Visibility Research and the Human Factors Guidelines for Road Systems

Christian M. Richard, John L. Campbell, James L. Brown
Battelle Center for Human Performance and Safety

Jerry Graham
Midwest Research Institute

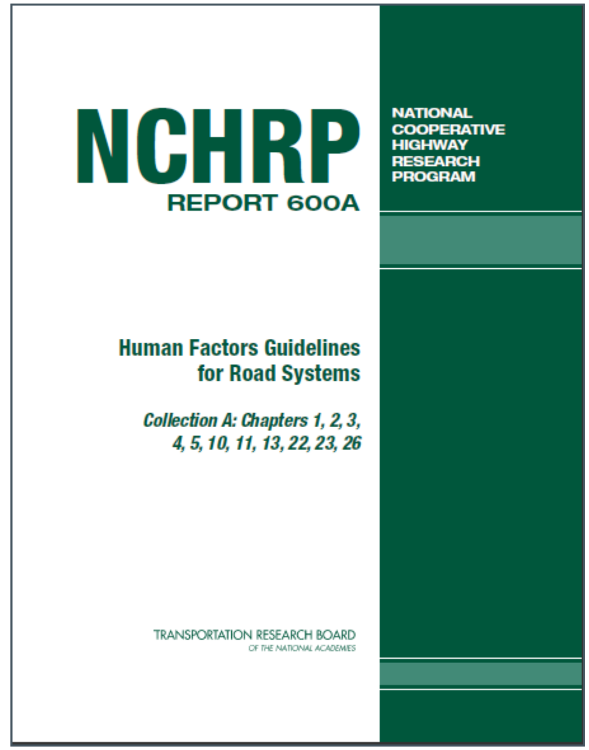
Discussion Topics

- Project Overview
- Conceptual Framework for Guideline Development
- Progress to Date
- Visibility Information in the HFG
- Next Steps

Project Overview

<u>NCHRP Report 600</u>

Human Factors Guidelines for Road Systems (HFG)



Sponsor/COTR: TRB/Chuck Niessner

Phase II, NCHRP 17-31, 2005 –2008

Phase III, NCHRP 17-41, 2008 –2010

Phase I (NCHRP 17-18 (8), 2001-2004) – not Battelle:
Key products were introductory HFG materials and guidelines for Sight Distance

Project Overview

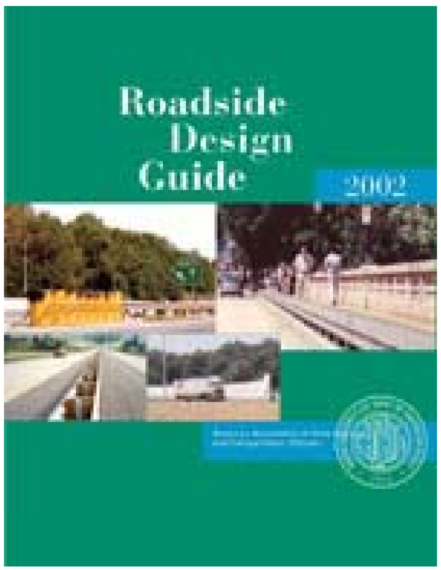
Why do we need Human Factors Guidelines for Road Systems?

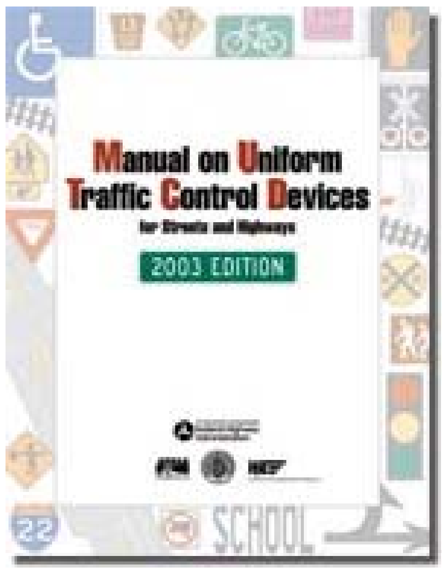
- Existing references for road system design do not always provide highway designers and traffic engineers with adequate guidance for incorporating road user needs, limitations, and capabilities.
- Considerable research exists on road users’ characteristics that is not included in existing reference materials.
- Designers and engineers value and will use factual information and insights on road users’ characteristics to facilitate safe roadway design and operational decisions.

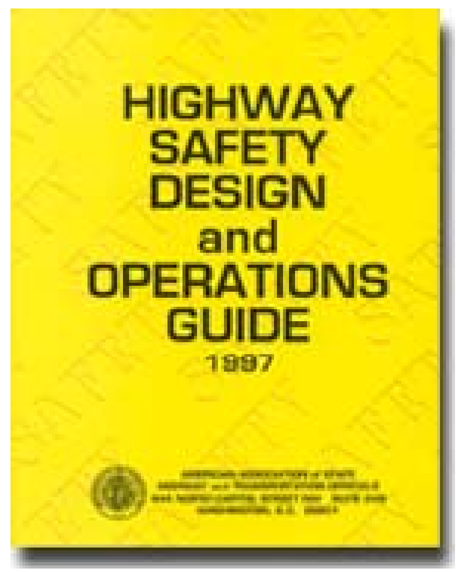
Project Overview

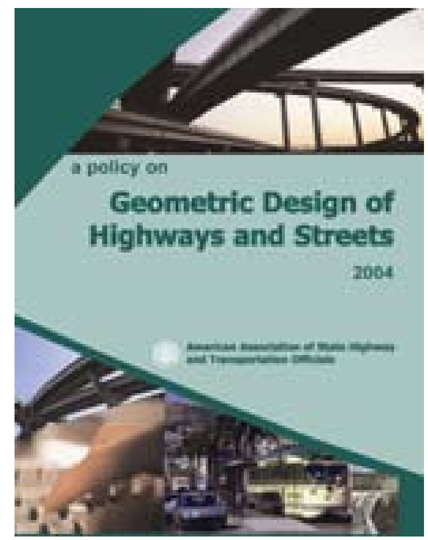
Why do we need Human Factors Guidelines for Road Systems?

- The HFG is intended to complement, not replace, existing sources of road design information.



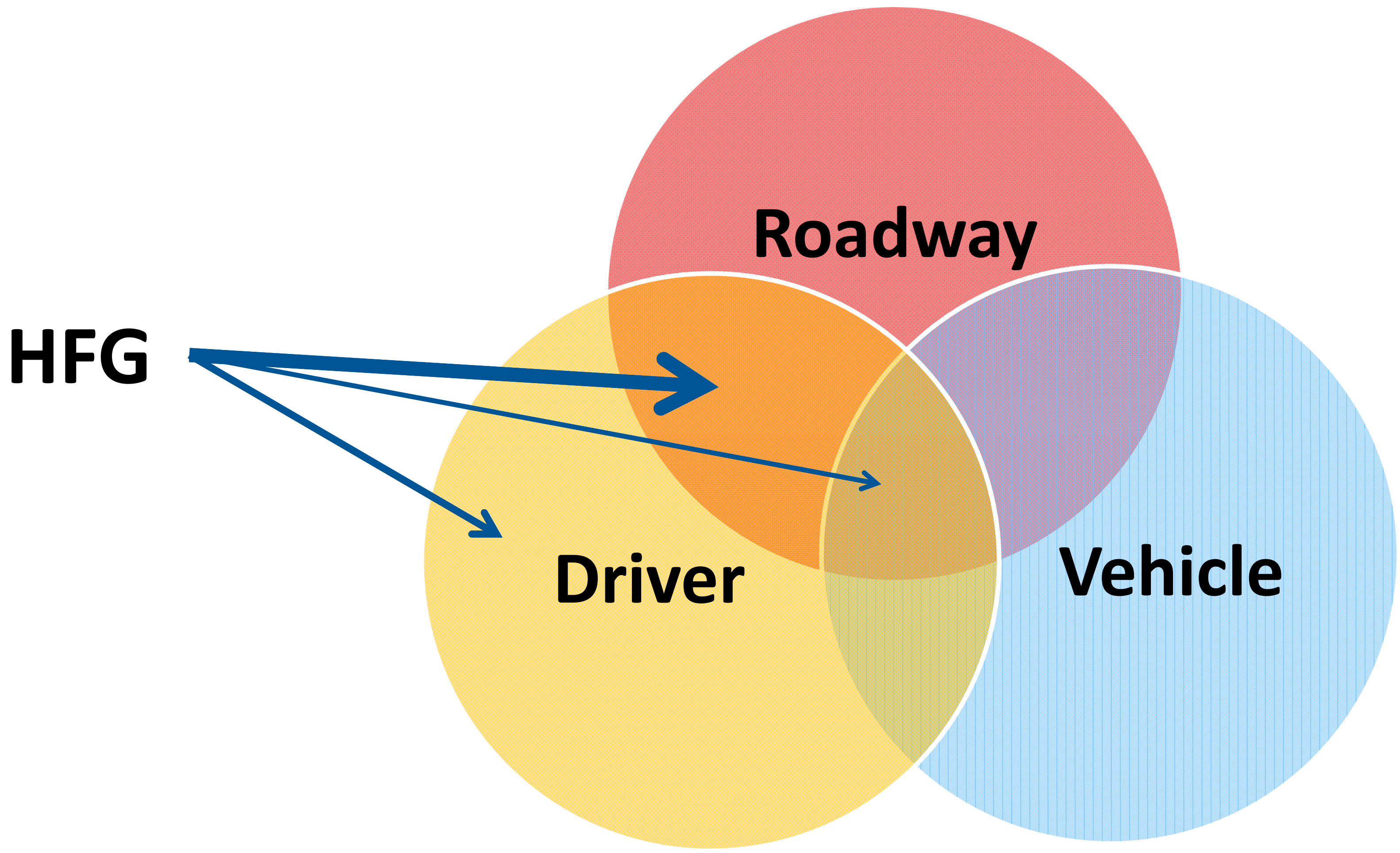






Project Overview

Scope of Human Factors Guidelines



Conceptual Framework for Guideline Development

- **What are human factors guidelines?**
- **Here are some key characteristics:**

1. Principles for system design or requirements for user performance that reflect **user needs, capabilities or limitations**
2. Focused on a specific aspect of system development or design
3. Reflect relevant research or analysis
4. Presented in either quantitative or qualitative terms
5. Often used by non-human factors professionals

Conceptual Framework for Guideline Development

Introduction

Guideline Title

Bar Scale Rating

Abbreviated Chapter Title *(Both Pages)*

Discussion

Design Guideline

Figure, Table, or Graphic

Design Issues

Cross References

References

KEY COMPONENTS OF SIGHT DISTANCE

Introduction

Sight Distance (SD) is the distance that a vehicle travels before completing a maneuver in response to some roadway element or condition that necessitates a change of speed and/or path. Sight Distance is based on two key components:

1) A Reaction Time (RT) required to initiate a maneuver (pre-maneuver phase), and
2) The time required to safely complete a maneuver (Maneuver Time; MT).

The reaction time includes the time needed to see/perceive the roadway element, time needed to complete relevant cognitive operations (e.g., recognize hazard, read sign, decide how to respond etc.), and time needed to initiate a maneuver (e.g., take foot off accelerator and step on brake pedal).

Maneuver Time includes actions and time required to safely coordinate and complete a required driving maneuver (e.g., stop at intersection, pass a vehicle, etc). Typically, a vehicle maintains its current speed and trajectory during the reaction time phase, while changing its speed and/or path during the maneuver time phase.

Design Guidelines

Sight Distance = Distance traveled while driver perceives, makes decisions about, and initiates action in response to roadway element (RT) + Distance traveled while the driver completes an appropriate maneuver (MT)

Based Primarily on Expert Judgment — Based Equally on Expert Judgment and Empirical Data — Based Primarily on Empirical Data

SCHEMATIC SHOWING THE REACTION TIME AND MANEUVER TIME COMPONENTS OF SIGHT DISTANCE

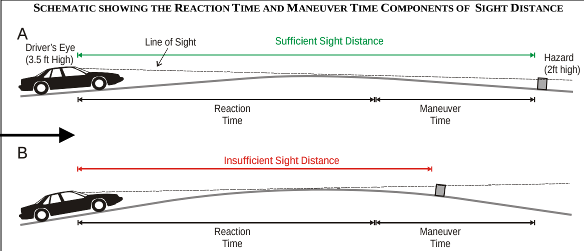


Diagram A: The hazard is visible to the driver far enough away that there is sufficient distance for the driver to recognize and react to the hazard and to complete the maneuver necessary to avoid it.
Diagram B: Because of the steeper vertical crest, the driver's sight distance is shorter than in Diagram A making it possible for a hazard to be hidden from sight until there is insufficient distance to avoid it.
*Note: distances not to scale

Discussion

Before drivers can execute a maneuver, they must first recognize there is a need for some action and decide what that action should be. Therefore, this mental activity–perception, cognition, and action planning–precedes an overt vehicle control action and takes some amount of time. The reaction time is typically defined as the period from the time the object or condition requiring a response becomes visible in the driver's field to view to the moment of initiation of the vehicle maneuver (e.g., first contact with the brake pedal). Although a particular reaction time value (e.g., 2.5 s from AASHTO 2004) is used in deriving sight distance requirements for a given design situation, this "reaction time" value should not be viewed as a fixed human attribute, since it is influenced by many factors. Some the of the key factors that influence reaction time are shown in the table below.

FACTORS THAT AFFECT THE DIFFERENT COMPONENTS OF REACTION TIME

	Factor	Explanation
Seeing/ Perceiving	Low contrast (e.g., night)	It takes longer to perceive low-contrast objects
	Visual glare	Objects are perceived less quickly in the presence of glare
	Older Age	Older drivers less sensitive to visual contrast and are more impaired by visual glare (e.g., oncoming headlights)
	Object size /height	Smaller objects/text require drivers to be closer to see them
	Driver expectations	It takes substantially longer to perceive unexpected objects
	Visual complexity	It takes longer to perceive objects "buried" in visual clutter
Cognitive elements	Older age	Older drivers require more time to make decisions
	Complexity	Drivers require more time to comprehend complex information or situations and to initiate more complex or calibrated maneuvers
Initiating Actions	Older age	Older drivers require more time to make vehicle control movements and they may be limited their range of motion

In contrast to the reaction time, the maneuver time is primarily affected by the physics of the situation, including vehicle performance capabilities. In particular, tire-pavement friction, road-surface conditions (e.g. ice), downgrades, etc. can increase maneuver time or make some maneuvers unsafe at higher speeds. Maneuver time is also affected to a lesser extent by driver-related factors (e.g., deceleration profile), but these factors are highly situation specific since the maneuvers are very different (e.g., emergency stop, passing, left turn through traffic etc.). These factors are covered in more detail in the relevant guideline sections (see GL…).

Design Issues

It is important to note that although most design requirements are expressed as a design *distance*, from the driver's perspective the critical aspect is *time*. It takes time to recognize a situation, understand its implications, decide on a reaction, and initiate the maneuver. While this process may seem almost instantaneous to us when driving, it can translate into hundreds of feet at highway speeds before a maneuver is even initiated. Speed selection is also critical, since the relative speed between the driver and the hazard determines how much distance is traversed in the time it takes the driver to initiate and complete the maneuver (see Speed GL).

Cross References

Specific types of sight distance (pg. 5-X, 5-X…); Greenbook section on calculating sight distance

Curves, Traffic engineering elements (signs), decision sight distance? (these are not currently included as HFG topics)

Key References

None

Left-hand page

Right-hand page

Conceptual Framework for Guideline Development

- **Despite increasing demands for HF design guidance, HF reference material has not been well-received by the system design community**
- **Some human factors heresies:**
  - Designers do not consider user requirements and have little interest in human factors information (Meister & Farr, 1967)
  - Designers find human factors research to be hard to understand (Rouse & Cody, 1988)
  - Relevant design guidance is: seldom available, too wordy, too general, and too hard to understand (Campbell, Rogers, & Spiker, 1990)
  - Human factors information is viewed as costly to obtain, with a low perceived value (Burns & Vicente, 1994)

Conceptual Framework for Guideline Development

Key Assumptions:

- Road system design will proceed with or without human factors inputs to the design process.
- The "best-available" human factors information is better than no HF information at all.
- Users should be able to determine the relative contribution of expert judgment and experience data in design guidelines.
- HF design guidelines are intended to augment, not replace, designer experience, skill, and judgment.

Conceptual Framework for Guideline Development

Key Challenges:

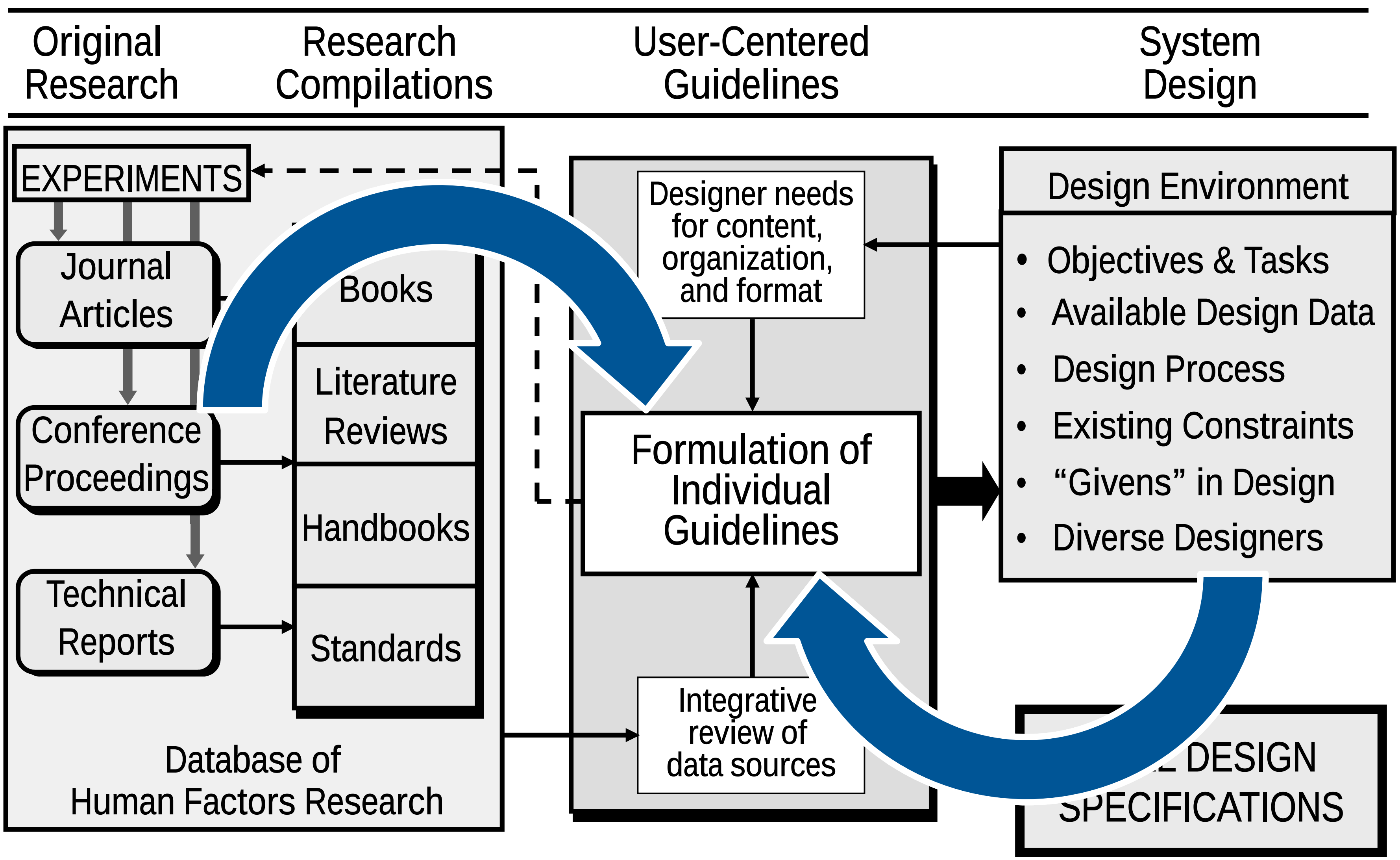
- Identifying appropriate content for the guidelines.
- Lack of directly applicable research data.
- Developing selection criteria for choosing data sources to be used to produce guidelines.
- Variability across guideline users.
- Developing effective guidelines without restricting innovative and effective design.

Conceptual Framework for Guideline Development

Type of research we look for:

- Field tests and on-road studies that show clear quantitative relationships to safety or safety-relevant behaviors are given priority
- Research involving more controlled conditions are acceptable in many case, but these receive closer scrutiny
  - Environmental validity is important, especially for visibility research
  - Lighting and dynamic conditions must be adequately represented

Conceptual Framework for Guideline Development



Progress To Date

Overview of Current HFG Contents

PART I: INTRODUCTION TO THE *HUMAN FACTORS GUIDELINES*

Chapter 1: Why Have Human Factors Guidelines (HFG) for Road Systems?

Chapter 2: How to Use this Document

PART II: BRINGING ROAD USER CAPABILITIES INTO HIGHWAY DESIGN AND TRAFFIC ENGINEERING PRACTICE

Chapter 3: Finding Information Like a Road User

Chapter 4: Integrating Road User, Highway Design, and Traffic Engineering Needs

Progress To Date

Overview of Current HFG Contents

PART III: HUMAN FACTORS GUIDANCE FOR ROADWAY LOCATION ELEMENTS

Chapter 5: Sight Distance Guidelines (8)

Chapter 6: Curves (Horizontal) (6) *

Chapter 10: Non-signalized Intersections (5)

Chapter 11: Signalized Intersections (4)

Chapter 13: Construction and Work Zones (6)

*** Not included in NCHRP 600A, included in NCHRP 600B**

Progress To Date

Overview of HFG Contents

PART V: ADDITIONAL INFORMATION

Chapter 22: Tutorials

- Tutorial 1: Real-World Driver Behavior Versus Design Models
- Tutorial 2: Diagnosing Sight Distance Problems and Other Design Deficiencies
- Tutorial 3: Detailed Task Analysis of Curve Driving*

Chapter 23: References

*** Not included in NCHRP 600A, included in NCHRP 600B**

Progress To Date

Phase III Chapter Development

PART III: HUMAN FACTORS GUIDANCE FOR ROADWAY LOCATION ELEMENTS

Chapter 16: Special Considerations for Rural Environments

Chapter 17: Speed Perception, Speed Choice, and Speed Control

Chapter 18: Signing

Chapter 19: Changeable Message Signs

Chapter 20: Markings

Visibility Information in HFG

- Scope of Vision-related information in HFG
  - **Detection** (e.g., visibility and visual salience of signs and markings)
  - **Perception** (e.g., speed/distance perception, curve perception)
  - **Cognitive aspects** (e.g., sign reading, visual scanning)

Visibility Information in HFG

- How visibility information is presented in the HFG
  1. Specific guidelines, e.g.:
     - "6-4: The influence of Perceptual Factors on Curve Driving"
     - "13-2: Procedures to Ensure Proper Arrow-Panel Visibility"
  2. Discussion or design issues related to other guidelines
     - Often a human factors issue is impacted by visual aspects
     - "5-2 Key Components of Sight Distance"
       - Describes the effects of low contrast, glare, visual complexity, etc on perception reaction times
  3. Tutorials
     - Task analyses of curve driving and gap judgment across traffic

Visibility Information in HFG: Detection

Procedures to Ensure Proper Arrow-Panel Visibility

Introduction

Arrow panel visibility is dependent on a number of factors, including the capability of the lamps in the panel, the type of roadway, the physical location of the panel, and its relation to horizontal and vertical curves, ambient light, and weather. Procedures to insure arrow panel visibility should include specifications for the arrow panel as well as field procedures to check in-service arrow panels.

Design Guidelines

Arrow Panel Specifications:
Recommended Photometric Requirements

Time of Day	Speed (mi/h)	Minimum On-Axis		Minimum Off-Axis		Maximum On-Axis
		cd/lamp	cd*	cd/lamp	cd*	cd*
Day	≥ 45	500	4000	100	800	NA
Night	≥ 45	150	1200	30	240	5500

*Intensity requirements for the entire panel when displaying a left or right flashing arrow (10 lamps illuminated)
Source: Reference 1.
Cd (Candela: the SI base unit of luminous intensity)

Angularity Requirements:
- Minimum angularity permitted for a Type C (high speed and high volume roads) arrow panel should be +/- 4 degrees in horizontal plane (8 degree beam width) and +/- 3 degrees in the vertical plane (6 degree beam width).

Field Procedures:
- Use of Luminance to Intensity Measurements.
- Arrow should be oriented to be recognizable from 1500 ft even in curves (see Figure below).

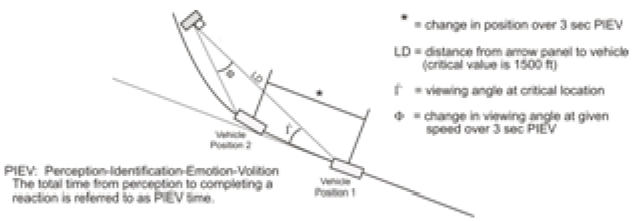
Effect of Arrow Panels:
- In lane closures, arrow boards produced almost-ideal lane changing patterns.
- In traffic diversions, arrow boards produced some unnecessary lane changing.
- Arrow boards had little effect on traffic operations in moving shoulder closures on freeways.

Panel Luminous Intensity:
- Field test resulted in recommendations of 4000cd/panel as the minimum on-axis daytime intensity, 800cd/panel as the minimum daytime off-axis intensity and a maximum nighttime on-axis intensity of 5500cd/panel.

Flash Rate:
- 25-40 flashes per minute

Based Primarily on Expert Judgment | Based Equally on Expert Judgment and Empirical Data | Based Primarily on Empirical Data

Viewing Angle on Horizontal Curve (Adapted from Reference 1)



Discussion

Human factors studies conducted as part of this research are discussed in detail in Reference 2.

In Reference 3, the effect of arrow panels was judged in three situations: (1) when a lane is closed, (2) in diversions where traffic is shifted, but lanes are not closed, and (3) for shoulder work zones.

Findings:

1. In lane closures, the presence of an arrow board produced lane changing patterns that are closer to ideal. In other words, the arrow board encouraged drivers to leave the closed lane sooner and, consequently, fewer lane changes occurred close to the lane closure taper.
2. In traffic diversions, arrow boards produced some unnecessary lane changing; however, the number of these lane changes was small, particularly at night and for truck traffic. In traffic splits, the arrow board caused vehicles to either remain in or move to the right lane, and decreased conflicts involving vehicles changing lanes near the split.
3. Arrow boards had little effect on traffic operations in moving shoulder closures on freeways. Conflicts due to slow-moving vehicles were greater when the caution-bar mode was used.
4. No differences were detected in the effect of various arrow board modes such as the flashing arrow or sequential chevron (Reference 4).

Reference 1 conducted a field test to examine requirements for panel luminance intensity and recommended:

- Minimum nighttime on-axis intensity of 150 cd/lamp luminance.
- Minimum nighttime off-axis intensity of 30 cd/lamp luminance is recommended.
- Researchers recommend a minimum daytime on-axis intensity of 500 cd/lamp luminance.
- Minimum daytime off-axis intensity of 100 cd/lamp luminance is recommended.
- If arrow panels are located on curves, they should be oriented to be seen by a vehicle 1500 ft downstream.
- The arrow panel should be realigned to be perpendicular to the driver's line of sight at the distance desired for observation.
- Field test resulted in recommendations of 4000cd/panel as the minimum on-axis daytime intensity, 800cd/panel as the minimum daytime off-axis intensity and a maximum nighttime on-axis intensity of 5500cd/panel.

Design Issues:

Field conditions such as fog or a high level of ambient light (advertising signs) might impact the visibility of the arrow panel in the field.

Reference 5 notes that the arrow panel should flash at a rate of 25-40 flashes per minute.

Cross References:

Caution Mode Configuration for Arrow Panels, 13-4
Determining When to Use Decision Sight Distance, 5-8

Key References:

1. Wooldridge, M.D., Finley, M., Denholm, J., Mace, D., and Patrick, B. (2001). *Photometric Requirements for Arrow Panels* (Report No. TX-02/4940-1). College Station: Texas A&M University.
2. Knapp, B. and Pain, R. (1979). Human Factors Considerations in Arrow-Board Design and Operation, *Transportation Research Record 703*, 1-8.
3. Graham, J.L., Migletz, J., and Glennon, J.C. (1978). *Guidelines for the Applications of Arrow Boards in Work Zones* (FHWA Report No. RD-79-58). Washington, DC: Federal Highway Administration.
4. Federal Highway Administration (FHWA). (2003). *Manual on Uniform Traffic Control Devices (MUTCD)*. Washington, DC: Author.
5. Mace, D., Finkle, M., and Pennack, S. (2001). Guidelines for the Effective Use and Procurement of Advanced Warning Arrow Panels. *NCHRP Research Results Digest 259*.

Visibility Information in HFG: Detection

Design Guidelines

Arrow Panel Specifications
Recommended Photometric Requirements

Time of Day	Speed (mi/h)	Minimum On-Axis		Minimum Off-Axis		Maximum On-Axis
		cd/lamp	cd[a]	cd/lamp	cd[a]	cd[a]
Day	$\geq$ 45	500	4000	100	800	NA
Night	$\geq$ 45	150	1200	30	240	5500

[a] Intensity requirements for the entire panel when displaying a left or right flashing arrow (10 lamps illuminated)
Source: Reference 1.
Cd (Candela: the SI base unit of luminous intensity)

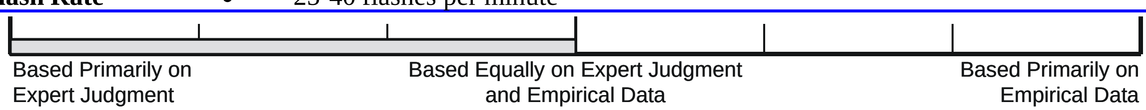
Angularity Requirements
- Minimum angularity permitted for a Type C (high speed and high volume roads) arrow panel should be +/- 4 degrees in horizontal plane (8 degree beam width) and +/- 3 degrees in the vertical plane (6 degree beam width).

Field Procedures
- Use of Luminance to Intensity Measurements.
- Arrow should be oriented to be recognizable from 1500 ft even in curves (see Figure below).

Effect of Arrow Panels
- In lane closures, arrow boards produced almost-ideal lane changing patterns.
- In traffic diversions, arrow boards produced some unnecessary lane changing.
- Arrow boards had little effect on traffic operations in moving shoulder closures on freeways.

Panel Luminous Intensity
- Field test resulted in recommendations of 4000cd/panel as the minimum on-axis daytime intensity, 800cd/panel as the minimum daytime off-axis intensity and a maximum nighttime on-axis intensity of 5500cd/panel.

Flash Rate
- 25-40 flashes per minute



Visibility Information in HFG: Perception

The Influence of Perceptual Factors on Curve Driving

Introduction

The perceptual factors in curve driving refer to the driver's use of visual information to assess the curvature of an upcoming curve. This is an important activity because a driver's perception of an upcoming curve's radius forms the primary basis for making speed and path adjustments prior to curve entry. The curve radius as seen from the driver's perspective is called the *Apparent Radius*. Although drivers will use speed information from signs, in practice, driver speed selection in curves is heavily influenced by roadway features (*1*), and the apparent radius appears be the primary determining factor of speed at curve entry (*2*). The primary design challenge regarding curve perception is that the apparent radius can appear distorted - either flatter or sharper - depending on the topography and other road elements. Of particular concern are combination curves that include a vertical sag superimposed on a horizontal curve. From the driver's perspective, this combination makes the horizontal curve appear flatter than it actually is (See figure A below). Consequently, drivers may be inclined to adopt a curve entry speed that is faster than appropriate based on horizontal curvature alone.

Design Guidelines

Sag horizontal curves that have a visual appearance (apparent horizontal radius) that is substantially different from the plan radius should be given careful consideration because they may lead to curve entry speeds that are faster than expected based on horizontal curvature alone.

Based Primarily on Expert Judgment — Based Equally on Expert Judgment and Empirical Data — Based Primarily on Empirical Data

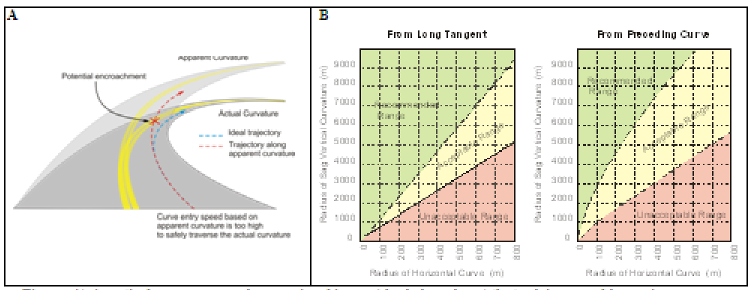


Figure: A) A vertical sag curve produces a visual image (shaded roadway) that a driver would perceive as having an apparent radius that is larger than the actual radius. B) Nomographs indicating vertical and horizontal curve radius combinations that result in apparent radii that may result in curve entry speeds that are unintentionally faster than expected based on horizontal curvature alone (red shaded region), and which possibly represent a safety risk (*2*).

Note that the nomographs present vertical curvature in terms of radius (in meters) and not K, which is the typical approach for representing vertical curvature. The reason for presenting curvature as a radius is that the geometric calculations for computing visual distortion rely on circular arcs. The nomographs can be used to provide a "rule of thumb" check for potentially problematic curve combinations assuming the vertical curvature component can be generally approximated by a circle with an arc intersecting the low point of Type III curves and Vertical Points of Curvature on both sides.

Discussion

Curve perception is an important part of curve driving because in the absence of extensive experience with a curve, drivers must rely on their judgments about a curve to select a safe speed for curve entry. Speed signage information can assist drivers, however, evidence suggests that this information is not a primary source for speed selection in curves (*1*). This leaves driver expectations (influenced by design consistency), and the visual information they obtain about the curve as the primary basis for speed selection.

Sag horizontal curves can cause drivers to significantly underestimate the sharpness of a curve because of a visual distortion from the driver's viewing perspective. In these sag horizontal curves, the apparent radius appears to be longer than the plan radius, and they are also associated with higher entry speeds and crash rates (*2, 3*).

The optical aspects of this phenomenon have been derived analytically, and the results were used to make the nomographs presented on the previous page. Horizontal and vertical curve radius combinations that fall in the Unacceptable Range are associated with significant visual distortion, and also associated with higher than 85th percentile speeds and higher crash rates (*2*). Note that this validation is based on European data, and these findings have not been investigated on US roads. However, the optical properties of this phenomenon are universal and should be equally applicable to all drivers (*4*). This analytical work also assumes a 75 m viewing distance, which is comparable to the start of the Curve Discovery phase of curve driving, in which drivers spend most of their time inspecting the curve. Distortion effects may be reduced somewhat at further viewing distances; however, assuming a 75 m viewing distance is consistent with driver behavior and is more conservative.

Visual distortion also occurs when crest vertical curves are superimposed on horizontal curves, which makes these curves appear sharper than the plan radius. This typically results in slower 85th percentile entry speeds (*2, 3*). However, a crest horizontal curve that has a vertical curvature that approximates a circular radius of *less than 3 times* the horizontal curve radius, could result in a visual image of the curve that is discontinuous (e.g., the part of the roadway just behind the crest is occluded) (*2*). This is potentially inconsistent with driver expectations, and could compromise roadway safety by causing drivers to suddenly brake hard if they are surprised by the curve appearance. However, there are currently no empirical data showing that this is an actual safety issue.

Design Issues

A summary of the relevant research findings regarding curve perception in general and the corresponding degree of empirical support is shown in the table below. While no specific values or recommendations can be made for these aspects, it is useful to take them into consideration during curve design, especially if other aspects of the curve design suggest that there may be a potential problem with the driver's perception of the actual curve radius.

Aspect	Effect	Empirical Support
Superimposed Vertical Sag	- Makes a curve appear flatter	Strong
Cross slope	- For sag horizontal curves, the greater cross slope and lane width the greater the apparent flattening of the horizontal curve	Analytical evidence
Superimposed Vertical Crest	- Makes a curve appear sharper and may cause discontinuities in curve	Strong
Deflection Angle	- Holding radius constant, greater deflection angle makes the curve appear sharper, especially for smaller radii	Moderate
Delineators	- Delineators provide drivers with more information to judge the curve radius, which improves accuracy of these judgments	Moderate
Spiral	- May make curve appear flatter, or make curve perception more difficult, since the onset of the curve is less apparent	Indirect
Signage	- Drivers perceive curve as "riskier" if signs indicate that the curve is hazardous	Suggestive

Cross References

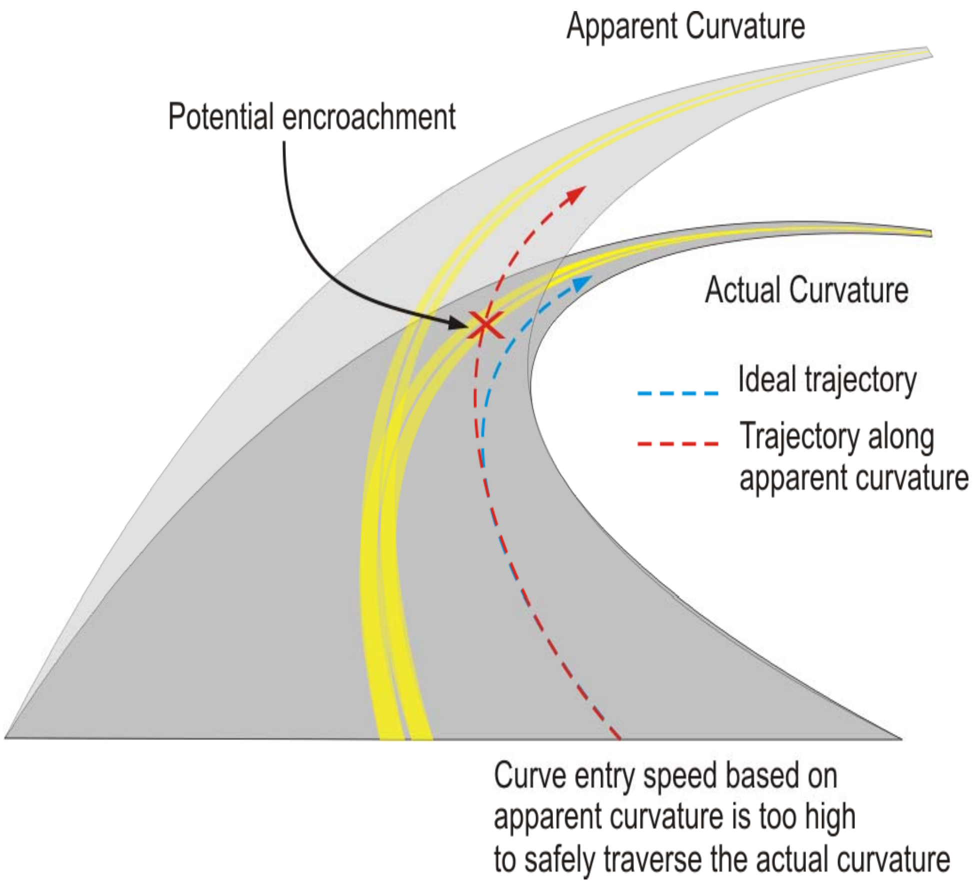
Task Analysis of Curve Driving, 6-2

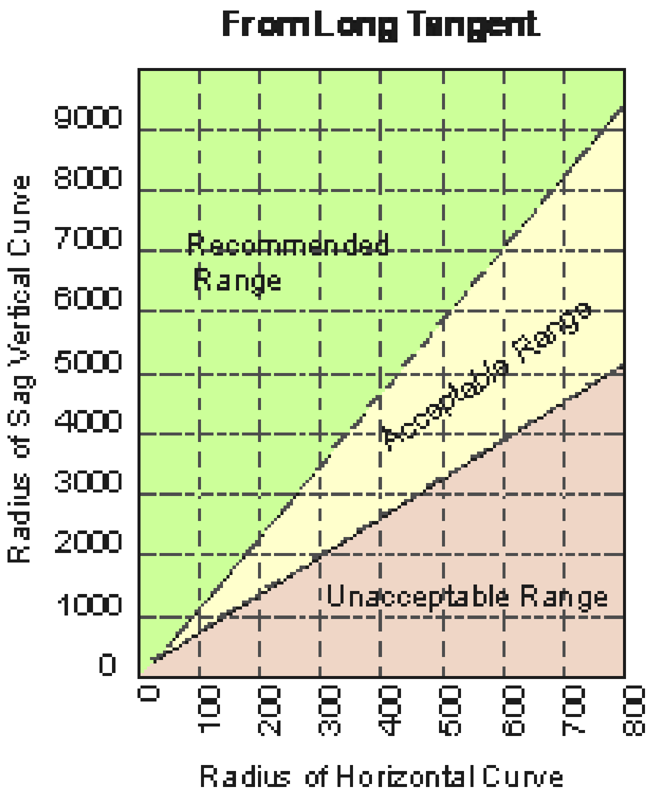
Key References

1. Fitzpatrick et al. (1997). *Design Speed, Operating Speed, and Posted Speed Practices* (NCHRP Report 504). Washington DC: Transportation Research Board.
2. Appelt, V. (2000). New Approaches to the Assessment of the Spatial Alignment of Rural Roads - Apparent Radii and Visual Distortion. *Proceedings of the 2nd International Symposium on Highway Geometric Design* (pp. 620-631). Cologne, Germany: Verlag.
3. Hassan, Y., & Easa, S. M. (2003). Effect of Vertical Alignment on Driver Perception of Horizontal Curves. *Journal of Transportation Engineering, 129*(4), 399-407.
4. Bidulka, S., Sayed, T., & Hassan, Y. (2002). Influence of Vertical Alignment on Horizontal Curve Perception: Phase I: Examining the Hypothesis. *Transportation Research Record, 1796*, 12-23.

Visibility Information in HFG: Perception

The Influence of Perceptual Factors on Curve Driving





Visibility Information in HFG: Cognitive Aspects

TASK ANALYSIS OF CURVE DRIVING

Introduction

This guideline identifies the basic activities that drivers would typically perform while trying to safely navigate a single horizontal curve. This information is useful because, 1) it can help identify segments of the curve driving task that are more demanding, and require the driver to pay closer attention to basic vehicle control and visual information acquisition, and 2) it identifies the key information and vehicle control requirements in different parts of the curve driving task. This information has design implications since workload is influenced by design aspects such as design consistency, degree of curvature, and lane width. In particular, identifying high workload components of the curve driving task provides an indication of where drivers could benefit from making their driving tasks easier to perform (e.g., clearer roadway delineation, wider lanes, longer radius), or benefit from the elimination of potential visual distractions.

Design Guidelines

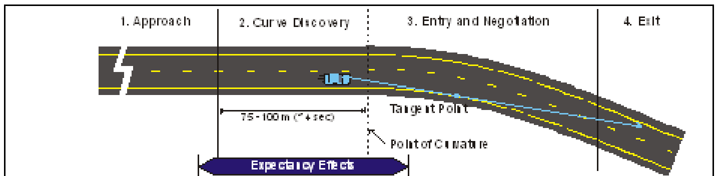
Because drivers have higher visual demands during curve entry and navigation - especially with sharp curves - curves should be designed to minimize additional workload imposed on drivers. Driver visual demands are greatest just before and during curve entry and navigation because drivers typically spend most of their time looking at the immediate roadway for vehicle guidance information.

Some General Implications for the Design of Horizontal Curves

- Avoid presenting visually complex information (e.g., that requires reading and/or interpretation) within 75-100 m or 4-5 sec of the point of curvature, or within it.
- Key navigation and guidance information, such as lane markings and delineators/reflectors, should be clearly visible in peripheral vision, especially under nighttime conditions.
- Minimize the presence of nearby visual stimuli that are potentially distracting (e.g., signage/advertisements that "pop out" or irregular/unusual roadside scenery/foliage).
- Visual demands appear to be linearly related to curve radius and unrelated to deflection angle. Curves with a curvature of 9 degrees or greater are highly demanding relative to more gradual curves.

Based Primarily on Expert Judgment | Based Equally on Expert Judgment and Empirical Data | Based Primarily on Empirical Data

The figure and table below show the different curve segments, as well as key driving tasks and constraints.



	1. Approach	2. Curve Discovery	3. Entry and Negotiation	4. Exit
Key Driving Tasks	1.1 Locate Bend 1.2 Get available speed information from signage 1.3 Make initial speed adjustments	2.1 Determine curvature 2.2 Assess roadway conditions 2.3 Make additional speed adjustments 2.4 Adjust path for curve entry	3.1 Adjust speed based on curvature/lateral acceleration 3.2 Maintain proper trajectory 3.3 Maintain safe lane position	4.1 Accelerate to appropriate speed 4.2 Adjust lane position
Visual Demands & info sources	Low/flexible - Primarily environment driven	Med. Increasing to High - Curvature perception cues - observing roadway conditions	High - Most fixations to tangent point	Low - Vehicle position information
Effective info modes	- Advisory/message signs	- Non-verbal (e.g. chevrons) and direct info (e.g., delineators)	- Direct info only (lane markings; raised markers)	- No constraints
Vehicle-control demands	- None	- Anticipatory positioning - Curve cutting	- Continuous heading adjustments	- Lane position adjustments
Primary Speed Influences	Previous roadway elements & signage	Expectations & curvature cues	Expectations & lateral acceleration	Posted speed or Expectations

Discussion

The information about driving tasks in the previous page is taken from the task analysis described in Tutorial X that breaks down curve driving into its perceptual, cognitive, and psychomotor components. A key concept for understanding the curve driving task is the visual and vehicle-control demand, which refers to the amount of time that drivers are required to focus their attention on curve-driving activities, such as acquisition of visual information and maintaining vehicle control, to the exclusion of other activities they could otherwise be doing while driving (e.g., scanning for hazards, viewing scenery, changing the radio station, etc.).

Visual Demands refer to the time and effort that drivers typically spend acquiring information needed to safely navigate a curve. During the Approach phase, visual demand is low and driven primarily by environment factors (e.g., other vehicles, viewing scenery). During Curve Discovery, visual demands increase to high levels at the Point of Curvature, as drivers scan the curve for information that they need to judge the degree of curvature. Visual demands are highest just after the Point of Curvature (Entry and Negotiation segment) and drivers spend most of their time looking at the Tangent point to keep their vehicle aligned with the roadway (*1, 2, 3*). For more gradual curves (e.g., 3 degrees), drivers spend more time looking towards the forward horizon than the Tangent Point (*3*).

Vehicle Control Demands refer to the driver workload imposed by the need to keep the vehicle safely within the lane. Visual demand is minimal up through the end of the Curve Discovery phase, at which point many drivers will adjust their lane position to facilitate curve cutting. Demands are highest during Curve Entry and Negotiation as drivers must continuously adjust the vehicle trajectory to stay within the lane. Moreover, these demands are higher for curves with a shorter radii and smaller lane width (*1*). During the Exit phase, drivers may adjust their lane position with minimal time pressure, unless there is another curve ahead.

Effective Information Modes refer to the type of curve-related sign/delineator information that is most likely to be useful to drives in each curve segment. During the approach, drivers have fewer visual demands and have more time available to read more complex signs, such as speed advisory signs. During the Curve Discovery stage, conspicuous non-verbal information, such as Chevrons, are more effective because drivers spend more time examining the curve and have less time available to read, comprehend, and act on text-based information. During Entry and Negotiation, drivers spend most of their time looking at the Tangent Point, and only direct information presented where they are looking (e.g., lane markings) or information that can be seen using peripheral vision (e.g., raised reflective marking at night) should be relied upon to communicate curve information.

Speed Selection: Driver expectancy and speed-advisory sign information form the primary basis for speed selection, however, the effectiveness of advisory information may be undermined by expectancy and roadway cues (*4*). Curve perception also plays an important role in speed selection, and inappropriate curvature judgments (e.g., in sag horizontal curves). Once in the curve, lateral acceleration felt by drivers and likely vehicle handling workload provide the primary cues for adjusting speed.

Expectancy Effects: Driver expectations about a curve, and more broadly design consistency, are an important factor in drivers' judgments about curvature, and corresponding speed selection during the Curve Discovery phase (*1*). While direct cues, such as lane width and the visual image of the curve influence speed selection, expectations based on previous experience with the curve and roadway (e.g., previous tangent length) also significantly influence speed selection (*4*). Mitigations to recalibrate driver expectancies (e.g., via signage) would likely be most effective prior to the Curve Discovery phase.

Design Issues

Visual demands appear to be related linearly and inversely to curve radius, but not to deflection angle. Curves sharper than 9 degrees are significantly more demanding than shallower curves or tangents, however, there is no clear, unambiguous threshold regarding what constitutes a sharp curve based on workload data (*1, 2*). Also, curve direction does not seem to affect workload (*2*).

Additionally, it is unclear whether the 75-100 m length of the Curve Discovery stage is based on distance or time. The primary studies that investigated visual demand used the same fixed 45 mph travel speed, so it is currently unknown whether the 75-100 m fore-distance applies with other speeds (*1, 2*).

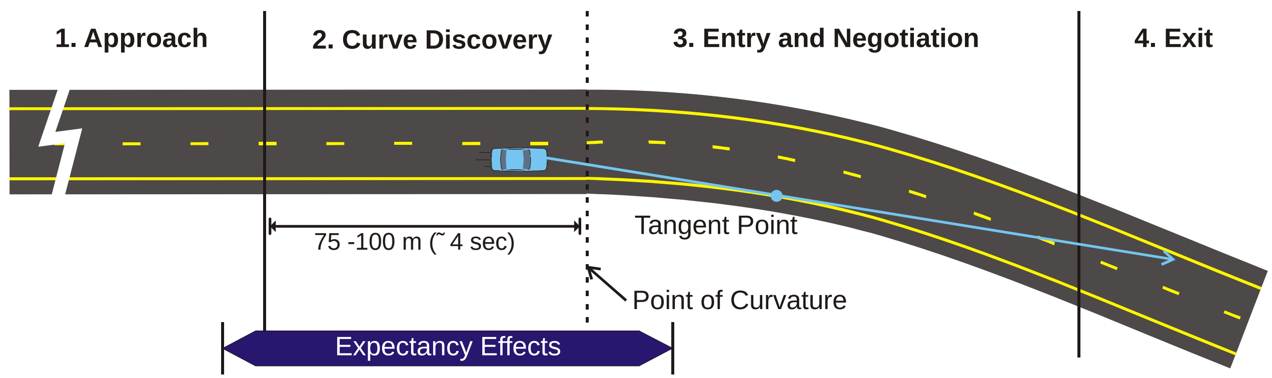
Cross References

The Influence of Perceptual Factors on Curve Driving, 6-4
Speed Selection on Horizontal Curves, 6-6
Countermeasures for Improving Steering and Vehicle Control on Curves, 6-8
Countermeasures to Improve Pavement Delineation, 6-10
Signs on Horizontal Curves, 6-12

Key References

1. Krammes, R. A., Brackett, R. Q., Shafer, M. A., Ottesen, J. L., Anderson, I. B., Fink, K. L., et al. (1995). *Horizontal Alignment Design Consistency for Rural Two-Lane Highways. Final Report.* (Report No. FHWA-RD-94-034). McLean, VA: Federal Highway Administration.
2. Fitzpatrick, K., Wooldridge, M. D., Tsimhoni, O., Collins, J. M., Green, P., Bauer, K. M., et al. (2000). *Alternative Design Consistency Rating Methods for Two-Lane Rural Highways.* (Report No. FHWA-RD-99-172, Final Report). McLean, VA: Federal Highway Administration.
3. Serafin, C. (1994). *Driver Eye Fixations on Rural Roads: Insight Into Safe Driving Behavior. Interim Report.* (Report No. UMTRI-94-21). Ann Arbor: University of Michigan Transportation Research Institute.
4. Fitzpatrick et al. (1997). *Design Speed, Operating Speed, and Posted Speed Practices* (NCHRP Report 504). Washington DC: Transportation Research Board.

Visibility Information in HFG: Cognitive Aspects



	1. Approach	2. Curve Discovery	3. Entry and Negotiation	4. Exit
Key Driving Tasks	1.1 Locate 1.2 Get available speed information from signage 1.3 Make initial speed adjustments	2.1 Determine curvature 2.2 Assess roadway conditions 2.3 Make additional speed adjustments 2.4 Adjust path for curve entry	3.1 Adjust speed based on curvature/lateral acceleration 3.2 Maintain proper trajectory 3.3 Maintain safe lane position	4.1 Accelerate to appropriate speed 4.2 Adjust lane position
Visual Demands & info sources	**Low/flexible** - Primarily environment driven	**Med. increasing to High** - Curvature perception cues - observing roadway conditions	**High** - Most fixations to tangent point	**Low** - Vehicle position information
Effective info modes	- Advisory/message signs	- Non-verbal (e.g. chevrons) and direct info (e.g., delineators)	- Direct info only (lane markings; raised markers)	- No constraints
Vehicle-control demands	- None	- Anticipatory positioning - Curve cutting	- Continuous heading adjustments	- Lane position adjustments
Primary Speed Influences	Previous roadway elements & signage	Expectations & curvature cues	Expectations & lateral acceleration	Posted speed or Expectations

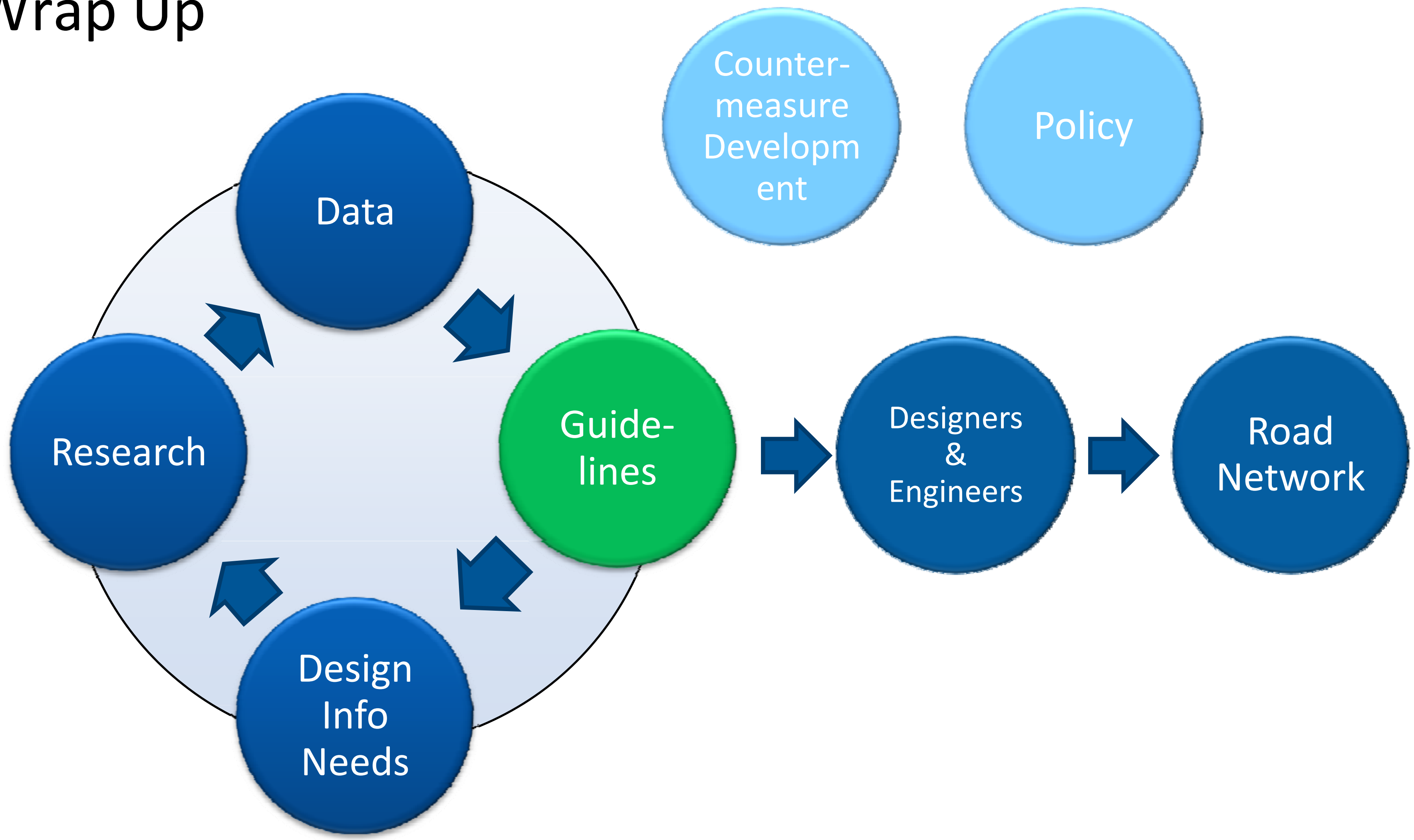
Next Steps: Focus for Phase III

- Chapters currently under development in Phase III of the HFG effort:
  - Chapter 16: Special Considerations for Rural Environments
  - Chapter 17: Speed Perception, Speed Choice, and Speed Control
  - Chapter 18: Signing
  - Chapter 19: Changeable Message Signs
  - Chapter 20: Markings

Next Steps: Future Chapters

- Future Chapters will also cover visibility information in details, especially the last set of Chapters (shown in bold)
  - Chapter 7, Grades (Vertical)
  - Chapter 8, Tangent Sections and Roadside (Cross Section)
  - Chapter 9, Transition Zones Between Varying Road Designs
  - Chapter 12, Interchanges
  - **Chapter 14, Rail-Highway Grade Crossings**
  - **Chapter 15, Special Considerations for Urban Environments**
  - **Chapter 21, Lighting**

Wrap Up


Counter-
measure
Developm
ent
Policy
Data
Research
Guide-
lines
Designers
&
Engineers
Road
Network
Design
Info
Needs

For More Information…

- NCHRP Report 600B
  http://www.trb.org/news/blurb_detail.asp?id=9867
- Project 17-41 (Phase III) website
  http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=1635
- Christian M. Richard, Battelle
  - 206-528-3249
  - richardc@battelle.org
- John L. Campbell, Battelle
  - 206-528-3254
  - campjohn@battelle.org
- Chuck Niessner, NAS/NCHRP
  - 202-334-1431
  - CNiessner@nas.edu