NCHRP
REPORT 504

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Design Speed, Operating Speed, and Posted Speed Practices

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Design Speed, Operating Speed, and Posted Speed Practices

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SUBJECT AREAS
Highway and Facility Design

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Kay Fitzpatrick, Research Engineer, Texas Transportation Institute, was the Principal Investigator. The other authors of this report, also of TTI, are Paul Carlson, Associate Research Engineer; Marcus A. Brewer, Associate Transportation Researcher; Mark D. Wooldridge, Associate Research Engineer; and Shaw-Pin Miaou, Research Scientist. The work was performed under the general supervision of Dr. Fitzpatrick.

The authors wish to acknowledge the many individuals who contributed to this research by participating in the mailout surveys and who assisted in identifying potential study sites for the field studies. In addition, the authors recognize Dan Fambro, whose insight and guidance during the early part of this project provides us with the interest and desire to improve the design process so as to create a safer and more efficient roadway system.

FOREWORD

By B. Ray Derr
Staff Officer
Transportation Research Board

This report examines the relationship between design speed and operating speed through a survey of the practice and a thorough analysis of geometric, traffic, and speed conditions. The basis for recent changes in speed definitions in AASHTO's *A Policy on Geometric Design of Highways and Streets* (Green Book) and the *Manual on Uniform Traffic Control Devices* (MUTCD) are presented. Researchers should find the data (available on the accompanying CD-ROM) to be very useful in further exploring relationships between roadway factors and operating speed. The report will be of interest to designers and others interested in understanding the factors that affect drivers' speeds.

Speed is a fundamental concept in transportation engineering. The Green Book, MUTCD, and other references use various aspects of speed (e.g., design speed, operating speed, running speed, 85th percentile speed) depending on the application, but the definitions of these aspects have not always been consistent between documents. These inconsistencies resulted in ambiguous and sometimes conflicting policies.

Design speed is a critical input to the Green Book's design process for many geometric elements. For some of these elements, however, the relationship between the design speed and the actual operating speed of the roadway is weak or changes with the magnitude of the design speed. Setting a design speed can be challenging, particularly in a public forum, and alternative approaches to design may be beneficial and should be explored.

Under NCHRP Project 15-18, the Texas Transportation Institute compiled and analyzed industry definitions for speed-related terms and recommended more consistent definitions for AASHTO's Green Book and the MUTCD. The researchers surveyed state and local practices for establishing design speeds and speed limits and synthesized information on the relationships between speed, geometric design elements, and highway operations. Next, researchers critically reviewed geometric design elements to determine if they should be based on speed and identified alternative design-element-selection criteria. Geometric, traffic, and speed data were collected at numerous sites around the United States and analyzed to identify relationships between the various factors and speeds on urban and suburban sections away from signals, stop signs, and horizontal curves (all elements previously found to affect operating speeds).

In addition to including the survey of practice and information on the relationships between speed and various geometric and traffic factors, this report suggests refinements to the Green Book in the following areas: design speed definitions; information on posted speed and its relationship with operating speed and design speed; how design speed values are selected in the United States (noting that anticipated posted speed and anticipated operating speed are also used in addition to the process currently in the

Green Book, which is based on terrain, functional class, and rural versus urban); changes to functional class material; and additional discussion on speed prediction and feedback loops. The included CD-ROM contains the field data that should be combined with future data collection efforts to gain a better understanding of the factors that influence operating speed in urban and suburban areas.

CONTENTS

DESIGN SPEED, OPERATING SPEED, AND POSTED SPEED PRACTICES

SUMMARY

Speed is used both as a design criterion to promote consistency and as a performance measure to evaluate highway and street designs. Geometric design practitioners and researchers are, however, increasingly recognizing that the current design process does not ensure consistent roadway alignment or driver behavior along these alignments. The goals of the NCHRP 15-18 research project were to reevaluate current procedures, especially how speed is used as a control in existing policy and guidelines, and then to develop recommended changes to the design process. Objectives completed included the following:

- Review current practices to determine how speed is used as a control and how speed-related terms are defined. Also identify known relationships between design speed, operating speed, and posted speed limit.
- Identify alternatives to the design process and recommend the most promising alternatives for additional study.
- Collect data needed to develop the recommended procedure(s).
- Develop a set of recommended design guidelines and/or modifications for the AASHTO *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book*).

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 the relationship between operating speed and posted speed limit can be defined, the relationship of design speed with either operating speed or posted speed cannot be defined with the same level of confidence. The strongest statistical relationship found in NCHRP Project 15-18 was between operating speed and posted speed limit for roadway tangents. Several variables other than the posted speed limit do show some sign of influence on the 85th percentile free-flow operating speed on tangents. These variables include access density, median type, parking along the street, and pedestrian activity level.

Previous studies have found roadway variables that are related to operating speed, including access density and deflection angle (suburban highways); horizontal curvature

and grade (rural two-lane highways); lane width, degree of curve, and hazard rating (low-speed urban streets); deflection angle and grade (rural two-lane highways); and roadside development and median presence (suburban highways).

A strong limitation with all 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.

Design speed has a minimal impact on operating speeds unless a tight horizontal radius or a low K-value is present. 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, 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 Department of Transportation (TxDOT) study.

The safety review demonstrated that there are known relationships between safety and design features 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. In other cases the selection of a design element value would be directly related to the anticipated operating speed.

Factors used to select design speed are functional classification, rural versus urban, and terrain (used by AASHTO); AASHTO *Green Book* procedure, legal speed limit, legal speed limit plus a value (e.g., 5 or 10 mph [8.1 to 16.1 km/h]), anticipated volume, anticipated operating speed, development, costs, and consistency (state DOTs); and anticipated operating speed and feedback loop (international practices).

Functional classification is used by the majority of the states, with legal speed limit being used by almost one-half of the states responding to the mailout survey conducted during NCHRP Project 15-18. A concern with the use of legal speed limit is that it does not reflect a large proportion of the drivers. Only between 23 and 64 percent of drivers operate at or below the posted speed limit on non-freeway facilities. The legal speed limit plus 10 mph (16.1 km/h) included at least 86 percent of suburban/urban drivers on non-freeway facilities with speed limits of 25 to 55 mph (40.2 to 88.5 km/h) and included at least 96 percent of rural drivers on non-freeway facilities with speed limits of 50 to 70 mph (80.5 to 112.7 km/h).

While the profession has a goal to set posted speed limits near the 85th percentile speed (and surveys say that 85th percentile speed is used to set speed limits), in reality, most sites are set at less than the measured 85th percentile speed. Data from 128 speed study zone surveys found that 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 *Manual on Uniform Traffic Control Devices* [*MUTCD*]). 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.

The classification of roadways into different operational systems, functional classes, or geometric types is necessary for communication among engineers, administrators, and the general public. In an attempt to better align design criteria with a roadway classification scheme, a roadway design class was created in NCHRP Project 15-18. To recognize some of the similarities between the classes for the new roadway design class scheme and the traditional functional classification scheme, similar titles were used. The classification of freeway and local street characteristics was straightforward. Determining the groupings 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 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.

CHAPTER **1**

INTRODUCTION AND RESEARCH APPROACH

RESEARCH PROBLEM STATEMENT

Geometric design refers to the selection of roadway elements that include the horizontal alignment, vertical alignment, cross section, and roadside of a highway or street. In general terms, good geometric design means providing the appropriate level of mobility and land use access for motorists, bicyclists, and pedestrians while maintaining a high degree of safety. The roadway design must also be cost effective in today's fiscally constrained environment. While balancing these design decisions, the designer needs to provide consistency along a roadway alignment to prevent abrupt changes in the alignment that do not match motorists' expectations. Speed is used both as a design criterion to promote this consistency and as a performance measure to evaluate highway and street designs. Geometric design practitioners and researchers are, however, increasingly recognizing that the current design process does not ensure consistent roadway alignment or driver behavior along these alignments.

A design process is desired that can produce roadway designs that result in a more harmonious relationship between the desired operating speed, the actual operating speed, and the posted speed limit. The goal is to provide geometric street designs that "look and feel" like the intended purpose of the roadway. Such an approach produces geometric conditions that should result in operating speeds that are consistent with driver expectations and commensurate with the function of the roadway. It is envisioned that a complementary relationship would then exist between design speed, operating speed, and posted speed limits.

RESEARCH OBJECTIVES

The goals of this research were to reevaluate current procedures, especially how speed is used as a control in existing policy and guidelines, and then develop recommended changes to the design process.

To accomplish these goals, the following objectives were met:

- Review current practices to determine how speed is used as a control and how speed-related terms are defined. Also identify known relationships between design speed, operating speed, and posted speed limit.
- Identify alternatives to the design process and recommend the most promising alternatives for additional study.
- Collect data needed to develop the recommended procedure(s).
- Develop a set of recommended design guidelines and/or modifications for the AASHTO *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book*).

RESEARCH APPROACH

The research project was split into two phases. Within Phase I, the research team conducted the following efforts:

- reviewed the research literature to identify known relationships between design, operating, and posted speed limit;
- determined current state and local practices using a mail-out survey;
- traced the evolution of various speed definitions and identified how they are applied;
- critically reviewed current design elements to determine if they are or need to be based on speed;
- prepared the interim report that summarized the findings from Phase I that included alternative design procedures; and
- prepared a revised work plan for Phase II.

At the conclusion of Phase I, the panel for this project reviewed the alternative design procedures and provided feedback on which alternatives should be investigated as part of Phase II of the project. The following alternatives were selected by the panel members for investigation:

- change definitions and
- develop roadway design class approach.

These alternatives were not selected for additional investigation, although the panel indicated interest in them:

- define intermediate speed class,
- add regional variation consideration,
- add consistency check–speed,

- add speed prediction, and
- add driver expectancy.

Within Phase II, the research team conducted the following efforts:

- facilitated the inclusions of similar speed definitions into key reference documents that were being revised during this project (i.e., *Green Book* and *MUTCD*),
- collected field data to more fully develop the recommendations on changes to the design process,
- investigated whether a driver simulator could be used to supplement the collected field data,
- collected data on the distribution of roadway and roadside characteristics for existing roadways,
- reviewed how design speed is selected,
- investigated how the 85th percentile speed influences the selection of the posted speed limit value,
- developed recommended changes to the AASHTO *Green Book*, and
- prepared the final report.

ORGANIZATION OF THIS REPORT

This report includes the following chapters and appendixes:

Chapter 1. Introduction and Research Approach. Presents an introduction to the report and summarizes the research objectives and approach.

Chapter 2. Findings. Contains the findings from the various efforts conducted during the project.

Chapter 3. Interpretation, Appraisal, Applications. Discusses the meaning of the findings presented in Chapter 2.

Chapter 4. Conclusions and Suggested Research. Summarizes the conclusions and suggested research from this project's efforts.

Appendix A. Suggested Changes to the *Green Book*. Contains suggested changes to the *Green Book* based on the findings from the research project.

Appendix B. Mailout Survey. Provides the individual findings from the mailout survey and a copy of the original survey.

Appendix C. Design Element Reviews. Discusses the relationship between speed and geometric design elements that were evaluated in three areas: use of design speed, operations, and safety. Also summarizes various definitions for design speed and operating speed.

Appendix D. Previous Relationships Between Design, Operating, and Posted Speed Limit. Identifies the relationships between the various speed terms from the literature.

Appendix E. Field Studies. Presents the methodology and findings from the field studies.

Appendix F. Driving Simulator Study. Presents the findings from a small preliminary study on driver speeds to different functional class roadway scenes.

Appendix G. Selection of Design Speed Values. Identifies approaches being used to select design speed within the states and discusses approaches that could be considered for inclusion in the *Green Book*.

Appendix H. Operating Speed and Posted Speed Relationships. Investigates how 85th percentile speed is being used to set posted speed limit.

Appendix I. Distributions of Roadway and Roadside Characteristics. Identifies the distribution of design elements in two cities and for the field data (see Appendix E) by posted speeds and design classes.

Appendix J. Alternatives to Design Process. Presents the alternatives to the design process identified in Phase I of the research.

CHAPTER **2**

FINDINGS

Several studies were conducted within NCHRP Project 15-18. The methodology for these studies is documented in the appendixes. Chapter 2 contains the key findings from the following studies:

- Speed Definitions
- Mailout Survey
- Design Element Review
- Previous Relationships
- Field Studies
- Selection of Design Speed Value
- Operating Speed and Posted Speed Relationships
- Distributions of Characteristics
- Design Approach

Tasks within Phase I of the project were performed to obtain a better understanding of how speed is used within design and operations and to identify existing practices or knowledge. The literature reviews provided information on the following:

- current use and the history of the various speed definitions (documented in the Speed Definitions section of this chapter);
- known relationships between operating speed and design speed or design elements (documented in Previous Relationships); and
- how design speed is used in designing a roadway, whether operating speed is influenced by a design element, and if the design element has a known relationship with safety (documented in Design Element Review).

The mailout survey was conducted to develop a better understanding of what definitions, policies, and values are used by practicing engineers in the design of new roadways and improvements to existing roadways. The findings from these efforts are summarized in Mailout Survey.

The second phase of the project could be grouped within five major efforts. Field studies gathered speed data and roadway/roadside design element characteristics. The Field Studies section documents the methodology and the findings from a graphical and statistical analysis of the relationship between operating speed and design elements. The field study speed data were also used as part of an analysis that examined the relationship between operating speed and posted speed limit (documented in Operating Speed and Posted Speed Relationships). The distribution of roadway and roadside characteristics were gathered for a sample of rural and urban roadways (documented in Distributions of Characteristics). These distributions, along with the findings from the field studies of which roadway variables influence operating speed, were used to develop a roadway design approach. The recommended approach is documented in Roadway Design Class Approach. The fifth major effort was to examine how design speed is currently selected. Findings from the mailout survey, along with information from the literature, provided information on current practices in the United States and other countries. The factors currently used in the *Green Book* were reviewed, and suggested changes were identified. The findings are documented in the Selection of Design Speed Values section.

SPEED DEFINITIONS

Following is a synthesis of the evolution of speed definitions and the latest information on various speed designations (e.g., running, design, operating, posted, advisory, and 85th percentile). Inadequacies and inconsistencies between the definitions and their applications are also identified.

Design-Related Definitions of Speed

Barnett's 1936 definition of design speed (*1*) was prompted by an increasing crash rate on horizontal curves. (See Table 1 for a complete listing of the "design speed" definitions discussed herein and the evolution of the term.) The main problem at that time was that the curves were designed for nonmotorized or slow-moving motorized vehicles; however, vehicle manufacturers were producing vehicles capable of faster speeds. Motorists were increasingly becoming involved in crashes along horizontal curves. Designers were typically locating roads on long tangents as much as possible and joining the tangents with the flattest curve commensurate with the topography and available funds. There was little consistency, only avoidance of sharp curves. Most designers superelevated the curves to counteract all lateral acceleration for a speed equal to the legal speed limit (35 to 45 mph [56.3 to 72.4 km/h]) but not exceeding a cross slope of 10 percent. When Barnett published his definition of design speed, he did

TABLE 1 Design speed definitions

Design Speed Definitions		
Source	**Year**	**Design Speed**
Barnett (*1*)	1936	**Assumed Design Speed** is the maximum reasonably uniform speed which would be adopted by the faster driving group of vehicle operations, once clear of urban areas.
AASHO, in Cron *(2)*	1938	**Design Speed** is the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones.
A Policy on Highway Types (Geometric). AASHO (3)	1940	The **Assumed Design Speed** of a highway is considered to be the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones. The Assumed Design Speed selected for a highway is determined by consideration of the topography of the area traversed, economic justification based on traffic volume, cost of right-of-way and other factors, traffic characteristics, and other pertinent factors such as aesthetic considerations.
A Policy on Criteria for Marking and Signing No-Passing Zones on Two and Three Lane Roads. AASHO (4)	1940	The **Design Speed** should indicate the speed at which vehicles may travel under normal conditions with a reasonable margin of safety. . . . The design speed of an existing road or section of road may be found by measuring the speed of travel when the road is not congested, plotting a curve relating speeds to numbers or percentages of vehicles, and choosing a speed from the curve which is greater than the speed used by almost all drivers.
A Policy on Design Standards. AASHO (5)	1941	**Assumed Design Speed**—The approved assumed design speed is the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones. The approved speed classifications are 30, 40, 50, 60 and 70 mph. The assumed design speed for a section of highway will be based principally upon the character of the terrain though a road of greater traffic density will justify choosing a higher design speed than one of lighter traffic in the same terrain.

(*continues on next page*)

TABLE 1 (*Continued*)

A Policy on Design Standards. AASHO (6)	1945	**Design Speed**-- Miles per hour Rural Sections: Minimum / Desirable Flat topography 60 / 70 Rolling topography 50 / 60 Mountainous topography 40 / 50 Urban sections 40 / 50
A Policy on Geometric Design of Rural Highways. AASHO (7, 8)	1954 & 1965	**Design Speed** is a speed determined for design and correlation of the physical features of a highway that influence vehicle operation. It is 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.
A Policy on Design of Urban Highways and Arterial Streets. AASHO (9)	1973	**Design Speed** is 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. **Average Highway Speed (AHS)** is the weighted average of the design speeds within a highway section, when each subsection within the section is considered to have an individual design speed, including a design speed of up to 70 mph for long tangent sections.
Leisch & Leisch (*10*)	1977	**Design Speed** is a representative potential operating speed that is determined by the design and correlation of the physical (geometric) features of a highway. It is indicative of a nearly consistent maximum or near-maximum speed that a driver could safely maintain on the highway in ideal weather and with low traffic (free-flow) conditions and serves as an index or measure of the geometric quality of the highway.
AASHTO *Green Book (11, 12, 13)*	1984, 1990, & 1994	**Design Speed** is 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. The assumed design speed should be a logical one with respect to the topography, the adjacent land use, and the functional classification of highway.
MUTCD, 1988 *(14)*	1988	**Design Speed** is the speed determined by the design and correlation of the physical features of a highway that influence vehicle operation.
Fambro et al. (*15*); *MUTCD*, 2000 *(16)*; AASHTO *Green Book*, 2001 (*17*)	1997, 2000, 2001	The **Design Speed** is a selected speed used to determine the various geometric design features of the roadway.

so with recommendations that superelevation be designed for three-quarters of the design speed and side friction factors be limited to 0.16. Barnett was aware of the potential pitfalls of his recommended policy. In fact, he stated, "The unexpected is always dangerous so that if a driver is encouraged to speed up on a few successive comparatively flat curves the danger point will be the beginning of the next sharp curve." He called for a balanced design where all features should be safe for the assumed design speed.

In 1938, the American Association of State Highway Officials (AASHO) accepted Barnett's proposed concept with a modified definition of design speed (*2*). The modified definition emphasizes uniformity of speed over a given highway segment and consideration for the majority of reasonable drivers.

Even with the modified definition of design speed, the problem of how to decide what the design speed should be for a given set of conditions remained. In 1954, AASHO (*7*) revised the definition of design speed to the version that was still present 40 years later in the 1994 publication of the *Green Book*. In conjunction with the revised definition, AASHO also provided additional information pertaining to the design speed.

- The assumed design speed should be logical for the topography, adjacent land use, and highway functional classification (paraphrased).
- "All of the pertinent features of the highway should be related to the design speed to obtain a balanced design."
- "Above-minimum design values should be used where feasible. . . ."
- "The design speed chosen should be consistent with the speed a driver is likely to expect."
- "The speed selected for design should fit the travel desires and habits of nearly all drivers. . . . The design speed chosen should be a high-percentile value . . . i.e., nearly all inclusive . . . whenever feasible."

A significant concern with the 1954 design speed concept was the language of the definition and its relationship with operational speed measures. The term "maximum safe speed" is used in the definition, and it was recognized that operating speeds and even posted speed limits can be higher than design speeds without necessarily compromising safety.

In 1997, Fambro et al. (*15*) recommended a revised definition of design speed for the *Green Book* while maintaining the five provisions noted above. The definition recommended was, "The design speed is a selected speed used to determine the various geometric design features of the roadway." The term "safe" was removed in order to avoid the perception that speeds greater than the design speed were "unsafe." The AASHTO Task Force on Geometric Design voted in November 1998 to adopt this definition and it was included in the 2001 *Green Book* (*17*).

Operational Definitions of Speed

Operational definitions of speed can take many forms. The term "operating speed" is a general term typically used to describe the actual speed of a group of vehicles over a certain section of roadway. Table 2 gives some historical and several current definitions of operating speed. The most significant finding from a review of the definitions is the trend toward one "harmonized" definition among the most common engineering documentation.

As recently as the 1990s, design manuals defined operating speed as "the highest overall speed at which a driver can travel on a given section of highway under favorable weather conditions and under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section basis." Unfortunately, this definition is of little use to practicing design and traffic engineers. Perhaps one of the greatest concerns about the operating speed definition was its assumed correlation to ". . . safe speed as determined by the design speed. . . ." While this assumption may be valid for facilities designed at very high speeds, such as freeways, it begins to deteriorate as the functional classification of the roadway approaches the local streets.

Today's profession uses several additional speed terms, such as 85th percentile speed or pace speed. Table 3 lists such speed terms and their respective definitions.

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 new roadways and improvements to existing roadways. Respondents were asked questions divided into four sections relating to definitions, policies and practices, design values, and speed values. Respondents were also asked to provide their comments on the topic and information regarding their current position and previous experience.

The survey was mailed to the members of the AASHTO Subcommittee on Design. A total of 45 completed surveys were received, representing 40 states. The respondents generally were directors or managers within a design division of a state department of transportation. The years of design experience for the respondents ranged from 3 to 40, with most having over 20 years of experience.

Appendix B contains more details on the findings from the survey. The findings from this survey were used to develop improvements or refinements to speed definitions that were considered for inclusion in key reference documents such as the *Green Book* and the *MUTCD*. Key findings include the following:

- Most states use the 1994 *Green Book* definitions; however, fewer respondents indicated that it was their preferred definition.
- Design practices and policies vary from state to state. For example, in selecting the design speed of a new road, the functional class or the legal speed limit were most commonly used.

TABLE 2 Operating speed definitions

Source	**Definitions**
HCM, 1950 (*18*)	The most significant index of traffic congestion during different traffic volumes, as far as drivers are concerned, is the overall speed (exclusive of stops) which a motorist can maintain when trying to travel at the highest safe speed. This overall speed is termed **Operating Speed**.
Matson et al., 1955 *(19)*	**Operating Speed** is the highest overall speed, exclusive of stops, at which a driver can travel on a given highway under prevailing conditions. It is the same as design speed when atmospheric conditions, road-surface conditions, etc., are ideal and when traffic volumes are low.
HCM, 1965 *(20)*	**Operating Speed** is the highest overall speed at which a driver can travel on a given highway under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section basis.
AASHO, 1973 *(9)*	**Operating Speed** is the highest overall speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions without exceeding the safe speed on a section-by-section basis used for design
Glossary of Transportation Terms, 1994 (21)	**Running Speed** is the highest safe speed at which a vehicle is normally operated on a given roadway or guideway under prevailing traffic and environmental conditions, it is also known as **Operating Speed**.
AASHTO, 1990 *(12)*, 1994 *(13)*	**Operating Speed** is the highest overall speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section basis.
Fitzpatrick et al., 1995 (*22)*	**Operating Speed** is the speed at which drivers are observed operating their vehicles. The 85^{th} percentile of the distribution of observed speed is the most frequently used descriptive statistics for the operating speed associated with a particular location or geometric feature.
TRB Special Report 254, 1998 *(23)*	**Operating Speed**—Operating speed is the speed at which drivers of free-flowing vehicles choose to drive on a section of roadway.
MUTCD, 1988 *(14)*	**Operating Speed—**A speed at which a typical vehicle or the overall traffic operates. May be defined with speed values such as average, pace, or 85^{th} percentile speeds.

TABLE 2 (*Continued*)

AASHTO *Green Book,* 2001 *(17)*	**Operating Speed** is the speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.
MUTCD 2000 *(16)*	**Operating Speed**—a speed at which a typical vehicle or the overall traffic operates. Operating speed may be defined with speed values such as the average, pace, or 85th percentile speeds.

- A majority (80 percent) responded that a senior designer review was part of the procedure for checking a preliminary design, and a little more than one-half (55 percent) stated that they use a review by the traffic operations section.

Following is a summary of the answers provided by the survey participants for each section of the mailout survey.

Section I. Definitions

The following two questions were asked for four different speed-related terms: design speed, operating speed, running speed, and advisory speed.

Which of the following definitions is the closest to your state's current definition? Which is your preferred definition?

Design Speed (45 Responses). There were 32 respondents who indicated that their state's current definition was the 1990/1994 *Green Book* definition (the two editions had the same definition) and 4 more who said that the *Green Book* definition was used in conjunction with another definition; however, only 11 respondents stated that the *Green Book* was their preferred definition. There were 17 respondents that preferred "a speed selected to establish specific minimum geometric design elements for a particular section of highway."

Operating Speed (43 Responses). As with design speed, a majority of respondents (29 of 43 responses) indicated that their state used the 1990/1994 *Green Book* definition. An alternate definition is used by 10 participants: "Operating speed is the speed at which drivers are observed operating their vehicles. The 85th percentile of the distribution of observed speeds is the most frequently used descriptive statistic for the operating speed associated with a particular location or geometric feature." This alternate definition was actually preferred by 27 respondents.

Running Speed (45 Responses). An overwhelming majority of participants (43 of 45) said that their state used the 1990/1994 *Green Book* definition, and 27 said it was their preferred definition. A simpler definition was preferred by 10 respondents: "the distance traversed divided by the time the vehicle is in motion."

Advisory Speed (43 Responses). Most participants (33) indicated one definition as their state's current definition and their preferred definition: "Advisory speed is used at certain locations on the highway system, such as horizontal curves, intersections, or steep downgrades where the safe speed on the roadway may be less than the posted speed limit. Although the sign provides a warning to approaching drivers, it is not legally enforceable."

Section II. Policies and Practices

What does your state use when selecting the design speed of a roadway?

Respondents (45 responses) were given six choices and asked to select only one. The *Green Book* was chosen by 15 participants, a state design manual was indicated by 19 participants, and a combination of the two was selected by 3 participants.

When selecting a design speed for a new road, what is the percent of use for the following factors: functional classification, legal speed limit (legislative or maximum value), legal speed limit plus 5 or 10 mph, traffic volume, anticipated operating speed, or other?

Almost all of the respondents (40 of 45) indicated that functional classification was used when selecting the design speed for a new road. Over one-fourth of the respondents stated that it was used in more than 80 percent of their selections. Legal speed limit, anticipated operating speed, and traffic volume are also frequently used when selecting the

TABLE 3 Descriptive operational speed terms

Source	**Definitions**
AASHO, 1965 *(8)*	**Average Running Speed** is the average for all traffic or component of traffic, being the summation of distances divided by the summation of running times. It is approximately equal to the average of the running speeds of all vehicles being considered. **Overall Travel Speed** is the speed over a specified section of highway, being the distance divided by overall travel time (the time of travel including stops and delays except those off the traveled way).
AASHO, 1973 *(9)*	**Average Running Speed** is the average for all traffic or a component of traffic, being the summation of distance divided by the summation of running times. It is approximately equal to the average of the running speeds of all vehicles being considered. **Overall Travel Speed** is the speed over a specified section of highway being the distance divided by overall travel time.
HCM, 1985 *(24)*, 1994 *(25)*	**Average Running Speed**—the average speed of a traffic stream computed as the length of a highway segment divided by the average running time of vehicles traversing the segment, in miles per hour. **Average Travel Speed**—the average speed of a traffic stream computed as the length of a highway segment divided by the average travel time of vehicles traversing the segment, in miles per hour.
Glossary of Transportation Terms, 1994 *(21)*	**Running Speed** is the highest safe speed at which a vehicle is normally operated on a given roadway or guideway under prevailing traffic and environmental conditions, it is also known as **Operating Speed**.
AASHTO, 1990 *(12)*, 1994 *(13)*	**Average Running Speed** is the average for all traffic or component of traffic, being the summation of distances divided by the summation of running times; it is approximately equal to the average of the running speeds of all vehicles being considered. A posted speed limit, as a matter of practicability, is not the highest speed that might be used by drivers. Instead, it usually approximates the **85th Percentile Speed** value determined by observing a sizable sample of vehicles. Such a value is within the "pace" or 15-km/h speed range used by most drivers.
Fitzpatrick et al., 1995 *(22)*	**85th Percentile Speed** is the speed below which 85 percent of motorists travel. It is frequently used to set speed limits.

TABLE 3 (*Continued*)

HCM, 1997 *(26)*	**Average Running Speed**—This is also called "space mean speed" in the literature. It is a traffic stream measurement based on the observation of vehicle travel times traversing a section of highway of known length. It is defined as the length of the segment divided by the average running time of vehicles to traverse the segment. "Running time" includes only time that vehicles spend in motion. **Average Travel Speed**—This is also a traffic stream measure based on travel time observations over a known length of highway. It is defined as the length of the segment divided by the average travel time of vehicles traversing the segment, including all stopped delay times. It is also a "space mean speed," because the use of average travel times effectively weights the average according to length of time a vehicle occupies the defined roadway segment or "space."
TRB *Special Report 254 (23)*	**10-mph Pace** X—The 10-mph pace is the 10-mph range encompassing the greatest percentage of all the measured speeds in a spot speed study. It is described by the speed value at the lower end of the range and the percentage of all vehicles that are within the range; as such, it is an alternative indicator of speed dispersion. Most engineers believe that safety is enhanced when the 10-mph pace includes a large percentage (more than 70 percent) of all the free-flowing vehicles at a location. (Note: 10 mph = 16.1 km/h). **85th Percentile Speed** —The 85th percentile speed is the speed at or below which 85 percent of the free-flowing vehicles travel. Traffic engineers have assumed that this high percentage of drivers will select a safe speed on the basis of the conditions at the site. The 85th percentile speed has traditionally been considered in an engineering study to establish a speed limit. In most cases, the difference between the 85th percentile speed and the average speed provides a good approximation of the speed sample's standard deviation. **Advisory Speed** —At certain locations on the highway system, such as horizontal curves, intersections, or steep downgrades, the sage speed on the roadway may be less than the posted speed limit. Rather than lowering the regulatory speed limits at each of these locations, traffic engineers often place standard warning signs accompanied by a square black-and-yellow advisory speed plate. Although this sign provides a warning to approaching drivers, it is not legally enforceable. **Average Speed** —The average (or mean) speed is the most common measure of central tendency. Using data from a spot speed study, the average is calculated by summing all the measured speeds and dividing by the sample size, *n*.

(*continues on next page*)

TABLE 3 (*Continued*)

MUTCD, 1998 *(14)*	**85th Percentile Speed** —The speed at or below which 85 percent of the motorized vehicles travel. **Average Speed—**The summation of the instantaneous or spot-measured speeds at a specific location of vehicles divided by the number of vehicles observed. **Pace Speed—**The highest speed within a specific range of speeds which represents more vehicles than in any other like range of speed. The ranges of speeds typically used is 10 mph.
MUTCD, 2000 *(16)*	**85th Percentile Speed**—The speed at or below which 85 percent of the motorized vehicles travel.
MUTCD, 2000 *(16)*	**Average Speed—**The summation of the instantaneous or spot-measured speeds at a specific location of vehicles divided by the number of vehicle observed. **Pace Speed—**The highest speed within a specific range of speeds that represents more vehicles than in any other like range of speed. The range of speeds typically used is 10 km/h or 10 mph.
MUTCD, 2000 *(16)*	**Average Speed**—The summation of the instantaneous or spot-measured speeds at a specific location of vehicles divided by the number of vehicles observed. **Pace Speed—**The highest speed within a specific range of speeds that represents more vehicles than in any other like range of speed. The range of speeds typically used is 10 km/h or 10 mph.

design speed of a new road. Almost one-half of those indicating legal speed limit used that factor in 50 percent of their selections, while the other half used the factor in 10 to 30 percent of their selections. Volume and anticipated operating speed were used less frequently in the selection of a new road's design speed. There were 13 responses given for the "other" factor, 8 of which mentioned terrain and/or topography; 9 of the 13 answers for these factors ranged from 20 to 40 percent.

After indicating the factors used in design, respondents were asked to explain the processes they used; their answers focused on the consideration of state law, area land use, functional classification, and state design manuals.

When selecting a design speed for a project with few changes (i.e., when alignment or cross section is changed for some of the elements), what is the percent of use for the following factors: existing design speed, design speed that would have been selected for a new road, existing posted speed limit, anticipated operating speed, existing operating speed, speed associated with the functional classification of the road, or other?

Responses to this question were highly mixed. Over one-half of the respondents (24 of 45) indicated that existing design speed, existing posted speed limit, and anticipated operating speed were used when selecting the new design speed. Twenty of the answers for existing design speed ranged from 10 to 50 percent usage. The distribution of answers for existing posted speed limit and anticipated operating speed were identical, with nine responses between 10 and 30 percent, nine responses between 40 and 60 percent, and six responses of 70 percent or greater. There were 17 responses indicating the use of the design speed that would have been selected for a new road, with 12 between 10 and 60 percent. There were also 17 responses for the speed associated with the functional classification of the road, with 15 between 10 and 60 percent. There were 12 responses given in favor of existing operating speed, ranging from 10 to 50 percent, and there were 12 responses that indicated other factors. There was no predominant "other" factor, but some of the factors mentioned included running speed, terrain, accident history, traffic volume, and *Green Book* guidelines. The respondents typically gave between 10 and 60 percent as the percent of use for those factors, although three were between 90 and 100 percent.

When selecting a design speed for a project where the roadway is changing in its functional class (e.g., when a two-lane highway is expanded to

add capacity and becomes a suburban arterial), what is the percent of use for the following factors: existing design speed, design speed that would have been selected for a new road, existing posted speed limit, anticipated operating speed, existing operating speed, speed associated with the functional classification of the road, or other?

Two-thirds of the respondents (30 of 45) indicated that they used the design speed that would have been selected for a new road. Eighteen of those respondents stated that it was used in between 20 and 60 percent of their selections, while eight indicated it was used in more than 90 percent. Speed associated with the functional classification of the road was chosen by 24 respondents; 21 answers were between 10 and 80 percent, while the remaining answers were between 90 and 100 percent. Existing posted speed limit, existing design speed, anticipated operating speed, and existing operating speed are also frequently used when selecting the design speed of a new road. Of the 45 responses for these four factors, all but five were between 10 and 60 percent. There were 10 responses given for other factors, which mentioned "all of the above," terrain, traffic volume, and accident history; answers for these factors ranged between 10 and 100 percent.

Once a preliminary design has been completed, what is the procedure for checking the design (check all that apply)?

A large number of respondents (39 of 45) said that they use a senior designer review, and more than one-half (27) used a traffic operations section review. Some (13) also used a safety section review and nearly half (22) used some other methods for checking the design. These other methods included review by the state design office or district personnel (9), review by other sections such as construction and maintenance (6), and peer review or quality assurance team review (6).

When justification is needed for a design exception (i.e., when all the elements for a roadway do not meet the selected design speed), what is the percent of use for the following factors: incremental cost, environmental, right of way, consistency with adjacent section, safety, historical preservation/societal concerns, public demands/expectations, or other?

Respondents (45 responses) indicated that they all use a wide variety of factors; all of the factors listed received at least 28 responses, and the vast majority of responses described usage of less than 30 percent for each factor. Factors listed included incremental cost, environmental, right of way, consistency with adjacent section, safety, historical preservation/societal concerns, and public demands/expectations.

When reconstructing a roadway, have you had a situation where the design speed of an existing roadway is greater than or equal to the operating speed and the citizens would like lower operating speeds on the facility?

Responses (45 responses) to this question were divided fairly evenly, with 25 answering "yes" and 20 answering "no." For those who answered "yes," 10 respondents indicated that conditions are reviewed on a case by case basis, perhaps with a speed study, and are sometimes lowered. Five responses indicated that nothing was done or that citizens were informed as to how speed limits are set and no changes would be made. Three responses referred to traffic calming, and three responses indicated that speed limit changes were under the authority of a specific entity, either local, regional, or statewide. The remaining responses generally referred to reconstruction or trial speed limits.

Effects of Geometric Elements on Speed

All of the respondents indicated that narrow lane widths cause drivers to drive slower on freeways, and most (89 percent) believe that narrow lane widths cause drivers to drive slower on local streets. When wide lane widths exist, most of the respondents believe they do not affect drivers' speeds on freeways but do affect local street speeds.

There were 29 respondents (71 percent) who indicated that shoulder width does affect speed. About two-thirds believed narrow shoulders cause drivers to drive slower on both urban and rural freeways. About one-half of the respondents believe that wide paved shoulders cause drivers to drive faster.

A large majority (more than 80 percent) believe that narrow clear zone/lateral clearance widths affect the speed that drivers select on both urban and rural roads. A smaller majority (about 60 percent) believe that wide lateral clearance/clear zone widths cause drivers to drive faster.

More than 60 percent of those responding believe that raised medians and two-way left-turn lanes (TWLTLs) affect the speed that drivers select.

Section III. Speed Values

An initial step in the design process is defining the function that a facility is to serve. The ability of the roadway to provide that function is related to the anticipated volume of traffic, the anticipated operating speed, and the geometric criteria present. For the following classes of roadways (shown as columns in Table 4), please use your engineering judgment to provide the appropriate speed (mph) for each item (shown as rows).

Table 4 lists the most common responses given for each category. Appendix B includes additional details on the findings.

TABLE 4 Speed values from mailout survey

URBAN						
Terrain	**Speed Terms**	**Two lanes**		**Multilane Arterial**		**Freeway**
		Local	**Collector**	**Undivided**	**Divided**	
Level / Rolling	Anticipated Operating Speed (mph)	30	35-45	45-55	50-60	60-70
	Anticipated Posted Speed (mph)	30	30-45	45	45-55	55
	Design Speed (mph)	30	35-50	45-50	45-60	60-70
Mountain	Anticipated Operating Speed (mph)	25-35	30-45	40-50	50	55-65
	Anticipated Posted Speed (mph)	25-30	35-40	45	45	55-60
	Design Speed (mph)	30	40	40-50	50	60-65

Section IV. Design Values

An initial step in the design process is defining the function that a facility is to serve. The ability of the roadway to provide that function is related to the anticipated volume of traffic, the anticipated operating speed, and the geometric criteria present. For the following classes of roadways (shown as columns in Table 5), please use your engineering judgment to provide the value or range of appropriate values for each item (shown as rows).

Table 5 lists the most common responses given for each category. Appendix B includes additional details on the findings.

Section V. General Comments/Concerns

Respondents were asked to provide any comments or concerns they had on this topic. The most common concerns mentioned the inconsistencies between design speed, posted speed, and operating speed. Respondents noted that there was a lack of a clear relationship between the three, and often the operating speed is higher than the design speed and/or posted speed. This issue was reported to lead to the possibility of increased liability for the engineer or the agency. Related comments indicated that standards for design speed should allow flexibility for topographic features and local/regional driving attitudes.

TABLE 4 (*Continued*)

RURAL						
Terrain	**Speed Terms**	**Two lanes**		**Multilane Highways**		**Freeway**
		Low	**High**	**Undivided**	**Divided**	
Level / Rolling	Anticipated Operating Speed (mph)	35-55	60-65	60-65	60-70	70-75
	Anticipated Posted Speed (mph)	55	55	55	65	70
	Design Speed (mph)	60	60	60	60-70	70
Mountain	Anticipated Operating Speed (mph)	30-35	30-60	50-60	50-60	60-70
	Anticipated Posted Speed (mph)	25-35	55	45-55	50-60	55-65
	Design Speed (mph)	30-40	35-60	50-60	50-60	65-70

DESIGN ELEMENT REVIEW

A goal of this research was to evaluate current procedures, especially how speed is used as a control in existing policy and guidelines. A detailed evaluation was conducted to determine how speed relates to design elements. The review determined (1) whether design speed is used to select the design element value, (2) whether there is a relationship between a design element and the operating speed, and (3) whether there is a relationship between a design element and the safety on a roadway.

For this review, the researchers established three levels at which design speed can affect a design element (or a design element component).

- Design speed can be directly related to the design element or component in that the design speed is used to select the appropriate element or component. This direct relationship assumes and consequently designs for an effect of speed.
- Design speed can be indirectly related to an element or component. Under this scenario, design speed is not used to select the design element or component, but operating

TABLE 5 Design values from mailout survey

URBAN					
Item	**Two lanes**		**Multilane Arterial**		**Freeway**
	Local	**Collector**	**Undivided**	**Divided**	
ROADWAY CROSS-SECTION ELEMENTS					
Lane Width (ft)	10-12	10-12	11-12	11-12	12
Shoulder Width (ft)	2-8	0-11	10-12	10	10-12
Clear Zone (ft)	1.5 (curb) 5-20 (no curb)	1.5 (curb) 10-30 (no curb)	1.5 (curb) 12-30 (no curb)	10-44	30
Median Width (ft)				< 30	> 30
ROADWAY ALIGNMENT ELEMENTS					
Radius (minimum) (ft)	300-400	200-1000	200-1000	262-2475	50-3000
Superelevation (ft/ft)	0.04	0.04	0.04	0.06	0.06
Maximum Grade (%)	15	8-12	5-11	5-11	3-6

speed is. Operating speed, as defined in the AASHTO *Green Book (13)*, is termed average running speed. An indirect relationship between design speed and design elements or components is defined herein as when an operating speed is used to select the appropriate design element or component and when the operating speed is based on some assumed relationship to design speed. (Note: the assumed design speed/operating speed relationship used for the selection of certain elements/components, however, is not well defined, as demonstrated in the subsequent sections.)

- Design speed may not be directly related to an element or component. Here, the element under consideration is determined from some other method than design speed.

TABLE 5 (*Continued*)

RURAL					
Item	**2 lanes**		**Multilane Highways**		**Freeway**
	Low	**High**	**Undivided**	**Divided**	
ROADWAY CROSS-SECTION ELEMENTS					
Lane Width (ft)	10-12	10-12	10-12	11-12	12
Shoulder Width (ft)	2-8	8-10	8-10	10-12	10-12
Clear Zone (ft)	10	30	30	30	30
Median Width (ft)				40-60	45-90
ROADWAY ALIGNMENT ELEMENTS					
Radius (minimum) (ft)	<1000	252-2477	1000-2000	1000-2000	1500-2000
Superelevation (ft/ft)	0.06-0.08	0.06-0.08	0.08	0.08	0.08
Maximum Grade (%)	0.5-16	0.5-16	4-6	4-6	3-6

Most of the design elements or 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. These relationships were identified from the *Green Book* and are summarized in Table 6.

Several of the design elements have been found to have a definable relationship with operating speed (see Table 7). For a design element component to be directly related to operating speed, the operational studies reviewed herein must show evidence that indeed the component under study affects operating speed. When the findings of the operational studies result in a mixed review, the relationship is classified as inconclusive. If no relationship has been determined and the design element component in question has been adequately studied, then the design component is classified as having no relationship with operating speed. 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 exist, there are ranges when the influence of the design element on speed is minimal. For example, a grade of 6 or 7 percent influences the operating speed of trucks and some passenger vehicles, while grades of 1 or 2 percent do not influence operating speeds.

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. An example is the width of shoulders. Research has shown that no distinctive relationship exists between shoulder width and operating speed (note that the clear zone component was reviewed separately). Using such a finding to encourage the use of no shoulders or minimal width shoulders on high-speed facilities could have negative safety implications. Table 8 summarizes the findings from the safety review.

The reviews demonstrated that there are known relationships between safety and design features and that the selection of design features varies based on the operating speed. Therefore, 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 should 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. In other cases the selection of a design element value should be directly related to the anticipated operating speed.

PREVIOUS RELATIONSHIPS

Several studies have investigated the relationships between the various speed elements. Some of the studies have tried to predict operating speed using roadway characteristics, while others have attempted to identify the relationship between posted speed limit and operating speed. Tables 9 and 10 summarize the roadway and roadside variables found to influence operating speed. Appendix D contains summaries of the relationships identified in the literature by functional classification. Following are key findings on the relationship between design elements and operating speed.

Two-Lane Rural Highways

- A 2000 FHWA study (*36*) collected speed data at more than 200 two-lane rural highway sites. The study developed speed prediction equations for several conditions, such as vertical curves on horizontal tangents, horizontal curves on grade, etc. The variables that influenced operating speed included radius, grade, and K-value (rate of vertical curvature). For those situations where a statistical relationship could not be established, a review of the data and engineering judgment were used to set a rounded maximum operating speed value of 62.1 mph (100 km/h).
- The analyses of 162 tangent sections on two-lane rural highways (*42*) showed that when determining 85th percentile speeds in the middle of a tangent section, it is necessary to observe a longer section—one that includes the preceding and succeeding curves—since these constitute the primary variables affecting speed. The influence of other, secondary geometric variables was investigated and was found to not impact speed as much as the primary variables.
- A 1991 article (*43*) found that for 28 horizontal curves, all of the curves with a design speed of 50 mph (80.5 km/h) or less had 85th percentile speeds that exceeded the design speed. Only on the single 60-mph (96.6-km/h) design speed curve was the observed 85th percentile speed less than the design speed.
- In a 1994 FHWA study, speed data were collected at 138 horizontal curves on 29 rural two-lane highways in five states (*33*). The data in these studies clearly showed that the radius of the horizontal curve affects operating speed.
- The NCHRP study on stopping sight distance measured operating speed on limited sight distance crest vertical curves (*15*). The data showed that as the inferred design speed increases (i.e., greater available sight distance), operating speeds are higher. The mean reductions in speed between the control and crest sections tend to increase as available sight distance is decreased; however, the reduction in speed is less than that suggested by the then-current AASHTO criteria.
- McLean (*30, 44*) found design speed/operating speed disparities on rural two-lane highways in Australia. Horizontal curves with design speeds less than 55.9 mph (90 km/h) had 85th percentile speeds that were consistently faster than the design speed, whereas curves with design speeds greater than 55.9 mph (90 km/h) had 85th percentile speeds that were consistently slower than the design speed.

TABLE 6 Geometric design review

Design Element	Design Speed Relationship with Design Element		
	Direct	Indirect	Other Method
SIGHT DISTANCE			
Stopping Sight Distance	✓		
Decision Sight Distance	✓		
Passing Sight Distance	✓	✓	
Intersection Sight Distance	✓		
HORIZONTAL ALIGNMENT			
Radius	✓		
Superelevation	✓		
VERTICAL ALIGNMENT			
Grades		✓	
Climbing Lanes		✓	
Vertical Curves	✓		
CROSS SECTION			
Cross Slope			Surface Type
Lane Width			Type of Roadway
Shoulder Width			Type of Roadway
Curb & Gutter	✓		
Clear Zone	✓		

TABLE 7 Operating speed review

Design Element	Operating Speed Relationship with Design Element		
	Direct	**Inconclusive**	**No**
SIGHT DISTANCE			
Stopping Sight Distance	yes (with limits)		
Decision Sight Distance		✓	
Passing Sight Distance		✓	
Intersection Sight Distance		✓	
HORIZONTAL ALIGNMENT			
Radius	✓		
Superelevation		✓	
VERTICAL ALIGNMENT			
Grades	✓		
Climbing Lanes	✓		
Vertical Curves		✓	

TABLE 7 (*Continued*)

CROSS SECTION			
Cross Slope		✓	
Lane Width	weak (however, *HCM* has adjustments)		
Shoulder Width			✓ (however, *HCM* has adjustments)
Curb & Gutter	✓ (per one study)		
Clear Zone/Lateral Clearance	✓		
OTHER			
Radii/Tangent Length Combination	✓ (per one study)		
Number of Lanes	✓ (Freeways, *HCM*)		
Median Type	✓		
Access Density	✓		

- Schurr et al. (*39*) developed regression equations for horizontal curves on rural two-lane highways in Nebraska that included approach grade, deflection angle, and curve length as the significant independent variables.
- Jessen et al. (*45*) collected speed data on 70 crest vertical curves in Nebraska. The posted speed of the highway was found to have the most influence on the operating speed. The inferred design speed of the vertical curves was not a significant factor.
- Dixon et al. (*41*) collected geometric and speed data at 12 rural multilane stationary county locations prior to and following speed limit increases from 55 mph (88.6 km/h) to 65 mph (104.7 km/h). The authors found that free-flow speeds increased as a result of the increase in the posted speed limit and that the number of access points and the vertical grade may influence free-flow speeds.

Low-Speed Urban Streets

- Three geometric variables helped explain the variability in speed (degree of curvature, lane width, and hazard

TABLE 8 Safety review

Design Element	Safety Relationship with Design Element		
	Direct	Inconclusive	Not Found
SIGHT DISTANCE			
Stopping Sight Distance		✓	
Decision Sight Distance			✓
Passing Sight Distance			✓
Intersection Sight Distance			✓
HORIZONTAL ALIGNMENT			
Radius	✓		
Superelevation			✓
VERTICAL ALIGNMENT			
Grades	✓		
Climbing Lanes			✓
Vertical Curves		✓	
CROSS SECTION			
Cross Slope	✓		
Lane Width	✓		
Shoulder Width	✓		
Curb & Gutter			✓
Clear Zone	✓		

TABLE 9 Variables influencing midpoint horizontal curve operating speed

Author (year) Functional Class	Influencing Roadway or Roadside Variable													R^2
	Degree of Curve	Radius	Length of Curve	Deflection Angle	Inferred Speed	Lane Width	Hazard Rating	Access Density	Speed Limit	Roadside	Grade	Median Presence	Several Variables*	
Tarigan (1954) (*27*)	X													74
Dept of Main Roads, New South Wales (1969) (*28*)		X												83
Emmerson (1969) (*29*)		X												na
McLean (1979) (*30*)		X			X									92
Glennon (1983) (*31*)	X													84
Lamm (1988) (*32*) Rural Two-Lane	X													79
Krammes et al. (1993) (*33*) Rural Two-Lane	X		X	X										82
Islam et al. (1994) (*34*)	X													98
Fitzpatrick et al. (1995) (*22*) Suburban Arterials		X												72
Poe et al. (1996) (*35*) Low-Speed Urban	X				X	X	X	X	X	X	X		X	75

(*continues on next page*)

TABLE 9 (*Continued*)

Author (year) Functional Class	Influencing Roadway or Roadside Variable													R^2
	Degree of Curve	Radius	Length of Curve	Deflection Angle	Inferred Speed	Lane Width	Hazard Rating	Access Density	Speed Limit	Roadside	Grade	Median Presence	Several Variables*	
Fitzpatrick et al. (2000) (*36*) Rural Two-Lane		X									X			53-76
Poe and Mason (2000) (*37*) Low Speed Urban	X					X	X							na
Fitzpatrick et al. (1999) (*38*) Suburban Arterial				X				X	X					75
Fitzpatrick et al. (1999) (*38*) Suburban arterial (w/o speed limit)										X		X		62
Schurr et al. (2002) (*39*) Rural Two-Lane			X	X							X			46

*Several Variables = sight distance, curbs, road surface, superelevation, land use, centerline markings, warning signs.

rating) on horizontal curves on a low-speed urban street environment (defined as below 40 mph [64.4 km/h]) in a 2000 study (*37*).

- An Arkansas study examined the relationship among urban street function (i.e., arterial versus local traffic), width, and resulting speed (*46*). For the streets having more local street characteristics (such as shorter length), the data did show a statistically significant difference between the mean speeds on wider and narrower street segments. When adjusted by eliminating vehicles that turned onto or off of the street in midsegment, the magnitudes of the differences were less than 4.3 mph

TABLE 10 Variables influencing operating speed on tangent

Author (year) Functional Class	Influencing Roadway or Roadside Variable										R^2
	Lane Width	Preceding & Succeeding Curves	Access Density	Speed Limit	Tangent Length	Region of Country	Grade	Pedestrian Activity	Median Type	On-Street Parking	
Parma (1997) (*40*) Rural Two-Lane			NF			X	X				NP
Dixon et al (1999) (*41*) Rural Multlane			O				O				NP
Polus et al. (2000) (*42*) Rural Two-Lane		X	NF		X						23-55
Fitzpatrick et al. (1999) (*38*) Suburban Arterial (w/speed limit)				X			NF				53
Fitzpatrick et al. (1999) (*38*) Suburban Arterial (w/o speed limit)	X						NF				25
Fitzpatrick et al. (Findings documented in this report) Urban/Suburban roadways			X	X				O	O	O	92

* NP = not provided.
NF = study design limited range for this variable.
X = found to be statistically significant or correlated with operating speed.
O = data indicated that the variable may affect operating speed.

(7 km/h), for the most part. The findings suggest that street width may play a small role in vehicle speed, but other factors such as trip function may be more significant determinants of the average and 85th percentile through vehicle speeds.

Suburban Arterials

- A 1995 TxDOT project found that inferred design speed (for vertical curves) and curve radius (for horizontal curves) are moderately good predictors of the 85th percentile curve speeds. The study included 10 horizontal and 10 vertical curve sites (*22*).
- A 1999 TxDOT project investigated which geometric, roadside, and traffic control device variables have an effect on driver behavior on major suburban arterials for 19 horizontal curve and 36 tangent sites (*38*). The only significant variable for tangent sections was posted speed limit. In addition to posted speed, deflection angle and access density classes influence speed on horizontal curve sections. Another series of analyses was performed without using posted speed limit. Only lane width was a significant variable for straight sections, explaining about 25 percent of the variability of the speeds. For curve sites, the impact of median presence now becomes significant, together with roadside development (*38*).

Freeways

- A case study was conducted on the effects of visibility and other environmental factors on driver speed on a 100-mi (161-km) stretch of Interstate 84 in southeast Idaho and northwest Utah (*47*). The data presented show that the drivers at the site respond to poor environmental conditions by reducing their speeds. The mean speed reduction for all vehicles was 5.0 mph (8 km/h) during the two fog events and 11.9 mph (19 km/h) during the 11 snow events.

Urban Roadways

- In a 1962 study on operating speeds within the urban environment, Rowan and Keese concluded that substantial speed reductions occurred when sight distance was less than 1,000 to 1,200 ft (305 to 366 m) and that the introduction of a curbed urban cross section and the adjacent land use (residential or commercial development) had an influence on speed reduction (*48*). Lateral restrictions (trees and shrubbery) were found to be a greater influence on speed reduction than development density.

Multiple Roadway Types

- In 1966, Oppenlander reviewed the literature to identify variables influencing spot speed (*49*). The roadway characteristics determined to be most significant included functional classification, curvature, gradient, length of grade, number of lanes, and surface type. Sight distance, lateral clearance, and frequency of intersections were also determined to have an influence.
- In 1989, Garber and Gadiraju examined speed variances on 36 roadway locations including interstates, arterials, and rural collectors (*50*). Analysis of variance tests found design speed and highway types significant, while time and traffic volumes were not significant (*50*).

FIELD STUDIES

The driver's view of a road can provide information on appropriate performance. For example, a view of a freeway with its ramps and concrete median barrier indicates that high operating speeds are expected. A freeway's purpose is clearly defined as mobility, and it tends to have high operating speeds in the range of 55 mph (88.5 km/h) and greater (with the obvious exception of congested conditions). At the other end of the spectrum is the local street, which has the purpose of providing access. Characteristics of local streets include on-street parking, residential driveways, and other features that indicate that lower operating speeds are appropriate. These facilities generally operate at speeds less than 30 or 35 mph (48.3 or 56.3 km/h). Between these extremes are collectors and arterials, which provide a mix of access and mobility. Along with the mix of access and mobility comes a mix of operating speeds. The profession is seeking to better understand what features influence speeds on a roadway. If those features could be identified, then roadways could be designed to better influence the performance of drivers.

Site Selection

The general criteria used to select study sites are summarized in Table 11. These criteria were selected to provide a degree of uniformity and minimize the effects of elements not under consideration in this study. They were developed based on the research team's knowledge, especially on experiences from collecting similar data in previous projects. In addition to the criteria listed in Table 11, a goal was to select sites from different regions of the United States. Data were collected in seven cities located in six states:

- Little Rock, Arkansas,
- St. Louis, Missouri,
- Nashville, Tennessee,
- Portland, Oregon,
- Boston, Massachusetts, and
- College Station and Houston, Texas.

To focus the site selection process, key variables were selected for emphasis in this effort. Based on the findings from previous studies *(36, 38)*, the variables selected included functional classification (arterial, collector, and local), edge treatment (i.e., curb and gutter versus shoulder), and speed limit. The data collected as part of the NCHRP 15-18 project emphasized suburban/urban data because of the amount of rural data available from previous FHWA projects (*33*, *36*).

TABLE 11 Site selection criteria

Control	Criteria
Grade	+4% to -4%
Terrain	Level to Rolling
Surface Condition	Fair to Good
Sight Distance	Adequate
Headway/Tailway	5/3 s
Distance from Adjacent Horizontal Curve	0.1 mi
Distance from Adjacent Signal or STOP Sign	0.2 mi

Data Collection

The data collection effort included obtaining both the characteristics of the site and the speed data of vehicles at the site.

Site Characteristics

The site characteristic data collected at each study site are listed in Table 12. Data focused on characteristics of the area between the upstream and downstream controls of the study site except signal density, which used the number of signals within a mile of either side of the site. Each cross-section feature was measured and recorded in the field. The presence of the following features was recorded: bike lane, on-street parking, and type of median. Also, the number of lanes and the type of edge treatment (shoulder, curb and gutter, etc.) were noted. A measuring wheel was used to obtain the width of each lane, median, and bike lane, if present.

Recording the characteristics of the roadside features for a site was more involved than collecting the data for the other site variables. Measurements were made for some of the features and then were converted into a rating scale in the office. Determination of pedestrian and roadside characteristics was based on measurements and observations made at the study sites and observations from pictures and video taken at the sites. Roadside development was recorded as being residential, commercial/industrial, park/school/campus, farm, and trees/cliff/mountain. The residential and commercial/industrial categories were expanded in the office during data analysis using the video and pictures of the sites. The residential classification was split into single-family residential and multi-family residential. Commercial/industrial was split into one of four subcategories: multistory office buildings, low-story

TABLE 12 Site characteristics data collected at each study site

Site • Area type (urban, suburban, rural) • Functional class (arterial, collector, local) • Date/time • City • Collector's name • Street • Weather	**Cross Section** • Number of lanes • Lane width (per lane) • Total pavement width • Shoulder (none, curb & gutter, flush) • Parking • Bike lane • Median type and width
Roadside • Roadside development (per direction) • Access density (per direction) • Roadside environment (per direction) • Pedestrian activity (low, medium, high)	**Traffic Control Devices** • Signals per mile (for 1 mile in each direction) • Posted speed limit
Alignment • Potential controlling feature upstream and downstream of site • Distance between potential controlling features • Distance to speed collection area from upstream controlling feature • Terrain	

office/doctor buildings, retail strip malls and high-volume restaurants, and industrial factories.

Access density, which is the number of access points per unit distance, is the number of driveways and roadways intersecting within the study site (control point to control point). The number of driveways and roadways was counted for both the study side of the roadway and the other side of the roadway. Roadside environment was determined for within 2 ft (0.6 m) and within 10 ft (3.0 m) of the roadway. One of five categories was selected for the section: clear with no fixed objects, yielding objects only, combination of yielding and isolated rigid objects, isolated rigid objects only, and many or continuous rigid objects. The pedestrian activity rating was based on the number of pedestrians observed during the study period, evidence of pedestrian activity, and the presence of a sidewalk. The pedestrian activity rating was assigned to one of three ratings: low (no pedestrians observed and no signs of pedestrian activity), medium (no or few pedestrians observed with evidence of some pedestrian activity), or high (pedestrians observed on sidewalks or evidence of high pedestrian activities).

The data associated with the characteristics of traffic control devices located near or at the site included the posted speed limit value and the number of signals per mile (the number of signals measured for 1-mi distance upstream and downstream of the collection area). Additional data obtained from photographs of the sites included the presence of centerline and edgeline pavement markings and the type of pavement (seal coat, asphalt, or concrete).

The alignment data included information on the features upstream and downstream that could affect the speed along the study section. The feature was either a traffic control device (i.e., signal or stop-control on the study roadway) or a horizontal curve with a radius ≤1,640 ft (500 m). In a few cases, the feature was a bridge or a T-intersection.

Speed Data Collection

Speeds of subject vehicles were recorded using a Kustom Pro-Laser LIDAR (Light Detection and Ranging) gun connected to a laptop computer. Only free-flowing vehicles were used as subjects; a free-flowing vehicle was defined as having a 5-s headway and a 3-s tailway. Vehicles that braked, turned, or exhibited any unusual behavior were not used. Data were only collected during dry pavement conditions during daylight hours, usually between 7:00 am and 6:00 pm. The data were only collected during the weekdays. A software program was developed within TTI to transmit the speed, time, and distance from the laser gun to a laptop computer. The transfer of data occurs at a rate of approximately three times per second.

On roadways with low volumes such as local streets, data collection with laser can require more than 4 hours to collect the desired 100 plus vehicles. Therefore, on this type of facility, sensors connected to traffic classifiers were used rather than the laser guns.

Data Reduction

The collected speed and distance data were transferred into a spreadsheet and examined for irregularities or errors. Any vehicles that had been tagged in the field for unusual behavior were removed from the file. For the sensor data, vehicles traveling closer than the minimum values for free-flow conditions (e.g., 5-s headway and 3-s tailway) were removed. In addition, the data collected after 6:00 pm and before 7:00 am were also removed.

Graphical Analyses

Plots showing the speed data by each site characteristic can provide a visual appreciation of which variables may have an impact on speed. Table 13 shows several of the plots generated, along with observations on the relationship shown in the plot between the roadway variable and 85th percentile speed for suburban/urban sites. The strongest relationship can be seen in the posted speed versus 85th percentile speed plot (see plot 13.1 in Table 13). The statistical analysis (see following section) clearly demonstrates that there is a strong relationship between the posted speed and the operating speed. This relationship is expected. The 85th percentile operating speed is a factor in selecting a posted speed, generally being used as a starting point from which the speed limit is selected for a roadway (see Appendix H). The posted speed is also related to the roadway environment. For example, posted speed limits of 55 mph (88.5 km/h) are not used on local streets, and posted speed limits of 35 mph (56.3 km/h) are not seen on freeways. Therefore, posted speed limit can be a surrogate for several factors associated with the roadway.

Another potentially strong relationship is shown in the access density versus 85th percentile speed plot (see plot 13.3 within Table 13). Previous studies (*35, 46, 49, 51*) have demonstrated that access density or levels of access density are associated with different speeds or speed ranges. The plot also demonstrates that higher access densities are associated with lower speeds.

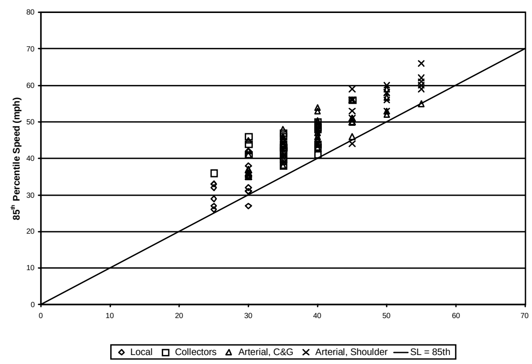
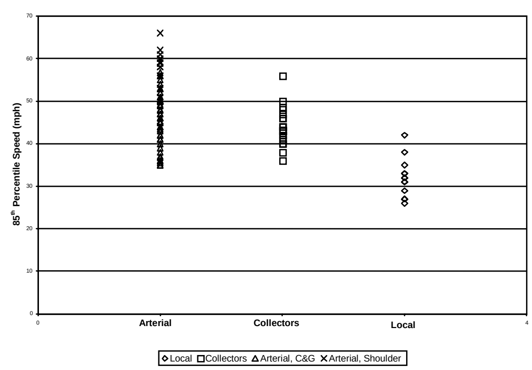
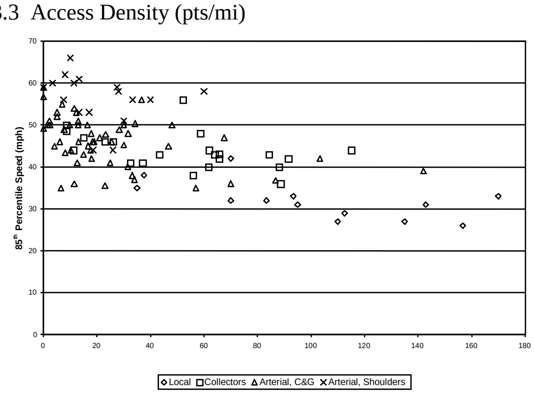
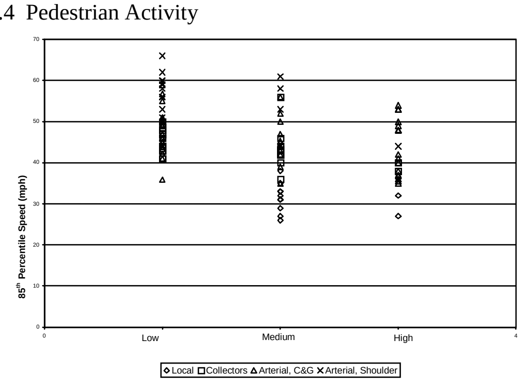
Statistical Analysis

Analysis for All Functional Classes and Speed Ranges

Assuming a linear relationship, Table 14 shows the results of the analysis that examined different percentiles. All five models—Q_{95} (95th percentile free-flow operating speed), Q_{90}, Q_{85}, Q_{50}, and Q_{15}—have very high R^2 (coefficient of determination) values, indicating that are highly correlated with the posted speed limit. In terms of the overall model goodness of fit (based on R_0^2 and R^2 values), the Q_{50} model is arguably the best model among the five.

(text continues on page 35)

TABLE 13 Plots of roadway variable versus 85th percentile speed

Comment	**Plot**
The strongest relationship to 85th percentile speed is with the posted speed limit. As posted speed increases the 85th percentile speed increases.	13.1 Posted Speed Limit (mph) 
The relationship between functional classes and roadway design class shows an expected plot. Roads with a functional class of local have the lowest speeds of the sites collected while the arterials had the highest speeds collected.	13.2 Functional Class 
Access density is the number of access points (driveways and intersections) per mile. It was measured between the features that could control the speeds along the section (e.g., signal, etc.). Access density also showed a strong relationship with 85th percentile speed with higher speeds being associated with lower access densities.	13.3 Access Density (pts/mi) 
Lower speeds occur as the level of pedestrian activity increases.	13.4 Pedestrian Activity 

(*continues on next page*)

TABLE 13 (*Continued*)

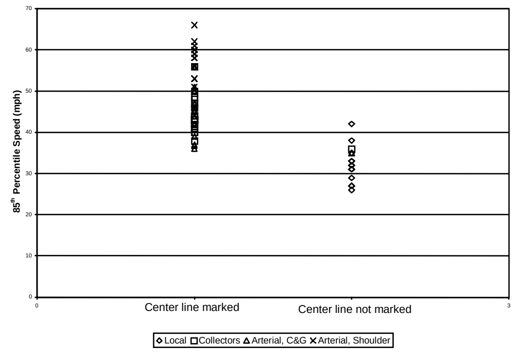
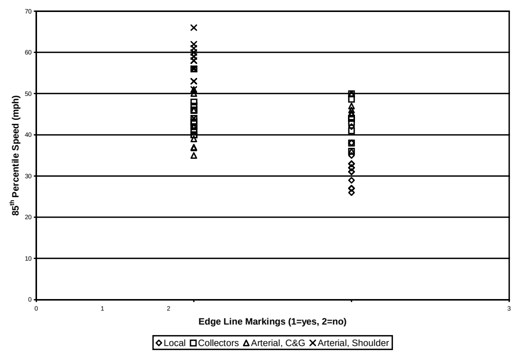
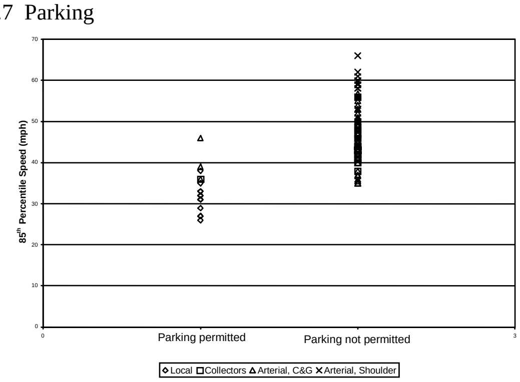
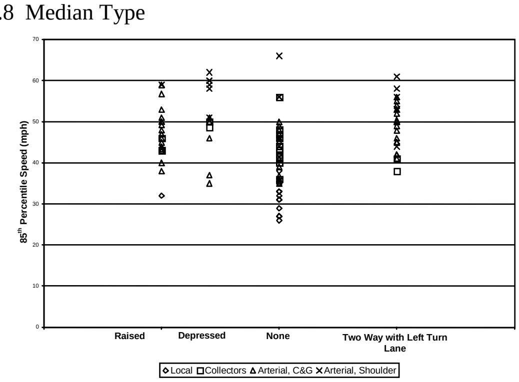
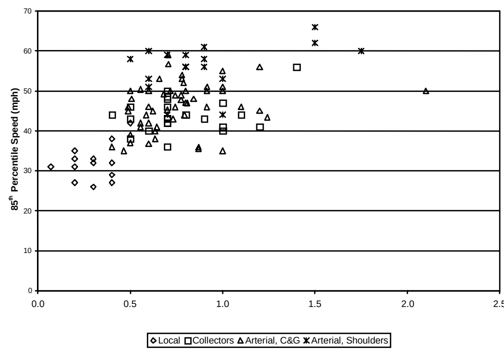
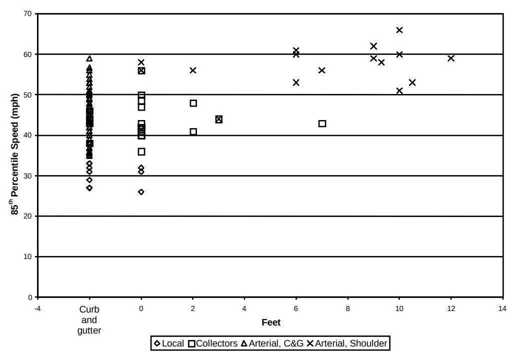
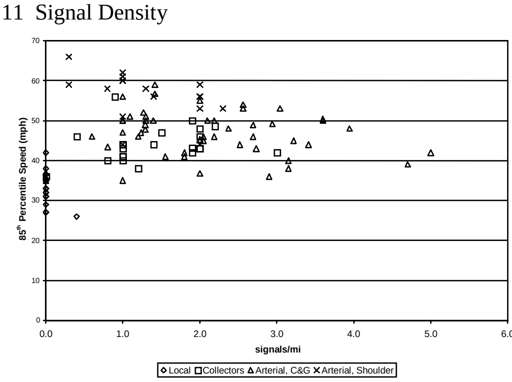
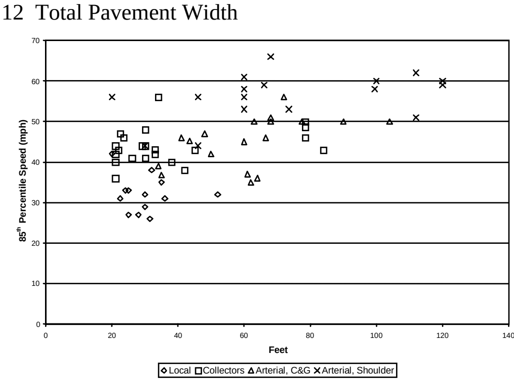
Comment	**Plot**
The absence of either centerline markings or edgeline markings is associated with lower speeds.	13.5 Center Line Markings 
	13.6 Edge Line Markings 
When on-street parking is permitted, speeds are lower.	13.7 Parking 
When no median is present, speeds are slightly lower than when a raised, depressed, or TWLTL is present with a few exceptions.	13.8 Median Type 

TABLE 13 (*Continued*)

Comment	**Plot**
As the distances between features that have influence on a driver's speed, such as a signal or sharp horizontal curve, increase, speeds increase.	13.9 Distance between Controls 
Speeds on roadways with shoulders that had widths equal to or greater than 6 ft had speeds above 50 mph (with one exception). Speeds on roadways with shoulders between 0 and 4 ft also had speeds up to 50 mph with most being less than the speeds observed 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). There is no evidence that the presence of curb and gutter results in lower speeds for a facility.	13.10 Shoulder Width 
Higher signal densities are associated with lower speeds.	13.11 Signal Density 
Fewer lower speeds are associated with larger total pavement widths.	13.12 Total Pavement Width 

(*continues on next page*)

TABLE 13 (*Continued*)

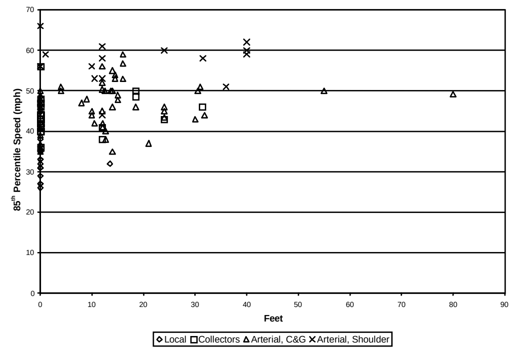
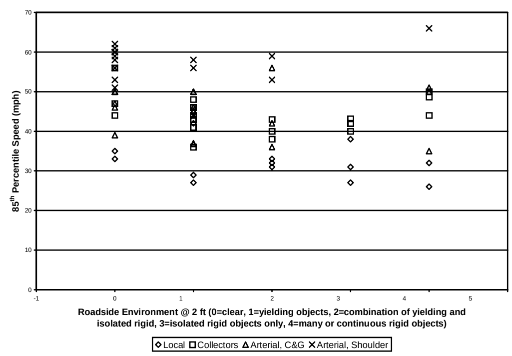
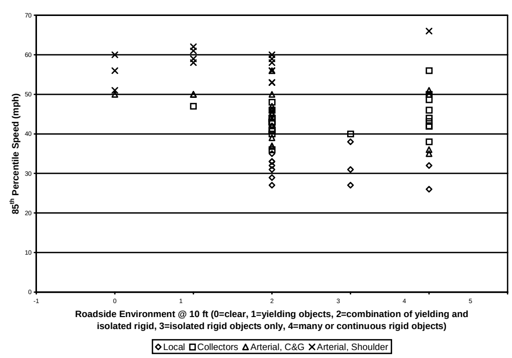
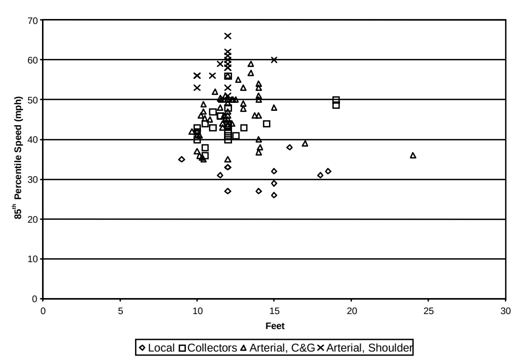
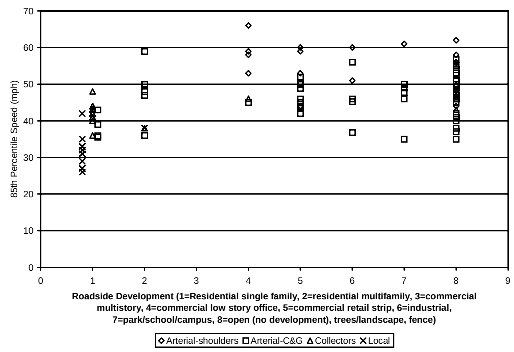
<table>
<tr><th>Comment</th><th>Plot</th></tr>
<tr><td>Fewer lower speeds are associated with the higher median widths.</td><td>13.13 Median Width

</td></tr>
<tr><td>A wide range of speeds were recorded for each roadside environment class.</td><td>13.14 Roadside Environment @ 2 ft

</td></tr>
<tr><td></td><td>13.14 Roadside Environment @ 10 ft

</td></tr>
<tr><td>This plot shows no relationship between lane width and speed.</td><td>13.15 Lane Width

</td></tr>
</table>

TABLE 13 (*Continued*)

Comment	Plot
Speeds on streets with single-family residential development tended to have lower speeds; however, some sites with residential development had speeds near 50 mph. A sizeable range of speeds occurred within each development type.	13.17 Roadside Development 
1 mph = 1.61 km/h, 1 ft = 0.30 m, 1 mi = 1.61 km	

To give an example of what these regression coefficient values mean, we describe the model for Q_{85} as follows: the model for the Q_{85} implies that the expected value of Q_{85} given the posted speed limit has the following linear relationship: $E[Q_{85}] = 7.675 + 0.98 \times$ Posted Speed Limit. That is, given an estimated slope of $\beta_1 = 0.98$ (which is very close to 1), it suggests that as the posted speed limit increases, the 85th percentile speed is expected to increase by approximately the same amount. In addition, for a given posted speed limit, the 85th percentile speed is expected to be about 7.675 mph higher than the posted speed limit. Note that if the posted speed limit is indeed set based on the 85th percentile operating speed and the distribution of operating speeds is not affected by the setting (or resetting) of the posted speed limit, then we could expect the Q_{85} model to have estimated β_o and β_1 of approximately 0 and 1, respectively.

Table 15 provides the models developed to predict 85th percentile operating speed. Except for posted speed limit, no other

TABLE 14 The Qth percentile free-flow operating speeds as a linear function of posted speed limits

Covariate & Statistics	Estimated Model Parameters (t-statistic)				
	Y = Q_{15}	**Y = Q_{50}**	**Y = Q_{85}**	**Y = Q_{90}**	**Y = Q_{95}**
Intercept, $ß_o$	-1.021 (-0.16)	3.336 (0.66)	7.675 (1.32)	8.761 (1.41)	10.196 (1.37)
Posted Speed Limit, $ß_1$	0.952 (6.47)	0.966 (8.13)	0.980 (7.18)	0.982 (6.68)	0.993 (5.65)
Adjusted R^2	0.890	0.911	0.901	0.895	0.879
R_o^2	0.983	0.914	0.904	0.899	0.886

TABLE 15 Free-flow 85th percentile operating speed as a linear function of posted speed limits and other variables

Model #	Estimated Model Parameters (t-statistic)			
	Intercept	Posted Speed Limit (mph)	Access Density per Mile (for PSL≤45 mph)	R_o^2
1	7.675 (1.32)	0.980 (7.18)		0.904
2	16.089 (2.03)	0.831 (5.26)	-0.054 (-1.31)	0.923

roadway variables were statistically significant at a 5 percent alpha level. The only variable that had a t-statistic greater than 1 was access density, which had a t-value of ±1.31, corresponding to approximately a 20 percent alpha level. Figure 1 shows a scatter plot of the relationship, with the sizes of the ovals representing the standard deviation for the site. Figure 2 provides a graphic illustration of the regression equations.

Analysis by Roadway Functional Class

The 78 sites were divided into four functional classes: suburban/urban (S/U) arterial, S/U collector, S/U local, and rural arterial. The number of sites available in each of the four functional classes for analysis is 35, 21, 13, and 9, respectively. Table 16 presents modeling results from linear regressions. Figure 3 provides a graphical illustration of the regression equations.

The posted speed limit continues to exhibit a strong statistical relationship with the 85th percentile speed for the S/U arterial and rural arterial classes. For S/U arterial, the estimated slope parameter of 0.963 suggests that a 1-mph (1.6-km/h) increase in the posted speed limit is likely to be associated with about a 1-mph (1.6-km/h) increase in the expected 85th percentile operating speed. On the other hand, the estimated slope parameter in the rural arterial model drops significantly to 0.517, indicating that a 1-mph (1.6-km/h) increase in the posted speed limit for rural arterial is likely to be associated with a 2-mph (3.2-km/h) increase in the expected 85th percentile operating speed. Note, however, given the small sample size for the rural arterial ($n = 9$), this interpretation should be used with caution.

Based on the model goodness of fit, the division by functional class results in a relatively weak statistical relationship between the posted speed and operating speed for S/U collector and S/U local roads. The weak relationships are due mainly to the narrow posted speed limit range within each functional class and smaller sample size.

To explore whether any of the roadway variables could help to improve the models in Table 15, a stepwise forward selection regression procedure was used. No other roadway variable was statistically significant (even at a 20 percent alpha level) in terms of providing additional explaining power on the variation of the 85th percentile speed. The only models that come close to meeting the 30 percent alpha level are presented in Table 17. Both models are for the S/U collector. One includes the access density as an additional explanatory variable, and the other includes the median type. The coefficient of the access density in the first model seems to be quite consistent with that obtained in the model presented in Table 15, where calibration was performed with the combined data set. The coefficient for the type of median is not as logical. One could expect that the speeds would be lower on a roadway where vehicles turning left are stopping in the travel lane and that the speeds could increase once a TWLTL is provided to store these vehicles. For the data set available, only two sites had a TWLTL, which may be insufficient to accurately capture the speed relationship between roads with or without left-turn treatments.

Analysis for Sites with a 30-mph (48.3-km/h) Posted Speed Limit

As can be seen from Figure 4, sites with a 30-mph (48.3-km/h) posted speed limit experienced relatively more variation in the 85th percentile operating speed as compared with the range present at other posted speed groups. It would be interesting to know if any of the roadway variables could explain this variation in a statistically significant way. No variable was found to pass the 20 percent alpha level. Only one variable comes close to the 30 percent alpha level: vehi-

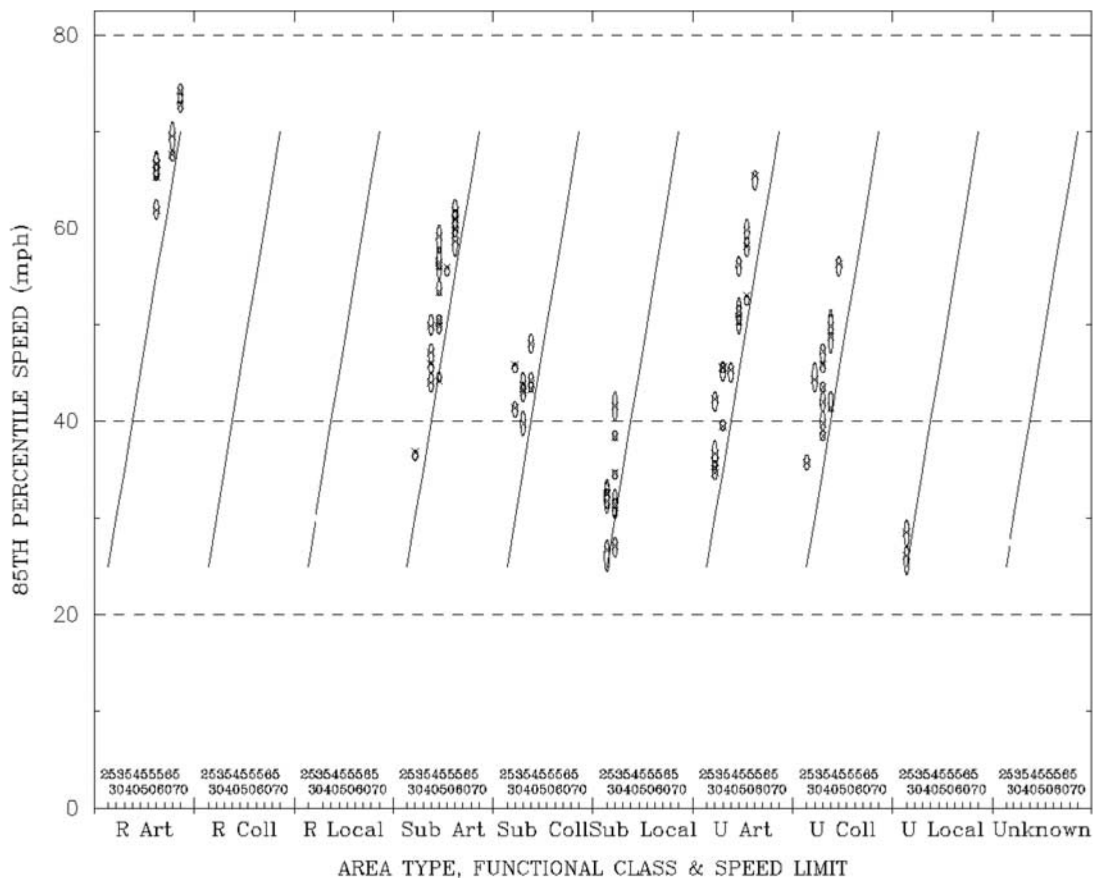


Figure 1. Scatter plot of the 85th percentile operating speed by area type, roadway class, and posted speed limit.

cle parking along the street. Table 18 shows this model. It seems to suggest that among the 30-mph (48.3-km/h) sites, those with vehicles parking along the street tend to have a lower 85th percentile operating speed by about 7.5 mph (12.1 km/h) when compared with other sites that do not have vehicles parking on the side. Again, because of the low t-value, this interpretation should be used with caution.

Cluster Analysis

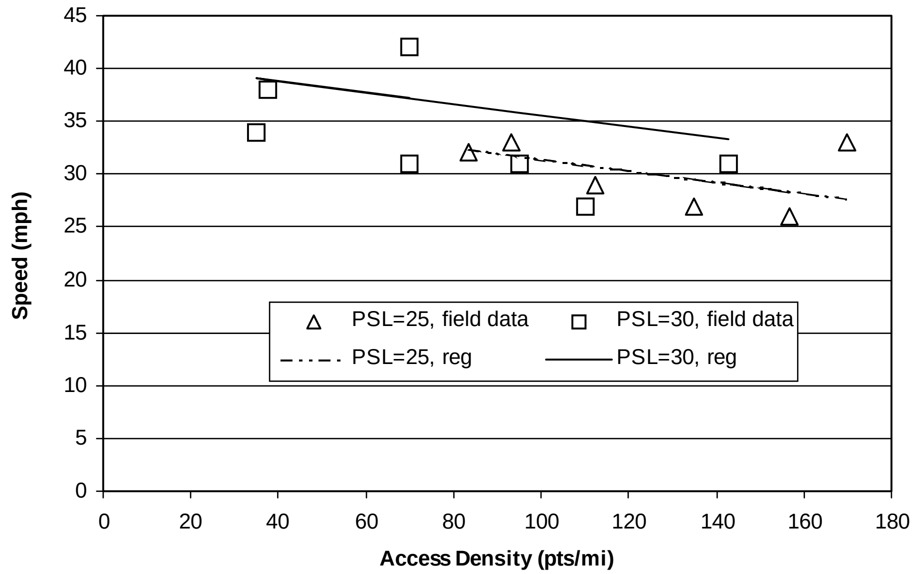
Given that we were unable to establish good statistical relationships for all considered roadway variables with the current sample size (except for the posted speed limit), a cluster analysis was performed to see if the project team could gain additional insights over educated inspection and judgment by classifying roadways quantitatively according to “similarities” of their attributes and perceived influences of these attributes on operating speeds. Cluster analysis is known to offer several advantages over a manual grouping process. For example, it usually provides a more objective and consistent way of grouping objects, particularly for objects with more than three features or dimensions. Appendix E, Field Studies, contains details on the cluster analysis. The analysis resulted in a seven-cluster model. The following were the noteworthy features found within the analysis: pedestrian activity, parking, use of centerline markings, median treatment, roadside development, area type, and signal density.

SELECTION OF DESIGN SPEED VALUE

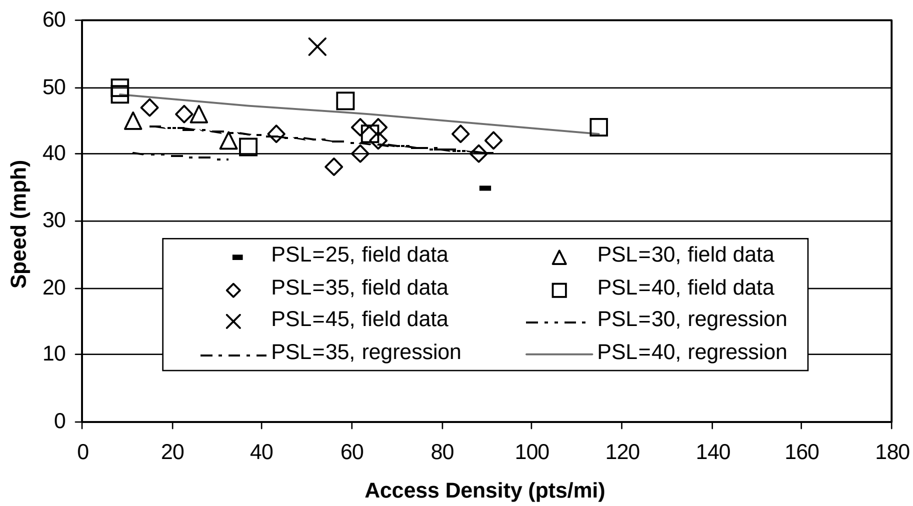
Simplified, the process of designing a roadway begins with selecting a speed called the design speed. Then, using this selected design speed in conjunction with a series of tables and figures, the appropriate design criteria are chosen for the roadway features. For example, once a value for design speed has been chosen, it is used to determine the allowable horizontal curve radii, whether curb and gutter should be used, and other roadway elements. The elements are then assembled to develop the roadway cross section and the design plans used in construction.

Selecting a Design Speed Value

Methods used to select a design speed value were identified from the AASHTO guidelines, from state agencies’ manuals, from a mailout survey, and from the literature for international practices. These reviews demonstrate that substantial variations exist in how design speeds are selected.



(a) Local



(b) Collectors

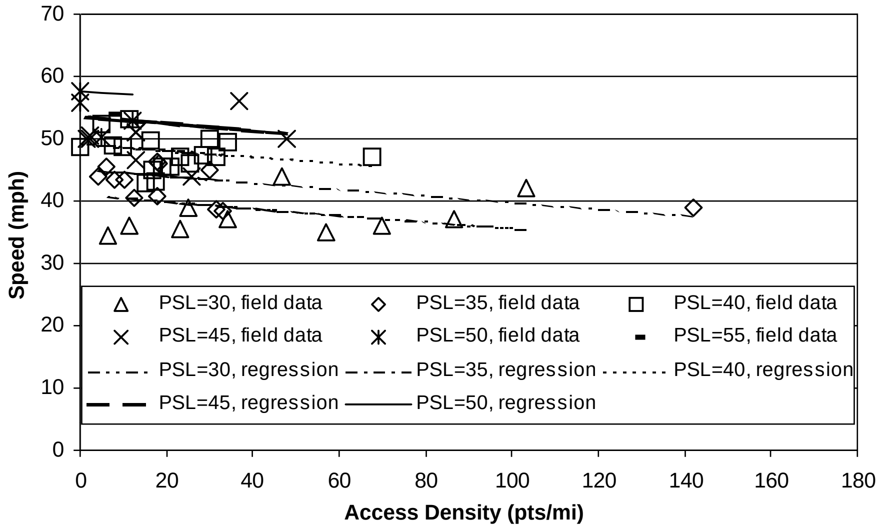
Figure 2. Plots of regression equations using posted speed limit and access density.

AASHTO Guidelines

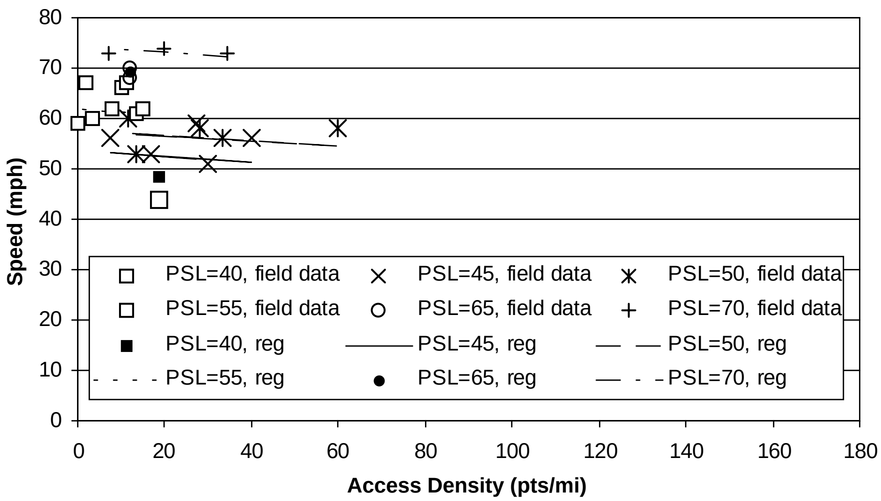
In the 1930s, U.S. Bureau of Public Roads engineers recommended that the design speed of a future highway should be the speed that only 5 percent or possibly 2 percent of the drivers will exceed after the road is built. In other words, the Bureau engineers were recommending design speed values equivalent to the anticipated 95th or 98th percentile operating speeds. Quantitative guidelines for design speed based on functional classification, rural versus urban, and terrain type (level, rolling, and mountainous) can be found in Chapters 5, 6, 7, and 8 of the 2001 *Green Book* (*17*). For example, AASHTO provides quantitative guidance for recommended design speeds for rural arterials by terrain type on page 448 in the 2001 *Green Book*. AASHTO also discusses other factors—such as operating speed, adjacent lane use, and safety—but provides little, if any, quantitative guidance related to how such factors should be considered or impact the selection process of a design speed value.

United States Practices

The results of the mailout survey conducted as part of the NCHRP 15-18 research project provide interesting insight into how the design speed value is selected. For instance, while most agencies use either the AASHTO *Green Book* or their state design manual in considering the traditional factors—such as functional classification and terrain, to name a few—some agencies also consider legislatively mandated



(c) Arterial, Curb and Gutter



(d) Arterial, Shoulder

Figure 2. (Continued)

maximum posted speed limits. To be more precise, some agencies select design speed values within 0 to 10 mph (0 to 16.1 km/h) above the legislatively mandated maximum posted speed limit for the functional classification under consideration. Furthermore, many agencies indicated that they consider anticipated operating speed as a key variable when determining an appropriate value for design speed. Still others combine these two approaches and select a design speed value 5 to 10 mph (8.1 to 16.1 km/h) above the anticipated operating speed.

The respondents were provided a list of factors that could be used when selecting a design speed for a new road (including an "other" choice) and were asked to indicate the percent of usage for each factor. The survey showed that many approaches are being used to select a design speed value within the United States. Table 19 lists the number of states that considered an approach when designing a new roadway in an urban environment. More than one-half of the states that responded indicated that they have used either legal posted speed limit or speed limit plus 5 or 10 mph (8.1 or 16.1 km/h) when selecting a design speed. More than one-third of the states have considered traffic volume or anticipated operating speed, and only 18 percent listed terrain as a factor considered when selecting the design speed for a new road. The survey results imply that the design speed for a facility in one state may have a different value than the design speed that would be selected for a similar roadway in another state.

As part of the question, the respondents were asked to indicate the percent of use for an approach. The respondent from Hawaii indicated that functional classification is used 100 percent, while Oklahoma split its response between functional classification (25 percent) and anticipated operating speed (75 percent). The factor used 100 percent of the time for most of the respondents was "functional classification."

TABLE 16 The 85th percentile free-flow operating speed as a linear function of posted speed limits by functional class

Covariate and Statistics	Estimated Model Parameters (t-statistic)			
	S/U Arterial	S/U Collector	S/U Local	Rural Arterial
Intercept	8.666 (0.92)	21.131 (1.05)	10.315 (0.19)	36.453 (3.41)
Posted Speed Limit	0.963 (4.50)	0.639 (1.14)	0.776 (0.41)	0.517 (3.02)
R_o^2	0.86	0.41	0.14	0.81
Sample Size (n)	35	21	13	9

S/U = suburban/urban.

The percent-of-use answers were used to weight the number of responses. The order of the factors most used, from highest to lowest, was as follows:

- functional classification,
- legal speed limit (legislative or maximum value),
- legal speed limit plus 5 or 10 mph (8.1 to 16.1 km/h),
- traffic volume, and
- anticipated operating speed.

Other factors occasionally considered when selecting the design speed for a new road include terrain, development, costs, and consistency within a corridor.

International Practices

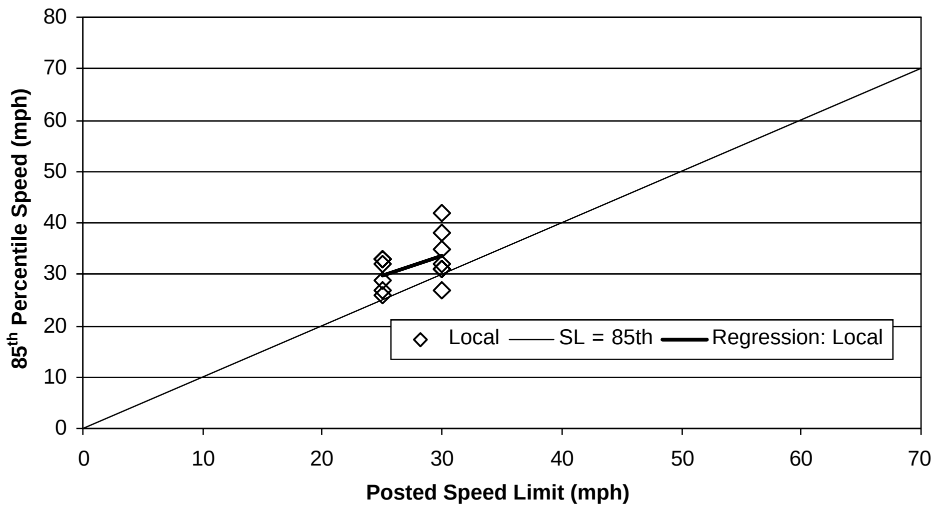
Krammes et al. (*33*) reviewed the design practices in seven countries (Australia, Canada, France, Germany, Great Britain, and Switzerland) to determine their procedures for selecting and applying a selected design speed value. At one time, most of the countries' policies on design speed were identical to current U.S. policy. Procedures for selecting a design speed are still similar to U.S. practice (i.e., based on the class of the roadway, rural versus urban, and terrain). However, during the last 20 years several countries have refined their procedures for applying design speed.

Australia, France, Great Britain, Germany, and Switzerland give more formal and explicit consideration of operating speeds than does AASHTO policy. Although the details vary, these countries include feedback loops in the alignment design procedures to identify and resolve operating speed inconsistencies. In all countries reviewed, design speed is used to determine minimum horizontal curve radii for the preliminary alignment design. In most countries, however, superelevation rates and sight distances are based on the estimated 85th percentile speed when it exceeds the design speed.

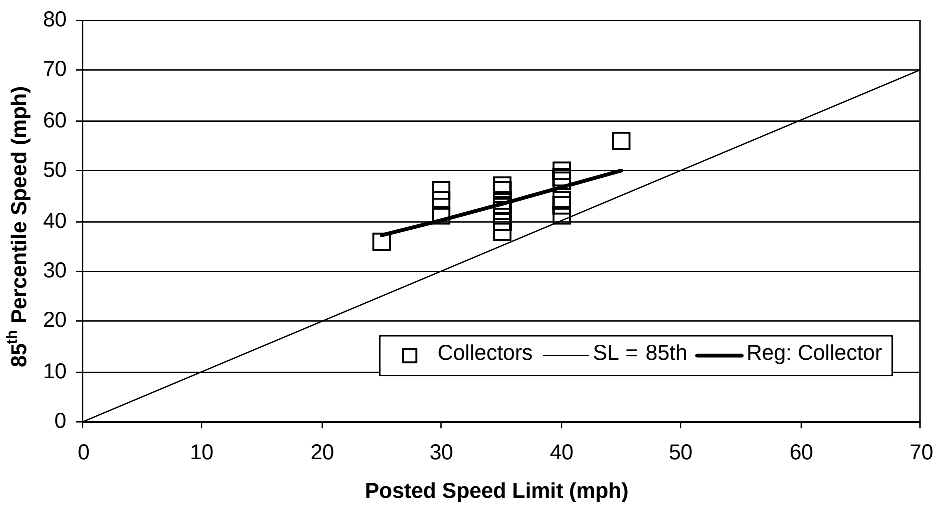
In addition, several countries provide quantitative guidelines on the radii of successive horizontal alignment features. France and Germany specify the minimum radius following long tangents. Germany also has a comprehensive guideline indicating acceptable and unacceptable ranges for the radii of successive curves.

Which Factors Make a Difference?

Table 20 lists the factors that are used to select design speed from the three methods reviewed in this project: AASHTO policy, state DOT practices, and international practices. If one believes that the design of the roadway (as represented by the design speed of the road) affects the operating speed of a facility (as represented by the 85th percentile speed), then the use of different design speeds should result in different operating speeds. Because functional class, rural versus urban, and terrain affect the design speed selected, then different operating speeds should be associated with differences in these factors. If



(a) Local



(b) Collector

Figure 3. Plots of regression equations using posted speed limit. (continued on next page)

differences in these factors are not associated with differences in operating speed, then one should question whether they should play a role in selecting the design speed of the highway.

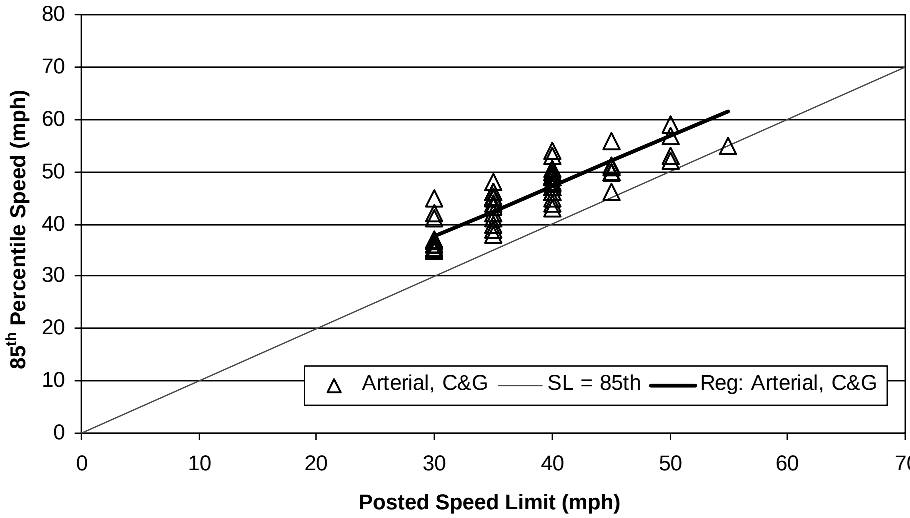
Of course, the use of the three factors (functional class, rural versus urban, and terrain) to select design speed may be justified based on reasons other than anticipated operating speed. The anticipated posted speed for the facility or the expected traffic volumes may need to be considered. Also, the use of lower design speeds on mountainous terrain may be justified by cost considerations and by driver expectancies.

Functional Classification/Urban versus Rural

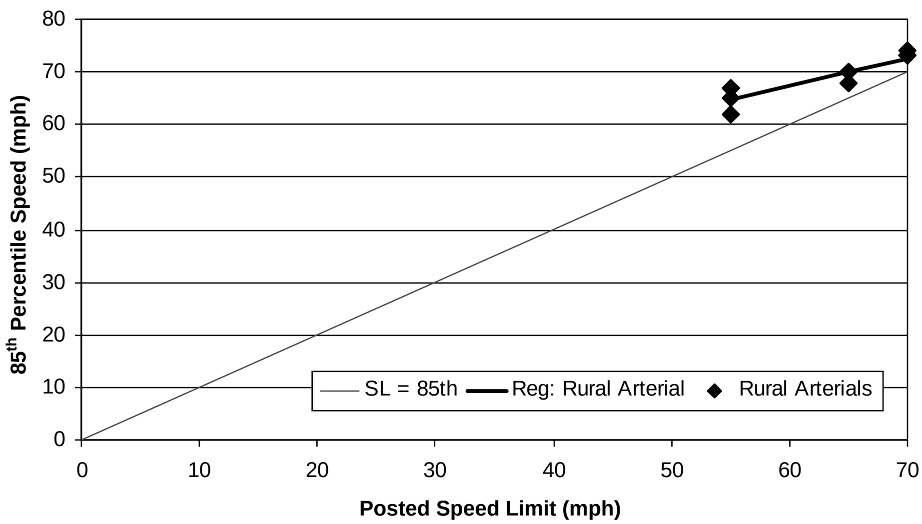
Figure 5 shows the cumulative speed distribution for urban/suburban arterials, collectors, and local streets. Most of the data were collected during the summer of 2000, with 35 of the 69 arterial sites collected in Texas during 1998 and 1999. At each site, spot speeds were collected on a tangent section of the roadway away from potential influences such as signals or horizontal curves. The remaining sites were in Boston, Little Rock, Nashville, Portland, St Louis, and the following Texas cities: Bryan, Corpus Christi, College Station, Houston, San Antonio, and Waco. Vehicles not at free-flow speed (defined as having less than a 5-s headway between vehicles) were removed from the data sets. Table 21 lists the speed values for the percentages previously suggested as the threshold that could be used for selecting a design speed. As expected, there are noticeable differences in operating speeds for local, collector, and arterial streets.

Terrain

While the authors did not have speed data by terrain type for freeways available, they did have access to data for rural



(c) Arterial, Curb and Gutter



(d) Rural Arterial

Figure 3. (Continued)

two-lane highways. Spot speed data were collected at 146 rural two-lane highway tangent sites (posted speed of 55 mph [88.6 km/h]) for a recent FHWA project (*36*). Table 22 lists the speed values for the percentages previously suggested as the threshold that could be used for selecting a design speed. Surprisingly, the curves for each terrain type are similar, demonstrating that little variation exists between the speeds measured on the 146 rural two-lane highways classified as level, rolling, and mountainous terrain. Generally, only a 1-mph (1.6-km/h) difference exists between the different terrain types.

AASHTO indicates that as much as a 20-mph (32.2-km/h) design speed difference is permissible between terrain types (see page 494 of 1994 *Green Book* [*13*]). An interpretation of the data provided in Table 22 is that drivers on rural two-lane highways prefer to travel near a 60- to 65-mph (96.6- to 104.7-km/h) operating speed; however, they can encounter a curve designed for as low as 40 mph (64.4 km/h) in a mountainous terrain. This observation does not speak well for providing a design that results in speed consistency along a highway. Speed data at the sites showed that even on small-radii curves (such as curves with less than an 820-ft [250-m] radius), 85th percentile speeds are still in the 52 to 53 mph (83.7 to 85.3 km/h) range.

Limitations of the data set should be mentioned. The data set excluded trucks, which are widely recognized as being influenced by terrain. The speed within a several mile length of roadway section with numerous horizontal and vertical curves could be significantly lower than the speed measured on a tangent section or at a single point. A better representative speed for a mountainous section would be running speed rather than spot speed. A speed that is 20 mph (32.2 km/h) lower than that measured at a tangent within the section,

TABLE 17 The 85th percentile free-flow operating speeds as a linear function of posted speed limits and other variables for suburban/urban collectors

Covariate & Statistics	Estimated Model Parameters (t-statistic)	
	Suburban/Urban Collector	Suburban/Urban Collector
Intercept	14.715 (1.67)	22.489 (1.47)
Posted Speed Limit	0.400 (1.59)	0.674 (1.66)
Access Density per Mile (for PSL ≤45 mph)	-0.059 (1.05)	
Median Type = Two Way Left Turn Lane		-7.860 (-1.10)
Median Type = No Median		-2.593 (-0.56)
R_o^2	0.586	0.583
Sample Size (n)	22	22

however, would not be expected. Therefore, the analysis indicates that the use of terrain to select an appropriate design speed that would result in a design that promotes speed consistency should be investigated. If predictable operating speeds along a two-lane rural highway are desired, the data indicate that the type of terrain would not be a valued variable in terms of predicting speed variability.

Potential Solutions

Potential solutions to the concerns discussed previously include limiting the range of design speed values available within each functional class, rural versus urban, or terrain type; using anticipated posted or operating speed (or using anticipated posted or operating speed plus a preset incremental increase); incorporating a feedback loop that would check the predicted speed along an alignment; or managing speeds on the tangent section by controlling the tangent length. Following is a brief overview of the two potential solutions that hold the most promise.

Consideration of Anticipated Posted or Operating Speed

Several states use the anticipated posted, anticipated operating, or the anticipated posted or operating speed plus 5 or

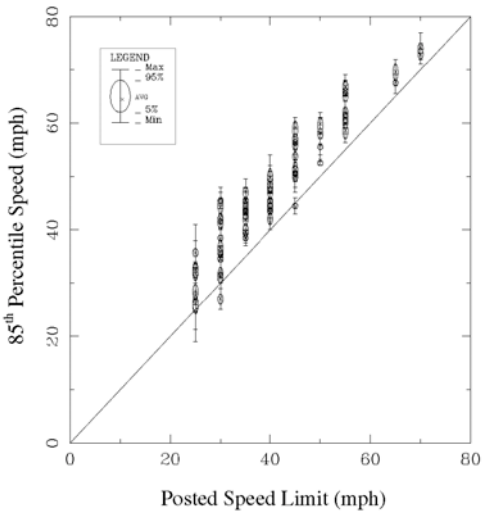


Figure 4. Relationship between the 85th percentile operating speed and posted speed limit (with sampling variations).

10 mph (8.1 or 16.1 km/h). A resulting benefit of this approach is that it ensures that the posted speed will not exceed the design speed—a liability concern expressed previously. A potential for discontinuity exists between states that have limited their freeway speeds to 55 mph (88.6 km/h) and those with 65- or 70-mph (104.7- or 112.7-km/h) speed limits. If all states adopt the procedure to set design speed at anticipated posted speed plus 5 mph (8.1 km/h), then state A with a legislatively mandated speed of 55 mph (88.6 km/h) would have a design speed of 60 mph (96.6 km/h) while state B with a legislatively mandated maximum speed of 70 mph (112.7 km/h) would have a design speed of 75 mph (120.8 km/h). In other words, there could be a 15-mph (24.2-km/h) difference in design speeds between neighboring states for a similar functional class road (e.g., freeways).

A challenge with this approach is the selection of the increment above the anticipated posted or operating speed. This increment can represent a “safety factor” for drivers or a “cushion” between the current anticipated posted speed and a higher, perhaps legislatively allowed, future posted speed. As a safety factor, is setting sight distances for 5 or 10 mph (8.1 or 16.1 km/h) greater than the posted or operating speed sufficient? As a cushion, is 5 or 10 mph (8.1 or 16.1 km/h) sufficient to anticipate future changes in posted speeds? A review of recent changes in speed limit laws showed that the 5 or 10 mph (8.1 or 16.1 km/h) currently used by some states would not be adequate for rural areas. In Texas, four legislative actions have changed the rural speeds limits from 55 to 75 mph (88.6 to 120.8 km/h) for certain areas. Therefore, debate is needed on what should be considered as an acceptable cushion for potential speed increases.

Feedback Loop with a Speed Prediction Model

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 predicted speed with the design speed. Krammes et al. (*33*) notes that several countries (Australia, England, France, Germany, and Switzerland) give more formal and explicit consideration to operating speeds than AASHTO policy does. The basic approach was provided as follows:

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

TABLE 18 A model of the 85th percentile free-flow operating speeds for sites with a 30-mph posted speed limit

Model Type	Estimated Model Parameters (t-statistic)		R_o^2	Sample Size
	Intercept	Parking Along Street = Yes		
Model for 30 mph sites	40.401 (7.74)	-7.565 (-0.99)	0.50	15

TABLE 19 Approaches used by states

Approach	Number of States (maximum of 40)	%
Functional Classification	36	90
Either Legal Speed Limit or Limit + Value	23	58
Legal Speed Limit	17	43
Legal Speed Limit plus 5 or 10 mph	11	28
Traffic Volume	15	38
Anticipated Operating Speed	15	38
Terrain	7	18

TABLE 20 Factors used to select design speed

AASHTO Policy	State DOT Survey	International Practices
Functional classification Rural versus urban Terrain type	Functional classification Legal speed limit Legal speed limit plus a value (e.g., 5 or 10 mph [8.1 to 16.1 km/h]) Anticipated volume Anticipated operating speed Terrain type Development Costs Consistency	Anticipated operating speed Feedback loop

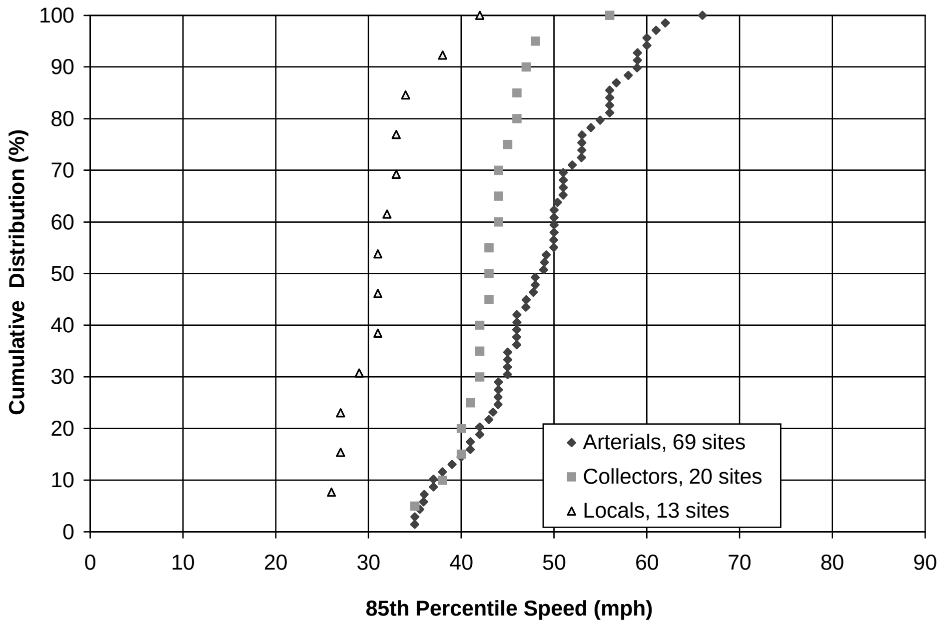


Figure 5. Distribution of 85th percentile speeds on tangent sections of urban and suburban roadways by functional class.

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.

OPERATING SPEED AND POSTED SPEED RELATIONSHIPS

It is generally acknowledged that 85th percentile operating speeds exceed posted speeds (*15, 22, 33, 36, 38, 43, 53*). Many of these reports have also demonstrated that the 50th percentile operating speed either is near or exceeds the posted speed limit. Data available within the NCHRP 15-18 project also

TABLE 21 Speed values by functional class for urban and suburban streets

Functional Class	Number of Sites	Number of Individual Readings	85th Percentile Speed mph (km/h)	95th Percentile Speed mph (km/h)	98th Percentile Speed mph (km/h)
Arterials (all)	69	16425	60 (96.6)	68 (109.5)	71 (114.3)
Collectors	20	5961	44 (70.8)	49 (78.9)	53 (85.3)
Local	13	3000	34 (54.7)	39 (62.8)	42 (67.6)

TABLE 22 Speed values by terrain type for rural two-lane highways

Terrain	Number of Sites	Number of Individual Readings	85th Percentile Speed mph (km/h)	95th Percentile Speed mph (km/h)	98th Percentile Speed mph (km/h)
Tangents					
Level	10	3268	59 (95.0)	63 (101.4)	67 (107.9)
Rolling	79	13324	60 (96.6)	64 (103.0)	67 (107.9)
Mountainous	57	11572	59 (95.0)	63 (101.4)	66 (106.3)
Horizontal Curve, Radius < 820 ft (250 m)					
Level	5	2903	53 (85.3)	58 (93.4)	62 (99.8)
Rolling	41	4371	53 (85.3)	57 (91.8)	59 (95.0)
Mountainous	33	6868	52 (83.7)	57 (91.8)	59 (95.0)
Horizontal Curve, Radius > 1967 ft (600 m)					
Level	no sites				
Rolling	6	836	60 (96.6)	63 (101.4)	65 (104.7)
Mountainous	4	474	61 (98.2)	65 (104.7)	68 (109.5)

support these observations (see Figure 6). The NCHRP 15-18 project included individual spot speed data collected on a tangent section from three sources. These sources (together with a brief name to describe the data set) follow:

- data for 78 sites collected during 2000 for rural arterials, S/U arterials, S/U collectors, and S/U local streets (NCHRP);
- data for 35 sites collected during 1998 and 1999 for suburban arterials in Texas (Texas) (*38*); and
- data for 171 sites collected during June 1996 to January 1997 for two-lane rural highways (FHWA) (*36*).

Data were also available from an FHWA study that examined the effects of raising and lowering posted speed limits on driver behavior:

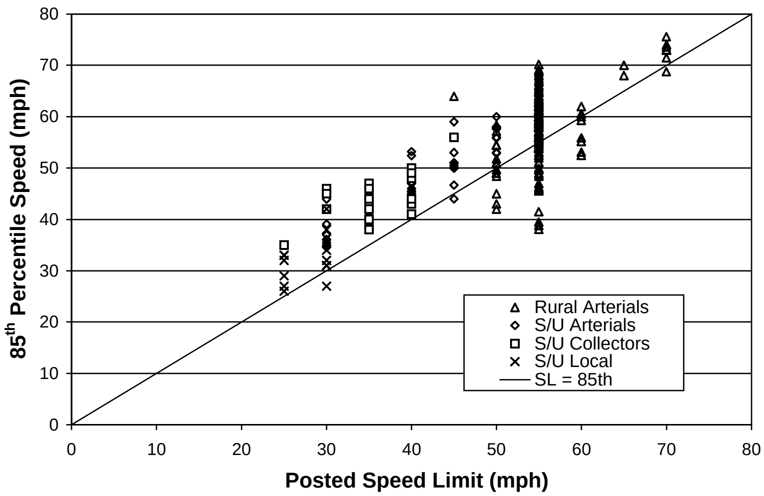


Figure 6. 85th percentile speed versus posted speed for NCHRP, Texas, and FHWA data.

- data for 98 sites collected between June 1986 and July 1989 on nonlimited access highways (Parker) (*53*).

The data within the NCHRP and Texas databases follow trends similar to those of the Parker data. In both those sets of data, the 85th percentile speeds at most sites exceed the posted speed. Parker determined that the typical posted speed limit represented the 43rd percentile speed. Statistics from the NCHRP, Texas, and FHWA data sets on the percentile of vehicles that travel at various speeds (including the posted speed limit) are given in Table 23.

Figure 6 and Table 23 illustrate differences between rural two-lane highways and S/U roadways. In most situations, posted speeds represent a higher percentile value in rural areas than S/U areas. The only exception is the rural, arterial subdivision for the nine sites collected within this NCHRP study. The results for these nine sites (37th percentile speed equals posted speed) is heavily influenced by two Portland sites that have operating speeds in excess of 65 mph (104.6 km/h) while speed limits are 55 mph (88.5 km/h). When these two sites are eliminated, the result goes to the 48th percentile, which is more in line with the findings for the other rural categories.

Rural two-lane highway sites accounted for most of the sites having 85th percentile speed values lower than the posted speed. Figure 6 shows that only one S/U local street site and one S/U arterial site had 85th percentile speeds less than the posted speed and that no S/U collector site did. Several of the rural two-lane highway sites had 85th percentile speeds less than the posted speed.

In addition to providing information on the percentile speed that equals the posted speed, Table 23 provides information on the percentile speed for posted speed plus 5 mph (8.1 km/h) and plus 10 mph (16.1 km/h). For rural roads where the functional classification is principal arterial (representing 36 sites in Washington), 72 percent of the free-flow vehicles were at the posted speed limit. For those roads, posted speed limit was either 50 or 55 mph (80.5 or 88.5 km/h). A total of 90 percent of the free-flow vehicles were at the posted speed limit plus 5 mph (8.1 km/h) (i.e, 55 or 60 mph [88.5 or 96.6 km/h]). When the posted speed limit plus 10 mph (16.1 km/h) is used, the percent of vehicles at or below that speed goes to 98 percent. For those 36 sites, almost all the vehicles on the roadways were at or below posted speed plus 10 mph (16.1 km/h). For all the rural classes, over 90 percent and in most cases over 97 percent of the vehicles on the roadways are within 10 mph (16.1 km/h) of the speed limit.

S/U classes show a different speed pattern. Overall, there are greater speed differences between the operating speed and the posted speed limit for the sites studied. Local streets had speeds that were the closest to the posted speed limit, with 96 percent of the vehicles at or below speed limit plus 10 mph (16.1 km/h). Collectors had the poorest performance, with only 86 percent of the measured free-flow vehicles being at or below speed limit plus 10 mph (16.1 km/h). Only 23 percent of the free-flow vehicles on collectors were at the posted speed limit.

Table 24 lists the percentile speed that equals speed limit, speed limit plus 5 mph (8.1 km/h), and speed limit plus 10 mph (16.1 km/h) grouped by the speed limit for the roadway. For rural nonfreeway facilities, speed limit plus 10 mph (16.1 km/h) would include almost all vehicles on the roadways. For suburban/urban areas, speed limit plus 10 mph (16.1 km/h) 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 suburban/urban nonfreeway roadways than on rural nonfreeway 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.

TABLE 23 Percentile speed compared with posted speed

Data Source	Development, Functional Class (Posted Speed Range)	Percentile at or below Given Speed*			Number of Sites (location)
		Speed Limit	Speed Limit Plus 5 mph	Speed Limit Plus 10 mph	
NCHRP	Rural, Arterial (55 to 70 mph)	37**	70	91	9 (near College Station, Portland, and St. Louis)
FHWA	Rural, Minor Arterial (55 mph)	59	87	99	9 (Washington)
FHWA	Rural, Principal Arterial (50 to 55 mph)	72	90	98	36 (Washington)
FHWA	Rural, no class given (50 to 70 mph)	64	86	97	126 (Minnesota, New York, Oregon, Pennsylvania, Texas)
Texas	Suburban/Urban, Arterial (30 to 55 mph)	31	69	91	35 (College Station, Corpus Christi, Houston, San Antonio, Waco)
NCHRP	Suburban/Urban, Arterial (30 to 55 mph)	32	69	92	35 (Boston, College Station, Houston, Little Rock, Nashville, Portland, St. Louis)
NCHRP	Suburban/Urban, Collector (25 to 40 mph)	23	57	86	22 (Houston, Nashville, Portland, St. Louis, Boston, College Station, Little Rock)
NCHRP	Suburban/Urban, Local (25 to 30 mph)	52	83	96	13 (Boston, Bryan, College Station, Nashville, Portland, St. Louis)

* Values represent an average for the sites included.

** Data heavily influenced by two Portland sites. Percentile with data from these sites removed = 48.

TABLE 24 Percentile speed that equals posted speed by area type and posted speed

Area Type	Speed Limit (mph)	Percentile at or below Given Speed*.			Number of Sites
		Speed Limit	Speed Limit Plus 5 mph	Speed Limit Plus 10 mph	
Rural	50	81	99	100	12
	55	61	85	96	151
	60	91	95	98	8
	65	59	89	98	2
	70	64	91	98	7
Suburban/ Urban	25	42	77	94	7
	30	28	64	86	19
	35	22	62	90	23
	40	32	68	92	25
	45	37	70	90	15
	50	43	76	95	9
	55	48	80	95	6

* Values represent an average for the sites included.

Note: 1 mph = 1.61 km/h.

Procedures Used to Set Speed Limits

The methods used to set speed limits have been reviewed by several authors *(22, 54, 55)*. A recent review was conducted by an Institute of Transportation Engineers (ITE) Technical Committee with the following findings *(56)*.

- The 85th percentile speed is the predominant factor used in setting speed limits (by 99 percent of the agencies surveyed). Both roadway geometry and accident experiences are “always or usually considered” by more than 90 percent of the agencies, and roadside development is also popular, being considered “always or usually” by 85 percent of the respondents.
- In an open-ended question, the top three factors used in establishing speed zones other than 85th percentile speed were roadway geometry, accident experience, and a new factor not present in the previous question: political pressure.
- Most jurisdictions allow deviations from the 85th percentile speed, with most being between 5 and 10 mph (8.1 and 16.1 km/h). Reasons for the deviation include politics (33 percent), accidents (13 percent), roadway areas (11 percent), and roadway geometry (9 percent).

General guidance on how to set speed limits is provided in several locations, such as in the *MUTCD* (*16*) and in state or city manuals. Table 25 summarizes the information provided in the *MUTCD* (*16*). A 2001 ITE publication (*56*) provides a summary of criteria for several states and cities. These documents, however, do not make specific recommendations on how much to adjust the speed limit when considering school children, accidents, or the geometrics present.

Operating Speed Compared with New Speed Limits

Figure 6 clearly shows that operating speeds as measured by the 85th percentile statistic are greater than the posted speed limit for most roadways. For several conditions, the mean speed is also in excess of the posted speed limit. In theory, if speed limits are set at the 5 mph (8.1 km/h) closest to the 85th percentile speed, then the posted speed limits should be much closer to the 85th percentile operating speeds than shown in Table 24. So a question is “are speed limits set with such disparity or do the speeds change after the speed limit is set?” A part of a survey conducted by the ITE Traffic Engineering Council (TENC) Committee 97-12 was a request for “speed zoning investigations your agency has recently conducted” (*56*). A total of 256 speed zoning reports were received from 124 respondents (average of 2.1 reports per survey). The material contained within the reports varied. For example, some contained only the speed statistics from a computer software program with no recommendations on changes to the existing speed limit. Other reports were complete in-depth

TABLE 25 MUTCD guidelines for speed limits

Standard:

After an engineering study has been made in accordance with established traffic engineering practices, the Speed Limit (R2-1) sign shall display the limit established by law, ordinance, regulation, or as adopted by the authorized agency.

The speed limits shown shall be in multiples of 10 km/h (5 mph).

Guidance:

When a speed limit is to be posted, it should be the 85th percentile speed of free-flowing traffic, rounded up to the nearest 10 km/h (5 mph) increment.

Option:

Other factors that may be considered when establishing speed limits are the following:

- Road characteristics, shoulder condition, grade, alignment, and sight distance;
- The pace speed;
- Roadside development and environment;
- Parking practices and pedestrian activity; and
- Reported crash experience for at least a 12-month period.

studies of a roadway's posted speed limits, including details on the geometric conditions and accident characteristics of the roadway.

Several surveys provided sufficient information to compare the 85th percentile speed with the existing and proposed posted speed limits. Plots were generated to illustrate the relationship between the existing posted speed limit and the measured 85th percentile speed (see Figure 7), the recommended posted speed limit and the measured 85th percentile speed (see Figure 8), and the difference between the measured 85th percentile speed and the recommended speed limit and the existing speed limit (see Figures 9 and 10).

Figure 7 illustrates findings similar to those collected as part of this study and presented in Figure 6. In general, for roadways with posted speed limits of 45 mph (72.4 km/h) and below, most of the measured speeds are higher than the posted speed limit. When the posted speed limit is 55 mph (88.5 km/h) or more, only about half of the measured speeds are above the posted speed limit. Figure 8 shows that, in almost all situations, the recommended posted speed limit is below the measured 85th percentile speed. The data were subdivided by whether the recommendation was for changing a speed limit or maintaining it. Both data sets had similar trends.

An appreciation for the amount of difference between the measured 85th percentile speed and the recommended posted speed can be obtained from Figures 9 and 10. Figure 9 shows that the range of speed differences does not vary by the exist-

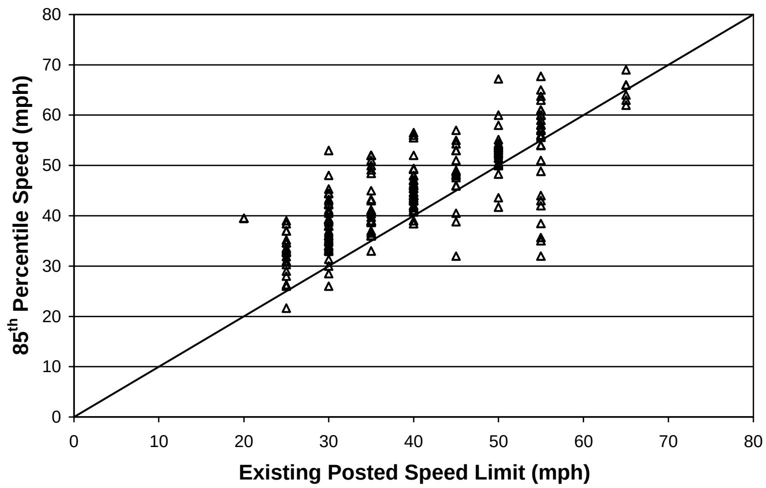


Figure 7. Existing posted speed limit versus 85th percentile speed for 128 speed surveys.

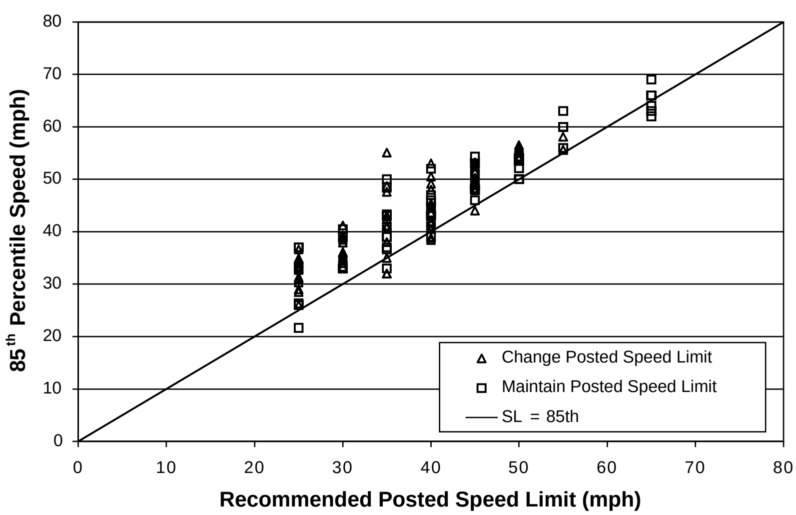


Figure 8. Recommended posted speed limit versus 85th percentile speed for 128 speed surveys.

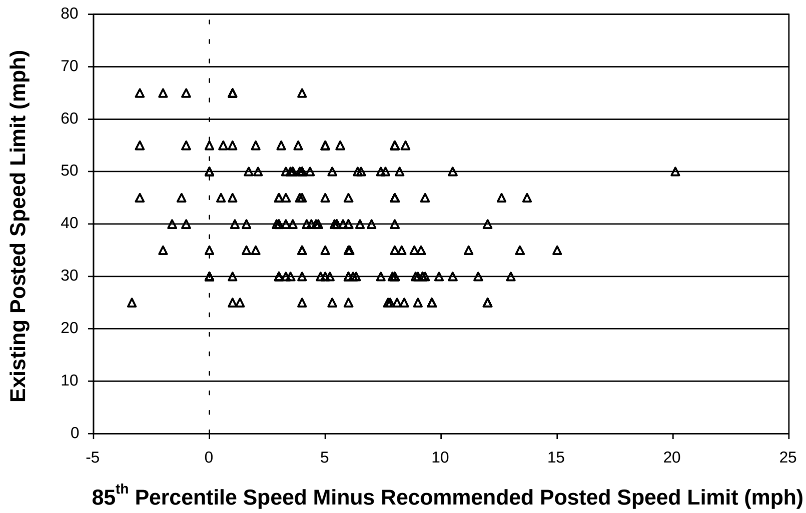


Figure 9. 85th percentile speed minus recommended posted speed limit versus existing posted speed limit for 128 speed surveys.

ing posted speed limit, except at the higher speed limits (55 mph [88.5 km/h] and greater) where the difference is less. Figure 10 shows the cumulative frequency of the difference. 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.

Changes in Posted Speed Limit

A frequently asked question is how much influence does the posted speed have on operating speed? If one changes the posted speed, would that change the speeds of the drivers on the roadway? Both sides of this debate have been argued. Some claim that posted speed limits are irrelevant and have no impact. Drivers, being reasonable and prudent, will operate their vehicles at a comfortable and safe speed. Operating speeds observed on rural two-lane highways during the mandatory 55 mph (88.5 km/h) maximum speed limit period are used as examples. These roads saw speeds in excess of 70 mph (112.7 km/h) during this time period, yet had some

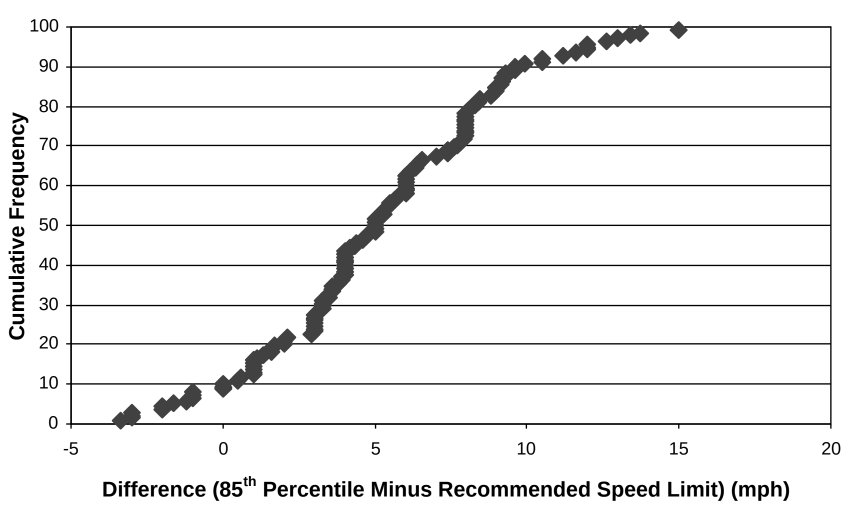


Figure 10. 85th percentile minus recommended posted speed limit versus cumulative frequency for 128 speed surveys.

of the best safety records. Now with the removal of the national speed limit, these roads are posted with a 70 mph (112.7 km/h) limit. Others comment that drivers are influenced by the speed limit, by at least staying within a certain range to avoid tickets.

Data collected by Parker for an FHWA study included the following findings *(53)*:

- Before the speed limit change, the typical posted speed limit for the experimental sites was set at the 20th percentile speed; after the speed limit change, this increased to the 43rd percentile speed.
- There was generally less than a 2-mph (3.2-km/h) difference in average speeds, speed standard deviation, and 85th percentile speed between the before and after speeds. These changes were statistically significant but were interpreted as "not sufficiently large to be of practical significance."
- Changes in posted speed limits led to changes in driver compliance, but this reflects the definition of compliance as driving at or below the posted speed limit rather than changes in driver behavior.
- Changes in posted speed limits had little effect on highway safety.

Parker's work has been referenced to support the argument that speed limits do not influence driver's operating speed. The thought is that because the change in posted speed did not produce a similar change in operating speed, the posted speed does not influence a driver's speed choice. However, Parker's study had an acknowledged major shortcoming in the site selection. The sites selected for the speed limit changes were chosen by local agencies on the basis of a predetermined need (e.g., request from the public, high incidence of crashes, compliance with local ordinances, changing land use patterns) rather than randomly *(23)*. Parker qualified his conclusions by stating that "the findings may apply to similar sites where the speed limits are changed for similar reasons. Generalization to other roadways are not appropriate." Therefore, the question still remains on how much influence a posted speed has on operating speed.

DISTRIBUTIONS OF CHARACTERISTICS

Ranges for design elements can vary from one region to another or from one city to another. Identifying these potential variations can help engineers to gain a more complete picture of the variables that are involved in specifying values for design elements. An approach to design that uses established roadway classes needs to provide information on acceptable ranges within each design element. Going beyond that range, such as having curb and gutter rather than shoulders, can communicate a different roadway environment to the driver and result in a different speed distribution for the road as compared with the same type of road in a different area of the country. A new approach will not be accepted if it recommends major changes to the roadway network, especially if those recommendations cannot be supported with strong evidence that the changes will result in a noticeable improvement in safety or speed consistency.

Data Collection and Reduction

Roadway and roadside characteristics data for a sample of roadways within three cities and three predominantly rural counties were collected. The roadways were to include examples of flat, rolling, and mountainous terrain. The research team reviewed the following to aid in creating a short list of candidate areas:

- population of cities,
- terrain present,
- contacts who could aid in gathering maps or other needed information,
- potential overlap with data collection efforts for the field speed studies, and
- reasonable data collection routes.

Based on the above, the following areas were selected:

Cities (2000 population)	Counties
College Station, TX (60,000)	Brazos County, TX
Portland, OR (486,000)	Somerset County, PA
Little Rock, AR (175,000)	Skagit County, WA

College Station, Texas

A database of streets in College Station was created using a city map. Data were collected by driving approximately 200 street segments and recording measurements while in the field. Collected data included information such as number of driveways, intersections, and signals; vertical profile; roadside environment; speed limit; roadside hazard; shoulder type and width; median type and width; lane width; and presence of on-street parking, bike lanes, or sidewalks. The city map was used to count the number of horizontal curves, calculate the average deflection angles, and obtain precise lengths for each street. In College Station, almost all of the local, collector, and arterial (intermediate and suburban) streets have curb and gutter (between 78 and 95 percent). Only 13 percent of the high-speed arterial streets had curb and gutter, with the remainder having shoulders. The average lane width was higher for the lower functional classes (local, collectors, and intermediate arterials) than the suburban or high-speed arterials. Only 21 percent of the local streets had sidewalks; however, 70 percent of the collectors and about one-half of the arterials had sidewalks. Driveway density decreased as the functional classification increased. Local streets had a weighted average of 78.7 driveways/mi (48.9 driveways/km), which equates to a spacing of approximately 67 ft (20.4 m) between driveways. Collectors and suburban arterials have weighted averages of 20.2 and 14.3 driveways/mi (12.6 and 8.9 driveways/km), respectively, which correspond to 261 and 370 ft (79.6 and 112.8 m) between driveways. The type of development for collectors and locals was uniformly residential; however, the other functional classes showed more variety (residential, commercial, park, etc.), which can contribute to the greater variety in posted and operating speeds along those corridors.

Little Rock, Arkansas

Using a detailed city map, a database was created that contains the name of each street within the city limits of Little Rock in the area south of Interstate 630 and west of U.S. Highway 65. Portions of selected neighborhoods in this area were driven and videotaped to record data for a sample of the streets on the street network. Collected data included number of driveways, intersections, and signals; vertical profile; roadside environment; speed limit; roadside hazard; shoulder type and width; median type and width; lane width; and presence of on-street parking, bike lanes, or sidewalks. About three-fourths of the collectors and locals in Little Rock have curb and gutter, with only 28 and 16 percent, respectively, having sidewalks. All the suburban arterial mileage has curb and gutter and four lanes, with 75 percent also having sidewalks. Driveway density in Little Rock is greater than that found in College Station. Local streets had 75.8 driveways/mi (47.1 driveways/km), which represents a 70-ft (21.3-m) spacing. Collectors, suburban arterials, and high-speed arterials had similar driveway densities, ranging from 35.5 to 29.7 driveways/mi (22.1 to 18.5 driveways/km), which equates to a spacing of 150 ft (45.7 m) for collectors and suburban arterials and 178 ft (54.3 m) for high-speed arterials. College Station's high-speed arterials had a 1,148-ft (349.9-m) driveway spacing.

Portland, Oregon

Portland is unique in that it has a database that includes nearly every street in four counties. The base network most closely resembles conditions in 1997. A copy of the Metro's all-street network used for planning was provided for use in this project. The fields include segment length, street name, street classification, direction type (one-way or two-way), county, city, speed limit, functional class, number of lanes, and other fields. Each segment's length (or link) includes a street name, left- and right-side address, and a from-node ID and to-node ID, which were based on unique nodes at each X, Y, Z location. To be able to identify where a specific link is on a map, cross street names are needed. If this information is available, then the number of intersections and the number of signalized intersections could be counted from the map or the number of driveways counted in the field could be associated with a specific section of roadway. Unfortunately, several efforts to obtain the names of the cross streets associated with the node numbers were not successful, thus limiting the ability to expand the roadway segment characteristics available.

The number of miles of roadway by functional class and speed limit were pulled from the database. In each case the majority of miles for a functional class represented a posted speed limit that would be expected for the class. There were some examples where the functional classes did include roadway segments with speed limits that do not agree with the expectations for the class. For example, the local street functional class included a few segments with posted speeds typically associated with higher functional classes of roadways. The majority of miles were at 25 mph (40.2 km/h) (192 mi [309.0 km]) with a few at 30 mph (48.3 km/h) (14 mi [22.5 km/h]) and 35 mph (56.3 km/h) (27 mi [43.5 km]); however, several miles were at 45 mph (72.4 km/h) (13 mi [20.9 km]) and 50 mph (80.5 km/h) (9 mi [14.5 km]). Having a "local" street with a 45- or 50-mph (72.4- or 80.5-km/h) speed limit provides an inconsistent message to the driver. These inconsistencies are easier to identify when databases on the order of the one being used in Portland are available. The questionable speed limits may be a function of a miscoded functional class rather than an incorrect speed limit.

Brazos County, Texas

The network of roads considered for Brazos County, Texas, included all U.S., state, and county roads not located within city limits. The database of the U.S. and state roads was obtained from TxDOT and included highway number, length, class, shoulder type, and ADT (Average Daily Traffic) range.

To collect additional data for the project, such as number of driveways, the entire length of each U.S. and state rural road was driven and videotaped. Data collected with a distance measuring instrument and software developed at TTI included number of driveways, intersections, and signals. Characteristics were also obtained for roads not on the state system (i.e., county roads) using the detailed county map. The lowest posted speed limit for each of the rural roadways was 55 mph (88.5 km/h) with shoulder widths ranging between 0 and 12 ft (0 and 3.6 m). Lane widths were almost always 12 ft (3.6 m). Driveway density and intersection density were about 10 access points per mi (6.2 access points per km) with no clear relationship of density to functional class (one could expect higher densities for the lower functional classes). The rounded average access point spacing was about 500 ft (152.4 m).

Skagit County, Washington

Based on advice from representatives within the Washington State Department of Transportation, Skagit County was selected to represent a rural, mountainous county. An electronic copy of the 2000 State Highway Log was obtained and used to construct the beginning of the database. Washington State maintains videologs of their roads on a web site. This web site was used and the roads “driven” to count number of driveways and intersections and to gather other information such as roadside environment. The lower road classes had lower speeds. Major collectors had posted speeds between 25 and 55 mph (40.2 and 88.5 km/h), while the freeways had posted speeds between 60 and 70 mph (96.6 and 112.7 km/h). Shoulder widths also increased as the functional class increased. Weighted average shoulder width for major collectors was 3.4 ft (1.0 m), for minor arterials it was 5.7 ft (1.7 m), for principal arterials it was 6.4 ft (2.0 m), and for freeways it was 10 ft (3.0 m). Lane width followed a similar pattern, widening from 10.7 ft (3.3 m) (major collector) to 13.4 ft (4.1 m) (freeway). The major collectors had higher driveway and access point densities than the arterials. The major collector had a typical rounded access point spacing of 400 ft (121.9 m), while the arterials had a spacing of about 800 ft (243.8 m).

Somerset County, Pennsylvania

The Pennsylvania Department of Transportation provided an electronic database of the state-maintained roads within Somerset County. With the extensive number of state and county roads on the Somerset County network, it was decided to concentrate efforts on the northern portion of the county, specifically that portion north of Interstate 70/76. A sample of roadways was driven and videotaped. The video tapes were reviewed in the office, and data on driveway and intersection density were reduced. For the roads driven in Pennsylvania, the lower functional classes had narrower shoulders and lanes. Major collector typical shoulder width was 1.9 ft (0.6 m) while minor arterials had 3.2 ft (1.0 m), and freeways had 8.3 ft (2.5 m). The driveway densities for the Pennsylvania sites were unexpected. The lower functional class (minor collector) only had 5.8 driveways per mile (3.6 driveways per kilometer), while the higher functional classes (minor arterial and major collector) had between 11.3 and 14.7 driveways per mile (7.0 and 9.1 driveways per kilometer) (weighted average). The low value for minor collectors may be a function of the limited sample size for the functional class (only 4.9 mi [7.9 km] were driven).

Distribution of Rural Roadway Characteristics

For roads driven in all three counties, there are some noteworthy observations that can be made from the characteristics collected. Roads in Brazos County had a fairly constant range of posted speeds (55 to 70 mph [88.5 to 112.7 km/h]) and operating speeds (55 to 75 mph [88.5 to 120.7 km/h]), while roads in Skagit County had a wider variety of posted speeds that increased as the roadway design class progressed from major collector to freeway. In general, the ADT increased as the design class increased, with the exception of freeways in Somerset County. Average lane widths were between 9.4 and 13.4 ft (2.9 and 4.1 m) for all categories; Brazos and Skagit Counties were very consistent in lane widths across all classes, and average lane widths tended to increase as the importance of the design class increased. Presence and width of shoulders was inconsistent in all three counties; widths ranged from 0 to 12 ft (0 to 3.6 m), with averages from 0 to 11.2 ft (0 to 3.4 m). However, the average shoulder width increased as the design class progressed from collector to freeway.

The use of wide medians on freeways was similarly distributed among all three counties, but median widths on other classes were widely scattered. In general, arterials had smaller medians and collectors had little to no median width. Driveway densities were also scattered among the design classes; freeways consistently had little to no driveway presence, while arterials and collectors had a significant presence. Ramp/intersection densities followed a trend similar to driveway densities. The access point spacing on the major collectors and minor arterials in Pennsylvania (about 400 ft [121.9 m] between driveways/intersections) is closer than found in other counties (approximately 800 ft [243.8 m] in Washington and 600 ft [182.9 m] in Texas).

Distribution of S/U Roadway Characteristics

The evaluation of S/U characteristics included consideration of the urban and suburban sites available from the field speed data (see Appendix E). The cities included in the evaluation (and their 2000 populations) are as follows:

<u>Roadway Inventory Cities</u>

College Station, TX (68,000)
Little Rock, AR (183,000)

<u>Field Speed Data Cities</u>

Boston, MA (589,000)
College Station, TX (68,000)
Houston, TX (1,954,000)
Little Rock, AR (183,000)
Nashville, TN (546,000)
Portland, OR (529,000)
St. Louis, MO (348,000)

The data were categorized as being from College Station, Little Rock, or field data. For the field data category, the speed data collected in the field studies (see Appendix E for additional information) were used.

Plots were generated for each roadway variable to illustrate the distribution for the different categories (see Appendix I). Selected findings on the relationship between design classes and the given variable include the following:

- The field studies and previous studies (see Appendix E and Appendix D) have shown that lower operating speeds are associated with on-street parking. Between 60 and 90 percent of the local streets surveyed allowed parking, and 30 percent of the collectors had parking (see Figure 11).
- The presence of pedestrian activities is also associated with lower speeds. One of the factors considered when estimating the level of pedestrian activity was the presence of sidewalks. The presence of sidewalks may also be required as part of policy related to the Americans with Disabilities Act (ADA). Currently, between 60 and 80 percent of the College Station and Little Rock curb and gutter arterials have sidewalks, while less than 30 percent of the College Station and Little Rock local streets have sidewalks (see Figure 12).
- A higher percentage of the higher design classes used medians (see Figure 13). However, more than a 20 to 30 percent of median use for arterials with shoulders was expected. On such a facility, high speeds are expected, which needs left-turn treatments to provide an acceptable level of operations and safety. A similar observation could be made for only 40 percent of Little Rock's curb and gutter arterials having medians. When the College Station data were checked, the approximately 70 percent of arterials with shoulders and no median were two-lane facilities in areas changing from rural to suburban, with associated development. Many of these roads are in the pre-design stage for widening.
- There is a downward trend in access density as one moves across the design classes (see Figure 14).
- A comparative observation of the distribution of residential and commercial development among the design

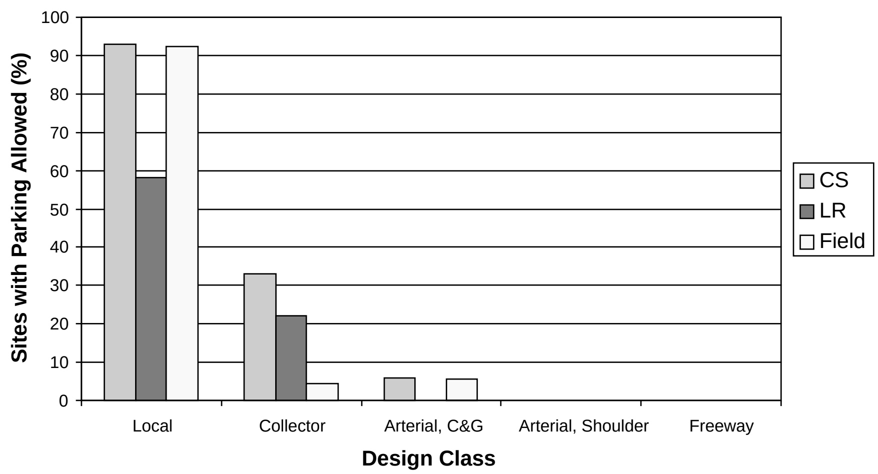


Figure 11. Parking by design class.

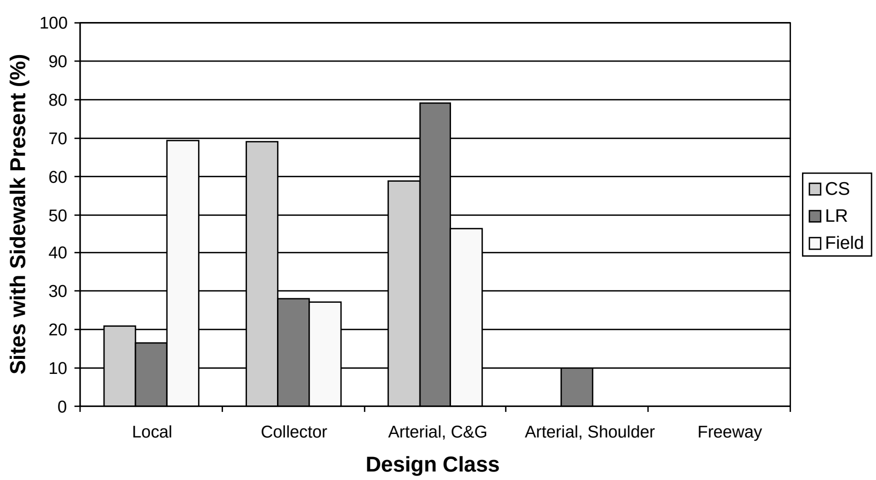


Figure 12. Sidewalk presence by design class.

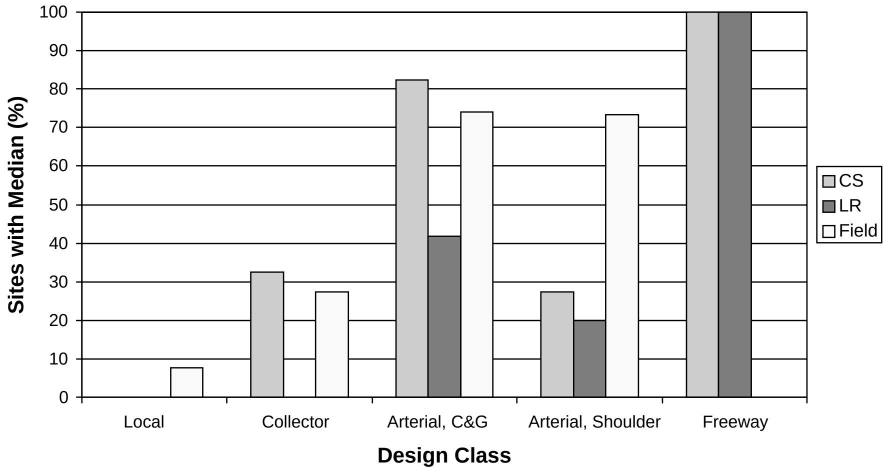


Figure 13. Median presence by design class.

classes shows that the percentage of arterials with curb and gutter that have residential development is nearly identical to the percentage that have commercial development. The mixed use of development could help explain the wide range of speeds recorded on arterials with curb and gutter.

Key findings from the comparison of a roadway element with posted speed include the following:

- A high percent of the lower posted speed roadways had on-street parking, as expected (see Figure 15).
- The use of sidewalks does not appear to be strongly related to the posted speed of the facility in the two cities (see Figure 16).
- Driveway density has the expected relationship with the speed ranges—the number of driveways per mile decreases as the speed range increases (see Figure 17).
- College Station, Little Rock, and the field speed data followed similar trends with respect to the percent of sites with residential or commercial development (see Figures 18 and 19). Lower posted speed limit sites had more residential development, while higher posted speed limit sites had more commercial development.

ROADWAY DESIGN CLASS APPROACH

Background

Geometric design refers to the selection of roadway elements that include the horizontal alignment, vertical alignment, cross section, and roadside of a highway or street. In general terms, good geometric design means providing the appropriate level of mobility and land use access for motorists, bicyclists, and pedestrians while maintaining a high degree of safety. The roadway design must also be cost effective in today's fiscally constrained environment. While balancing

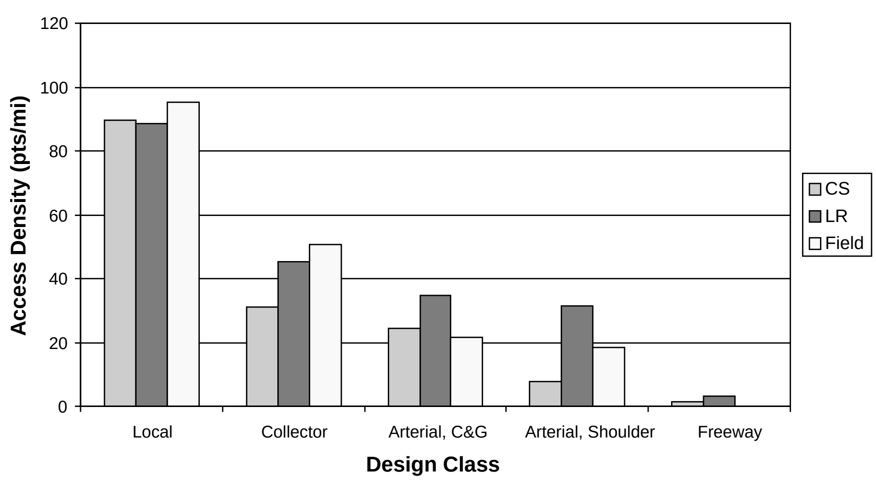


Figure 14. Access density by design class.

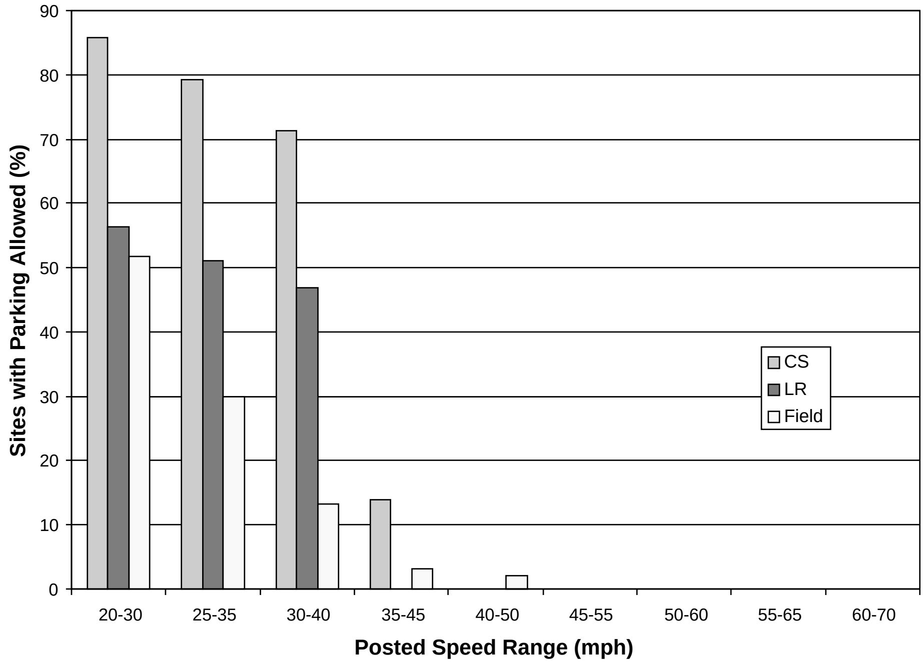


Figure 15. Parking by posted speed range.

these design decisions, the designer needs to provide consistency along a roadway to prevent abrupt changes in the design that do not match motorists' expectations. In addition, the designer needs to select appropriate values for the different roadway variables to communicate to the driver the appropriate speed and operations along a facility. Providing several lanes, a straight and relatively level alignment, few access points, and an open roadside environment will not encourage drivers to maintain low speeds. To increase the designer's appreciation that the overall look of a roadway will influence the operations along a facility, the roadway design class approach has been developed.

The classification of roadways into different operational systems, functional classes, or geometric types is necessary for

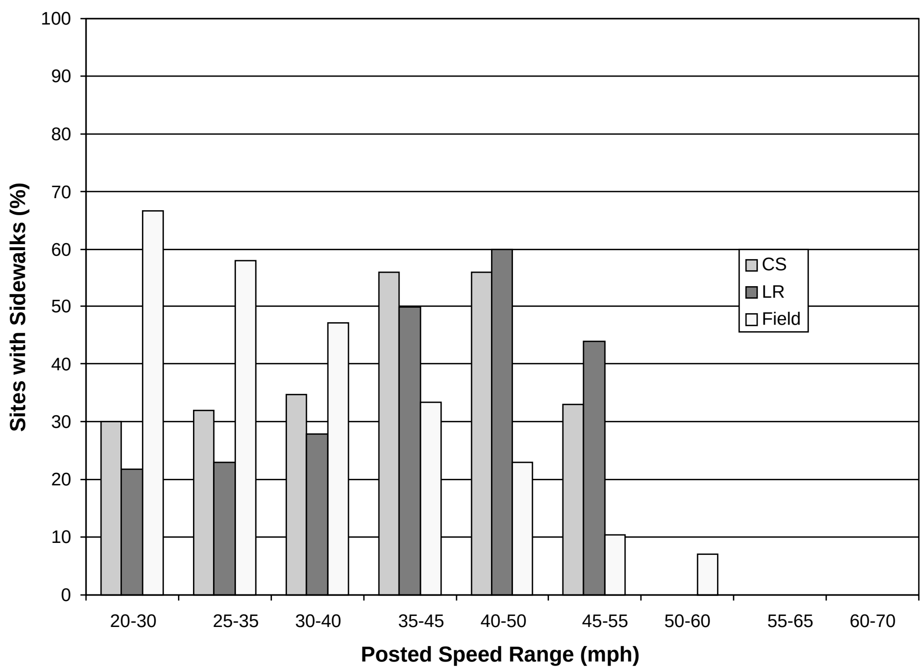


Figure 16. Sidewalks by posted speed range.

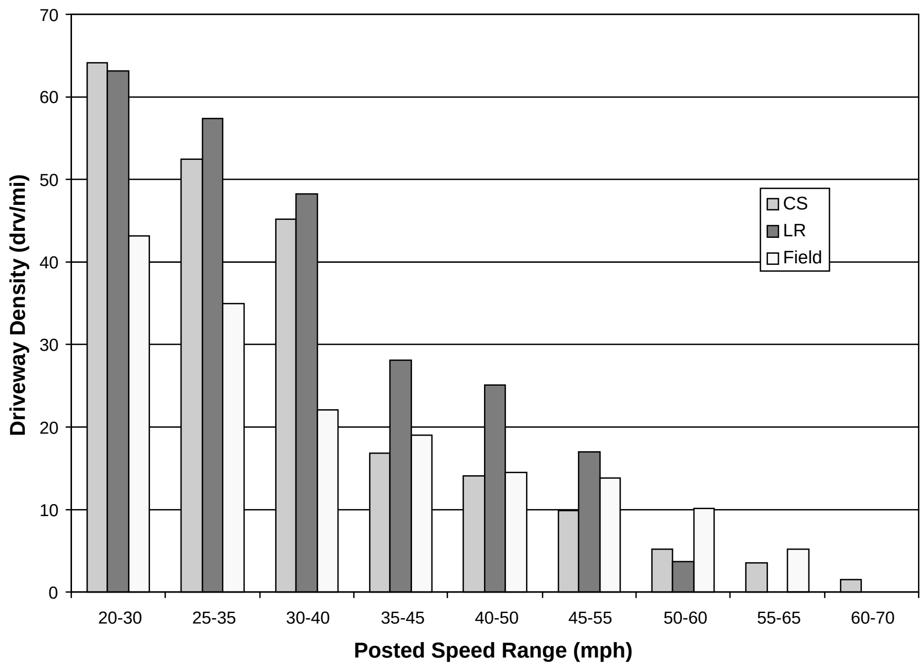


Figure 17. Driveway density by posted speed range.

communication among engineers, administrators, and the general public. Various classification schemes have been applied for different purposes for rural and urban regions. The most common scheme used within the roadway design and traffic operations groups is functional classification, which includes three major divisions: arterial, collector, and local. This classification scheme emphasizes the type of service or function the roadway is to provide. The determination is made based upon whether the roadway is primarily for access (i.e., local street), for mobility (i.e., arterials), or a mix (i.e., collectors). The classification scheme does not provide the level of detail needed to establish unique characteristics between roadways that provide similar functions but at different levels. For example, an interstate freeway and a four-lane high-speed

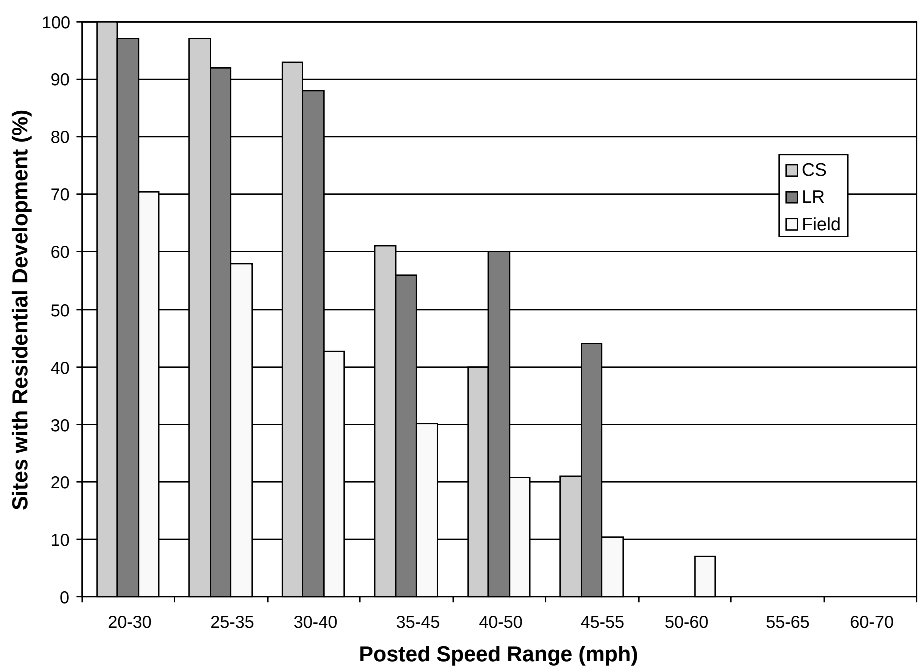


Figure 18. Residential development by posted speed range.

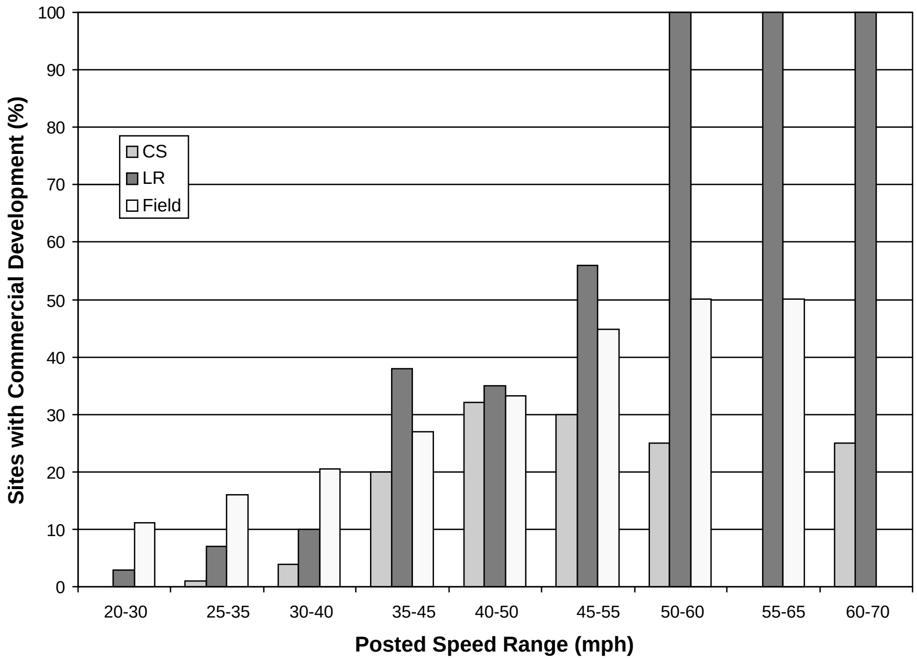


Figure 19. Commercial development by posted speed range.

arterial provide the same function (mobility) but have very different design qualities. The freeway would provide access by ramps and would not have signals, while the four-lane high-speed arterial would have some driveways, some provision for left turns across opposing traffic streams, and signals. To better align design criteria with a classification scheme, a roadway design class 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.

Development

The process for developing a roadway design class approach began with identifying roadway and roadside characteristics that could be logically grouped to describe a type of road. Information from the mailout surveys (see Appendix B), the literature (see Appendix D), and existing reference materials (e.g., *Green Book*) were used to determine preliminary groups. Grouping freeway and local street characteristics was simple. Determining the splits for roads between those limits was not as simple. 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 (see Appendix E) 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.

Adding to the complexity is the variation in features that are currently present for different roadway groups. Because of the rigid design features associated with freeways, freeways are easy to identify. When access is controlled by ramps and either a wide median or a barrier separates opposing traffic, then the roadway is probably a freeway. The distribution of existing features associated with other streets is not so clear. As shown in Appendix I, certain features are related to the classes. For example, the number of lanes increases and the use of on-street parking decreases as the class of roadway goes from local to freeway. The relationships for other features are not so clear. Is a characteristic of local or collector streets the provisions for pedestrians? If so, then a high percentage of those facilities should have sidewalks. However, for the two cities surveyed, only 20 and 18 percent of the local streets and 70 and 27 percent of the collectors had sidewalks. If the recommendation in a roadway design class approach is that all local or collector streets have sidewalks (to provide for consistency for this road type between cities and states), then several existing facilities would not meet the guidelines.

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. Following is the research team recommendation for roadway design classes.

Roadway Design Classification Procedure

A decision tree of the roadway design classification procedure is shown in Figure 20. The completion of the first three steps leads to the appropriate roadway design class. Tables 26 and 27 provide an overview of the different classes within the S/U and rural environments, respectively. These tables can be used to assist in selecting the appropriate class.

Features identified as being related to operating speed include (in general order of the strength of the relationship) posted speed limit, functional classification, access density, median presence, and on-street parking. Other features that have been shown to be related to the speed level include pedestrian activity, use of pavement markings, distance between features that are known to control speed (e.g., signals), and the signal density. The value selected for these features or the presence of the feature should be considered in the design of a facility.

The appropriate roadway design class can be determined using the flow chart in Figure 20 or by reviewing the characteristics tables (see Tables 26 and 27). Example pictures, along with a brief description for each roadway design class, are provided in Tables 28 through 37. This information can be used to verify that the selected roadway design class fits the designer's intentions.

The following steps are used within the roadway design classification procedure:

Step 1: Decide if the facility will be in a rural or S/U area.

According to the *Green Book*, urban and rural areas have fundamentally different characteristics with regard to density and types of lane use, density of street and highway networks, nature of travel patterns, and the way in which these elements are related. *Urban areas* are considered to be those places within boundaries set by the responsible state and local officials having a population of 5,000 or more. Urban areas are further subdivided into *urbanized areas* (population of 50,000 and over) and *small urban areas* (population between 5,000 and 50,000). For design purposes, the population forecast for the design year should be used. *Rural areas* are those areas outside the boundaries of *urban areas*. For the roadway design class, *suburban/urban* areas should be considered the traditional *urban* areas as defined in the *Green Book*.

Step 2: Determine the type of service to be provided by the facility.

The *Green Book* explains that roadway networks provide dual roles in that they provide both access to property and travel mobility. Regulated access control is needed on arterials to ensure their primary function of mobility. On the other hand, the function of local roads and streets is to provide access, which inherently limits mobility. The relationship between mobility and access is one of give and take, with collectors and arterials serving both purposes.

Step 3: Select the anticipated operating speed or adjusted posted speed.

Once the environment and type of service have been selected, the next step is to estimate the speed at which the facility is to operate once completed. This speed can be the

(*text continues on page 78*)

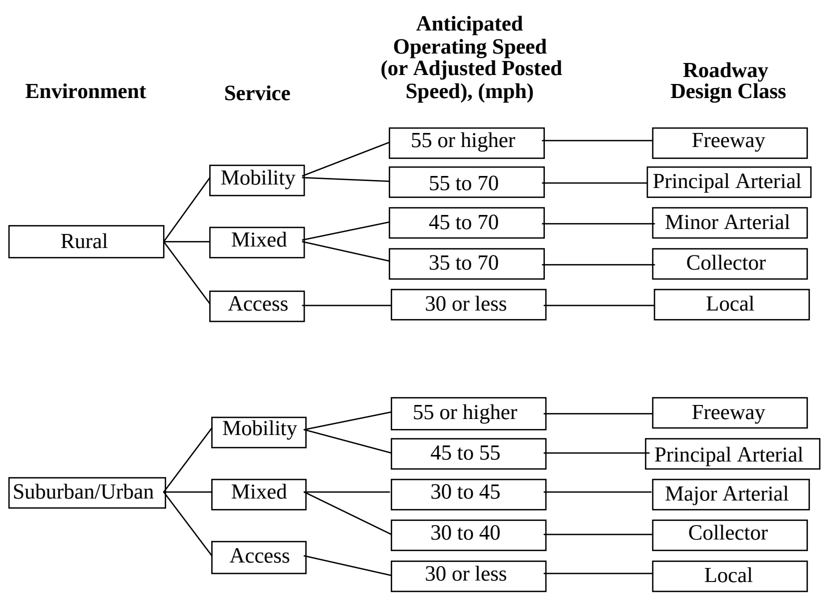


Figure 20. Roadway design class flow chart.

TABLE 26 Typical characteristics for urban (and suburban) classes

Class/Subclass:	Freeway	Arterials		Collectors	Local
Item		Principal	Minor		
Anticipated Speed or Speed limit	55 to 70 mph	45 to 55 mph	30 to 45 mph	30 to 40 mph	≤ 30mph
Purpose	High mobility, access limited to ramps	High mobility, limited access	Balance between mobility and access	Connects local roads to arterial	Permits access to abutting land
Cross Section	Multilane divided	Multilane divided or undivided	Multilane divided or undivided; one-way; two-lane	Two- or three-lane with curb and gutter	Two-lane with curb and gutter
Signals per mile	N/A	1 to 2	4 to 6	≥ 6	None
Access Density (typical spacing per direction)	none (ramps)	Low (600 ft)	Moderate (400 ft)	High (200 ft)	High (100 ft)
Parking	No	No	Some	Usually	Yes
Roadside Development	None	Low density	Moderate density	High density	Residential/ parks/schools
Median	Yes, restrictive	Yes, restrictive	Usually	Some, unrestrictive	No
Sidewalks	No	Preferred	Yes	Yes	Preferred
Anticipated traffic	High volumes	High volumes	Moderate to high volumes	Low to moderate volumes	Low volume with access by garbage and fire trucks
Bike Lanes	No	No	Maybe (or wide curb lane)	Maybe (or wide curb lane)	No

TABLE 27 Typical characteristics for rural classes

Class/subclass:	Freeway	Arterials/Highways		Collectors	Local
Item		**Principal**	**Minor**		
Anticipated Speed or Speed limit	55 to 70 mph	45 to 70 mph	45 to 70 mph	35 to 55 mph	35 to 55 mph
Purpose	High mobility, access limited to ramps	High mobility, limited access	High mobility, limited access	Connection between local streets and arterials	Provides access to land adjacent to collector network and serves travel over relatively short distances
Cross Section	Multilane divided	Multilane divided and two-lane undivided /divided	Two- or three-lane	Two- or three-lane	Two-lane
Driveway Access Density	None (ramps)	Low	Low to Moderate	Moderate to High	High
Roadside development	None	Low to Medium	Medium	Medium to High	High
Median	Yes (restrictive)	Yes (restrictive)	Usually	Occasionally	No
Anticipated traffic	High	High	High to Moderate	Moderate	Low

TABLE 28 Typical characteristics for rural freeways

Anticipated Speed	$\geq$55 mph
Description	• Low to high volumes and long distance trips • Includes all interstate mileage • High mobility, access limited to ramps
Typical Cross Section	Multilane divided
Information on Design Considerations	2001 *Green Book*, Chapter 8, pages 507 to 516

TABLE 29 Typical characteristics for rural principal arterials

Anticipated Speed	≥45 mph
Description	• High volumes and long distance trips • Provide for relatively high travel speeds and minimum interference to through movement • High mobility, limited access
Typical Cross Section	Multilane divided and undivided
Information on Design Considerations	2001 *Green Book,* Chapter 8, pages 507 to 516

TABLE 30 Typical characteristics for rural minor arterials

Anticipated Speed	45 to 70 mph
Description	• Serves most of the larger communities not served by the principal arterial system • Trip length and travel density is larger than collector systems • Travel is at relatively high speed with minimal interference to through movement • High mobility, limited access
Typical Cross Section	Two or three lanes
Information on Design Considerations	2001 *Green Book*, Chapter 7, pages 447 to 472

TABLE 31 Typical characteristics for rural collectors

Anticipated Speed	35 to 70 mph
Description	• Travel is of intra county and regional importance rather than statewide importance. • Roads provide service to any county seat not on an arterial road. • Connection between local streets and arterials.
Typical Cross Section	Two lanes
Information on Design Considerations	2001 *Green Book*, Chapter 8, pages 507 to 516

TABLE 32 Typical characteristics for rural local streets

Anticipated Speed	35 to 70 mph
Description	• Roads to residential development or to isolated industry facility. • Feeds traffic to collectors. • Access to abutting land.
Typical Cross Section	Two lanes
Information on Design Considerations	2001 *Green Book*, Chapter 5, pages 383 to 393

TABLE 33 Typical characteristics for suburban/urban freeways

Anticipated Speed	≤ 55mph
Description	High mobility, access limited to ramps
Typical Cross Section	Multilane divided
Information on Design Considerations	2001 *Green Book*, Chapter 8, pages 507 to 512 and 517 to 558

TABLE 34 Typical characteristics for suburban/urban principal arterials

Anticipated Speed	45 to 55 mph
Description	High mobility, limited access
Typical Cross Section	Multilane divided
Information on Design Considerations	2001 *Green Book*, Chapter 7, pages 447 and 473 to 506

TABLE 35 Typical characteristics for suburban/urban minor arterials

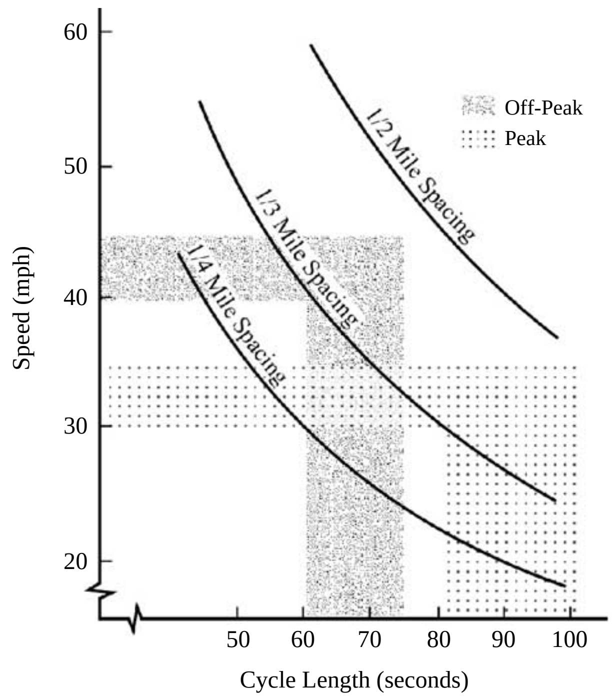
Anticipated Speed	35 to 55 mph
Service	Balance between mobility and access
Typical Cross Section	Multilane divided or undivided; one way; two lane In CBD could be one way; two way, two or more lanes
Information on Design Considerations	2001 *Green Book*, Chapter 7, pages 447 and 473 to 506

TABLE 36 Typical characteristics for suburban/urban collectors

Anticipated Speed	30 to 50 mph
Service	Connects local roads to arterial
Typical Cross Section	Two or three lanes with curb and gutter
Information on Design Considerations	2001 *Green Book*, Chapter 6, pages 423 to 424 and 433 to 445

TABLE 37 Typical characteristics for suburban/urban local streets

Anticipated Speed	25 to 35 mph
Service	Permits access to abutting land
Typical Cross Section	Two lanes with curb and gutter
Information on Design Considerations	2001 *Green Book*, Chapter 5, pages 383 and 393 to 408



Source: Transportation and Land Development, ITE, 1998

Figure 21. Operating speed depending on anticipated signal spacing and cycle length.

TABLE 38 Regression equations for calculating estimated 85th percentile speed

The data from the field studies produced the following regression equation for predicting operating speed using posted speed limit:

All roadways (R_o^2 = 0.904)

EV85 = 7.675 + 0.98 (PSL)

Where:

EV85 = Estimated 85th percentile speed (mph)
PSL = posted speed limit (mph)

If the functional class of the roadway is known, the following regression equations can be used for predicting operating speed using posted speed limit:

Suburban/Urban Arterial (R_o^2 = 0.86)

EV85 = 8.666 + 0.963 (PSL)

Suburban/Urban Collector (R_o^2 = 0.41)

EV85 = 21.131 + 0.639 (PSL)

Suburban/Urban Local (R_o^2 = 0.14)

EV85 = 10.315 + 0.776 (PSL)

Rural Arterial (R_o^2 = 0.81)

EV85 = 36.453 + 0.517 (PSL)

TABLE 39 Typical dimensions for urban (and suburban) classes

Class/Subclass:	Freeway	Arterials		Collectors	Local
Item		**Principal (Nonfreeway)**	**Minor**		
Anticipated Speed or Speed limit (mph)	55 to 70	45 to 55	30 to 45	35 to 45	≤ 30
CROSS SECTION					
Lane Width (ft)	12	11 to 12	10 to 12	10 to 12 industrial: 12	residential: 9 to 11 industrial: 11 to 12
Shoulder Width (ft)	Right = 10 Left = 4 to 8	8 to 10 Parking lanes not recommended	8 (if used), or 10 to 12 (parking lane)	2 to 6 (if used), or 7 to 8 (parking lane)	2 (if used), or 7 (parking lane)
Clear Zone (ft)	30	Curbed = 1.5, otherwise 10	Curbed = 1.5, otherwise 10	Curbed = 1.5, otherwise 10	Curbed = 1.5, otherwise 7 to 10
Median Width (ft)	Lanes Min Width 4 10 6 22 - 26	12 to 18	TWLTL = 12 to 18	TWLTL = 10 to 16	N/A
ALIGNMENT					
Radius (minimum)	See tables in *Green Book (17)*		See tables in *Green Book (17)*		
Superelevation (ft/ft)	12 8 with snow & ice		Avoid but max = 6	Avoid but max = 6	Avoid but max = 4
Maximum Grade (%)	3 to 4 (level) 4 to 5 (rolling)	5 to 8 (level) 6 to 9 (rolling)	up to 8, desirably less than 5	5 to 9 (level) 6 to 12 (rolling)	up to 15
Cross Slope (%)	1.5 to 2.0	1.5 to 3.0	1.5 to 3.0	1.5 to 3.0	0.5 to 1.0

TABLE 40 Sample dimensions for rural classes

Class/Subclass:	**Freeway**	**Arterials**		**Collectors**	**Local**
Item		**Principal** **(Nonfreeway)**	**Minor**		
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70	45 to 70	35 to 55	35 to 55
CROSS SECTION					
Lane Width (ft)	12	12	12	Speed Width (ft)/ ADT mph <1500 >1500 ≤ 50 10 12	Speed Width (ft)/ ADT mph <1500 >1500 ≤ 50 10 12
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70	45 to 70	35 to 55 ≥ 55 11 12 [*GB* Ex. 6-5]	35 to 55 ≥ 55 11 12 [*GB* Ex. 5-5]
Shoulder Width (ft)	10 to 12 ft	Volume Width (ft) <400 4 400-1500 6 1500-2000 6	Volume Width (ft) <400 4 400-1500 6 1500-2000 6	Volume Width (ft) <400 2 400-1500 5 1500-2000 6	Volume Width (ft) <400 2 400-1500 5 1500-2000 6
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70 >2000 8 [*GB* Ex. 7-3]	45 to 70 >2000 8 [*GB* Ex. 7-3]	35 to 55 >2000 8 [*GB* Ex. 6-5]	35 to 55 >2000 8 [*GB* Ex. 5-5]
Horizontal Clearance (ft)	30	Volume Min Des 0-750 10 16 750-1500 16 30 ≥ 1500 30	Volume Min Des 0-750 10 16 750-1500 16 30 ≥ 1500 30	10	7 to 10

TABLE 40 (*Continued*)

Class/Subclass: Item	**Freeway**	**Arterials** Principal (Nonfreeway)	**Arterials** Minor	**Collectors**	**Local**
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70	45 to 70	35 to 55	35 to 55
Median Width (ft)	50 to 100 (10 to 30 ft with barrier)	Min: 4 to 6 Preferred: 12 to 30	N/A	N/A	N/A
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70	45 to 70	35 to 55	35 to 55
ALIGNMENT					
Radius (minimum)	See *Green Book (17)*				
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70	45 to 70	35 to 55	35 to 55
Maximum Superelevation (%)	12 8 (when snow and ice conditions prevail)			10 8 (when snow and ice conditions prevail) 12 (aggregate roads)	
Maximum Grade (%)	Speed (mph) / Grade: Lev, Roll, Mou ≥ 60: 3, 4, 5	Speed (mph) / Grade: Level, Rolling, Mount ≥ 60: 3, 4, 5		Speed (mph) / Grade: Lev, Roll, Mou ≥ 60: 5, 6, 8	Speed (mph) / Grade: Lev, Roll, Mou ≥60: 5, 6, --
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70	45 to 70	35 to 55	35 to 55

(*table continues on next page*)

TABLE 40 (*Continued*)

Class/Subclass:	**Freeway**	**Arterials**		**Collectors**	**Local**
Item		**Principal (Nonfreeway)**	**Minor**		
	<60 4 5 6 [*GB* Ex. 8-1]	50-55 4 5 6-7 ≤ 45 5 6 7-8 [*GB* Ex. 7-2]		50-55 6 7 9 40-45 7 8 10 30-35 7 9 10 [*GB* Ex. 6-4]	50-55 6 7-8 10 40-45 7 9 12 25-30 7 10 14 [*GB* Ex. 5-4]
Cross Slope	1.5 to 2 %			high: 1.5 to 2% intermediate 1.5 to 3%	high: 1.5 to 2% intermediate 1.5 to 3%
Anticipated Speed or Speed limit (mph)	55 to 70	55 to 70	45 to 70	35 to 55	35 to 55 low: 2 to 6%

Notes:

GB Ex. = refers to Exhibits in *Green Book (17).*

Speed = previously called design speed, suggested that it reflects the anticipated 85th percentile speed of the roadway.

ADT = anticipated ADT in design year.

anticipated operating speed, the posted speed, the anticipated posted speed plus a set increment such as 5 or 10 mph (8.1 or 16.1 km/h), or the adjusted operating speed as determined using a regression equation and then rounded to nearest 5 mph (8.1 km/h).

It should be noted that there are relationships established that are available to help designers select the anticipated operating speed, if unknown. For instance, if the facility contains traffic signals, there are relationships such as the one shown in Figure 21 that can be used to estimate the operating speed depending on the anticipated signal density and cycle length. Table 38 lists the equations that can be used to calculate the adjusted posted speed with the known posted speed.

Step 4: Look up appropriate design element values using the roadway design class.

The remaining step is to use Tables 39 and 40 to identify the values for the roadway features. These tables also provide a reference to the relevant chapter of the *Green Book*. Additional information may also be contained in a state's design manuals.

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.

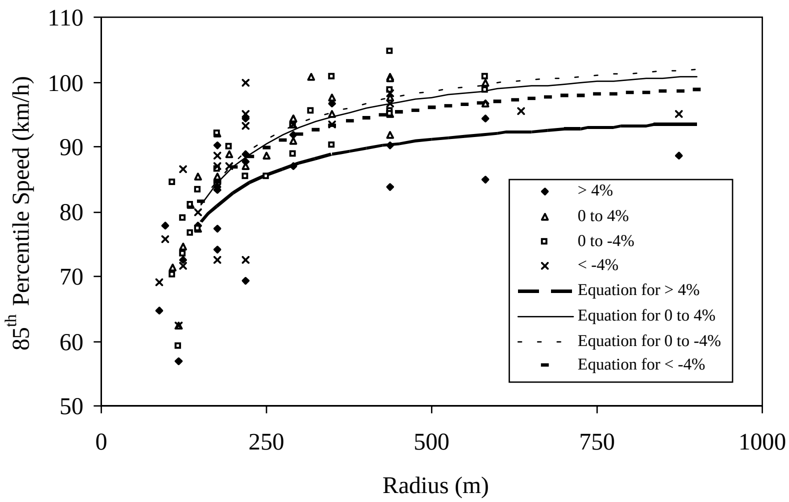
Table 38 lists the regression equations developed for predicting operating speed using posted speed limit. The only variable that had a t-statistic greater than 1 was access density (a t-statistic greater than 1 corresponds to an approximate 20 percent alpha level). Despite the low t-values obtained, 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



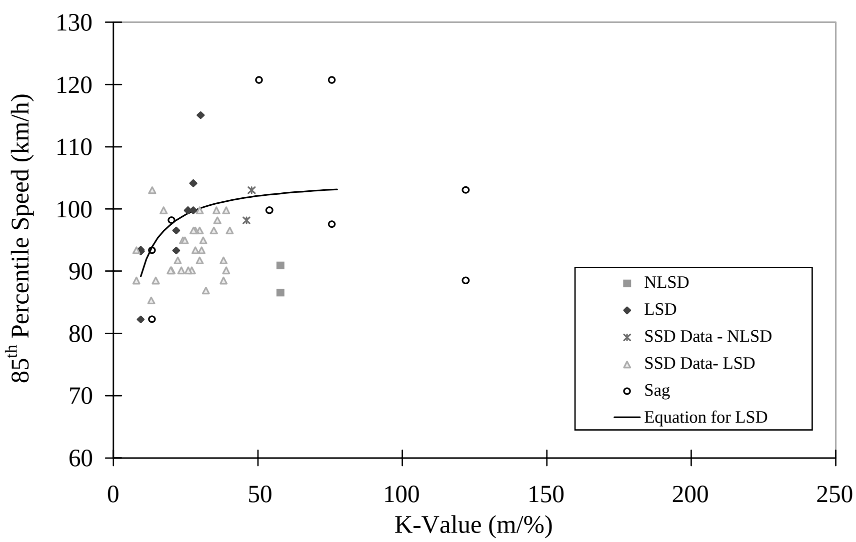
(1 m = 3.28 ft, 1 km/h = 0.62 mph)

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.

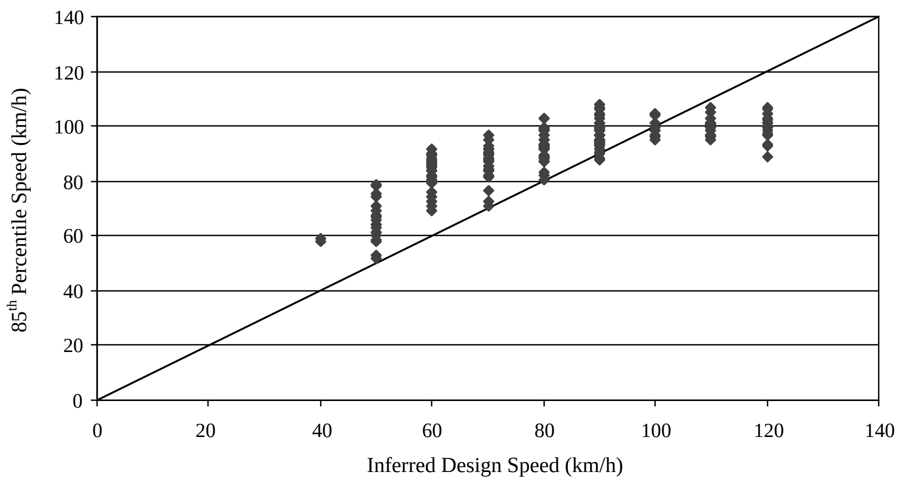
DESIGN SPEED AND POSTED SPEED

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.

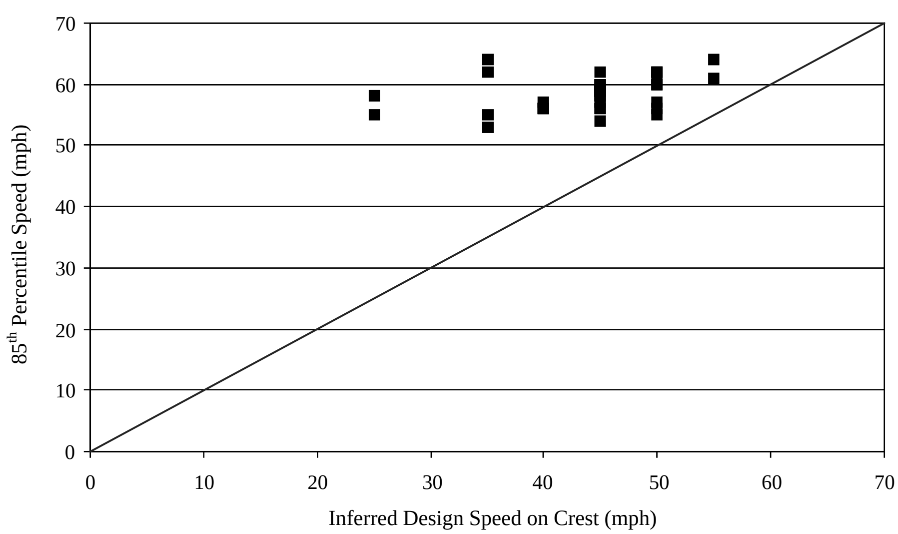
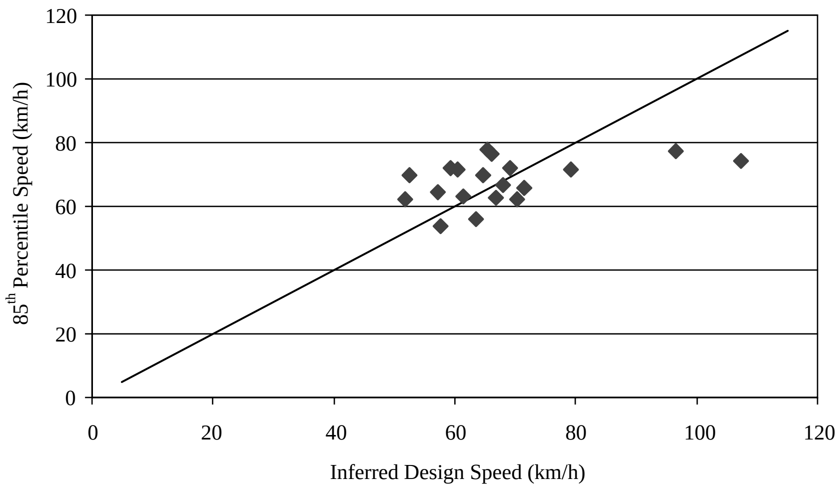


Figure 25. 85th percentile speed versus inferred design speed on rural two-lane highway limited sight distance crest vertical curves.



(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)	Point where 85th percentile speed is approximately equal to inferred design speed (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.

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).

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APPENDIXES

The appendixes are published on the accompanying CD. Their titles and contents are as follows:

Appendix A. Suggested Changes to the *Green Book*. Contains suggested changes to the *Green Book* based on the findings from the research project.

Appendix B. Mailout Survey. Provides the individual findings from the mailout survey and a copy of the original survey.

Appendix C. Design Element Reviews. Discusses the relationship between speed and geometric design elements that were evaluated in three areas: use of design speed, operations, and safety. Also summarizes various definitions for design speed and operating speed.

Appendix D. Previous Relationships Between Design, Operating, and Posted Speed Limit. Identifies the relationships between the various speed terms from the literature.

Appendix E. Field Studies. Presents the methodology and findings from the field studies.

Appendix F. Driving Simulator Study. Presents the findings from a small preliminary study on driver speeds to different functional class roadway scenes.

Appendix G. Selection of Design Speed Values. Identifies approaches being used to select design speed within the states and discusses approaches that could be considered for inclusion in the *Green Book*.

Appendix H. Operating Speed and Posted Speed Relationships. Investigates how 85th percentile speed is being used to set posted speed limit.

Appendix I. Distributions of Roadway and Roadside Characteristics. Identifies the distribution of design elements in two cities for the field data (see Appendix E) by posted speeds and design classes.

Appendix J. Alternatives to Design Process. Presents the alternatives to the design process identified in Phase I of the research.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation