CHAPTER **3**

INTERPRETATION, APPRAISAL, APPLICATIONS

Strong relationships between design speed, operating speed, and posted speed limit would be desirable, and these relationships could be used to design and build roads that would produce the speed desired for a facility. While a relationship between operating speed and posted speed limit can be defined, a relationship of design speed to either operating speed or posted speed cannot be defined with the same level of confidence.

Another strong limitation with the speed relationships is the amount of variability in operating speed that exists for a given design speed, for a given posted speed, or for a given set of roadway characteristics. Because of strong interactions between roadway features, changing one or a few features of a roadway may not always result in a change in speed. For instance, the field data showed that higher operating speeds exist when centerline and edgeline markings are present. Adding centerline and edgeline markings to a roadway, however, may not increase the speeds on that roadway, nor would it be reasonable to expect that the removal of pavement markings would result in lower speeds.

Following is a summary of the identified relationships between the various speed terms and discussions on potential changes to the *Green Book*.

OPERATING SPEED AND POSTED SPEED LIMIT

The strongest relationship found in this study was between operating speed and posted speed limit. Free-flow speed data were collected at 79 sites in S/U and rural areas in seven cities located in six states. The statistical evaluations began with attempts to predict operating speed using the collected roadway and roadside variables. Except for posted speed limit, no other roadway variable was statistically significant at a 5 percent alpha level.

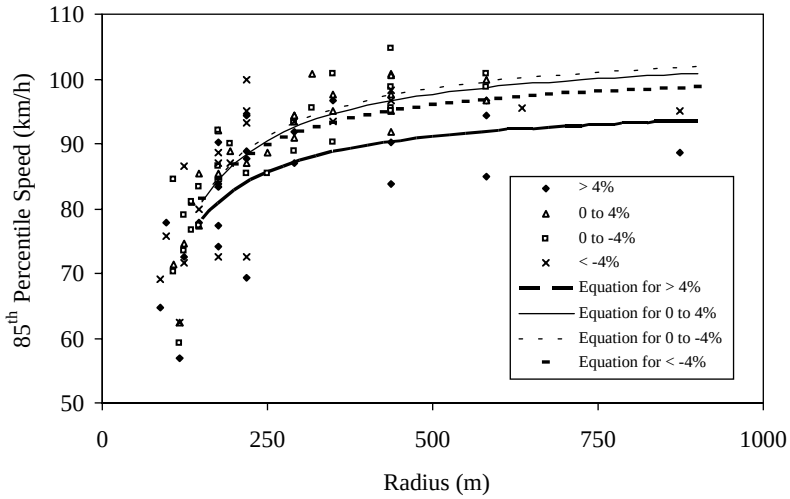
Table 38 lists the regression equations developed for predicting operating speed using posted speed limit. The only variable that had a t-statistic greater than 1 was access density (a t-statistic greater than 1 corresponds to an approximate 20 percent alpha level). Despite the low t-values obtained, several variables other than the posted speed limit show some sign of influence on the 85th percentile free-flow operating speed. These variables include access density, median type, parking along the street, and pedestrian activity level.

One encouraging aspect of this analysis is that regardless of the low t-values, most of the estimated regression coefficient values did have "expected" algebraic signs. This suggested that the influences of these variables on the 85th percentile free-flow operating speed are likely to be present, and the reason for not being able to estimate them to a good statistical accuracy is most likely due to the limited number of sites available for analysis.

DESIGN SPEED (OR ROADWAY/ROADSIDE ELEMENTS) AND OPERATING SPEED RELATIONSHIP

The design of a road appears to have minimal impact on operating speeds unless a tight horizontal radius or a low K-value is present. As shown in Figures 22 and 23, horizontal radii less than 250 m (656 ft) and vertical K-values below approximately 20 m/% on rural two-lane highways are associated with lower operating speeds. Values above those limits are associated with similar speeds (although large variability in speeds is present). Figures 24 and 25 illustrate the large variance in operating speed for a given inferred design speed on rural two-lane highways. They also show that operating speeds are within similar ranges (between 90 and 110 km/h [56 and 68 mph]) for each of the design speeds above 90 km/h (55.9 mph) on rural two-lane highways. The inferred design speeds for 19 suburban arterial horizontal curve sites in Texas (*39*) were determined and plotted in Figure 26. The suburban arterial data show a similar trend as the rural two-lane data—the variance for 85th percentile speed is constant for most of the data. Between 31.1- and 43.5-mph (50- and 70-km/h) inferred design speed, the operating speed is generally between 36.0 and 49.7 mph (58 and 80 km/h). Even with an inferred design speed above 62.1 mph (100 km/h), the 85th percentile speed was still below 49.7 mph (80 km/h). At design speeds above 43.5 mph (70 km/h), 85th percentile speeds are below the design speed of the roadway. Therefore, there is evidence that the use of design speeds higher than 49.7 mph (80 km/h) on rural two-lane highways and 43.5 mph (70 km/h) on suburban arterials will not result in higher operating speeds.

Table 41 lists the point where the 85th percentile speed is approximately equal to the inferred design speed as found in several previous studies. On suburban horizontal curves, drivers operate at speeds in excess of the inferred design speed on



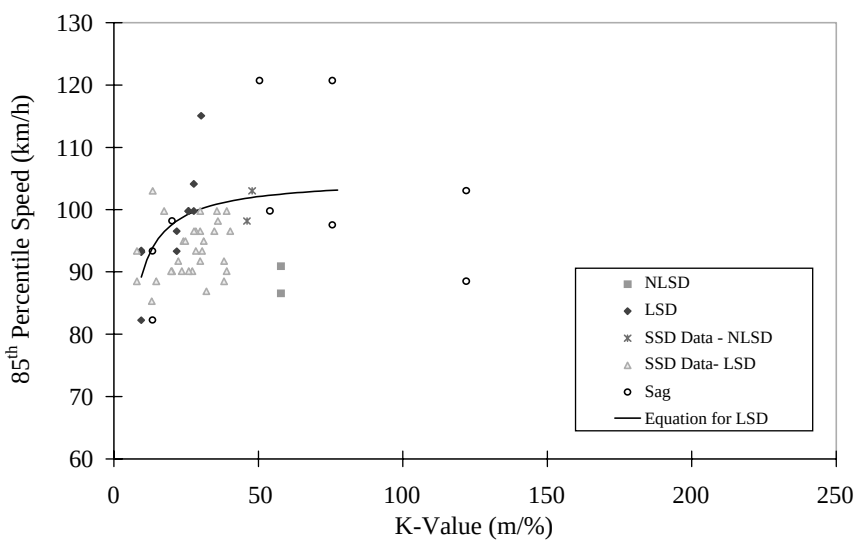
(1 m = 3.28 ft, 1 km/h = 0.62 mph)

Figure 22. Rural two-lane highway horizontal curves on grades: V_{85} versus R.

curves designed for 43.5 mph (70 km/h) or less, while on rural two-lane roadways, drivers operate above the inferred design speed on curves designed for 55.9 mph (90 km/h) or less.

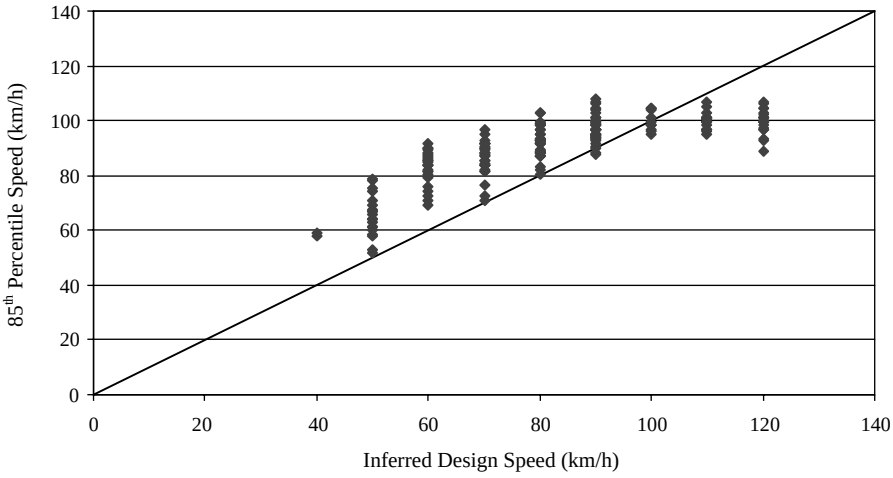
DESIGN SPEED AND POSTED SPEED

There is a concern within the profession of having a posted speed limit set higher than the design speed. Design speed is the primary factor in selecting a roadway's horizontal and vertical alignments. Its use was initiated in the 1930s. Use of statistical analysis of individual vehicular speeds observed at a spot on the roadway was initiated at about the same time. Because of differences in design and operation criteria, there are locations where the posted speed limit based on an 85th percentile speed exceeds the roadway's design speed. This situation is because criteria used in highway design incorporate a significant factor of safety. Consequently, it is not sur-



(1 m = 3.28 ft, 1 km/h = 0.62 mph)

Figure 23. Rural two-lane highway vertical curves on horizontal tangents: V_{85} versus K.



(1 km/h = 0.62 mph)

Figure 24. 85th percentile speed versus inferred design speed for 138 rural two-lane highway horizontal curves.

prising that motorists feel comfortable traveling at speeds greater than the roadway's design speed during good weather conditions.

When posted speed exceeds design speed, however, liability concerns arise even though drivers can safely exceed the design speed. While there is concern surrounding this issue, the number of tort cases directly involving that particular scenario was found to be small among those interviewed in a Texas DOT study (*22*). The respondents to the survey indicated that the primary concern associated with the posted speed versus design speed issue rested with the then-current AASHTO definition of design speed ("the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern"). Although it is obvious that the "maximum" safe speed can be exceeded without difficulty on vertical and horizontal curves when good weather conditions are present, it is difficult to convince the general public that a roadway's design speed can be exceeded with safety. The study concluded that if the AASHTO definition for design speed were changed (as it was in the 2001 edition of the *Green Book*), then liability concerns may be reduced substantially. Based on the findings from the survey and interviews and the research team's knowledge and experience, the guidelines in Table 42 were developed.

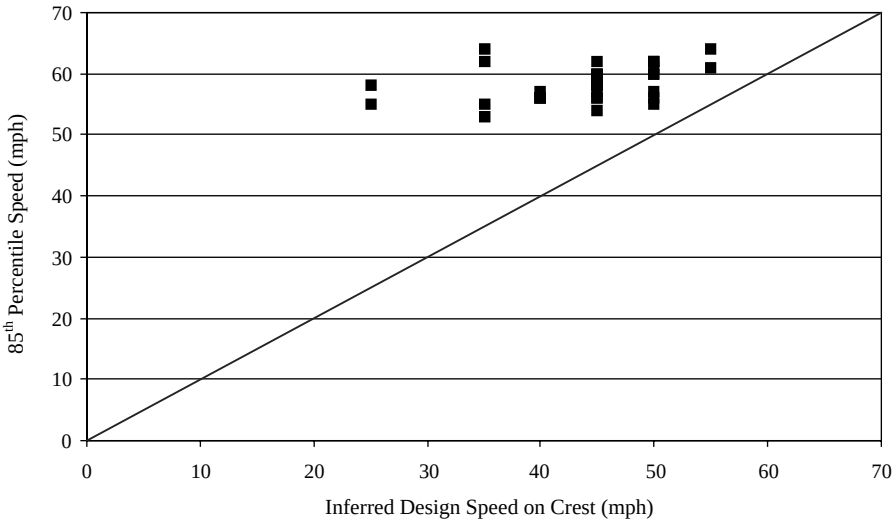
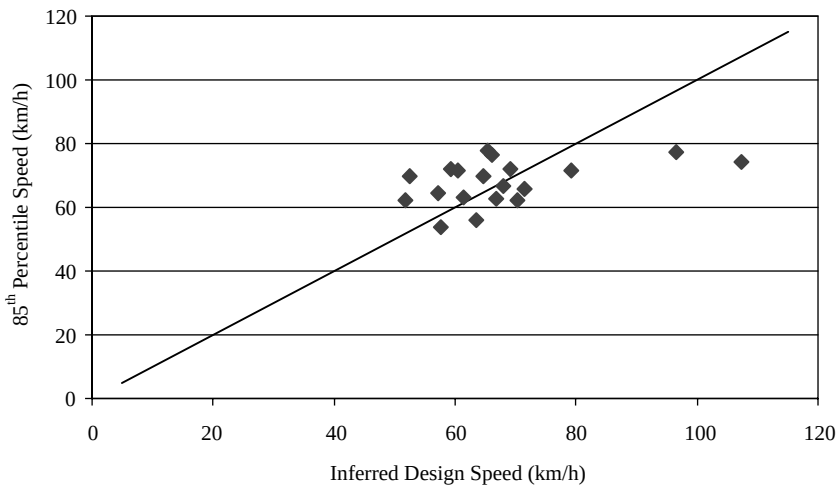


Figure 25. 85th percentile speed versus inferred design speed on rural two-lane highway limited sight distance crest vertical curves.



(1 km/h = 0.62 mph)

Figure 26. 85th percentile speed versus inferred design speed for suburban arterial horizontal curves.

REFINEMENTS TO DESIGN APPROACH

Design Speed Definitions

As part of this study, the research team assisted with encouraging those groups responsible for various key reference documents, such as the *Green Book* and *MUTCD*, to include similar definitions for speed terms.

Posted Speed Limit

Speed limit is the maximum (or minimum) speed applicable to a section of highway as established by law. Posted speed is the speed limit determined by law and shown on the speed limit sign. Information on posted speed and its relationship with operating speed and design speed was developed and included in Appendix A as suggested changes to the *Green Book*.

Selection of Design Speed Values

Of the 40 states responding to the mailout survey, 38 percent use anticipated posted speed and 58 percent use legal speed limit (plus a value, where the value ranges among 0, 5, or 10 mph) to select design speed. The use of posted speed limit provides an appreciation of the intended operations on the facility. Unfortunately, because posted speed limit does not represent in most cases the majority of the drivers on the facility, its use can result in geometric design criteria that are less than desired. For example, designing a suburban arterial for 40 mph may result in the use of curb and gutter along with other features that are appropriate for 40 mph and lower-speed operations but not desirable for higher-speed operations. Speed data collected in this project for S/U arterials with a posted speed limit of 40 mph showed that only 29 percent of the vehicles on those facilities were at or below the posted speed limit.

To provide a better representation of the operations on a facility, the anticipated operating speed would be preferred over the posted or anticipated posted speed. If the 85th percentile speed is not available, then use of the regression equations developed within this project can be used (see Table 38). Another alternative is to use posted speed plus 10 mph, which will capture approximately 86 percent of the vehicles using S/U non-freeway facilities or 96 percent of the vehicles on rural non-freeway facilities.

Roadway Design Class/Functional Class

A roadway design classification system was developed as part of this project (see Chapter 2). The vision was to identify the characteristics of a roadway that would result in different speeds. Classes associated with high speeds (e.g., freeways) and low speeds (e.g., local streets) were easy to identify because the differences are apparent. Freeways have medians and ramps that provide for limited access. Local streets frequently do not have pavement markings, have parking, and have almost unlimited access. The classes between the two extremes could not be clearly defined. The speeds within this group overlapped, as did the roadway characteristics. Therefore, to determine the number of classes and the characteristics of each class, engineering judgments and policy decisions must be made. The research team for this project used both to develop recommended roadway design classes.

TABLE 41 Point where 85th percentile speed is approximately equal to inferred design speed

Roadway Type	Curve	Reference	Point where 85th percentile speed is approximately equal to inferred design speed	
			km/h	mph
Rural	Vertical	Fambro et al. (*15*)	97 to 105	60 to 65
Two-lane rural	Vertical	Messer et al. (*57*)	97 to 113	60 to 70
Suburban	Vertical	Fitzpatrick et al. (*22*)	90	56
Two-lane highways	Horizontal	Chowdhury et al. (*43*)	90	56
Two -lane rural	Horizontal	Krammes et al. (*33*)	90	56
Suburban	Horizontal	Fitzpatrick et al. (*22*)	70	43
Suburban	Horizontal	data available from Texas DOT project 1769 (*38*)	70	43
Low-speed	Horizontal	Poe et al. (*37*)	42*	26*

* estimated from graph

1 mph = 1.61 km/h, 1 ft = 0.30 m

A part of the effort of developing the roadway design classes was to investigate the current distribution of roadway characteristics. The current distribution of roadway characteristics supported the findings from the field studies. Roadways between a freeway and a local street have a mix of speeds and characteristics, with many overlaps between the classes.

Because freeways are easily identified as a unique class of roadway, the *Green Book* should include information and discussion on its characteristics. There are chapters within the *Green Book* that include such discussions. Chapter 8 covers freeways, and Chapter 10 discusses grade separations and interchanges. The material in Chapter 1, however,

TABLE 42 Guidelines for setting speed limits while considering design speed

Guidelines for Setting Speed Limits:

- Speed limits on all roadways should be set by an engineer based on spot speed studies and the 85th percentile operating speed. Legal minimum and maximum speeds should establish the boundaries of the posted speed limits. If an existing roadway's posted speed limit is to be raised, the engineer should examine the roadway's roadside features to determine if modifications are necessary to maintain roadside safety.
- The 85th percentile speed is considered the appropriate speed limit even for those sections of roadway that have an inferred design speed lower than the 85th percentile speed. Posting a roadway's speed limit based on its 85th percentile speed is considered good and typical engineering practice. This practice remains valid even where the inferred design speed is less than the resulting posted speed limit. In such situations, the posted speed limit would not be considered excessive or unsafe.
- Arbitrarily setting lower speed limits at point locations due to a lower inferred design speed is neither effective nor good engineering practice.
- If a section of roadway has (or is expected to have) a posted speed greater than the roadway's inferred design speed and a safety concern exists at that location, appropriate warning or informational signs should be installed to warn or inform drivers of the condition. Inferred design speeds slightly less than the posted speed limit do not present an unsafe operating condition because of the conservative assumptions made in establishing design stopping sight distances. It is important to remember that any sign is a roadside object and that it should be installed only when its need is clearly demonstrated.
- New or reconstructed roadways (and roadway sections) should be designed to accommodate operating speeds consistent with the roadway's highest anticipated posted speed limit based on the roadway's initial or ultimate function.

Source: Fitzpatrick et al. (*22*)

presents freeways as a subclass of arterial streets. To support the uniqueness of freeways as a roadway class with design criteria that are different from both S/U and rural arterials, we recommend that the *Green Book* Chapter 1 be revised to include freeways as a unique class. Therefore, information on freeways as a unique roadway class was developed and presented as suggested changes to the *Green Book* (see Appendix A).

Speed Prediction/Feedback Loop

A method for ensuring that operating speeds are considered within the design is to use a speed prediction model with a feedback loop. The method would predict the operating speed along an alignment and then compare the speed to the design speed. Several countries have a more explicit consideration of operating speeds than AASHTO policy. The basic approach is as follows:

- Design a preliminary alignment based on the selected design speed.
- Estimate 85th percentile speeds on the alignment.
- Check for large differences between 85th percentile speeds.
- Revise the alignment to reduce these differences to acceptable levels.

The Federal Highway Administration is developing the Interactive Highway Safety Design Model (IHSDM) in an

attempt to marshal available knowledge about safety into a more useful form for highway planners and designers (*52*). One of the IHSDM modules is the Design Consistency Module. It provides information on the extent to which a roadway design conforms with drivers' expectations. The primary mechanism for assessing design consistency is a speed-profile model that estimates 85th percentile speeds at each point along a roadway. Potential consistency problems for which alignment elements will be flagged include large differences between the assumed design speed and estimated 85th percentile speed and large changes in 85th percentile speeds between successive alignment elements.

The findings from the field studies conducted as part of this NCHRP project could be used as a starting point for an S/U speed prediction model. The model could start with the speeds predicted from the identified relationship between posted speed limit and operating speed. The predicted speeds could then be adjusted using developed modification factors. The approach of calculating a predicted value and then modifying it by using adjustment factors was employed in developing an algorithm for predicting the safety performance of a rural two-lane highway (*58*). The adjustment factors were selected based upon available information on relationships between the geometric element and safety and the consensus of an expert panel.

Numerous studies have examined the relationships between design features and operating speeds (see Appendix D). Relationships identified in this project in addition to the strong relationship between operating speed and posted speed limit include association of the following with lower speeds: higher access density, higher signal density, higher pedestrian activities, the absence of centerline or edgeline markings, the presence of parking, and the lack of a median. The relationships identified in this project and in other projects could be used to develop a speed prediction and feedback loop approach to design.