CHAPTER **4**

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Following the conclusions that are subdivided by the major efforts within the project is a summary of the suggested changes for the next edition of the *Green Book*

Relationships

- 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.
- The strongest relationship found in NCHRP Project 15-18 was between operating speed and posted speed limit. Except for posted speed limit, no other roadway variable was statistically significant at a 5 percent alpha level.
- Design speed appears to have minimal impact on operating speeds unless a tight horizontal radius or a low K-value is present. Large variance in operating speed was found for a given inferred design speed on rural two-lane highways. On suburban horizontal curves, drivers operate at speeds in excess of the inferred design speed on 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.
- 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.

Mailout Survey

- A mailout survey was conducted in early 1999 to develop a better understanding of what definitions, policies, and values are used by practicing engineers in the design of roadways. Responses indicate that most states used the 1994 *Green Book* definitions (the 2000 *Green Book* was not yet published during the survey), but far fewer respondents indicated that it was their preferred definition. Therefore, there was a degree of dissatisfaction with the 1994 definitions and their applications to the design process.
- Responses to Section II of the survey illustrate how design practices and policies can vary widely from state to state. In selecting the design speed of a new road, the functional class or the legal speed limit were most commonly used. For existing roads with few changes, each possible answer was chosen by between one-fourth and one-half of the respondents. In projects where the roadway is changing its functional class, the design speed for a new road of similar nature (55 percent) and the speed associated with the functional class (47 percent) were identified as the most important.
- A senior designer review was part of the procedure for checking a preliminary design, according to a large majority (80 percent) of respondents, and reviews by the traffic operations section were used by a little more than one-half (55 percent) of the respondents.
- Almost all respondents (97 percent) believed that lane width affected drivers' speed. Shoulder width (71 percent), clear zone (79 percent), presence of a raised median (61 percent), and presence of a two-way left-turn lane (66 percent) were often identified as having a perceived influence on speed.

Design Element Review

- Most of the design elements and their values are either directly or indirectly selected based on design speed. In a few situations, the type of roadway is used to determine the design element value or feature; however, the type of roadway is strongly associated with the operating speed of the facility.
- The relationship with operating speed has been identified for several design elements. In some cases the relationship is strong, such as for horizontal curves, and in other cases the relationship is weak, such as for lane width. In all cases when a relationship between the design element and operation speed exists there are ranges when the influence of the design element on speed is minimal.

- A third review investigated the safety implications of design elements. While the relationship between a design element and operating speed may be weak, the consequences of selecting a particular value may have safety implications. The safety review demonstrated that there are known relationships between safety and design feature and that the selection of the design feature varies based on the operating speed of the facility. Therefore, the design elements investigated within this study should be selected with some consideration of the anticipated operating speed of the facility. In some cases the consideration would take the form of selecting a design element value within a range that has minimal influence on operating speed or that would not adversely affect safety, while in other cases the selection of a design element value would be directly related to the anticipated operating speed.

Previous Relationships Between Design, Operating, and Posted Speed Limit

- A late 2000 Federal Highway Administration (FHWA) research project developed regression equations that predict operating speed on rural two-lane highways (*36*). Speed data were collected at over 200 two-lane rural highway sites for use in the project. Several other research projects have also developed regression equations to predict speeds on rural two-lane highways, especially at horizontal curves. The feature that is most frequently identified as influencing speed on two-lane rural highways is horizontal curvature (degree of curve, radius, length of curve, deflection angle, superelevation, or inferred design speed). Grade, tangent length, and lane width have also been found to influence speed.
- Other studies have developed regression equations or identified roadway features that affect speed on suburban arterials and local streets. Features identified include lane width, hazard rating, access density, speed limit, roadside development, and median presence.

Field Studies

- Free-flow speed data were collected at 78 sites in S/U and rural areas in seven cities located in six states. For each site, roadway and roadside characteristics were also collected, such as number of access points within the study section, roadside development type, and lane width.
- Initial graphical evaluation provided a visual appreciation of potential relationships between a roadway or roadway variable and operating speed. Findings from the evaluation included the following:
  - Posted speed limit: This has the strongest relationship to 85th percentile speed. As posted speed increases the 85th percentile speed increases.
  - Functional class: Local roads had the lowest speeds collected, while arterials had the highest.
  - Access density (the number of access points, such as driveways and intersections, per mile): It showed a strong relationship with 85th percentile speed, with higher speeds being associated with lower access densities.
  - Pedestrian activity: Lower speeds occur as pedestrian activity increases.
  - Centerline or edgeline markings: The absence of either is associated with lower speeds.
  - On-street parking: When permitted, speeds are lower.
  - Median: When present, speeds are slightly lower than when a raised, depressed, or TWLTL is present, with a few exceptions.
  - Distance between features that have influence on a driver's speed, such as a signal or sharp horizontal curve: As the distance increases, speeds increase to a point and then plateau.
  - Shoulder width: Roadways with shoulders that have widths of 6 ft (1.8 m) or more have speeds above 50 mph (80.5 km/h), with one exception. Roadways with shoulders between 0 and 4 ft (0 and 1.2 m) also had speeds up to 50 mph (80.5 km/h), but most speeds observed were lower than on the roadways with wider shoulders. Roadways with curb and gutter had speeds across the entire range seen on roadways with shoulders (25 to almost 60 mph [40.2 to almost 96.6 km/h]). There is no evidence that the presence of curb and gutter results in lower speeds for a facility.
  - Signal density: Higher signal density is associated with lower speed.
  - Pavement width: Fewer lower speeds are associated with wider pavement.
  - Median width: Fewer lower speeds are associated with wider medians.
  - Lane width: No relationship was apparent between lane width and speed.
  - Type of residential development: Speeds on streets with single-family residential development tended to have lower speeds; however, some sites with residential development had speeds near 50 mph (80.5 km/h). A sizeable range of speeds occurred within each development type.
- The statistical evaluation began with attempting to predict operating speed using the collected roadway and roadside variables.
  - The site variation in operating speeds is highly correlated with the variation in posted speed limits.
  - Access density had a t-statistic greater than 1, which corresponded to an approximate 20 percent alpha level.
  - No other roadway variable was statistically significant at the 20 percent alpha level or higher. Despite their low t-values, however, several variables do show

some sign of influence on the 85th percentile free-flow operating speed, including 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 do have "expected" algebraic signs. This suggests that the influences of these variables on the 85th percentile free-flow operating speed are likely to be there, 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.

- A cluster analysis was performed to determine if the project team could gain additional insight on the perceived influences of a roadway attribute on operating speed. The analysis resulted in a seven-cluster model. The following were the noteworthy features found within the analysis: pedestrian activity, parking, centerline, median treatment, roadside development, area type, and signal density.
- A 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.

Selection of Design Speed

- Factors used to select design speed include the following:
  - AASHTO: functional classification, rural versus urban, terrain;
  - State DOTs: AASHTO *Green Book* procedure, legal speed limit, legal speed limit plus a value (e.g., 5 or 10 mph [8.1 or 16.1 km/h]), anticipated volume, anticipated operating speed, development, costs, and consistency; and
  - International Practices: anticipated operating speed and feedback loop.
- Currently one-third of the responding states have used operating speed to select a design speed value, and one-half have used anticipated posted speed. The anticipated posted speed implicitly considers the functional class of the roadway, whether it is in a rural or urban area, and, in some cases, the terrain; however, it also represents a departure from the procedure present in the *Green Book*.

Operating Speed and Posted Speed Relationships

- Several studies have demonstrated that 85th percentile operating speeds typically exceed posted speeds. These studies also show that the 50th percentile operating speed either is near or exceeds the posted speed limit.
- The data analyzed within this study showed that between 37 and 64 percent of the free-flow vehicles on rural roads are at or below the posted speed limit. The percent of vehicles at or below the speed limit is much lower for S/U roadways (on the order of only 23 to 52 percent).
- For rural non-freeway facilities, speed limit plus 10 mph would include almost all vehicles on the roadways. For S/U areas, speed limit plus 10 mph would only include between 86 and 95 percent of the vehicles on the roadways. A much larger percentage of vehicles exceed the speed limit on S/U non-freeway roadways than on rural non-freeway roadways. For the 30-, 35-, and 40-mph (48.3-, 56.3-, and 64.4-km/h) speed limits, only 28, 22, and 32 percent, respectively, of the vehicles on the road were at or below the posted speed limit.
- While the *MUTCD* recommends setting posted speed limits near the 85th percentile speed (and the surveys say that agencies are using the 85th percentile speed limit to set speeds), in reality those agencies consistently set a majority of sites lower than the measured 85th percentile speed by 5 mph (8.1 km/h) or more.
- Data for 128 speed study zone surveys were used in the analysis. About one-half of the sites had between a 4- and 8-mph (6.4- and 12.9-km/h) difference from the measured 85th percentile speed. At only 10 percent of the sites did the recommended posted speed limit reflect a rounding *up* to the nearest 5-mph (8.1-km/h) increment (as stated in the *MUTCD*; see Table 25). At approximately one-third of the sites, the posted speed limit was rounded to the *nearest* 5-mph (8.1-km/h) increment. For the remaining two-thirds of the sites, the recommended posted speed limit was more than 3.6 mph (5.8 km/h) below the 85th percentile speed.
- Drivers' attitude that they can drive 5 to 10 mph (8.1 to 16.1 km/h) higher than the speed limit and avoid a ticket does not encourage compliance with posted speed; however, neither does setting speed limits that are more than 5 mph (8.1 km/h) from the measured 85th percentile speed.
- Most agencies report using the 85th percentile speed as the basis for their speed limits, so the 85th percentile speed and speed limits should be closely matched. However, a review of available speed studies demonstrates that the 85th percentile speed is only used as a "starting point," with the posted speed limit being almost always set below the 85th percentile value by as much as 8 to 12 mph.

Distributions of Roadway and Roadside Characteristics

- An approach to design that uses established roadway classes needs to provide information on acceptable ranges for each design element. Going beyond an acceptable

range for a design element would theoretically communicate a different roadway class (or speed environment) to the driver. To gain a better appreciation of existing conditions, roadway and roadside characteristics data for a sample of roadways within three cities and three predominantly rural counties were collected.

- The results for the rural roadways illustrate some noteworthy trends.
  - There appear to be design class relationships with ADT, average lane width, average shoulder width, average median width, and average deflection angle.
  - Less apparent from the data were expected relationships between design class and posted speed and between design class and driveway or intersection density.
- The S/U roadway characteristics indicate that some expected relationships between variables do exist, while other anticipated relationships were not as apparent from the data.
  - Design class appears to be related to posted speed, operating speed, presence of parking, pedestrian activity, number of lanes, driveway density, intersection density, signal density, and roadside development.
  - Relationships between design class and lane width, median presence, or median width were anticipated and may possibly exist, although the extent of those relationships is not apparent from the data.
  - There are apparent relationships between posted speed range and the following: operating speed, presence of parking, presence of curb and gutter, average number of lanes, lane width, median width, shoulder width, driveway density, intersection density, and roadside development.
  - The use of sidewalks does not appear to be strongly related to the posted speed of the facility in the two cities.

Design Approach

- The classification of roadways into different operational systems, functional classes, or geometric types is necessary for communication among engineers, administrators, and the general public. To better align design criteria with a classification scheme, a roadway design classification system was created. To recognize some of the similarities between the classes for the roadway design class scheme and the functional classification scheme, similar titles were used.
- Grouping freeway and local street characteristics was straightforward. Determining the splits for roads between those limits was not as straightforward. The goal of the field studies was to identify the characteristics that, as a group, would produce a distinct speed. For example, what are the characteristics that would result in a high speed and high mobility performance as opposed to those characteristics that would result in a lower speed? The results of the field studies demonstrated that the influences on speed are complex. Even when features that are clearly associated with a local street design are present (e.g., no pavement markings, on-street parking, two lanes, etc.), 85th percentile speeds still ranged between 26 and 42 mph (41.8 and 67.6 km/h) for the 13 sites. Such wide ranges of speeds are also present for other groupings of characteristics.
- Because of the variability in speeds observed in the field for the different roadway classes and the large distribution in existing roadway characteristics, the splits between different roadway design classes need to be determined using a combination of engineering judgment and policy decisions.

Suggested Changes to the Design Approach/Next Edition of the *Green Book*

- Add discussion on posted speed limit to encourage a better understanding of the relationship between 85th percentile speed and posted speed limit (i.e., posted speed limits are generally set between 4 and 8 mph [6.4 and 12.9 km/h] less than the measured 85th percentile speed). Comment that between only 23 and 64 percent of vehicles operate below the posted speed limit in urban areas.
- Change text to recognize freeways as a unique functional class. Encourage the recognition that the look of a roadway (e.g., ramps, wide shoulders, and medians) is associated with the anticipated speeds on the facility.
- Add comments in the design speed discussion to identify that the following may affect operating speed: radius, grade, access density, median presence, on-street parking, pedestrian activity, and signal density.
- Add information on the state of the practice for selecting design speed values. Anticipated operating speed and anticipated posted speed limit are being used by a notable percentage of the states.
- Introduce the concept of speed prediction and feedback loops. Reference the FHWA work on the IHSDM.

SUGGESTED RESEARCH

- Develop speed prediction model(s) for use in the S/U environment. Currently, FHWA is developing a speed prediction model for rural two-lane highways as part of the IHSDM. A speed prediction model is also needed for other than two-lane highways in the rural environment. 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 and consideration of signal spacing. 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. The adjustment factors were selected based upon available information on relationships between geometric elements and safety and the consensus of an expert panel. The relationships identified in this project and in other projects could use a similar approach to develop a speed prediction and feedback loop approach to design.

- Collect additional data to expand the speed data set developed in this NCHRP study to confirm (or not confirm) indications observed in available data. The statistical evaluation in this study found only posted speed limit to be significant at a 5 percent alpha level. The only other variable that had a t-statistic greater than 1 was access density, which corresponded to an approximate 20 percent alpha level. Despite the low t-values obtained, several variables other than the posted speed limit do show some sign of influence on the 85th percentile free-flow operating speed. One encouraging aspect of the analysis was that regardless of the low t-values, most of the estimated regression coefficient values did have "expected" algebraic signs. This suggests that the influences of these variables on the 85th percentile free-flow operating speed are likely to be there, 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. A simple calculation suggests that using the same site selection practice, about three times more sites are needed to allow the estimates of some roadway variables to achieve a 5 percent alpha level. However, with a carefully planned site selection procedure following good experimental design principles, the project team estimated that the desirable statistical level may be achievable with just one and one-half to two times more sites.
- Conduct research that emphasizes drivers' speed choice behaviors. For example, in this NCHRP study many of the speed distribution plots show three modes, indicating that there are perhaps three types of drivers in terms of their speed choices: (1) conservative drivers who always try to stay below the posted speed limit, (2) moderate drivers, who constitute the majority of the drivers, who try not to exceed the speed limit to an unreasonable degree, and (3) aggressive drivers, who use the posted speed limit as the lower bound and constantly look for opportunities to drive at higher speeds. This kind of research recognizes the importance of human factors in determining driving speeds and the heterogeneity of the driver population. Studies developed to these ends should be careful to separate causality from correlation.
- Perform research that would use simultaneous equation modeling to evaluate the speed data. The approach would recognize that both posted speed limits and operating speeds are exogenous variables and that many variables other than the operating speed have been used by the engineer to determine the posted speed limit. This research will require data on how the posted speed limit is determined.
- Evaluate the effects of considering the entire speed distribution, instead of focusing on a particular percentile speed in designing and operating roadways.
- Examine the roles of engineers, legislators, and enforcement officers in the setting of speed limits. Develop recommendations on how to encourage uniformity in the setting and enforcement of speed limits. Some of these efforts are ongoing with current FHWA projects.
- Determine the percent of freeway vehicles in both the rural and S/U environments that are driving at the posted speed limit, at the posted speed limit plus 5 mph (8.1 km/h), and at the posted speed limit plus 10 mph (16.1 km/h).