons between intercepts, or constants, however, showed that those intercepts generally were significantly different.

The finding of no difference in the slope of the regression line when comparing test track results with on-road results, but of a difference in the intercept, would indicate that *relative* levels of workload can be ascertained, but not *absolute* levels. This finding shows promise in determining *differences* in workload levels between successive highway features, but not baseline levels. Because most applications of driver workload are expected to reflect changes in level rather than any absolute terms, the general agreement with respect to the slope of the workload measures used is very encouraging.

Relationships of Design Consistency Measures to Safety

Of the candidate design consistency measures, the speed reducton on a horizontal curve relative to the preceding curve or tangent clearly has the strongest and most sensitive relationship to accident frequency. Other candidate design consistency measures investigated were ratio of an individual curve radius to the average radius for the roadway section as a whole, average rate of vertical curvature on a roadway section, and average radius of curvature on a roadway section. Table 1 is an example of the relationship of speed reduction between successive geometric elements and accident rate. Accident frequency is not as sensitive to the alignment indices reviewed as it is to the speed reduction for individual horizontal curves. In addition, the evaluation has shown that the speed reduction on a horizontal curve is a better predictor of accident frequency than the radius of that curve. This observation makes a strong case that a design consistency methodology based on speed reduction provides a better method for improving the potential safety performance of a proposed alignment alternative than does a review of horizontal curve radii alone.

Table 1. Accident Rates at Horizontal Curves by Design Safety Level

Design Safety Level*	Number of Horizontal Curves	3-Yr Accident Frequency	Exposure (million veh-km)	Accident Rate (accidents/ million veh-km)
Good: $\Delta V_{85} \leq$ 10km/h	4,518	1,483	3,206.06	0.46
Fair: 10km/h < $\Delta V_{85} \leq$ 20km/h	622	217	150.46	1.44
Poor: ΔV_{85} > 20km/h	147	47	17.05	2.76
Combined	5,287	1,747	3,373.57	0.52

* ΔV_{85} = Difference in 85th percentile speed between successive geometric elements (km/h)

Researcher: This study was performed by the following agencies: Texas Transportation Institute, The Texas A&M University System, College Station, TX 77843-3135, phone no. (409) 845-7321; Midwest Research Institute, Kansas City, MO 64110-2229, phone no. (816) 753-7600, ext. 1571; The Pennsylvania Transportation Institute, The Pennsylvania State University, University Park, PA 16802-4710, phone no. (814) 863-7923; and University of Michigan, Transportation Research Institute, Ann Arbor, MI 48109-2150, phone no. (734) 763-3795. Contract No. DTFH61-95-C-00084.

Distribution: This technical summary is available in hard copy and online formats. Direct distribution is being made to the Regions and Divisions.

Availability: Additional print copies of this technical summary can be obtained by contacting Ann Do, FHWA/HRDS, 6300 Georgetown Pike, McLean, VA 22101-2296 and via e-mail: ann.do@fhwa.dot.gov as well as by visiting the Design Consistency Module portion of the Interactive Highway Safety Design Model (IHSDM) Web site. (See subsequent Web site access information.)

The three reports referenced in the technical summary are available for online viewing only. To access the technical summary and the three reports online, visit the IHSDM Web site at www.tfhrc.gov and click “Safety” and then “Interactive Highway Safety Design Model.” Click on the Design Consistency Module page to view all materials in their entirety.

Key Words: Two-lane rural highway, design consistency, IHSDM, speed prediction, acceleration/deceleration, alignment indices, speed distribution, driver workload, visual demand.