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TRANSPORTATION RESEARCH BOARD

Geometric Highway Design Process for the 21st Century

Tuesday, August 22, 2017
2:00-3:30 PM ET

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

Purpose

Discuss NCHRP Research Report 839: A Performance-Based Highway Geometric Design Process

Learning Objectives

At the end of this webinar, you will be able to:

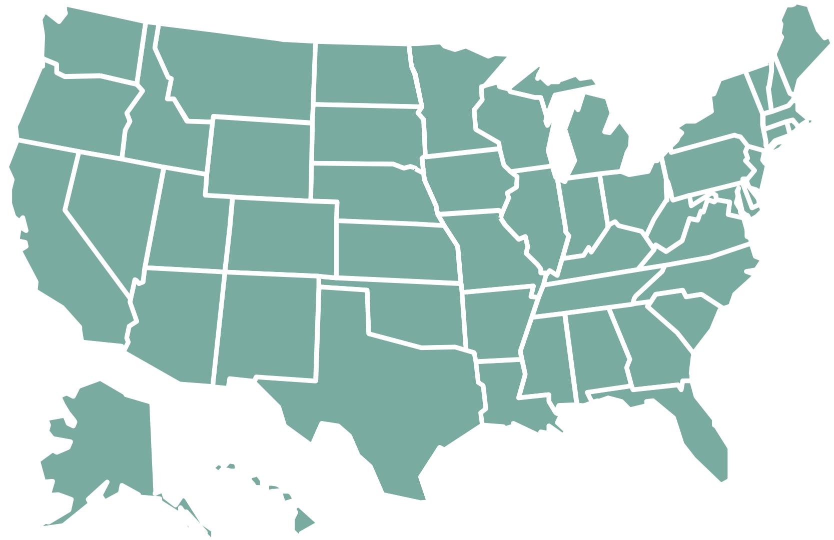
- Understand the historic evolution of design policies and project development, and how fundamental changes in the approach have become both possible as well as necessary
- Identify the basic differences among new alignment projects, reconstruction projects, and resurfacing, restoration, and rehabilitation projects.
- Understand how to objectively define the context of a project, and how that context influences the approach to highway design project development
- Understand how to directly incorporate advances in the science of highway safety into project development

NCHRP Research Report 839: Geometric Highway Design Process for the 21st Century

NCHRP Project 15-47

NCHRP is a State-Driven Program

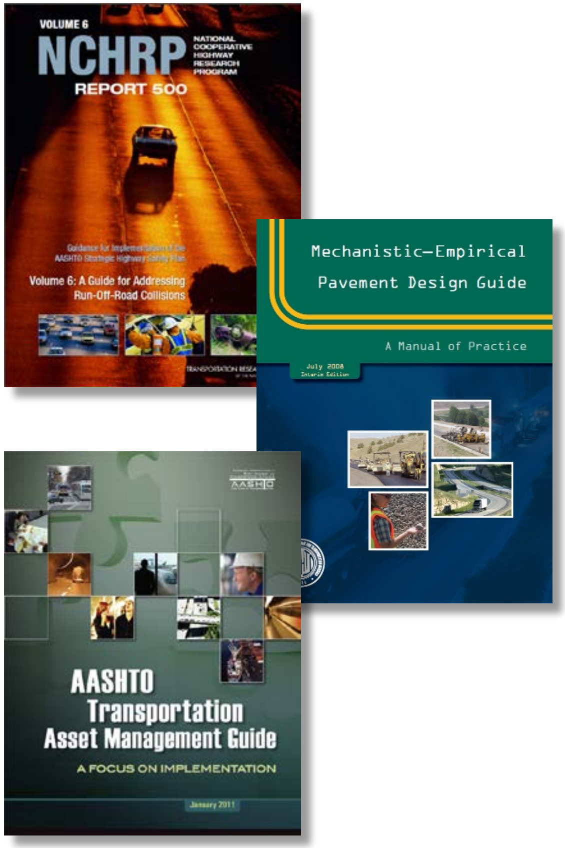
- Sponsored by individual state DOTs who
  - Suggest research of national interest
  - Serve on oversight panels that guide the research.



- Administered by TRB in cooperation with the Federal Highway Administration.

Practical, ready-to-use results

- Applied research aimed at state DOT practitioners
- Often become AASHTO standards, specifications, guides, syntheses
- Can be applied in planning, design, construction, operations, maintenance, safety, environment



Today's Speakers

- *Timothy R. Neuman*
- *Richard C. Coakley*
- *Barton A. Thrasher*

Geometric Design Process for the 21st Century

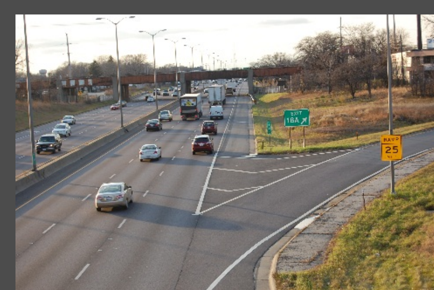
NCHRP 839 - Webinar

August 22, 2017

Richard C. Coakley, PE, PTOE

Timothy R. Neuman, PE

Bart Thrasher, PE



NCHRP

RESEARCH REPORT 839

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

A Performance-Based Highway Geometric Design Process

TRB TRANSPORTATION RESEARCH BOARD
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Project Team and Panel

CH2M

- Tim Neuman
- Richard Coakley
- Srikanth Panguluri
- Richard Storm

MRI Global

- Doug Harwood
- Ingrid Potts

Panel

Barton Thrasher
Anthony Buczek
Daniel Dulaski
James Gattis
Deanna Maifield
Peter Martin
Hugh McGee
Dennis Toomey
Ms. Lilly Shoup
Brooke Struve
Dale Widner
Ray Derr

Webinar Learning Objectives

- Understand the evolution of design policies and project development
- Learn the basic differences among
  - New alignment projects
  - Reconstruction projects
  - 3R projects
- Learn how the context influences the project development
- Gain understanding of how to incorporate advances in the AASHTO Highway Safety Manual into project development

Introduction
NCHRP 15-47
An Improved Geometric Design Process

The recommended geometric design process reflects an understanding of:

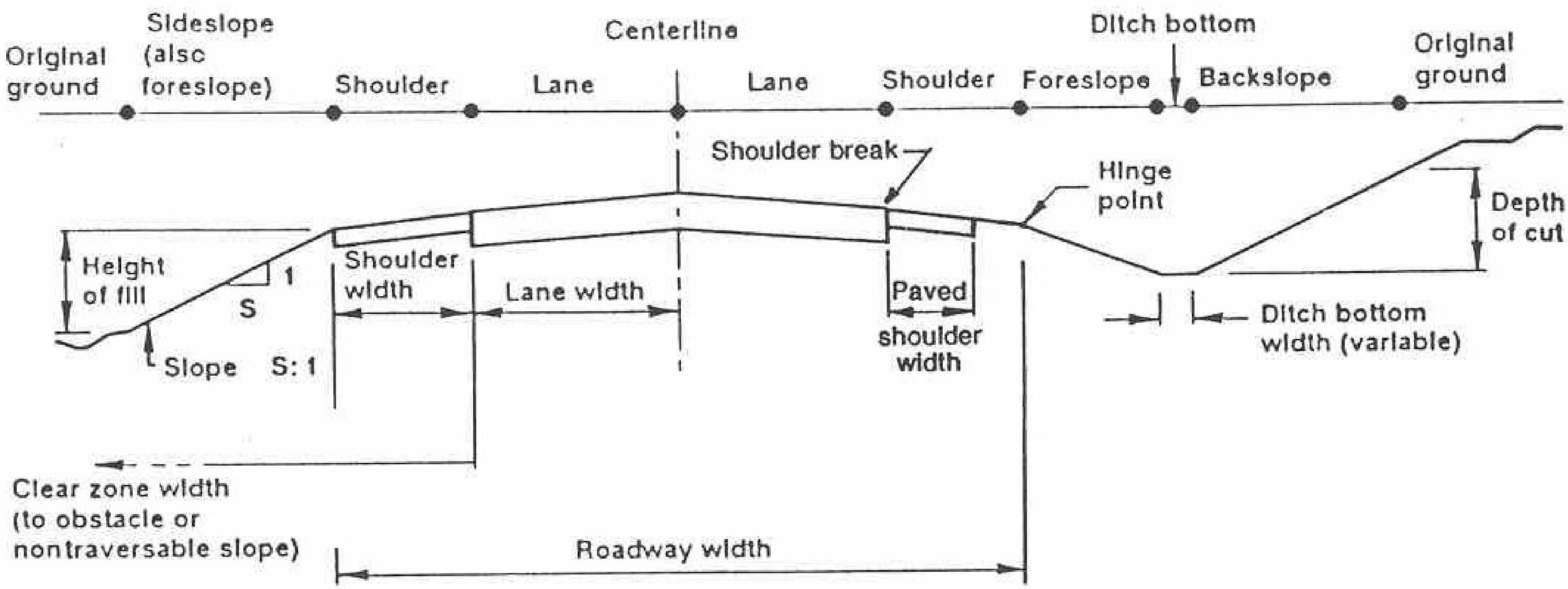
- History of highway design
- Growth in knowledge of design effects on roadway performance,
- Changes in emphasis and importance of road design and all road users
- Legal framework that shapes implementation of public infrastructure,
- Advances in technology that facilitate roadway design
- Growing and seemingly permanent condition of limited resources for
  - Construction
  - Operation
  - Maintenance of roads

‘During the past 60 years, transportation needs have changed and much has been learned about the relationships among geometric design, vehicle fleet, human factors, safety, and operations. AASHTO has continually updated its policies to respond to these changes, but such updates have provided limited changes to the fundamental process or basic design approaches.... An assessment of the current design process is needed to ensure that recent advances in knowledge (e.g., the AASHTO Highway Safety Manual) and emerging issues (e.g., complete streets, flexible design) are appropriately addressed.’

Early Research Findings

Important Insights for the Design Process	Alternative Design Processes and Initiatives									
	Complete Streets	CSS	Perfomance-Based Design	Practical Design	Design Matrix	Safe Systems	Travel Time Reliability	Value Engineering	Designing for 3R	Designing for VLVLR
Roads serve more than just motor vehicles	●	●								
Road design involves many different disciplines	●	●	●			●		●	○	
Context matters and it varies	●	●	○	○	●	○	○	○		●
Performance (operational, safety) is important		○	●	●	●	●	●	○		
Performance may have many dimensions	●	●	●	●	●		●	○	○	
Safety performance should focus on elimination or mitigation of severe crashes			○	○	○	●		○		○
Speed and crash severity are closely linked			●			●				
Existing roads with known problems are different from new roads				●	●				●	○
Traditional design approaches (full application of AASHTO criteria) are believed by professionals to yield suboptimal results	●	●		●	●			○		
Focusing on identifying and addressing the problem(s) should be central to developing design solutions	○	○	●	●	●		○	●	○	
Safety risk and cost-effectiveness are related to traffic volumes			●		●				○	●

What is the purpose of geometric design? Of each of the elements of the road?



Fundamental Bases for Roadway Design

Roadway design projects begin with a stated transportation problem. The purpose of geometric design is to provide the necessary three-dimensional framework for a facility to address the problem by providing the appropriate service to the users.

Dimensional and other design standards and criteria are a means to an end. The end is transportation performance, such performance to include mobility, accessibility, safety, and state-of-good repair.

Solving objectively defined transportation problems is the reason for any and every project

Replacement of infrastructure in disrepair

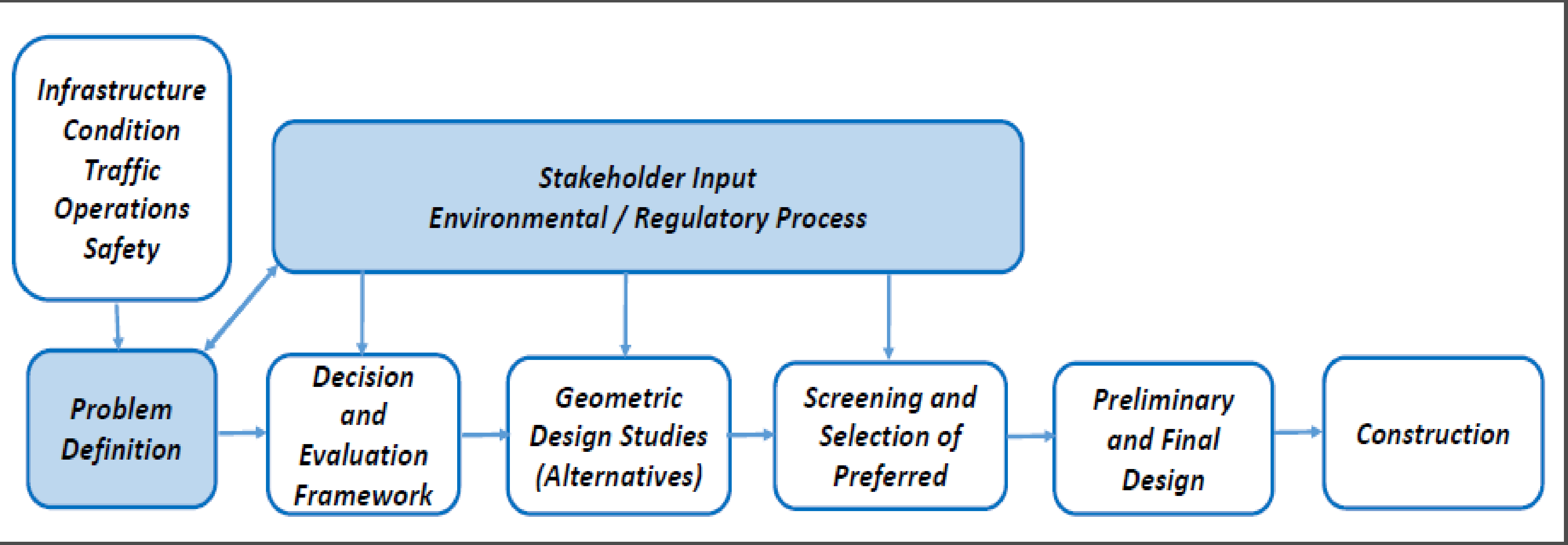
Mobility or traffic operational problems; and accessibility

Safety problems (crash prevention and/or severity mitigation)

Attributes of an Effective Geometric Design Process

- Efficiently conducted
- Scalable
- Executed by properly trained professionals
- Transparent to all stakeholders
- Defensible

Simplified Geometric Design Process



Recommended Highway Design Process

- Step 1: Define the Transportation Problem or Need
- **Step 2: Identify and Charter All Project Stakeholders**
- Step 3: Develop the Project Scope
- **Step 4: Determine the Project Type and Design Development Parameters**
- **Step 5: Establish the Project's Context and Geometric Design Framework**
  - Framework for Geometric Design Process – New/Reconstruction
  - Develop Project Evaluation Criteria w/in Context Framework
  - Establish Decision-making Roles and responsibilities
  - Determine Basic Geometric Design Control – Design or Target Speed
  - **Determine Basic Design Controls**
    - Design Traffic Volumes, Design LOS, Road User Attributes

Recommended Highway Design Process

- **Step 6: Apply the Appropriate Geometric Design Process and Criteria**
- **Step 7: Designing the Geometric Alternatives**
- Step 8: Design Decision-Making and Documentation
- Step 9: Transitioning to Preliminary and Final Engineering
- Step 10: Agency Operations and Maintenance Database Assembly
- Step 11: Continuous Monitoring and Feedback to Agency Processes and Database

Geometric Design Context and Framework (Step 5)

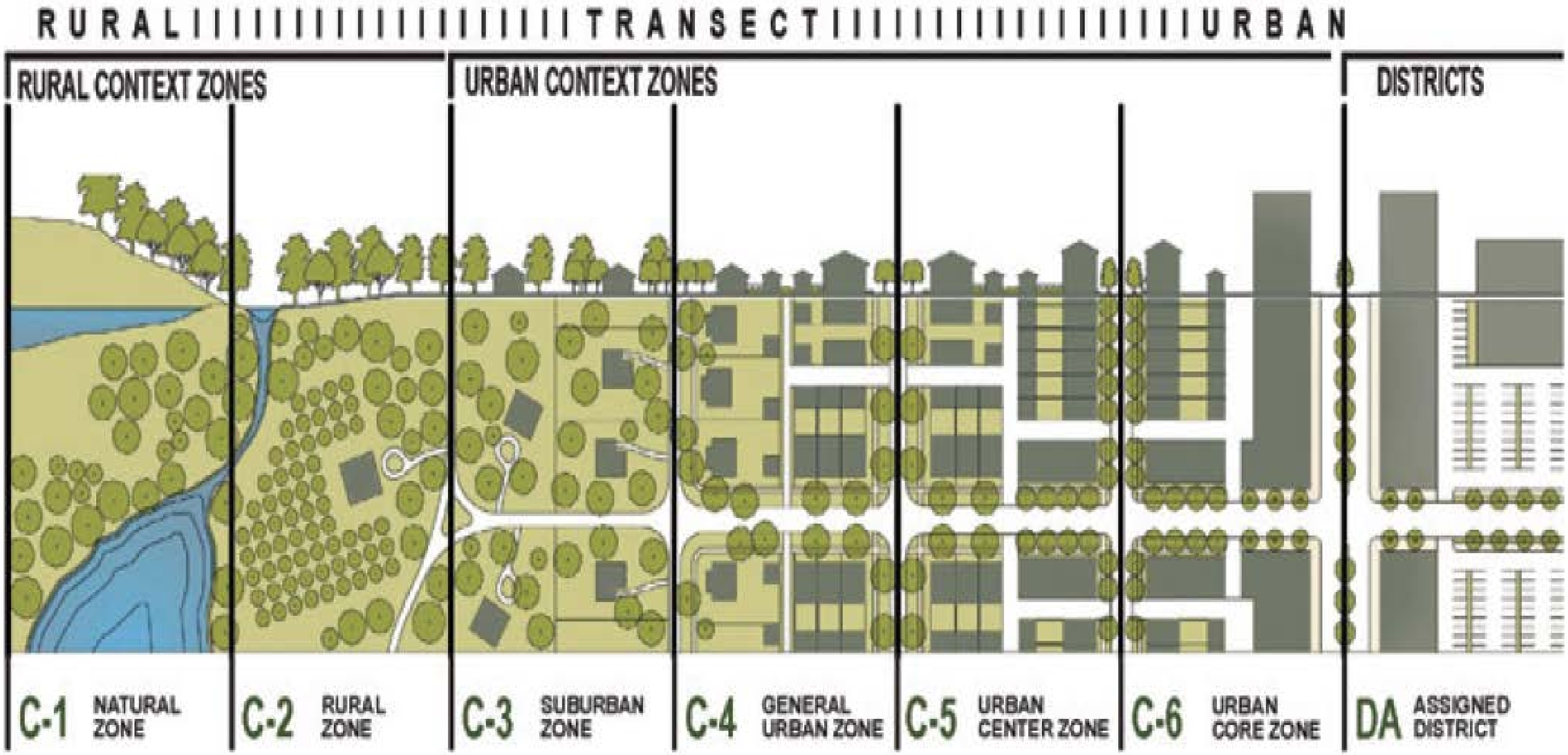
Current AASHTO Policy

- Functional Classification (3)
- Urban/Rural (Land Use)
- Terrain (3)
- Design Vehicles
- Design Year Traffic
- Project Types (2)
  - New Construction & Reconstruction
  - 3R

Proposed Framework

- Functional Classification (5)
- **Land Use / Context Zones** (6)
- **Design Users**
- Design Traffic
  - Design Year
  - **Service Life**
- **Project Types (3)**
  - New Construction
  - Reconstruction
  - 3R

Roadway Context Zones



ITE *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach*

NCHRP Research Report 855 Pre-Publication Draft—Subject to Revision

An Expanded Functional Classification System for Highways and Streets

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Submitted January 2017

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Characteristics of Severe Crashes by Context Zone

Roadway Segments, Context Zones 1 & 2, Highway Safety Manual*

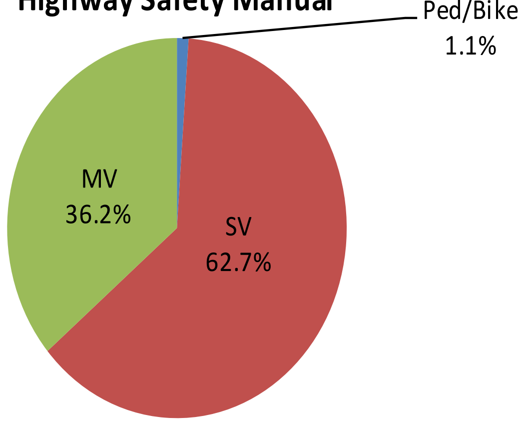


*Table 10-4. Default Distribution by Collision Type for Specific Crash Levels on Rural Two-Lane, Two-Way Roadway Segments (Total Fatal and Injury)

Intersections, Context Zones 1 & 2, Highway Safety Manual*

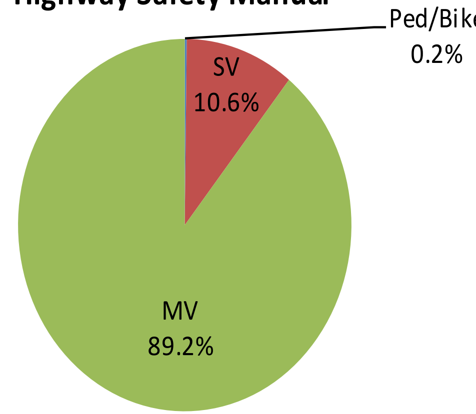
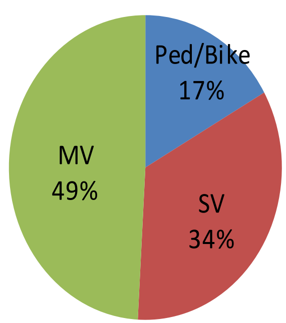


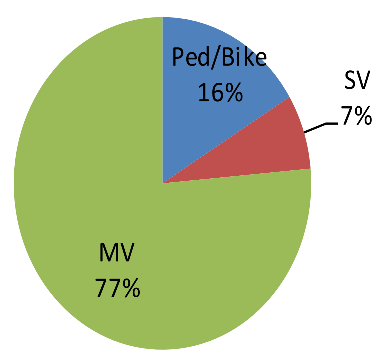
*Table 10-6. Default Distribution for Collision Type and Manner of Collision at Rural, Two-Way, Four-Leg, Stop Controlled Intersections (Total Fatal and Injury)

Roadway Segments in Cook County (Chicago excluded), Context Zones 3 & 4



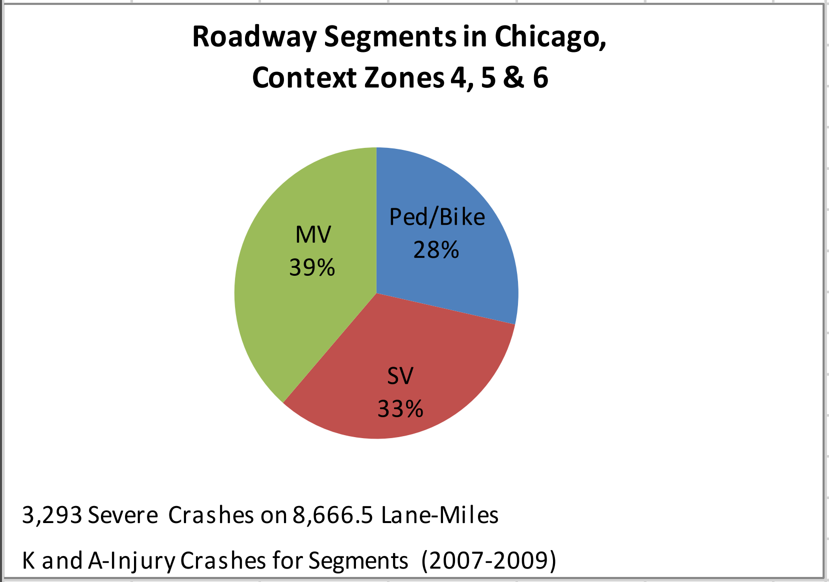
2,659 Severe Crashes on 17,563.5 Lane-Miles
K and A-Injury Crashes for Road Segments (2007-2009)

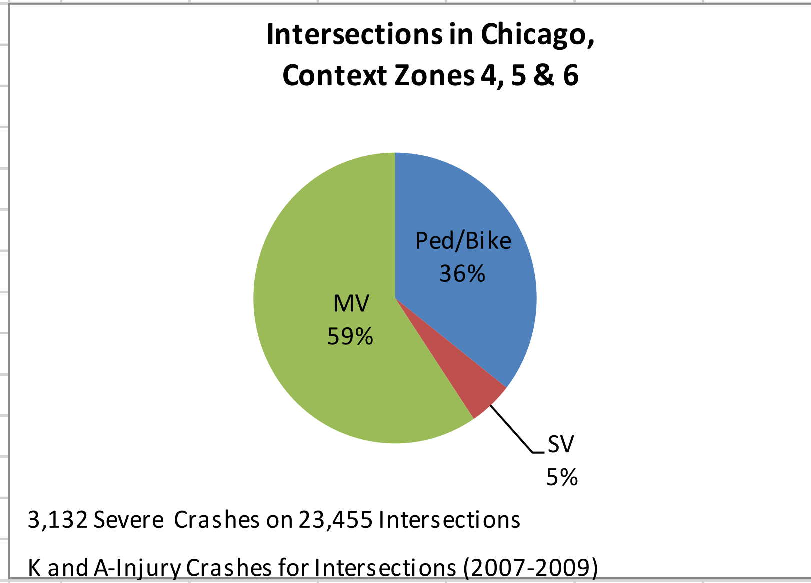
Intersections in Cook County (Chicago Excluded), Context Zones 3 & 4

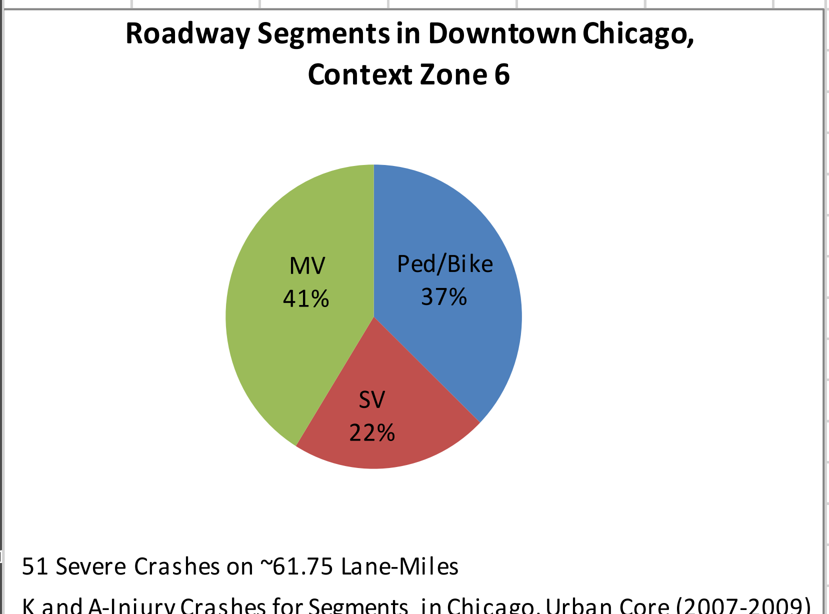


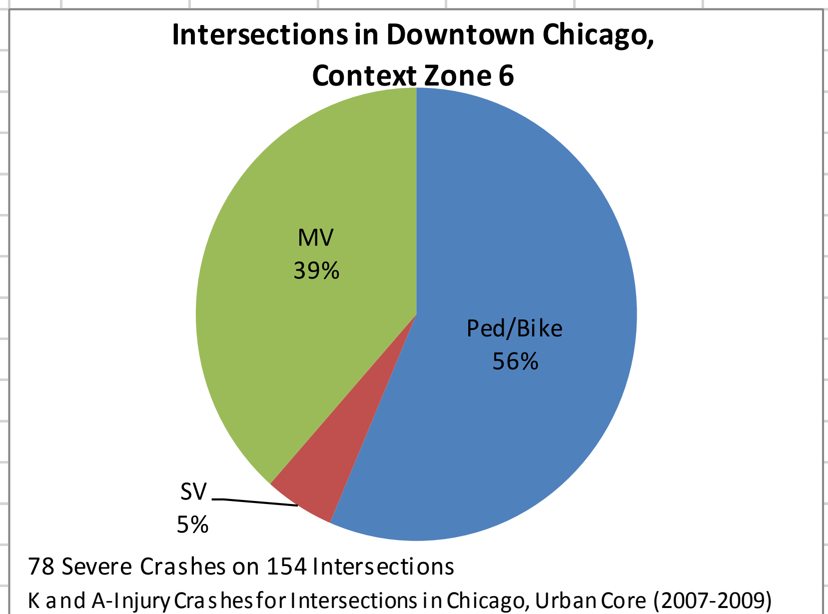
2,735 Severe Crashes on 47,008 Intersections
K and A-Injury Crashes for Intersections (2007-2009)

Characteristics of Severe Crashes by Context Zone









Critical Substantive Safety Issues by Context Zone and Functional Class of Road

Roadway Type	Rural Natural Zone	Rural Zone	Suburban Zone	General Urban Zone	Urban Center Zone	Urban Core Zone
Local	Single-vehicle Run-off-road (low speed, low frequency)		Multi-vehicle Intersection and driveway-related; pedestrian and bicycle; low speed		Pedestrian -- intersections and mid-block	
Collector	Single-vehicle Run-off-road (high speed, higher frequency); multivehicle intersection-related		Multi-vehicle Intersection and driveway-related; median and access related			
Arterial					Pedestrian -- intersections and mid-block; multivehicle intersection-related	
Freeway	Single-vehicle Run-off-road; truck involved; merging and exiting (interchanges); cross median		Single-vehicle Run-off road; weaving, entering and exiting (interchange related)	Multi-vehicle weaving, entering and exiting; congestion-related rear-end and sideswipe		

Traffic Operational Issues Vary by Context Zone and Functional Class of Road

Roadway Type	Rural Natural Zone	Rural Zone	Suburban Zone	General Urban Zone	Urban Center Zone	Urban Core Zone
Local	Accessibility to adjacent land uses with minimal cost and environmental disruption		Access to land uses for motor vehicles and vulnerable users		Access to land uses by pedestrians, transit users and bicyclists; access for freight and goods delivery.	
Collector	Mobility and reliability of traffic service (travel time and travel time variance) for reasonable range of vehicle types		Mobility for full range of road users including motor vehicles, bicycles and pedestrians			
Arterial					Travel time reliability for transit buses and taxis; mobility for pedestrians	
Freeway	Minimization and reliability of minimization of total costs of motor vehicle trips of all types (including especially freight), such costs to include both vehicle operating and travel time costs					

Geometric design approaches and solutions should be ‘context sensitive’

- Apply appropriate performance measures and benchmarks
- Incorporate local costs and impacts
- Address regulatory and environmental considerations
- Respect stakeholder inputs

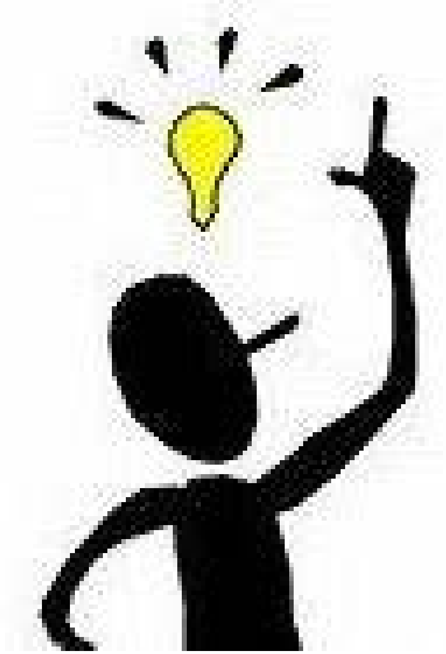
Project Types and Transportation Problems

	Transportation Problem			
Project Type	Mobility	Access	Safety	State-of-good Repair
New Location	X	X		
3R				X
Reconstruction	X	X	X	X

Design Standards and Problem Definition

The presence of one or more geometric design features that fail to meet current design criteria ***is NOT a transportation problem….***

It is merely a condition of the context of a reconstruction or 3R project.



'Upgrade to current standards' is NOT an appropriate purpose and need

New Construction vs reconstruction

New Construction vs. Reconstruction

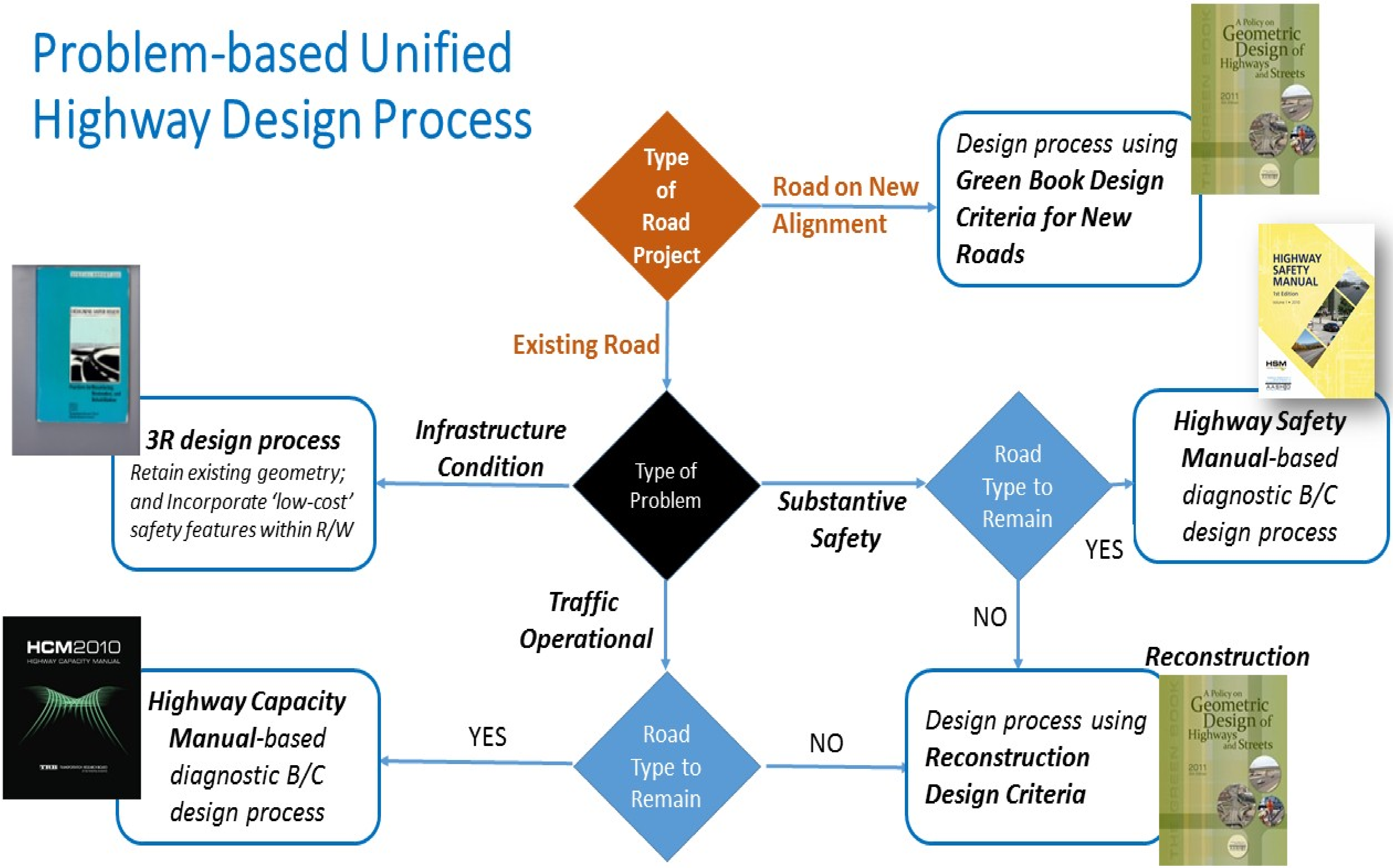
New Construction

- Unknown Safety Performance
- Unknown Operational Performance
- Available R/W of Sufficient Width
- Minimal Impacts to Adjacent Development
- Construction Costs are Quantity Based

Reconstruction

- Known Crash History
- Known Operational Performance
- Known Limited R/W
- Adverse Impacts to Adjacent Development
- Maintenance of Traffic / Local Access Drive Construction Cost

Problem-based Unified Highway Design Process



Proposed Reconstruction Design Process

- Benefit/Cost Analysis Based (crash and/or operational and travel time; implementation costs)
- Context specific
- Incorporate service life
- Incorporate operations and maintenance costs

Reconstruction project decisions should employ a *Benefit – Cost Framework*

User Benefits

- Travel Time Savings
- Crash Reduction Costs

Agency Costs

- Construction Costs
- Annual Maintenance Costs*
- Terminal Value

Projects should be evaluated over a Service Life that is much longer than the Design Life

Basic Design Controls

- Design Year Traffic
- Service Life Traffic
- Design or Target Speed
- Design Operating Conditions
  - Design Level of Service
  - Travel Time Reliability
- Road User Attributes

Service Life

Process should acknowledge that the facility will last much longer than the design year

Project Type	Service Life of Infrastructure
3R (Pavement Resurfacing)	20 to 30 years
Roadway Reconstruction	75 to 100 years
New Alignment Roadway	75 to 100 years
Bridges, Walls, and Related Infrastructure	50 to 75 years
Major Watercourse Crossings	100 years

Design Exceptions

'Doing the right thing' may require a design exception under current policy guidance

- If design exceptions are done routinely, what does that tell us about the validity of the underlying design standard or model?
- If the problem is solved with it operating safely and efficiently, does it matter if it meets a dimensional criteria?

Implications of the proposed reconstruction design process

Each project is uniquely designed to reflect the context

Cost effectiveness is directly embedded in the solution

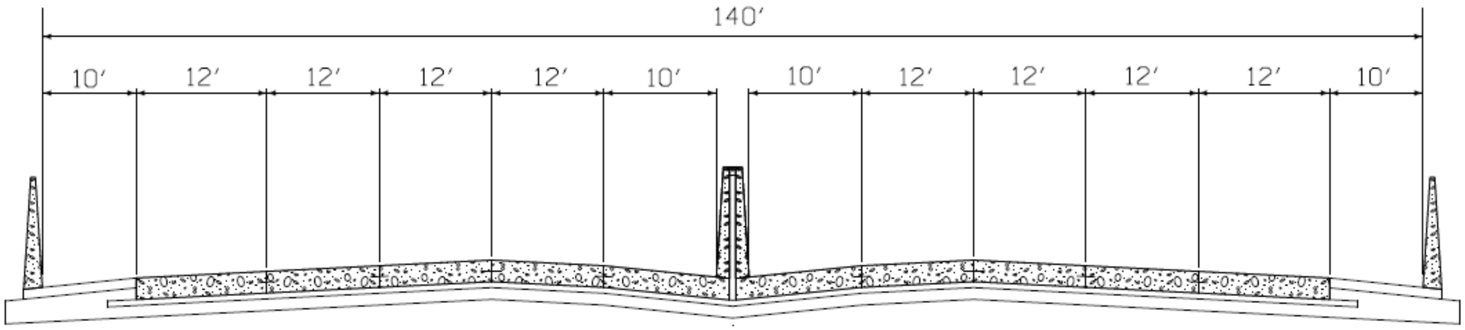
No design exceptions – the right answer is what it is

Agencies should be spending less on projects than they do now

Case study comparison of four lane standard and five lane reduced width cross sections

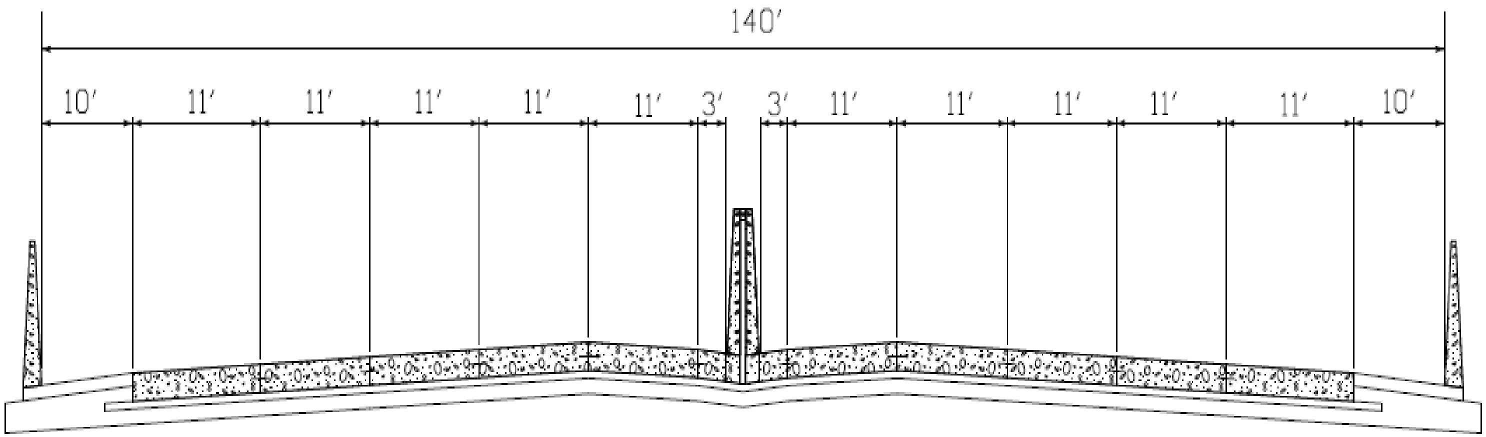
Alternative 1:

4 – 12 ft lanes with 10 ft right shoulders and 10 ft left shoulders



Alternative 2:

5 – 11 ft lanes with 10 ft right shoulders and 3 ft left shoulders



Case study comparison of four lane standard and five lane reduced width cross sections

Alternative	Capacity Analysis results		
	Level of Service	Density (pc/mi/ln)	Speed (mph)
1	F	61.3	43.7
2	E	35.5	60.5

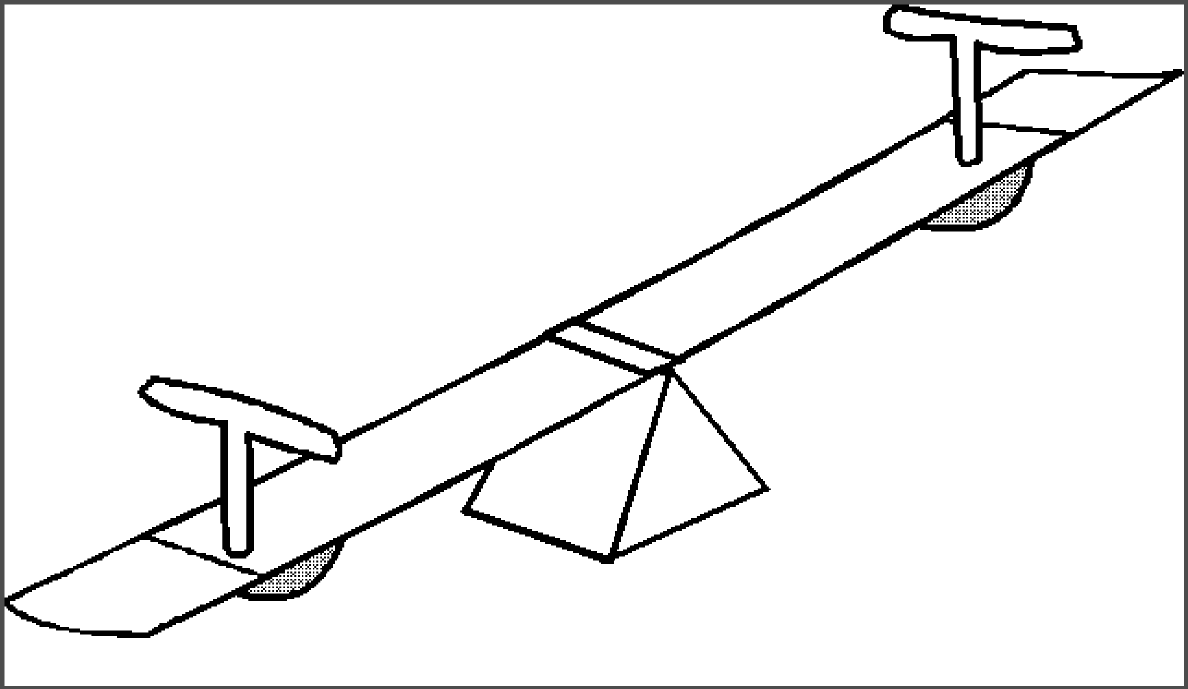
LOS was determined using HCS 2010 Freeways Version 6.60

Alternative	Predicted Crashes per mile per year					
	Total	K	A	B	C	PDO
1	46.8	0.2	0.6	3.2	9.7	33.2
2	40.1	0.3	0.6	3.5	8.1	27.7

Predicted crashes were determined using ISATe (Build 6.10) (uncalibrated model without crash data input)

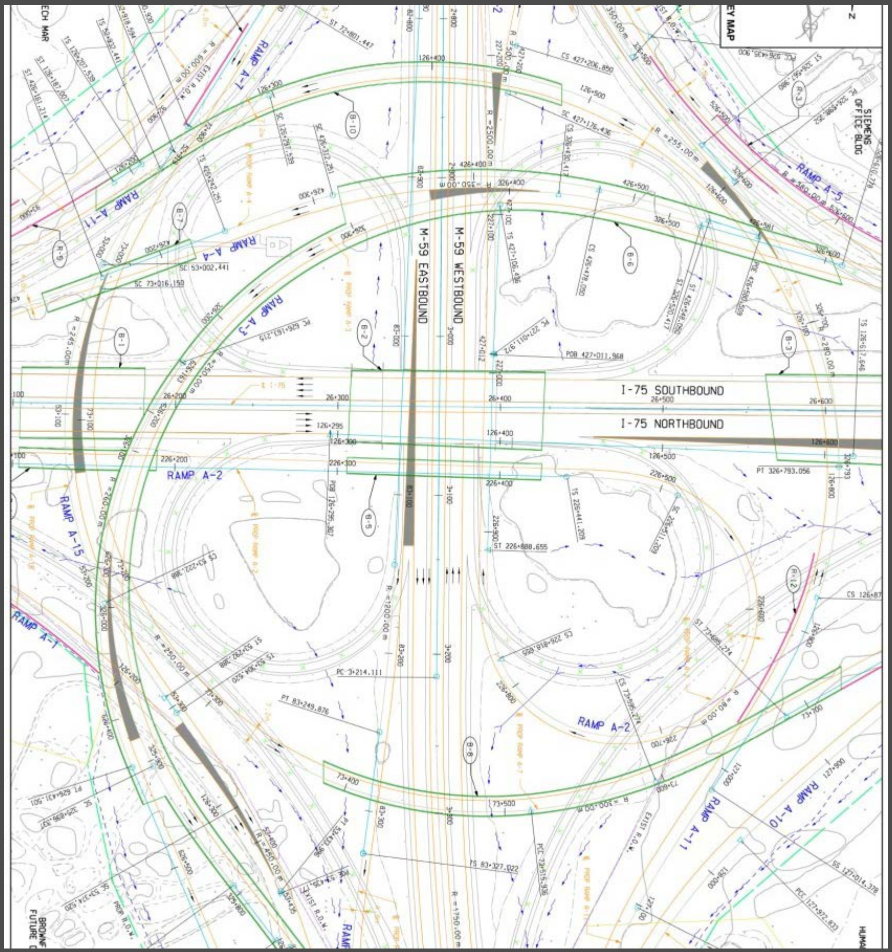
The Future of Geometric Design

Lessened time, effort and expense to complete the design in steps 6 - 9 (per advances in design technology)



Greater effort to engage stakeholders, test and evaluate design effects and apply complex decision processes involving trade-offs (steps 1 – 8)

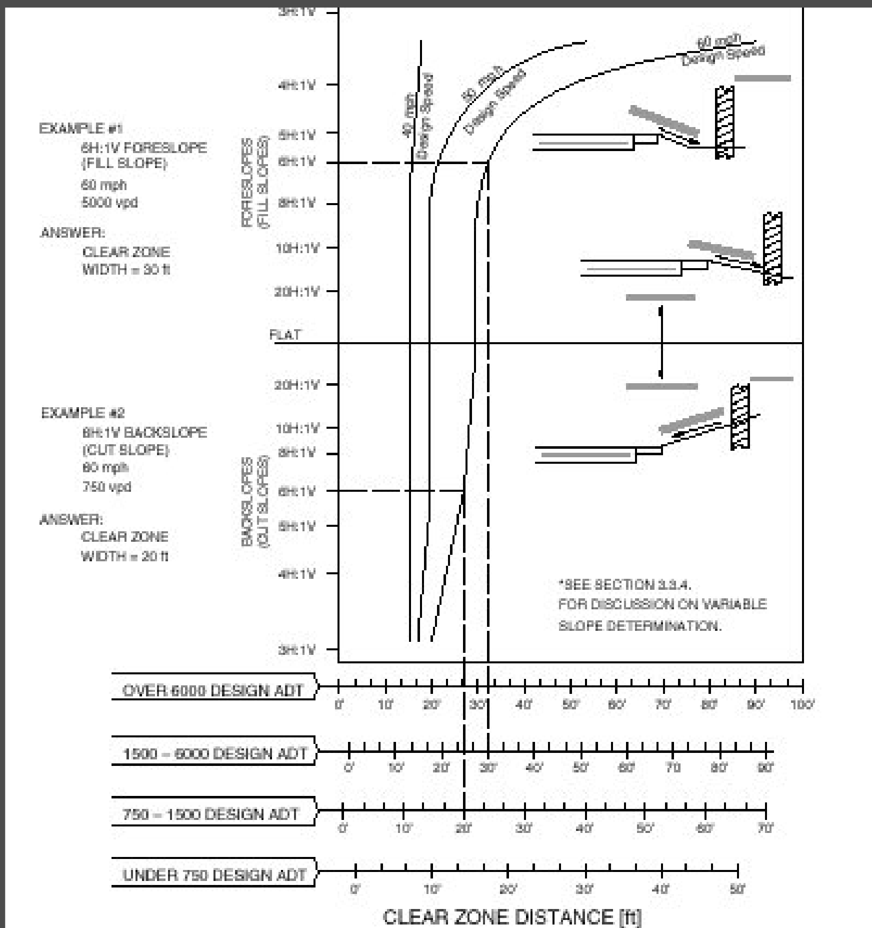
Geometric design is much less labor and time intensive



Advanced computer aided design technologies enable

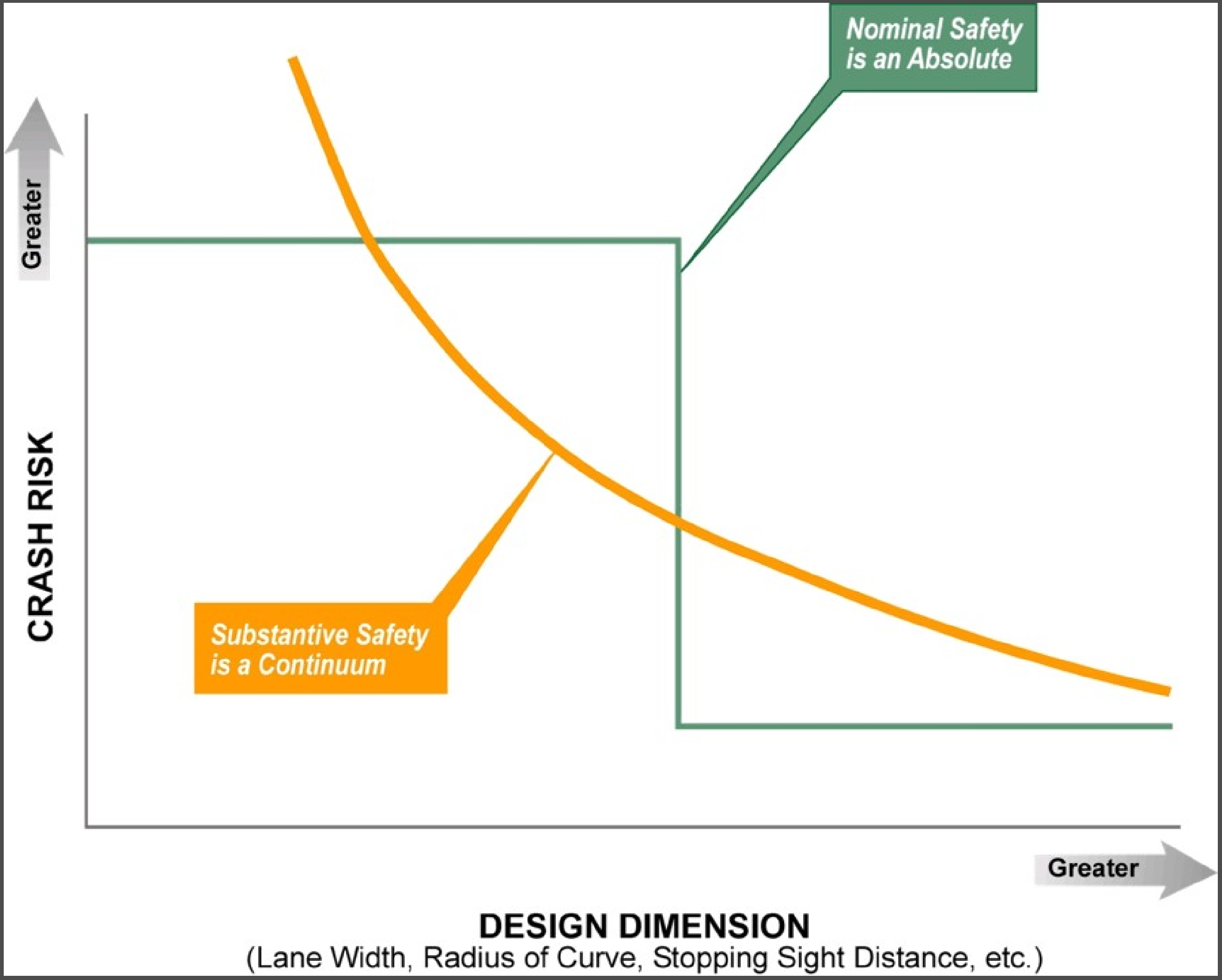
- Rapid testing of alternative design solutions
- Quality control
- Constructability reviews
- Cost estimating

Recommendations for revised approach to geometric design criteria for roads on new alignment



- Established dimensional criteria are still needed for roads on new alignment and new roads on existing R/W
- AASHTO criteria in need of improvement
  - Sight Distance
  - Horizontal Curvature
  - Lane Widths

Nominal vs. Substantive Safety – The conundrum of geometric design criteria



Geometric design criteria for new roads should reflect cost-effectiveness principles and be more ‘context sensitive’

- Functional models require a new look
- Models may need to vary by road type and context
- Criteria should include traffic volume (relative safety risk)
- Criteria should incorporate known safety relationships

The AASHTO horizontal curve design model

$$e + f = V^2 / 15R$$

where

V = design speed (mph)

R = radius of curve (ft)

e = superelevation

f = design side friction

AASHTO Design Assumptions

- **Passenger car** tracks the curve as a point mass
- Passenger car operates at constant design speed through curve
- **'f' values reflect driver comfort**
- Curve design should **avoid loss of control due to skidding** (i.e., during cornering)
- **Applies to all functional classes and volume ranges**

Does the simple AASHTO curve model make sense for all project contexts?

- What about safety performance?
- What about other vehicles such as trucks, buses, emergency equipment, recreational vehicles, etc.?
- How important is comfort vs. other operational conditions?
- What about other performance criteria (e.g., off-tracking)?
- What about interactive effects of other criteria (grade, width, roadside)?

Strawman Framework for Design of Horizontal Curvature for Road Types by Context

Strawman' Framework for Design of Horizontal Curvature for Road Types by Context						
Roadway Type	Rural Natural Zone	Rural Zone	Suburban Zone	General Urban Zone	Urban Center Zone	Urban Core Zone
Local	Based on off-tracking requirements of larger design vehicles (nominal DS = 20 to 30 mph) or loss of control from skidding (DS = 40 mph)		Based on loss of control from skidding	Based on off-tracking requirements of typical large vehicles (perhaps vary by road type and context zone) at very low speeds; urban buses, single unit trucks, semi-trailers		
Collector	Based on loss of control from skidding					
Arterial	Based on volume-sensitive, cost effective design criteria derived from safety performance, operating cost; and infrastructure life-cycle cost; include interactive effects of grade as appropriate		Based on loss of control from skidding	Based on off-tracking requirements of typical large vehicles (perhaps vary by road type and context zone) at moderate speeds		
Freeway			Based on volume-sensitive, cost-effective design criteria derived from safety performance, operating cost, and throughput/capacity; and infrastructure life-cycle cost; include interactive effects of grade; include consideration of decision or stopping sight distance limited by horizontal			

Potential approaches to horizontal curvature design criteria

Functional Basis for Curve Design	Design Vehicle Assumption	Speed Input Assumptions	Potential Geometric Interactions	Comments	Research Issues
Driver Comfort	Passenger Car	Requires Design Speed Assumption	None	Current AASHTO approach; requires updated data and model	Replicate studies using current vehicles and drivers; or potentially use SHRP2 naturalistic driver database
Vehicle Overturn Potential	Single Unit or Semi-trailer	Requires Design Speed Assumption	Could be combined with grade	May be appropriate for Special purpose roads, loop ramps, or roads with high proportion of large vehicles (TBD)	Determine relationship of curvature to overturn risk
Driver Loss of Control	Passenger Car	Requires Design Speed Assumption	Could be combined with grade	Apply models of actual driver behavior through curves; establish margin of safety for range of pavement friction based on studies or agency policy	Apply models of vehicle path and speed behavior (validate and update); potentially use SHRP2 naturalistic database; collect pavement performance data
Off-tracking of Critical Design Vehicle	Semi-trailer or other long vehicle	None -- would by definition apply to low speed roads with minimal risk of severe crashes	Could be combined with roadway or lane width	May be appropriate for very low speed and/or low volume roadways	Develop radius and width for low speed turns based on AUTOTURN or other computer models
Off-tracking at speed of Frequent Design Vehicle	Bus, semi-trailer or single unit truck	None -- would by definition apply to moderate speed roads irrespective of speed	Could be combined with roadway or lane width	May be appropriate for collectors and urban arterials up to 40 to 45 mph	Confirm and validate insensitivity of horizontal curvature to crashes on urban and suburban arterials; Conduct field studies observing offtracking at moderate speeds
Cost Effectiveness Analysis; Quantitative Safety and Operating Cost vs. Construction and Maintenance Cost	None	None -- process tests incrementally larger radii curves for their quantitative benefits	Could be combined with shoulder width and roadside; automatically incorporates radius and length (or central angle)	May be appropriate for 2-lane highway reconstruction projects	Model operating costs (fuel consumption, wear and tear); incremental safety benefits using HSM models for various road types)
Cost Effectiveness Analysis; Quantitative Safety and Operating Cost vs. Construction and Maintenance Cost; including effects of curvature on capacity and throughput	None		Could be combined with shoulder width and roadside; automatically incorporates radius and length (or central angle)	May be appropriate for reconstruction of high volume urban freeways	Model operating costs (fuel consumption, wear and tear); incremental safety benefits using HSM models for various road types); study effects of curvature on capacity and include these

Strawman Framework for Design of Lane Widths for Road Types by Context

Roadway Type	Rural Natural Zone	Rural Zone	Suburban Zone	General Urban Zone	Urban Center Zone	Urban Core Zone
Local	Total road width based on operating characteristics of vehicle; 9 ft minimum lanes may suffice		10-ft minimum; additional width where bicycles are to be considered	10 to 11-ft widths; greater dimension where bicycles, on-street parking, bus and loading zones occur		
Collector	Total road width based on providing minimum LOS and reflecting expected crash risk; 10 ft lanes should suffice for most volume ranges		10- 12 ft; additional width where bicycles are to be considered	10 to 11-ft widths; greater dimension where bicycles, on-street parking, bus and loading zones occur		
Arterial	Range of 10 ft to 12 ft may apply based on volume, context (terrain, trucks, environmental); shoulder dimensions of 2 ft or more based on crash risk and maintenance costs		10- 12 ft; additional width where bicycles are to be considered	10 to 11-ft widths; greater dimension where bicycles, on-street parking, bus and loading zones occur		
Freeway	12 ft lane widths for most cases; in extreme context constraints 11-ft to 11.5 ft may be considered		12-ft lane widths; full right shoulders	11 to 12-ft lanes; consider total width of shoulders and develop optimal solution given right-of-way, maintenance and performance analysis		

Transition in skills, knowledge and approach

The 'old model' designer

- Understands basics of vehicle-centric AASHTO models
- Applying the policy and standards to produce a solution that fully meets criteria
- Calculation of alignment
- Balancing of earthwork
- Detailing of construction plans
- Compiling quantities for contract documents

The 'new model' designer

- Engaging multiple stakeholders (some non-technical)
- Proficient in application of tools, models and evaluation methods for operational and safety effects of design (HCM, HSM, IHSDM)
- Always testing multiple alternatives
- Able to design in range of speed and land-use contexts
- Fully knowledgeable in environmental regulations, laws, and processes
- Applying multi-attribute decision models
- Knowledgeable in economic analysis

Contents of Future Green Books

- **New Construction Design Criteria**
  - **Performance-based (proven crash and/or operational and travel time relationships)**
  - **Sensitive to traffic volume**
  - **Varies by road type**
  - **Sensitive to context**
  - **Incorporate Service Life**
  - **Incorporate known operations and maintenance relationships**
- **Reconstruction Design Process**
  - **Benefit/Cost Analysis Based (crash and/or operational and travel time; implementation costs)**
  - **Context specific**
  - **Incorporate service life**
  - **Incorporate operations and maintenance costs**

Final Report

- Documents the findings
- Performance based critique of Green Book
- Includes detailed outline for a new Green Book
- Provides case studies demonstrating the process
- Research recommendations for new construction criteria

Questions

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Panelists Presentations

http://onlinepubs.trb.org/onlinepubs/webinars/170822.pdf

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