Visibility Research and the Human Factors Guidelines for Road Systems

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Discussion Topics

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

NCHRP Report 600
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
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

- Roadway
- Driver
- Vehicle

HFG
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
Introduction

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 manual activity—perception, cognition, and action planning—precedes an event where 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 of the key factors that influence reaction time are shown in the table below:

- Low contrast (e.g., night)
- Old age
- Complexity
- Presence of glare
- Size of objects/text
- Speed
- Maneuver time
- Vehicle control

**Factors that affect the different components of reaction time**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low contrast (e.g., night)</td>
<td>It takes longer to perceive low-contrast objects</td>
</tr>
<tr>
<td>Older age</td>
<td>Older drivers require more time to process visual information</td>
</tr>
<tr>
<td>Object size</td>
<td>Smaller objects require drivers to be closer to see them</td>
</tr>
<tr>
<td>Driver expectations</td>
<td>Drivers require more time to recognize unexpected objects</td>
</tr>
<tr>
<td>Visual complexity</td>
<td>Visionally complex environments require more time for detection</td>
</tr>
<tr>
<td>Cognitive demands</td>
<td>Drivers require more time to comprehend complex information or situations</td>
</tr>
<tr>
<td>Actions</td>
<td>Older drivers require more time to initiate desired maneuvers</td>
</tr>
</tbody>
</table>

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 in speed and/or path. Sight Distance is based on two key components:

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

The reaction time includes the time needed to recognize the roadway element or condition, time needed to complete relevant cognitive operations (e.g., recognize hazard, read signs, 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.

**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.

**Visual glare** Objects are perceived less quickly in the presence of glare.

**Older Age** Older drivers are more sensitive to visual contrast and are more likely to experience glare.

**Seeing/Design** Older drivers require more time to make decisions.

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 course of action, 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 ER).
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

**Original Research**
- **EXPERIMENTS**
  - Journal Articles
  - Conference Proceedings
  - Technical Reports

**Research Compilations**
- Books
- Literature Reviews
- Handbooks
- Standards

**User-Centered Guidelines**
- Designer needs for content, organization, and format

**System Design**
- **Design Environment**
  - Objectives & Tasks
  - Available Design Data
  - Design Process
  - Existing Constraints
  - “Givens” in Design
  - Diverse Designers

**FINAL DESIGN**
- Integrative review of data sources

**SPECIFICATIONS**
- Database of Human Factors Research
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
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**

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, its relation to horizontal and vertical curves, ambient light, and the time of day. Adequate visibility at arrow panels is essential for proper alignment and functioning of traffic signs and signals.

### Arrow Panel Specifications

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<tbody>
<tr>
<td>Day</td>
<td>15</td>
<td>1000</td>
<td>100</td>
<td>4000</td>
<td>600</td>
</tr>
<tr>
<td>Night</td>
<td>60</td>
<td>20</td>
<td>20</td>
<td>80</td>
<td>120</td>
</tr>
</tbody>
</table>

- **Visibility Requirements:**
  - Minimum intensity required for the arrow panel when displaying a left or right flashing arrow (50% of lamps illuminated).
  - **Recommended Treatment:**
    - **Lamp Intensity:**
      - Minimum intensity, recommended at a 1200 ft. radius, is 1000 lumens.
      - Aiming points should be 1200 ft. from the panel for proper visibility.

### Design Considerations

- **Luminance:**
  - Maximum luminance for a Type C high-speed and high-volume rural area panel should be -4 degrees in horizontal plane and -3 degrees in the vertical plane (3 degree beam width).

### Field Procedure:

- **Effect of Arrow Panels:**
  - Field test results are consistent with the recommendations of 400000 cd per panel as the minimum on-axis intensity and a maximum nighttime on-axis intensity of 120000 cd per panel.

### Design Considerations

- **Environmental Conditions:**
  - Outdoor conditions such as fog or smoke creating a low visibility environment may impact the visibility of traffic signs.

### Cross References:

- [American National Standards Institute (ANSI), 1974](#)
  - Determining the Use of the Eight Second Design.

### Key References:

   - Lighting Design, 2400 W. Main St., Suite 200, Cincinnati, OH 45217.
2. [Hays, W.H.](#)
   - Lighting Design, 2400 W. Main St., Suite 200, Cincinnati, OH 45217.
3. [Hays, W.H.](#)
   - Lighting Design, 2400 W. Main St., Suite 200, Cincinnati, OH 45217.
4. [Hays, W.H.](#)
   - Lighting Design, 2400 W. Main St., Suite 200, Cincinnati, OH 45217.

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**Diagram:**

- **Viewing Angle:**
  - Horizontal Curve: 50° change in position over 3 sec PIEV.
  - Vertical Curve: (critical value is 1500 ft).

**PIEV:**

- Perception-Identification-Emotion-Vision
  - The total time perceived by the observer is referred to as PIEV time.

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**Design Considerations:**

- **Luminance:**
  - Minimum luminance, recommended at a 1200 ft. radius, is 1000 lumens.
  - Aiming points should be 1200 ft. from the panel for proper visibility.

**Field Procedure:**

- **Effect of Arrow Panels:**
  - Field test results are consistent with the recommendations of 400000 cd per panel as the minimum on-axis intensity and a maximum nighttime on-axis intensity of 120000 cd per panel.
Visibility Information in HFG: Detection

### Design Guidelines

#### Arrow Panel Specifications

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Speed (mi/h)</th>
<th>Minimum On-Axis</th>
<th>Minimum Off-Axis</th>
<th>Maximum On-Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>cd/lamp</td>
<td>cd°</td>
<td>cd/lamp</td>
</tr>
<tr>
<td>Day</td>
<td>&gt; 45</td>
<td>500</td>
<td>4000</td>
<td>100</td>
</tr>
<tr>
<td>Night</td>
<td>≥ 45</td>
<td>150</td>
<td>1200</td>
<td>30</td>
</tr>
</tbody>
</table>

*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 unoccupied curve. This is an important activity because it drives the temptation of an unoccupied curve's radius forms the perimeter value for blocking 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 use speed information from signs, in practice, drivers use speed information in curves is largely determined by environmental factors (A), and the apparent radius is affected by the primary determining factors of speed at curve entry (B). The primary design challenge is that curve perception is that the apparent radius for a given value of curve radius, depending on the longitudinal and other road elements. Optimal design is determined by the characteristics of the curve that includes visual and symptoms on a horizontal curve. From the driver's perspective, this mechanism requires the horizontal curve appear sharper than it actually is (see Figure A below). Consequently, curves may need to adopt a curve entry speed that is faster than appropriate based on horizontal curve data.

Design Guidelines

- Curve Relief Plan
- Sound Checking Segments
- Transition Design

Discussion
Curve perception is an important part of curve driving because the absence of extensive experience with a curve, drivers may rely on their judgment about a curve to select a safe speed for curve entry. Speed and angle information can assist drivers, however, evidence suggests that the information is not a primary source of speed selection in curves. This leaves drivers exposed to the chance of becoming too fast, and the visual information they obtain about the curve as a temporary basis for speed selection.

Horizontal curves cause drivers to underestimate the sharpness of a curve because of visual distortion from the vehicle's dimensioning perspective. In these top horizontal curves, the apparent radius appears to be larger than the plan radius, and they are also slower and with higher entry speeds and crack rates (C, D). The optimal properties of this phenomenon have been derived statistically, and the results were used to modify the nomograph presented in the previous page. Horizontally and vertically curved radius combinations that fall in the insensitive range are associated with significant visual distortions, and also associated with higher than 57% percentile speeds and higher crash rates (E). Note that this validation is based on European data, and these findings have not been investigated on US roads. However, the optimal properties of this phenomenon are universal and should be equally applicable in all design (F). This analytical work also assumes a 7.5 m passing distance, which is consistent with the use of the Curve Design for share of curve driving, in which drivers spend most of their time adapting their curves. Additionally, there are no specific standards specific to horizontal curves; however, assuming a 7.5 m passing distance is consistent with driver behavior and is more conservative.

Visual design also contains more vertical curves are superimposed on horizontal curves, which makes these curves appear sharper than the plan radius. This typical result is for horizontal 57% percentile speeds (G, H). Apart from a curve, a curve has a critical feature that appears as a critical value of data input (I). Even the design curve radius and critical value of data input (J). This is primarily consistent with driver behavior, and could be compensated with speed reduction by making drivers to consider other data if they are surprised by the curve appearance. However, these are currently unexplored data showing that this is an actual safety issue.

Design Plans
A summary of the relevant research, design guidelines curve perception is present, and the corresponding design support should be included in the table below. Within an specific value of horizontal curve data can be made from 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.

Cross References
Task Analysis of Curve Driving 6-2

Key References
Visibility Information in HFG: Perception

The Influence of Perceptual Factors on Curve Driving

- Apparent Curvature
- Actual Curvature
- Potential encroachment
- Ideal trajectory
- Trajectory along apparent curvature

Curve entry speed based on apparent curvature is too high to safely traverse the actual curvature.
Visibility Information in HFG: Cognitive Aspects

**TASK ANALYSIS OF CURVE DRIVING**

**Introduction**

This article identifies the basic activities that drivers would typically perform while driving a curve on a single-lane road. This information is useful because, if we help identify the critical aspects of curve driving behavior, we can reduce the risk. We then divide the curve driving task into two main phases: the search phase, where the driver identifies the curve, and the perceptual task, where the driver navigates the curve. In particular, identifying high-resolution components of the curve driving task provides an indication of what devices and search stages best suit the cognitive aspects of curve driving. In this section, we define visibility and interpret some of the key ideas that inform the design of visibility. The key ideas are divided into four categories: (1) how well drivers can see the curve, (2) how drivers process the visual information, (3) how drivers react to the visual information, and (4) how drivers interact with the visual information.

**Design Guidelines**

Because drivers have a given visual demands during curve entry and exit, a combination of single lane curves should be designed to minimize additional workload imposed on drivers. Curve visual demands are greater prior to and during curve entry and exit, and because of the increase in visibility demands, visual demands can be minimized by using visual aids. The following paragraphs are based on the visibility demands.

- **Some General Implications for Design of Horizontal Curves.**

  - **Visional Function:** Visual attention (e.g., through visual feedback) is required at the critical points of the curve or the vision. This attention is required during the search phase, where the driver identifies the curve. During the search phase, the driver needs to look at the curve to identify the curve's shape and ensure that it is visible. This attention is required during the perceptual phase, where the driver navigates the curve. During the perceptual phase, the driver needs to look at the curve to identify the curve's shape and ensure that it is visible. This attention is required during the execution phase, where the driver interacts with the curve. During the execution phase, the driver needs to look at the curve to identify the curve's shape and ensure that it is visible.

- **Specific Implications for Design of Vertical Curves.**

  - **Visional Function:** Visual attention (e.g., through visual feedback) is required at the critical points of the curve or the vision. This attention is required during the search phase, where the driver identifies the curve. During the search phase, the driver needs to look at the curve to identify the curve's shape and ensure that it is visible. This attention is required during the perceptual phase, where the driver navigates the curve. During the perceptual phase, the driver needs to look at the curve to identify the curve's shape and ensure that it is visible. This attention is required during the execution phase, where the driver interacts with the curve. During the execution phase, the driver needs to look at the curve to identify the curve's shape and ensure that it is visible.

**The Figure and Table above show the different curve segments, as well as key driving tasks and contexts.**

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**Design Remarks**

Visual demands are relatively low at low speeds and increase as speed increases. However, the effective visual demands are not significantly different across speeds. The effective visual demands are not significantly different across speeds.

**Cross References**

- The Influence of Visual Information on Curve Driving, 84
- Speed Selection for Horizontal Curves, 84
- Environmental Factors Affecting Visibility, 84
- Psychological Aspects of Curve Driving, 84
- A New Approach to Curve Design, 84
- Cognitive Aspects of Visibility, 84
- Key References:
Visibility Information in HFG: Cognitive Aspects

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<thead>
<tr>
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<tbody>
<tr>
<td><strong>Key Driving Tasks</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1.1 Locate</td>
<td>2.1 Determine curvature</td>
<td>3.1 Adjust speed based on curvature/lateral acceleration</td>
<td>4.1 Accelerate to appropriate speed</td>
</tr>
<tr>
<td>1.2 Get available speed information from signage</td>
<td>2.2 Assess roadway conditions</td>
<td>3.2 Maintain proper trajectory</td>
<td>4.2 Adjust lane position</td>
</tr>
<tr>
<td>1.3 Make initial speed</td>
<td>2.3 Make additional speed adjustments</td>
<td>3.3 Maintain safe lane position</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.4 Adjust path for curve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expectancy Effects</td>
<td>Tangent Point</td>
<td>Point of Curvature</td>
<td></td>
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<tbody>
<tr>
<td><strong>Low/flexible</strong></td>
<td>Low/flexible</td>
<td>Med. increasing to High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Primarily environment driven</td>
<td>Curvature perception cues</td>
<td>Most fixations to tangent point</td>
<td>- Vehicle position information</td>
<td></td>
</tr>
<tr>
<td><strong>Effective info modes</strong></td>
<td>Advisory/message signs</td>
<td>Non-verbal (e.g. chevrons) and direct info (e.g., delineators)</td>
<td>Direct info only (lane markings; raised markers)</td>
<td>No constraints</td>
</tr>
<tr>
<td><strong>Vehicle-control demands</strong></td>
<td>None</td>
<td>- Anticipatory positioning</td>
<td>- Continuous heading adjustments</td>
<td>- Lane position</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Curve cutting</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary Speed Influences</strong></td>
<td>Previous roadway elements &amp; signage</td>
<td>Expectations &amp; curvature cues</td>
<td>Expectations &amp; lateral acceleration</td>
<td>Posted speed or Expectations</td>
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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

Data

Countermeasure Development

Policy

Guidelines

Designers & Engineers

Road Network

Research

Design Info Needs
For More Information…

• NCHRP Report 600B

• Project 17-41 (Phase III) website
  http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=1635

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