Performance-Based Analysis of Roadway Geometric Design

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Module Outline

- **Geometric Highway Design…how did we get here?**
- What's in and how to use NCHRP Report 785
- Connections to:
  - Context Sensitive Solutions (CSS)
  - Flexibility in design
  - Performance based practical design
- A look to the future…

What are the origins of our "standards"?

- Railroad engineering
- Early motoring

What were the design controls back in the day?

What are “standards”?

- Uniform approaches to provide consistency in design
- Tools to match criteria to similar design environments
- Representative approaches that represent the standards of care of our profession
- Anything else?

What are "standards"?

"Standards" have become safety surrogates

Are the following true?

- If it meets standards it must be safe
- If it doesn't meet standards it is not safe
- If there is no standard for it, it must not be allowable
- If a design exception is needed it must be "bad"
- If we meet standards, we won't be sued

…but what is the research behind our standards?

What are the origins of our "standards"?

Late 1930s and 1940s

Bureau of Public Roads and AASHO

- Looking for uniformity on roadway designs
- No research done to establish "standards of care"
- A synthesis of practical knowledge to address issues
  - i.e., Physics to cover vehicles in motion on a curve
- "Pamphlets" based on consensus of the practice
- Compiled in a 3 ring notebooks

These were combined to form "policies" based on committees, agency leaders, and professionals consensus of the practice

What are the origins of our “standards”?

Late 1950s and 1970s

- Interstate system founded on military applications
  - Pavement studies
  - Roadway clearances
  - Bridge capacities
- Initially primarily focused on rural design (“blue book”) but urban freeways and arterials needs expanded (“red book”)

Need for consistency in Interstate system led to policies that were still not based on research

What are the origins of our “standards”?

1980s The origins of AASHTO’s “Green Book”

- Combine “Blue Book” and “Red Book”
- “Purple Book” at that time was for 3-R Guidance
- Hence the birth of the “Green Book” in 1984

1980s-1990s

- **NCHRP research efforts on new and emerging topics; exploring basis of some existing topics (i.e., SSD)**

2000’s

- Numerous supplemental guidance documents for topics of interest.

Recent National Funding Acts

- 2005 – Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)
- 2012 – Moving Ahead for Progress in the 21st Century Act (MAP-21)
  - Performance Measures
- 2015 – Fixing America's Surface Transportation Act (FAST Act)
  - Recognition of NACTO Urban Street Design Guide
  - Application of Highway Safety Manual

Keys: Multimodal, Safety, Urban Form, Environment, Freight Movement, Economic Vitality, and Implementation

Soft performance metrics such as livability, heritage, community values is fueling flexible design demands

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NCHRP Report 785 Performance-Based Analysis of Geometric Designs of Highways and Streets

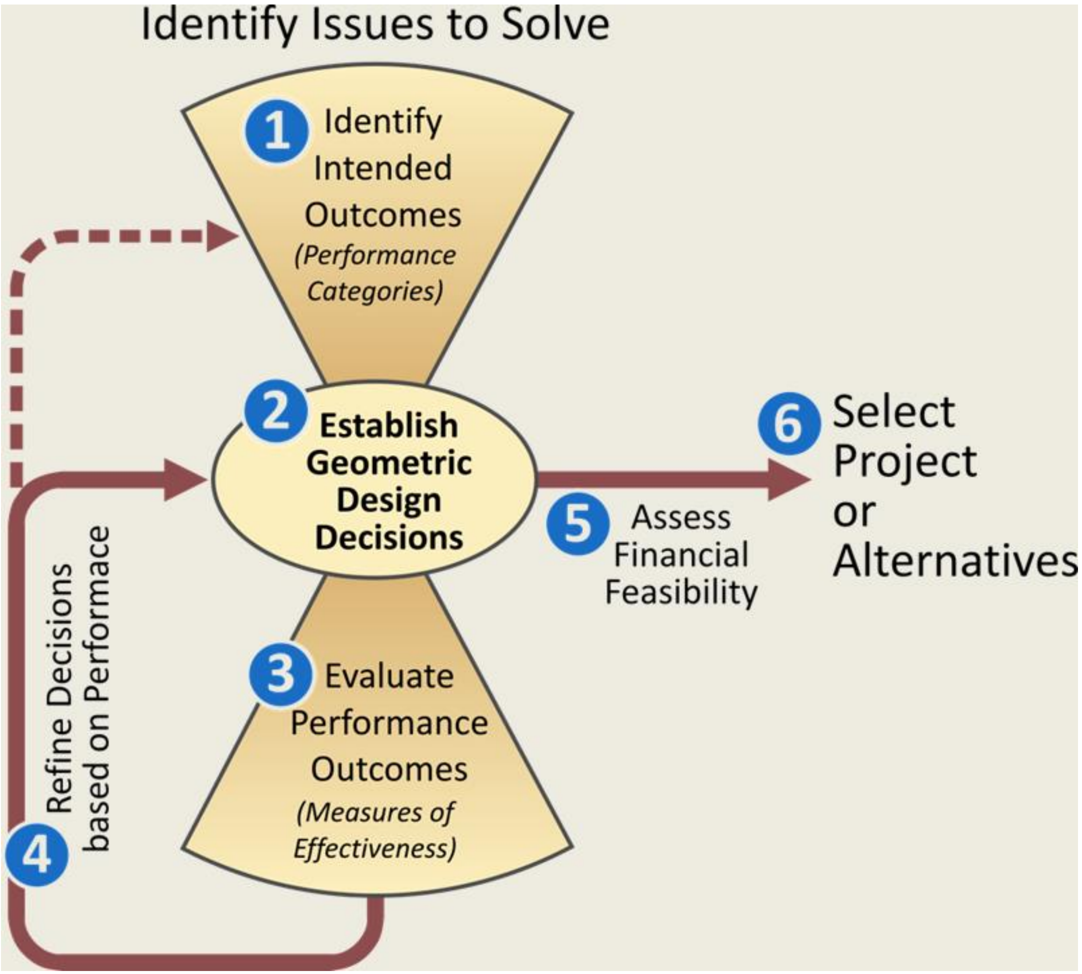
(Terrible title….excellent framework)

NCHRP Report 785

- Chapter 1 – Introduction
- Chapter 2 – Overview
- Chapter 3 – Identify Project Outcomes
- Chapter 4 – Geometric Design Elements
- Chapter 5 – Process Framework
- Chapter 6 – Project Examples

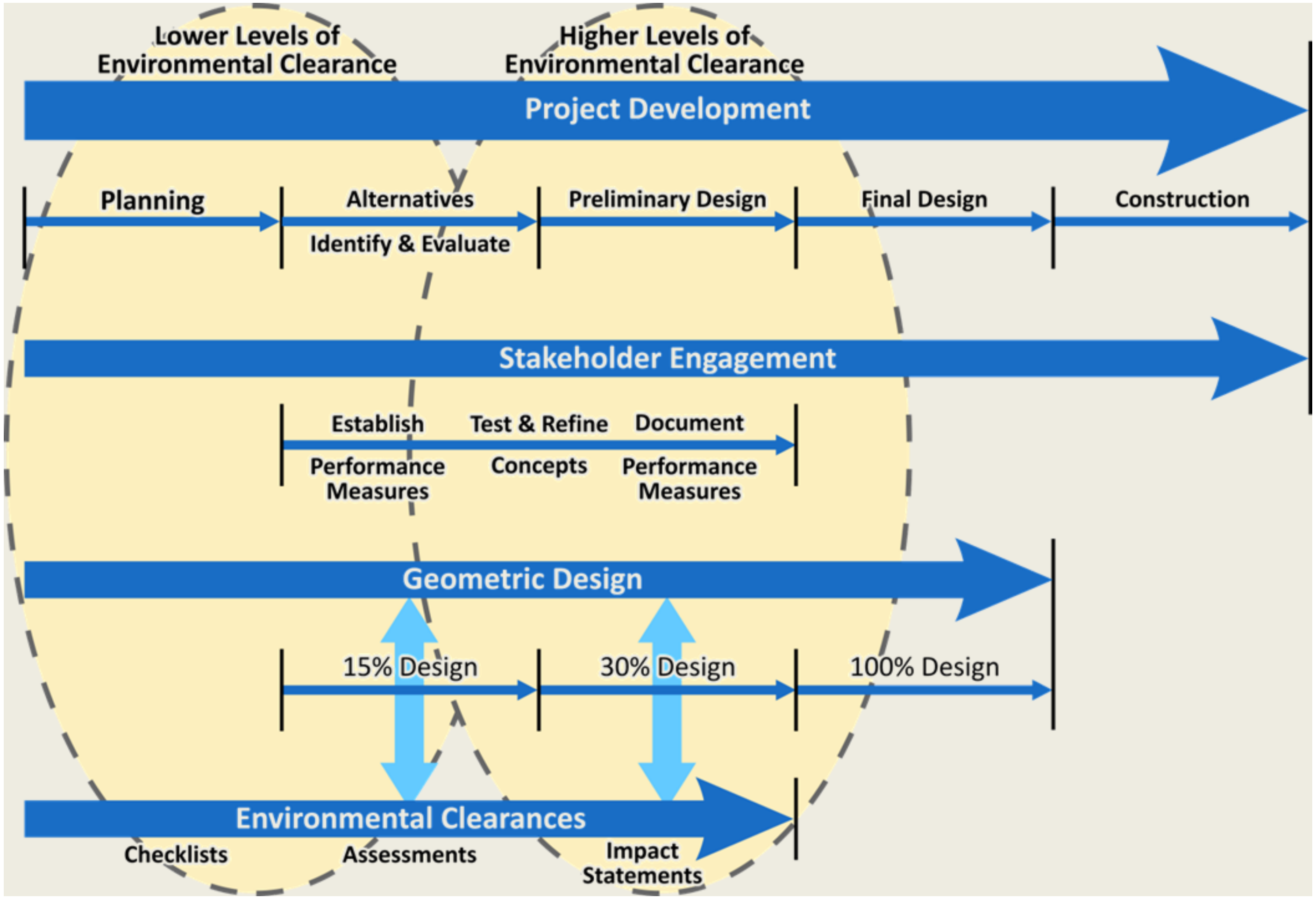
NCHRP Report 785 Model

- Fundamental model of the approach



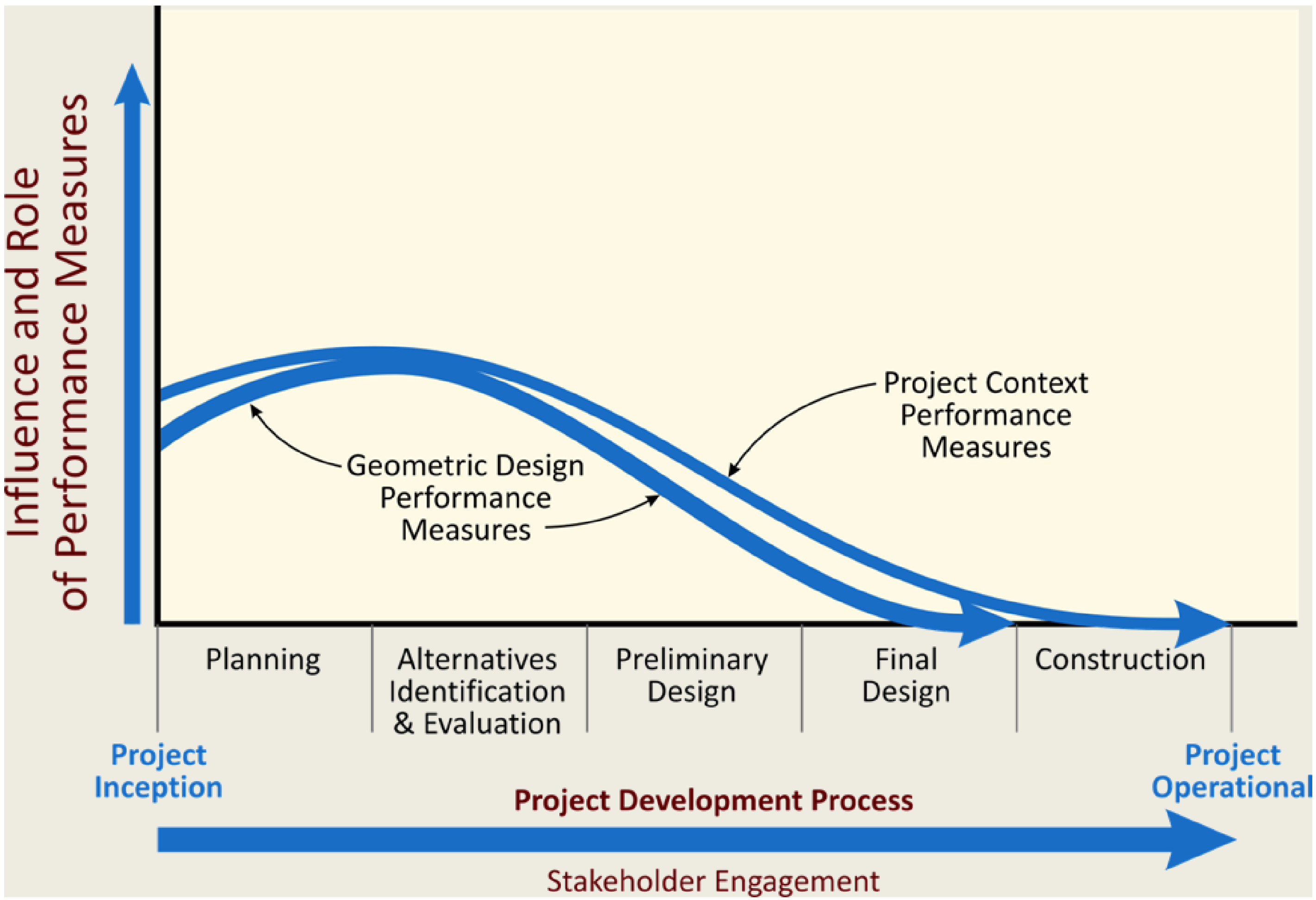
NCHRP Report 785

- Overview of geometric design decisions



NCHRP Report 785

- Relationship between project-level and performance measures



Chapter 3 – Identify Project Outcomes

- Fundamentally: Whom are we serving?
  - Whom are we serving?
    - Identifying the key road users and stakeholders for a given project and project context
  - What are we trying to achieve?
    - Identifying and articulating the core desired outcomes from the project

Establishing project context—Users and Performance

Chapter 3 – Identify Project Outcomes

- **Defining Project Performance – Goals and Measures**

US DOT's Strategic Plan for 2012-2016

- Economic competitiveness
- Environmental sustainability
- Livable communities
- Organizational excellence
- Safety
- State of good repair

Moving Ahead for Progress in the 21st Century Act (MAP-21)

- Congestion Reduction
- Infrastructure Condition
- Environmental Sustainability
- Freight Movement and Economic Vitality
- Reduced Project Delivery Delays
- Safety
- System Reliability

The continued shift to softer performance measures…

Chapter 3 – Identify Project Outcomes

- Geometric Design Performance Categories
  - Accessibility
    - Ability to approach a desired destination or potential opportunity for activity using highways and streets (including the sidewalks and/or bicycle lanes).
  - Mobility
    - Ability to move various users efficiently from one place to another using highways and streets.
  - Quality of Service
    - Perceived quality of travel by a road user.
  - Reliability
    - Consistency of performance over a series of time periods.
  - Safety
    - Expected frequency and severity of crashes occurring on highways and streets.

Chapter 3 – Identify Project Outcomes

- Role and Influence of Geometric Design Features

Performance Category	Defined Role/Influence of Geometric Design Features		
	Well Documented	Moderate Documentation	**Limited Documentation**
Accessibility		X	
Mobility	X		
Reliability			**X**
Safety		X	
Quality of Service		**X**	

Chapter 3 – Identify Project Outcomes

- Geometric Design Decisions
  - Consider overall intended project outcomes, project performance, and transportation performance.
    - How do the features influence performance measures related to accessibility, mobility, quality of service, reliability, and safety?
  - May have incremental and cumulative effects
  - Discrete choices may impact broader concepts
    - Sustainability, economic competitiveness, or livability
  - Identifying project design controls
    - Leads to appropriate design criteria to meet those design control needs

Chapter 4 – Geometric Design Elements

Introduction

- Summarize critical or high priority known relationships between design elements and performance
- Document the general relationship
- Identify possibly performance trade-offs
- Present resources and tools that can be used

This information can be expanded with future research

Chapter 4 – Geometric Design Elements

- Expected relationships between geometric design elements and performance categories
  - Segments
  - Nodes – Intersections and Interchanges

● = expected direct effect
☐ = expected indirect effect
-- = expected not to have an effect
* = relationship can be directly estimated by existing performance prediction tools
◊ = relationship can be indirectly estimated using more than one existing tool
x = relationship cannot be estimated by existing tools

WARNING: SCARY SLIDE AHEAD!!!!

Segment Geometric Elements/Characteristics	Accessibility	Mobility	Quality of Service	Reliability	Safety
Access points and density	●*	●*	●*	□◊	●*
Design speed and target speed	--	□◊	□◊	□◊	□*
Horizontal alignment	--	●◊	●◊	□◊	●*
Number of travel lanes	●*	●*	●*	□*	●*
Sidewalk and pedestrian facilities	●	●*	●*	□x	●x
Bicycle accommodation features	●	●*	●*	□x	●x
Median provisions	●◊	●*	●*	□◊	●*
Travel lane width(s)	●◊	●*	●*	□*	●*
Auxiliary lane width(s)	●x	●x	●x	□x	●x
Type and location of auxiliary lanes	●◊	●*	●*	□◊	●*
Shoulder width(s) and composition	●◊	●*	●*	□*	●*
Shoulder type(s)	●◊	●x	●x	□◊	●*
Lane & shoulder cross slopes	--	--	--	□x	●x
Superelevation	--	●x	●x	□◊	●*
Roadside design features	●x	●x	●x	□x	●*
Roadside barriers	●◊	●*	●*	□◊	●*
Minimum horizontal clearances	●◊	●*	●*	□◊	●*
Minimum sight distance	●x	●x	●x	□x	●x
Maximum grade(s)	□◊	□*	□*	□◊	□*
Minimum vertical clearances	●◊	□x	□x	□x	□x
Vertical alignment(s)	--	●*	●*	□*	●*
Bridge cross section	●◊	●*	●*	□*	●*
Bridge length/ termini	--	--	--	□◊	●*
Rumble strips	●◊	--	--	□x	●*

Chapter 4 – Geometric Design Elements

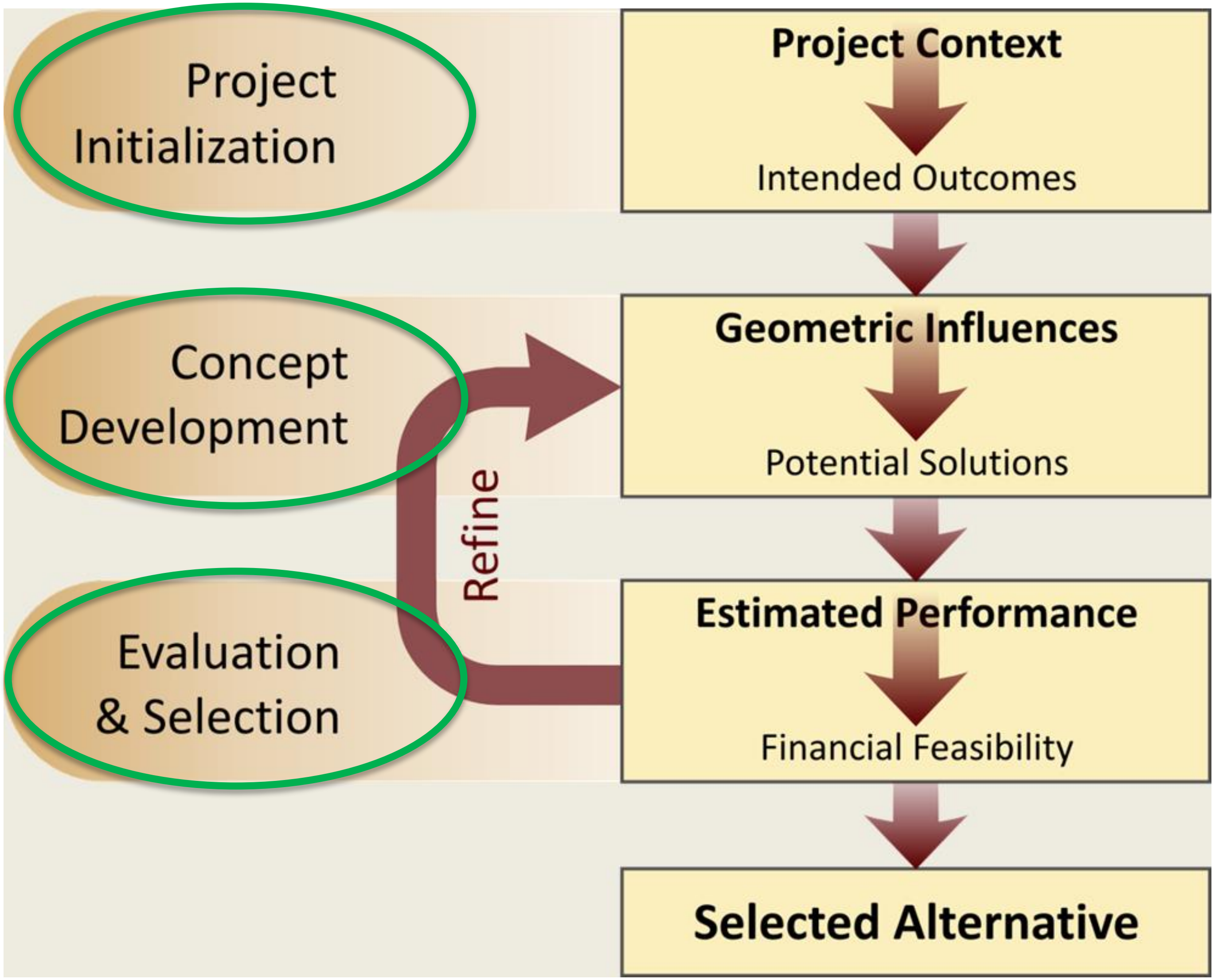
- Tables summarize the design elements/decisions and their relationship to performance measures from each of the transportation performance categories:
  - Accessibility
  - Mobility
  - Quality of Service
  - Reliability
  - Safety

For example: Accessibility

Chapter 4 – Geometric Design Elements *Accessibility*

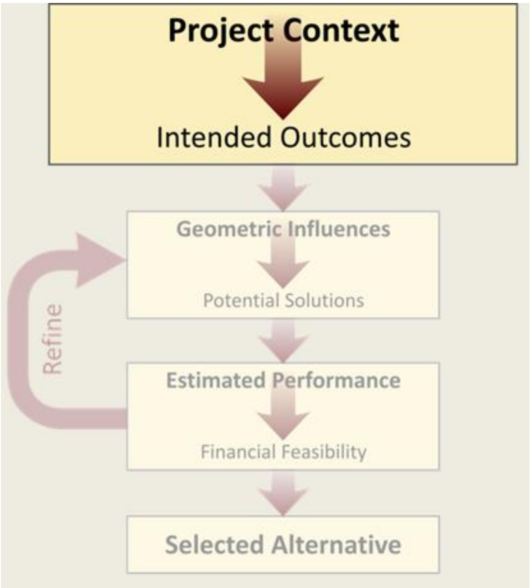
Facility Type	Performance Measure	Definition	Geometric Design Elements	Basic Relationship	Potential Performance Tradeoffs
Segment	Driveway Density	Number of driveways per mile	Access points and density	Higher density of driveways associated with higher motor vehicle access	Degrade bicycle LOS, Increase crash likelihood, Increase average travel speed
Urban/ Suburban Segment	Transit stop spacing	Distance between transit stops along a roadway segment	Transit accommodation features	Higher frequency increases access for transit riders	Increases transit travel time and may degrade mobility for other vehicle modes
Segment	Presence of Pedestrian Facility	Presence of a sidewalk, multiuse path or shoulder	Sidewalk and pedestrian facilities	Greater connectivity and continuity of pedestrian network increases access for pedestrians	Implementing pedestrian facilities in a constrained environment may require removing capacity or parking for vehicle mode
Segment	Presence of Bicycle Facility	Presence of bicycle lanes, multiuse path, or shoulder	Bicycle accommodation features	Greater connectivity and continuity of bicycle network increases access for bicyclists	Implementing bicycle facilities in a constrained environment may require removing capacity or parking for vehicle mode

Chapter 5 – Process Framework



Chapter 5 – Process Framework

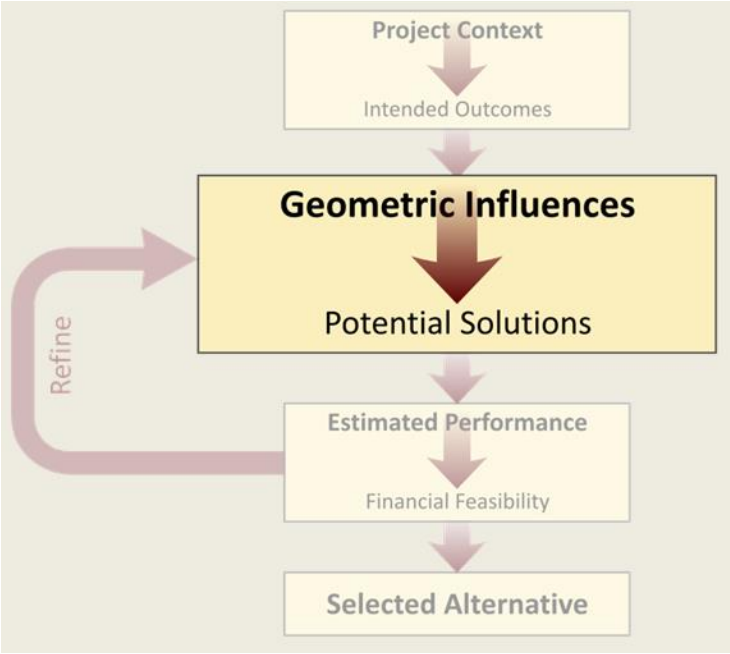
- Project Initiation
  - Project Context
    - Existing site constraints
    - Current performance
    - Surrounding land uses
    - Planned improvements
    - Anticipated form and function
  - Intended Outcomes
    - Clarity of the characteristics defining the current and desired future of the site;
    - A clear and concise understanding of the primary project purpose; and
    - A set of performance measures to be used to evaluate a design's impact on the desired project purpose.



Chapter 5 – Process Framework

Concept Development

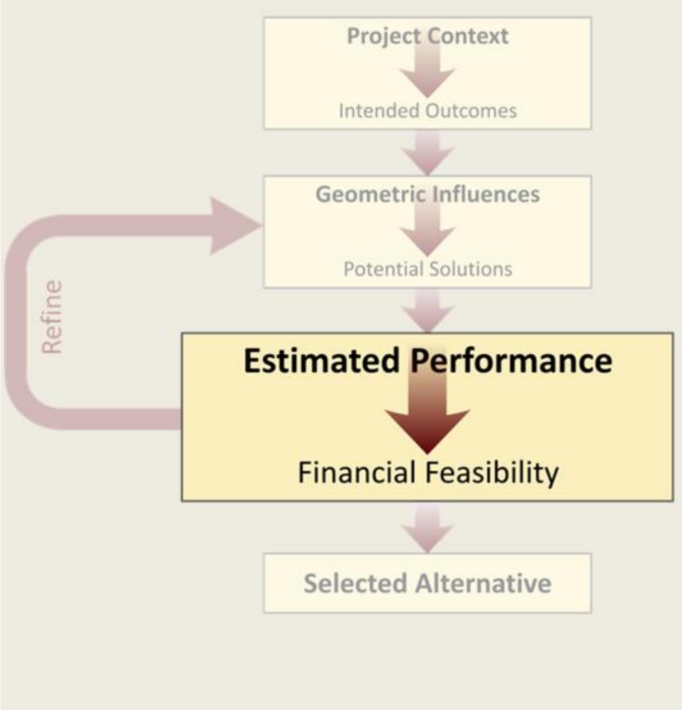
- Geometric Influences
  - Identify the geometric characteristics that influence a project's performance
  - Identify the geometric characteristics or decisions influenced by the desired performance of a project.
- Potential Solutions – specific awareness of the:
  - Project context
  - Intended outcomes
  - Geometric characteristics and decisions



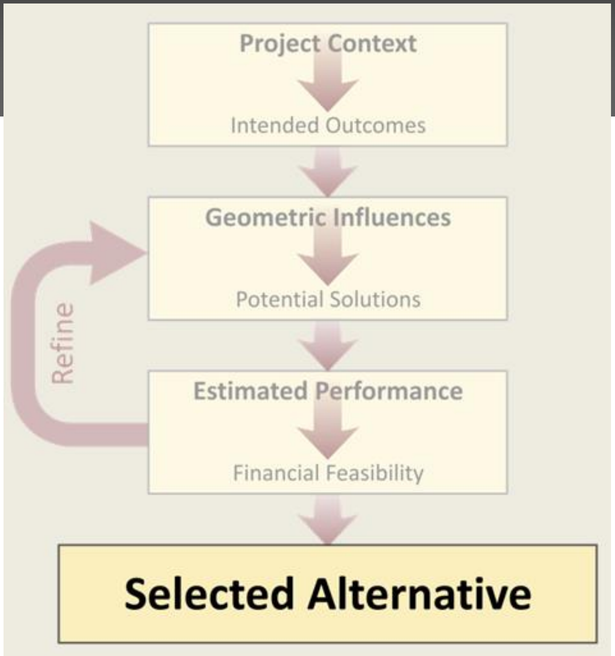
Chapter 5 – Process Framework

Evaluation and Selection

- Estimated Project Performance
  - Selecting the evaluation resource
    - For the stage in the project development process.
    - Applicable to the project context
- Financial Feasibility
  - Total construction and maintenance cost
  - Cost effectiveness
  - Benefit/Cost ratio (B/C ratio)
- Interpreting Results
  - Estimated Project Performance
  - Financial Feasibility



Chapter 5 – Process Framework



- Selection
  - Are the performance evaluation results making progress towards the intended project outcomes?
  - Do the alternatives serve the target audience and achieve the desired objectives?
  - Are there reasonable adjustments that can be made to the geometric design elements most significantly influencing project performance?
  - Do the performance measures help differentiate between the alternatives?
- Environmental Review Process
  - Environmental checklists, assessments and impact statements

Chapter 6 – Project Examples

Example#	Site - Area and Facility Type	Project Development Stage	Performance Categories	Project Type
1	US 21/Sanderson Road - Rural Collector (Two-Lane Highway)	Alternatives Identification and Evaluation	Safety	Intersection – Consider alternative intersection control to improve safety.
2	Richter Pass Road - Rural Collector	Preliminary Design	Safety, Mobility	Segment – Consider alternative horizontal curve radii to improve safety while minimizing costs and maintaining appropriate speed.
3	Cascade Ave - Suburban/Urban Arterial	Preliminary Design	Safety, Mobility, Reliability, Accessibility, Quality of Service	Corridor – Retrofitting an existing auto-oriented urban arterial to incorporate complete street attributes. Focus on alternative street cross-sections.
4	SR 4 - Rural Collector	Preliminary Design	Safety, Reliability, Quality of Service	Segment – Consider alternative shoulder widths and sideslopes to minimize impact to an environmentally sensitive area.
5	27th Avenue - Urban Minor Arterial	Alternatives Identification and Evaluation	Quality of Service, Safety, Accessibility	Segment – Alignment and cross-section considerations for new urban minor arterial being constructed to entice employers to a newly zoned industrial area.
6	US 6/Stonebrook Road - Rural Interchange	Alternatives Identification and Evaluation	Safety, Mobility	Interchange - Converting an at-grade intersection to a grade-separated interchange. Focus on selecting the appropriate interchange form and location

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“Thinking Beyond the Pavement” and Context Sensitive Solutions:

- “Context Sensitive Design”
- “Context Sensitive Solutions”
- “Common Sense Solutions”
- “Community-based Solutions”
- “Thinking Beyond the Pavement”

It’s all the same thing: Good Products and Processes

Performance-based analysis supports adaptive solutions

Kentucky has been an early implementer of CSS

Context Sensitive Solutions

- What is CSS?
  - A <u>collaborative, interdisciplinary approach</u> that involves all <u>stakeholders</u> to develop a transportation facility that <u>fits</u> its physical setting, and preserves scenic, aesthetic, historic, and environmental resources, while maintaining safety and mobility
- Why is CSS Important?
  - CSS Provides a balance between:
    - Mobility
    - Safety
    - Enhancing the Natural Environment
    - Preserving Community Values
  - Can eliminate potential conflicts during the project development process and does not delay projects

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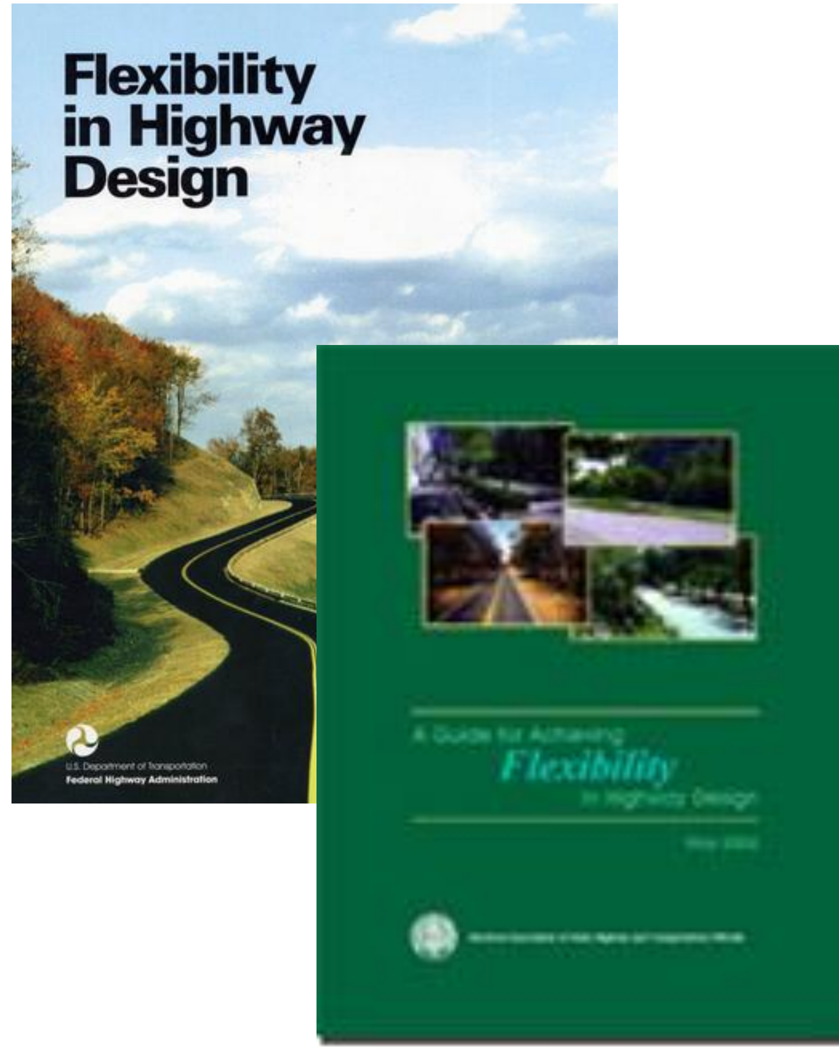
What if we can't meet "standards"?—Flexibility In Design

- Confirm "controls" to select appropriate design values
- Employ your "engineering judgment"
- Apply fundamental operations and design principles for that condition
- Evaluate and understand safety and operational trade offs of your choices
- Document your decisions



FHWA Controlling Criteria

- Created in 1985 following publication of first Green Book
- 13 criteria
- Design exceptions required if values not met on National Highway System (NHS)
- Changed in 2016
  - Reduced from 13 to 10 for NHS facilities with design speeds of 50 MPH or greater (and all Interstates)
  - Reduced from 13 to 2 for NHS facilities with design speeds under 50 MPH

Fewer controlling criteria increase the opportunity for flexibility

FHWA Controlling Criteria

1985

- Design speed
- Lane width
- Shoulder width
- Bridge width
- Horizontal alignment
- Superelevation
- Vertical alignment
- Grade
- Stopping sight distance
- Cross slope
- Vertical clearance
- Lateral offset to obstruction
- Structural capacity

2016

- **Design speed**
- Lane width
- Shoulder width
- Horizontal curve radius
- Superelevation
- Maximum Grade
- Stopping sight distance
- Cross slope
- Vertical clearance
- **Design Loading Structural Capacity**

Flexible Design Implementation

- Generally incorporates "practical" limitations such as cost, time, and ability to implement
- Incorporates performance analysis, such as safety and valuations ("bang for the buck")
- Based on fundamentally understanding design controls and then establishing the corresponding design values
- Best supported by performance-based analysis
- Emphasized as Performance Based Practical Design (PBPD)

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U.S. Department of Transportation
Federal Highway Administration

PERFORMANCE BASED PRACTICAL DESIGN

RESOURCE CENTER

THE CHALLENGE FACED BY DOTS

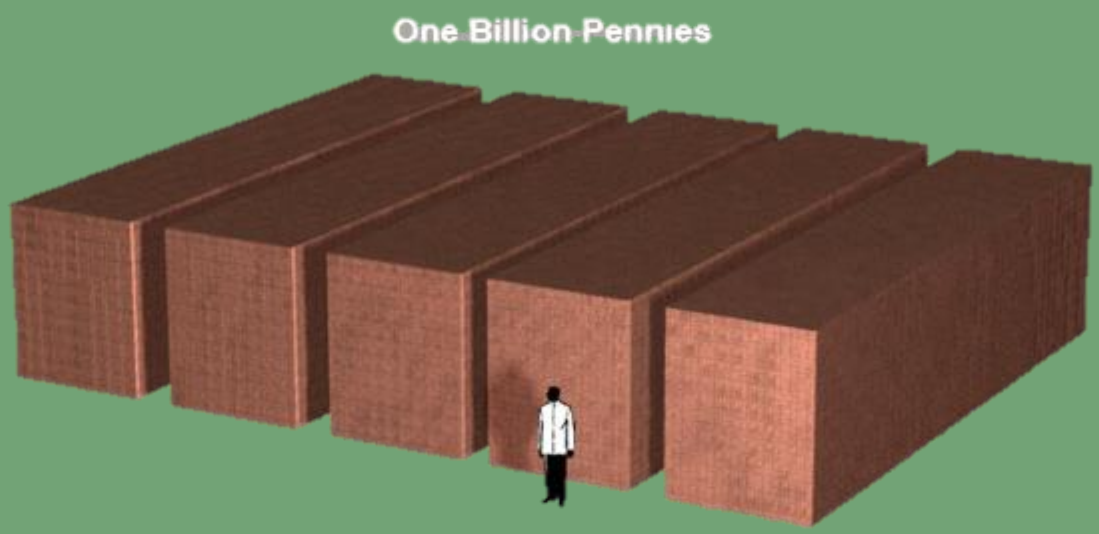
- Ever-expanding surface transportation system
- Need to provide increased mobility and safety
- Need to address all users
- Decreasing Finances & Resources

WHAT IS PBPD?

PBPD is a decision making approach that helps agencies better manage transportation investments and ***serve system-level needs and performance priorities*** *with limited resources.*

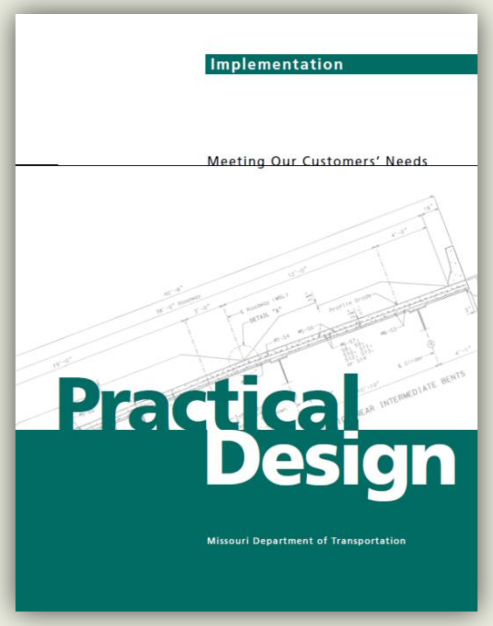
PBPD CONTRIBUTES TO SYSTEM PERFORMANCE

If 100% of the program were delivered in any given year at 90% of the cost, then the left-over money is available to invest in more improvements to the system



PRACTICAL DESIGN

- In 2005, Missouri DOT began implementing Practical Design
  - Focused attention on “cost drivers” while still serving user needs
  - Stressed:
    - No compromise on safety
    - Collaboration on solutions
  - Notable example:
    - Design speed = posted speed



WHAT ARE KEY EXAMPLES OF "PRACTICAL DESIGN"?

MoDOT

MoDOT

15 miles of roadway and shoulder improvement versus traditional typical section for fewer miles.

PRACTICAL DESIGN TODAY

- Many States have developed their own version of a Practical Design Program
  - **Minnesota**
  - **Utah**
  - **Washington**
  - **Oregon**
  - **Kentucky**
  - **Indiana**
  - **Maryland**

Others.....

HOW IS PBPD ACCOMPLISHED?

- PBPD involves using relevant, objective data to support engineering decisions
  - Start with the basics:
    - Determine user needs
    - Determine what the project is trying to provide (purpose & need)

Almost everything else is up for consideration!

GOALS & OBJECTIVES

Sample objectives that are "*generic*"

- Improve safety
- Reduce congestion
- Improve livability

Sample Objectives that are *Specific* –

- Improve mainline freeway operations during PM peak hour from current 32 mph average speed to 50 mph
- Remove barriers to pedestrian travel between Elkhorn subdivision and Main Street central business district.

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A look to the future

- Focused research by NCHRP and others will continue to expand our knowledge base on new topics
- Close AASHTO and TRB Committee engagement is positive:
  - More research funding is needed to progress us faster
  - States can support by pool funding and participating
- We know safety is our priority and will need to continue to fight our tendency to build bigger
- The term "CSS" may be out, but livability, heritage, community issues are driving projects
- Multimodal considerations will be a priority; we need to reduce the number of severe and fatal crashes
- Service life and value of investment will increasingly guide our decision making as funding remains limited

Questions?

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