U.S. Department of Transportation
Federal Highway Administration

Speed Management and Safe Systems

Evolving Highway Design for Safety

Stephen Ratke, PE (NV), RSP1
FHWA – Texas Division
stephen.ratke@dot.gov

Agenda

- The Safe Systems Approach
- Current Practices Around Speed
- The Changing Philosophy of Design
- New and Emerging Designs for Speed Management and Safety
- FHWA Speed Management and Other Resources

The Safe Systems Approach

Paradigm Shift - *a fundamental change in approach or underlying assumptions*

Source:Vision Zero Network
https://visionzeronetwork.org/resources/

Ethical Imperative: No human should be killed or seriously injured for using the road system

The road system should be designed and operated such that no human is killed or seriously injured using it

Paradigm Shift

It's not about eliminating crashes, but eliminating fatal and serious injuries.

What determines whether a crash is a fatal/severe injury or minor injury (or better yet "Property Damage Only") crash?

Paradigm Shift

FHWA

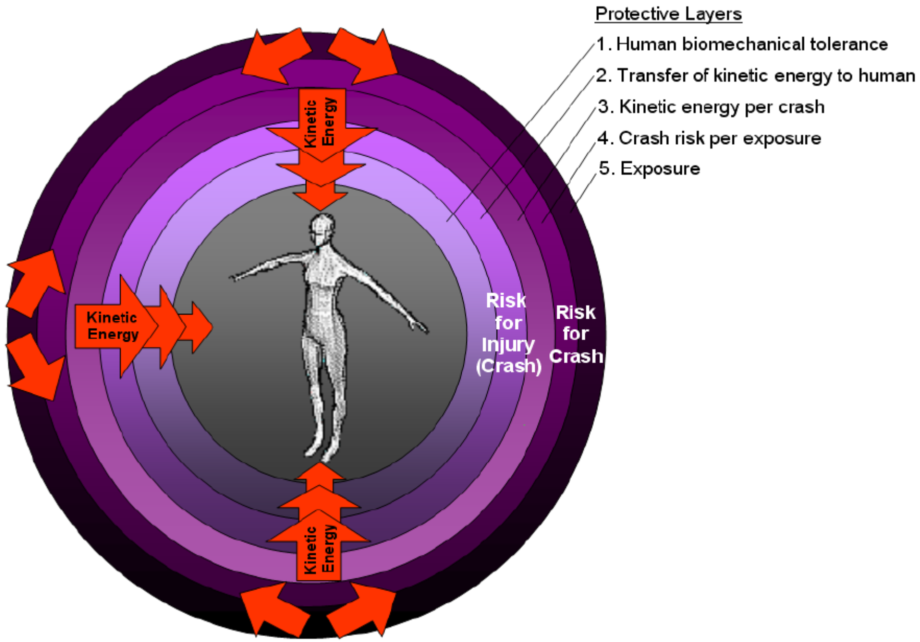
Designing Safer Roads is an Exercise of Managing Kinetic Energy

$$K = \frac{1}{2}mv^2$$

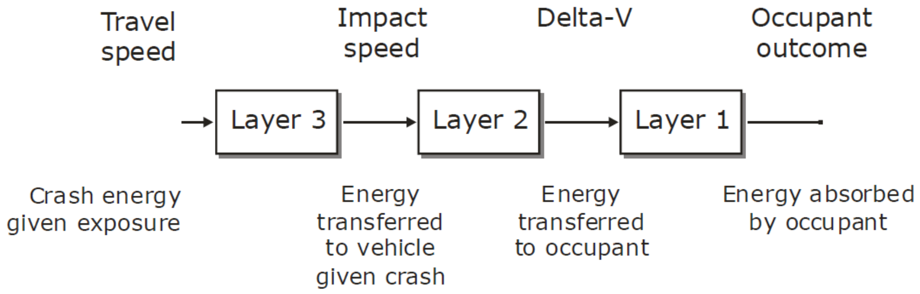
Physical Tolerance to Crash Forces

The mechanics by which kinetic energy is transferred from the vehicle to humans in a crash is influenced by:

- seat belts
- air bags
- vehicle design features to extend the time and area over which kinetic energy is transferred



How much kinetic energy the human body may absorb without harm will vary based on individual characteristics such as size, age, and general overall health.



"Safe System" Approach

Guiding Principles:

Principle	Description
No Death or Serious Injury on the Road Network is Acceptable	The Safe System Approach is grounded on this moral and ethical imperative
Humans Make Errors	Errors can lead to crashes / Crashes will occur / Minimize Harm
Shared Responsibilities	Shared responsibility among users, vehicle manufacturers, and those who design, build and maintain the roads
Tolerance to Crash Forces	The human body has a certain tolerance to crash forces before harm occurs
Proactive vs. Reactive	Using data, research and evaluation to understand crash risks

Adapted from: ITE Safe Systems Framework - www.ite.org/technical-resources/topics/safe-systems/

People Make Mistakes

Traditional Approach

Focus on education and correcting user behavior

Safe System Approach

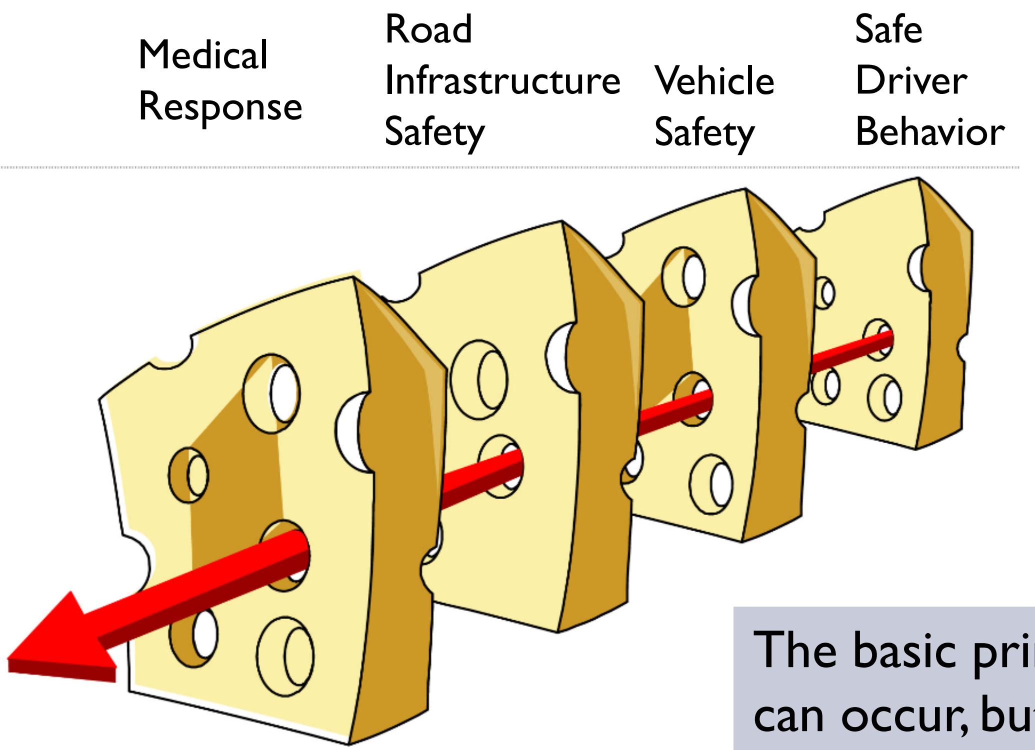
Recognize that road users are human beings who will inevitably at some time make mistakes that can lead to crashes

Human error is human nature and is to be expected.

The key objective for those managing the roads is that, as road users will continue to make mistakes, when crashes do occur, high severity outcomes such as serious injuries and death do not. Therefore, roads need to be equipped with a 'forgiving' infrastructure, taking into account the vulnerability of human beings.

Source: Austroads (2016) 'Research Report AP-R509-16: Safe System Assessment Framework'
https://www.onlinepublications.austroads.com.au/items/AP-R509-16

Shared Responsibility / Strengthen All Parts

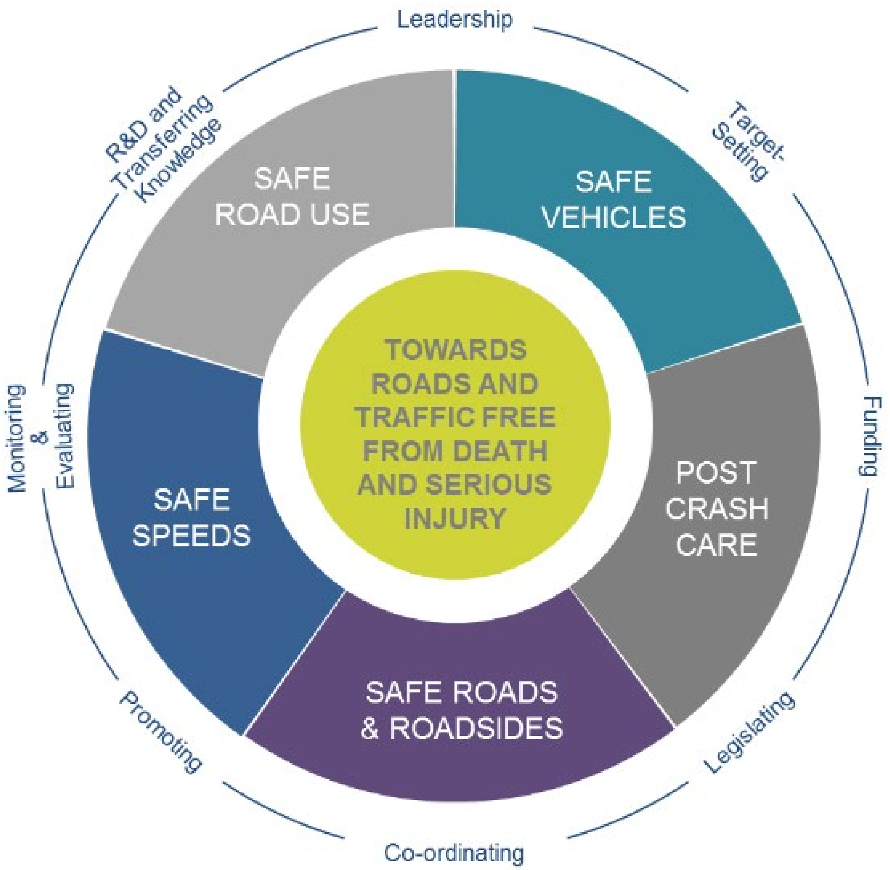


- Layered security measures are represented as slices of swiss cheese with the holes being weaknesses in individual parts of the system.
- A "failure" only results when a hole in each slice momentarily aligns, permitting a hazard to pass through holes in all of the slices.

The basic principle is that lapses and weaknesses in one part of the system can occur, but other parts compensate to not allow a failure.

The "Swiss Cheese Model" is applicable to numerous risk management fields and was originally propounded by Dante Orlandella and James T. Reason of the University of Manchester

Shared Responsibility / Strengthen All Parts



The "Five Pillars" of a Safe System:
- Safe Users
- Safe Vehicles
- Safe Speeds
- Safe Roads and Roadsides
- Post Crash Response

Source: Safe System Factsheet - Royal Society for the Prevention of Accidents
https://www.rospa.com/rospaweb/docs/advice-services/road-safety/roads/safe-system.pdf

What is the Safe System Approach?

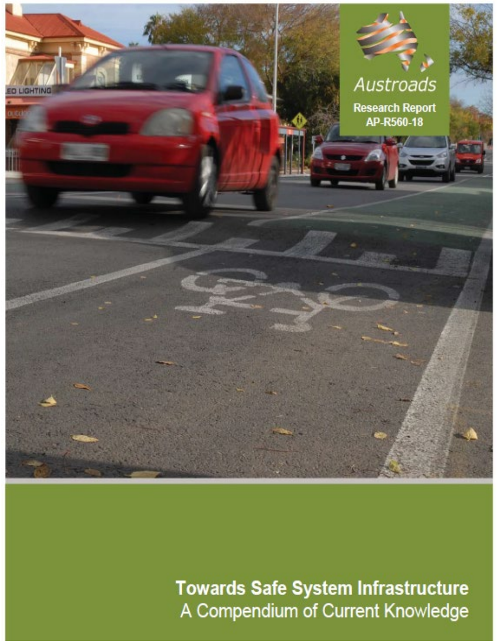
“Safe System is the management and design of the road system such that impact energy on the human body is <u>firstly avoided</u> or <u>secondly managed at tolerable levels</u> by manipulating speed, mass and crash angles to reduce crash injury severity.”

1st AVOID — Anticipate Human Error

- Separate Users in Space
- Separate Users in Time
- Increase User Attentiveness and Awareness

2nd MANAGE — Accommodate Human Injury Tolerance

- Reduce Speeds
- Reduce Impact Forces



Reference: Austroads Report AP-R560-18 Towards Safe System Infrastructure: A Compendium of Current Knowledge

- https://www.youtube.com/watch?v=hZINNGuU788

Additional videos

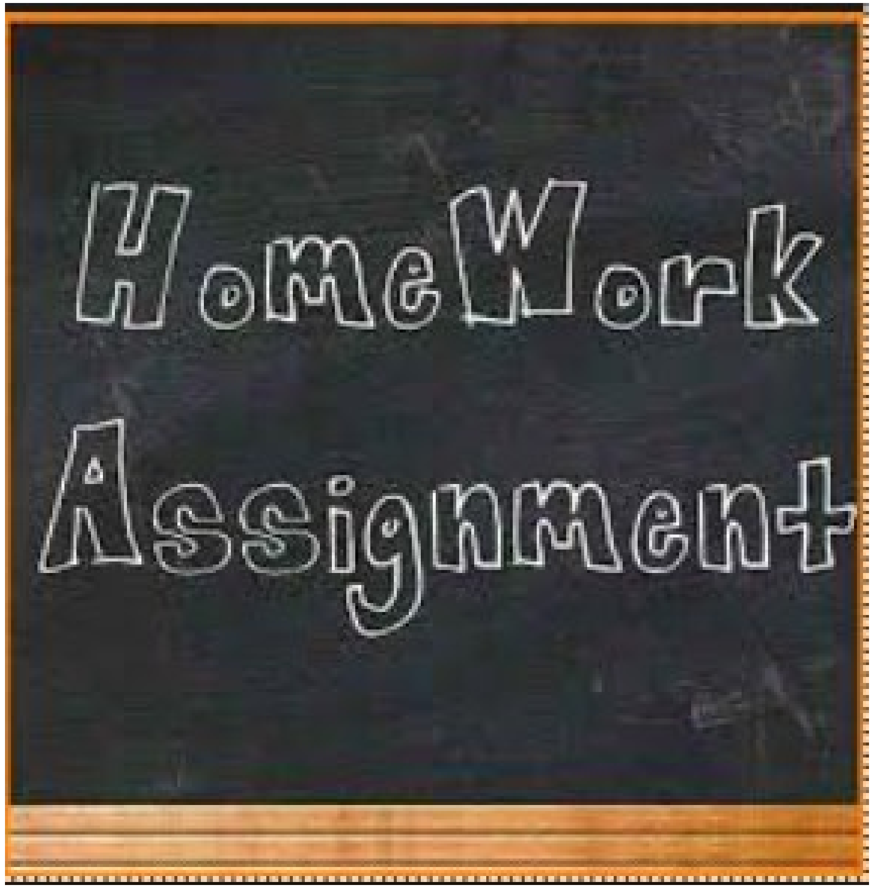
Overview of the Safe System Concept:
https://www.youtube.com/watch?v=MigxAs0KjBw

There's no one someone won't miss:
https://youtu.be/yHhiUv9hX-o

The truth about how most of us drive:
https://www.youtube.com/watch?v=nyOfJTi0jFw

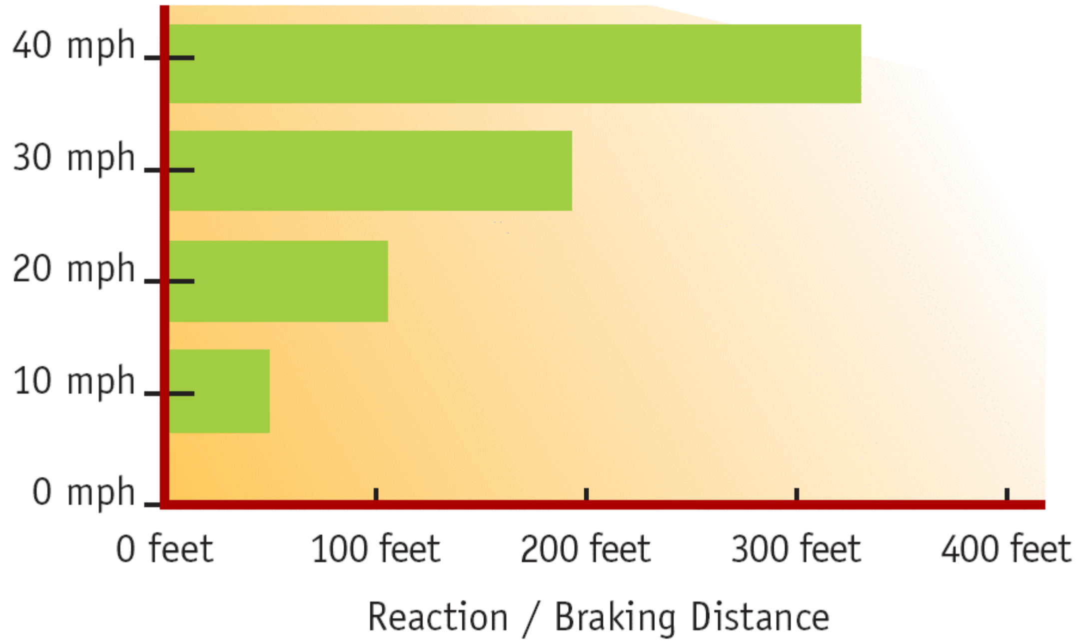
Could we get the NFL to do this at midfield?
https://www.youtube.com/watch?v=Sz9lyIizFwU

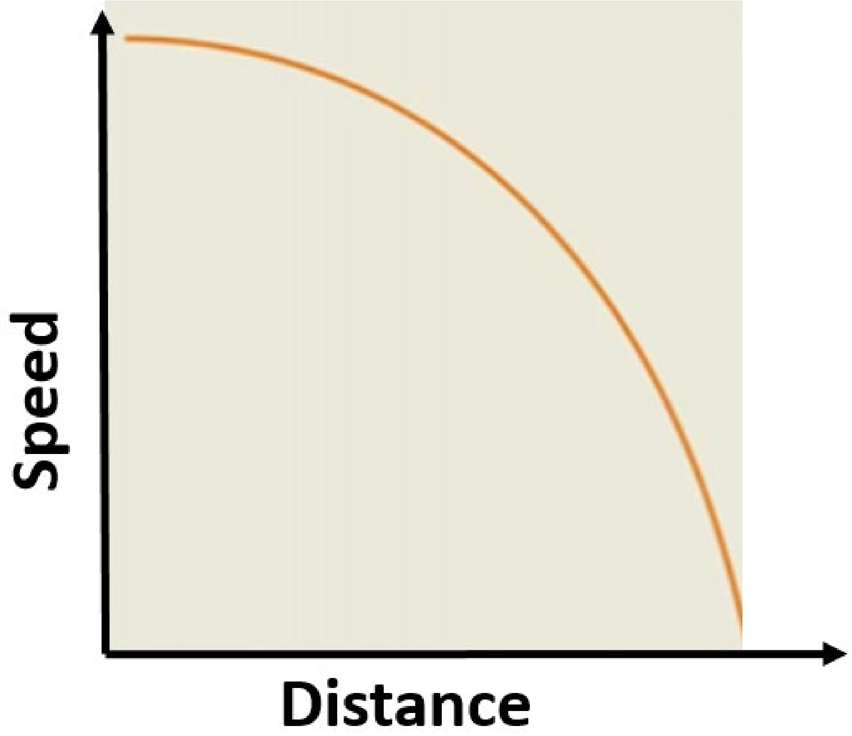
Speed and pedestrian safety
WARNING: this one is graphic
https://www.youtube.com/watch?v=IflF49rkMrM



Speed and Braking

Higher speeds equate to greater reaction and stopping distance





"We wipe off most our speed during the last moments of braking"

Velocity is a Vector
Collision Angle is also Important

Intersection crash severity is highly influenced by SPEED and ANGLE of IMPACT

Transferable Kinetic Energy (Lateral) vs Impact Angle and Travel Speed

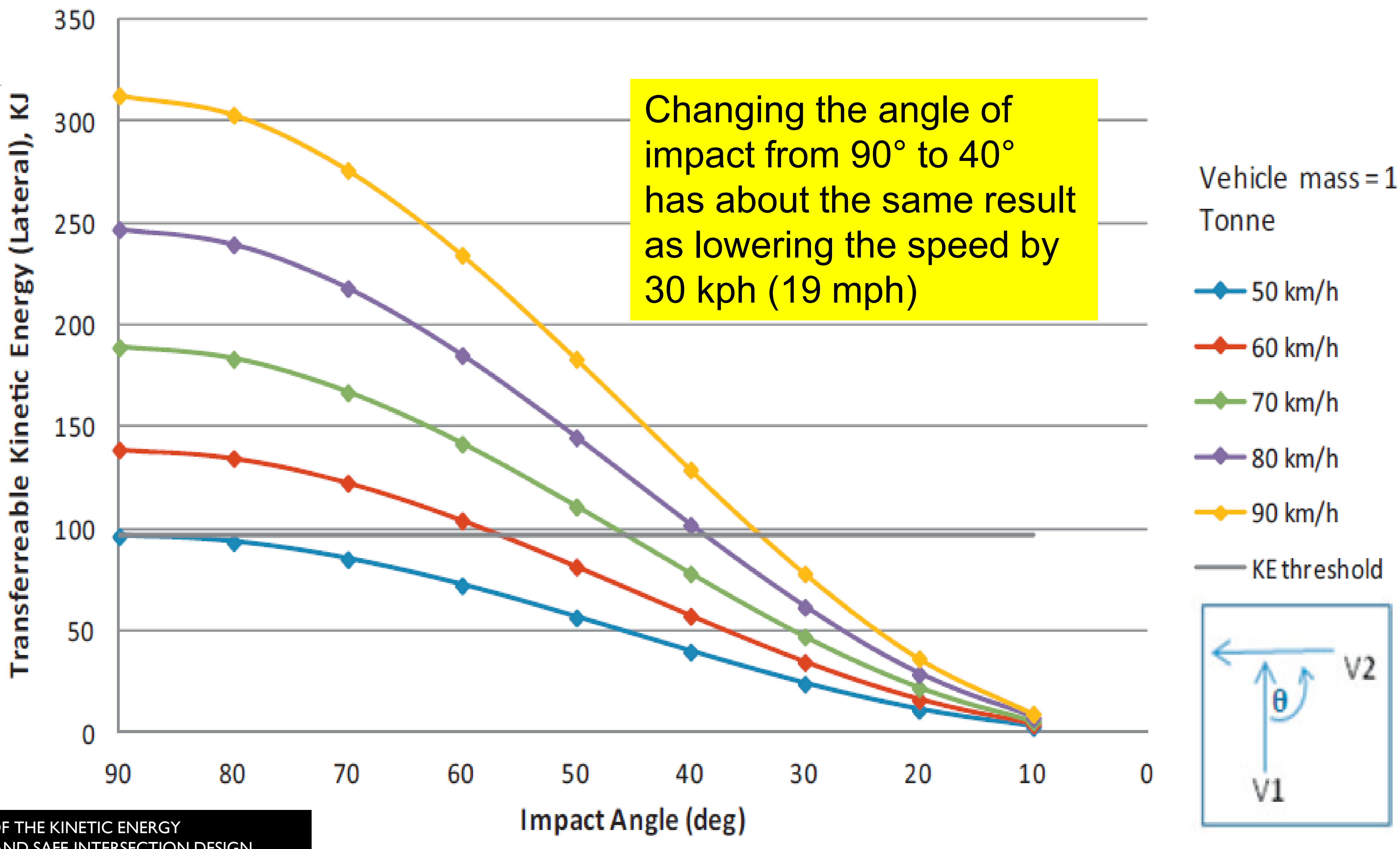


Fig. 1. Influence of impact angle on transferrable kinetic energy.

Source: DEVELOPMENT OF THE KINETIC ENERGY MANAGEMENT MODEL AND SAFE INTERSECTION DESIGN PRINCIPLES
MONASH UNIVERSITY (Melbourne, Australia)

Speed and angle combinations that produce safe system compatible levels of kinetic energy

The relationship between conflict angle and travel speed (impact speed) to avoid intersection designs with a probability of death in a vehicle to vehicle collision that remains below about 10%

Maximum impact speed (km/h)	**Maximum acceptable conflict angle**
40 and below	All OK
50	90°
60	52°/128° (from KEMM-X)
70	0°/180°
80 and above	None feasible

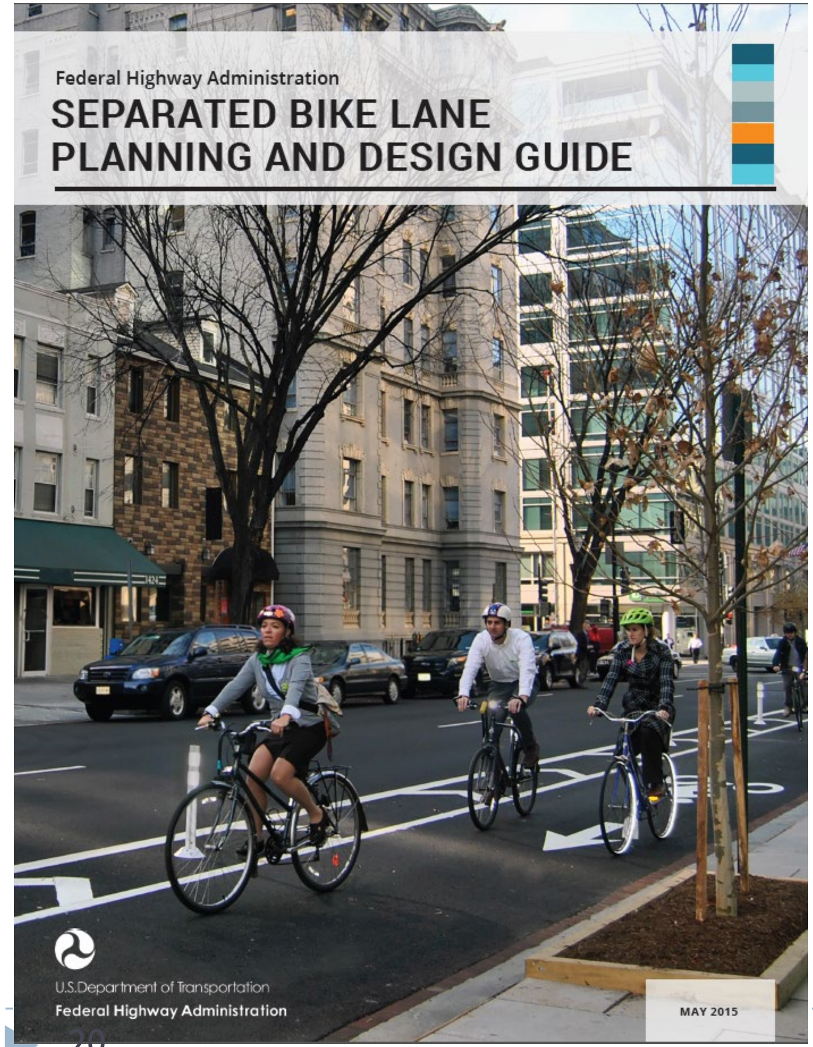
NOTE: 0° and 180° in the above table indicate a head-on and rear-end collision respectively.

Source: Candappa, N., Logan, D., Van Nes, N. and Corben, B., 2015. An exploration of alternative intersection designs in the context of Safe System. Accident Analysis & Prevention, 74, pp.314-323.

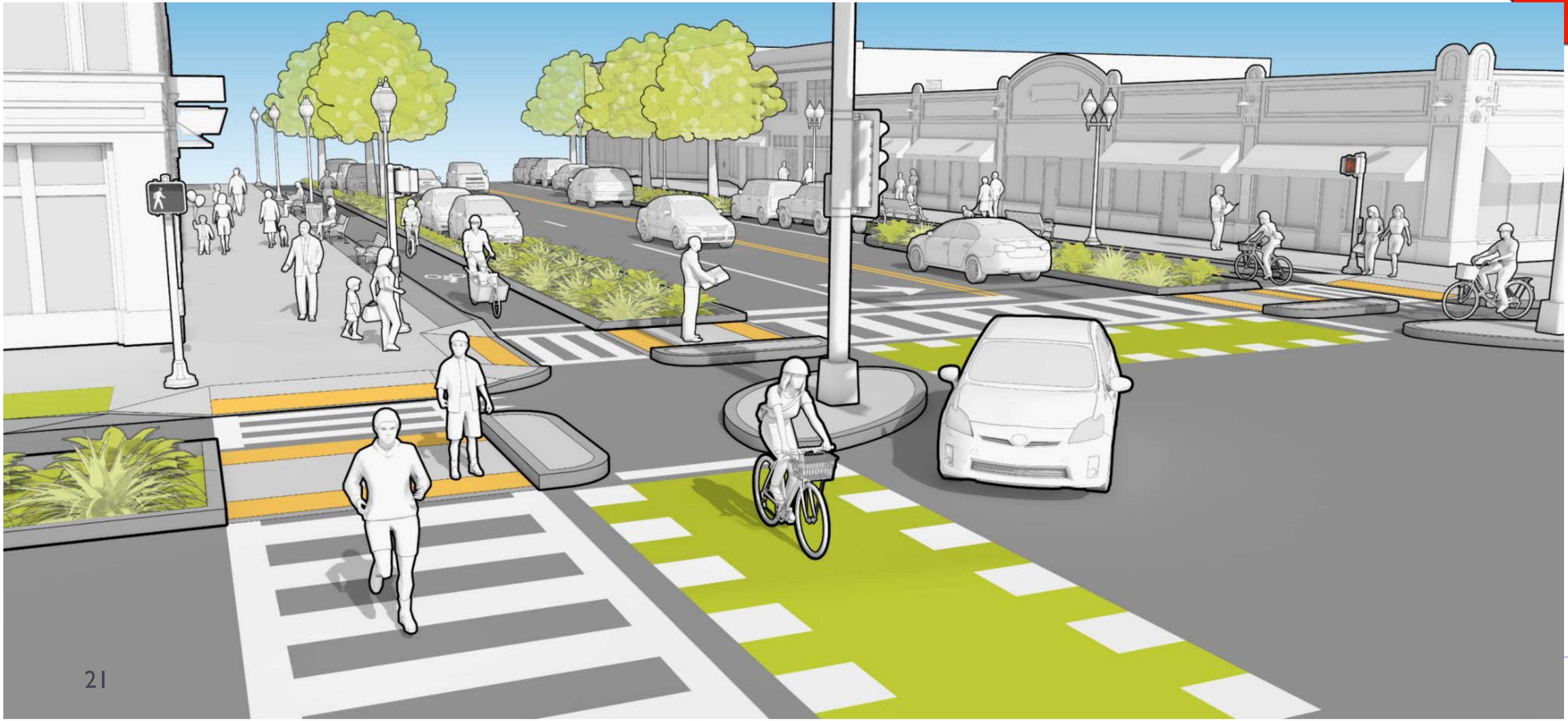
If speeds are incompatible … SEPARATE

Separated Bike Lanes

FHWA



‘Protected’ Intersections



The application of Safe System approaches to infrastructure planning, design, and operations would represent a fundamental shift in how transportation agencies consider, analyze, and make decisions during project development and offer mechanisms to advance safety across the U.S.

Current Practices Around Speed

Design Speed

- The Design Speed is a selected speed used to determine the various geometric design features of the roadway.

-AASHTO Green Book, 2001

Operating Speed

- Operating Speed is the speed at which drivers are observed operating their vehicles during free flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.

-AASHTO Green Book, 2001

Posted / Regulatory Speed

- Posted speed is the maximum speed limit on a section of highway using a regulatory sign as determined in accordance with the Texas Transportation Code.
- Prima Facie speed is the maximum speed limit for certain types of roads as directed in the Texas Transportation Code.

Relationship Between Design, Operating, and Posted Speeds

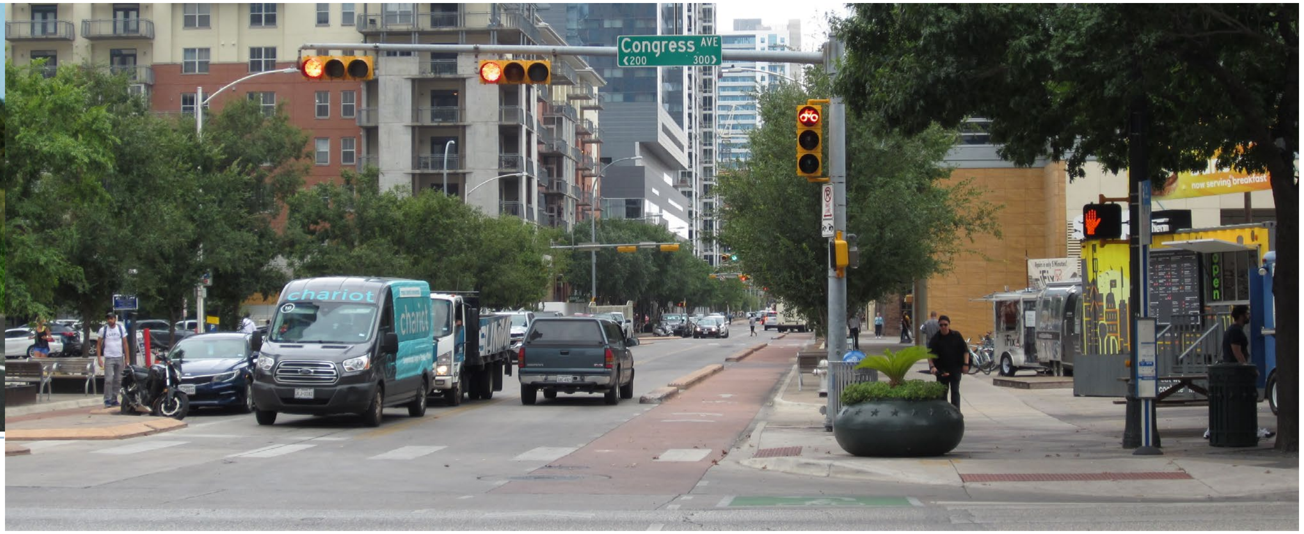
- Are design, operating, and posted speed equal?
- Should they be?
- FHWA Memorandum 2015: Relationship between Design Speed and Posted Speed
  - Replaces a 1985 memo that suggested design speed should be equal or greater than the posted speed of facility.
  - There is no regulatory requirement for a relationship between design speed and posted speed
  - NCHRP 504 failed to develop a relationship between design speed and posted or operating speeds

Source: https://www.fhwa.dot.gov/design/standards/151007.cfm

Selecting a Design Speed

FHWA

- "The higher the better" approach has not helped us reduce fatalities and injuries on our roadways.
- Who is helped by traditional practices of setting design speeds above posted speeds?
  - No One!!
- "Forgiving design" practices are valid, but past approaches built primarily on rural contexts are not sophisticated enough for most situations.



Setting Appropriate Speed Limits

- USLIMITS2
  - A web based tool for recommended speed limits safety.fhwa.dot.gov/uslimits
  - NTSB speeding crash study recommendation H-17-27)
  - Expert based system
  - FHWA Proven Safety Countermeasures

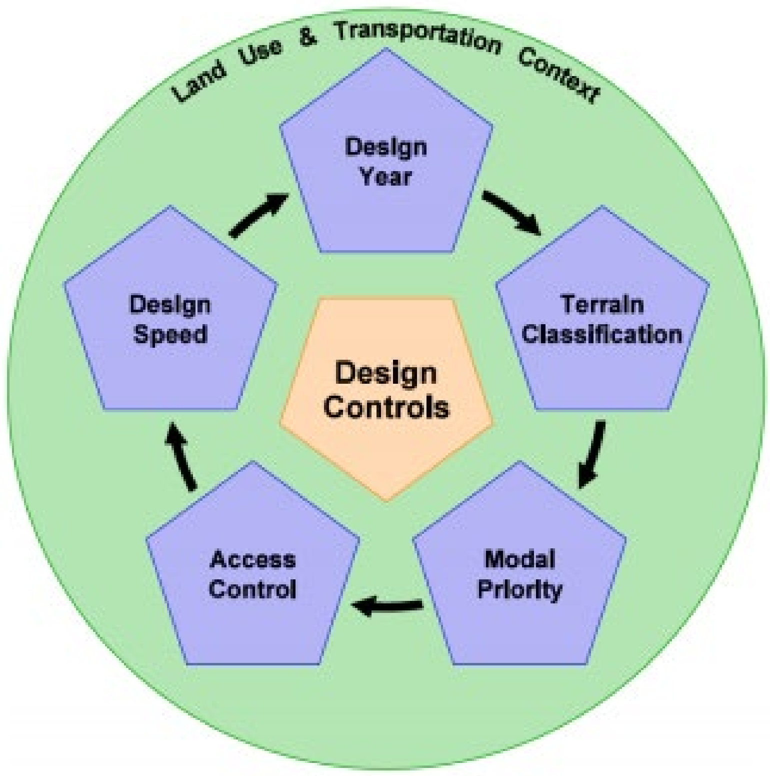
The changing philosophy of design

Target Speed

- A proactive approach to establishing a speed consistent with the context characteristics. Target speed is the design operating speed, which aligns design, posted and operating speed as the same value.
- The target speed selection is derived from other design controls, as well as transportation and land use context characteristics.

-WSDOT

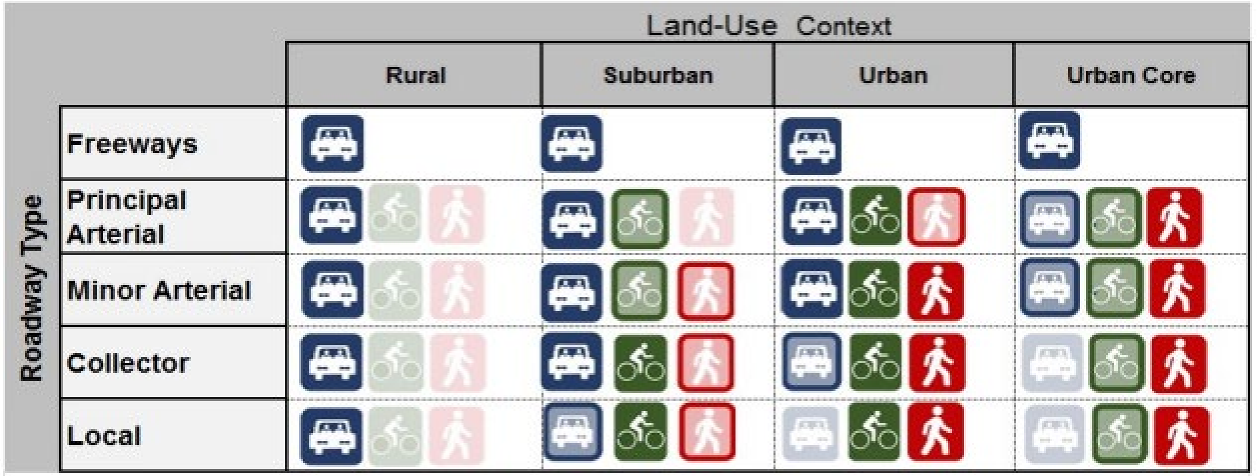
Exhibit 1103-1 WSDOT Design Controls



https://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1102.pdf

Target Speed

Modal Accommodation



Land Use Context and Roadway Type

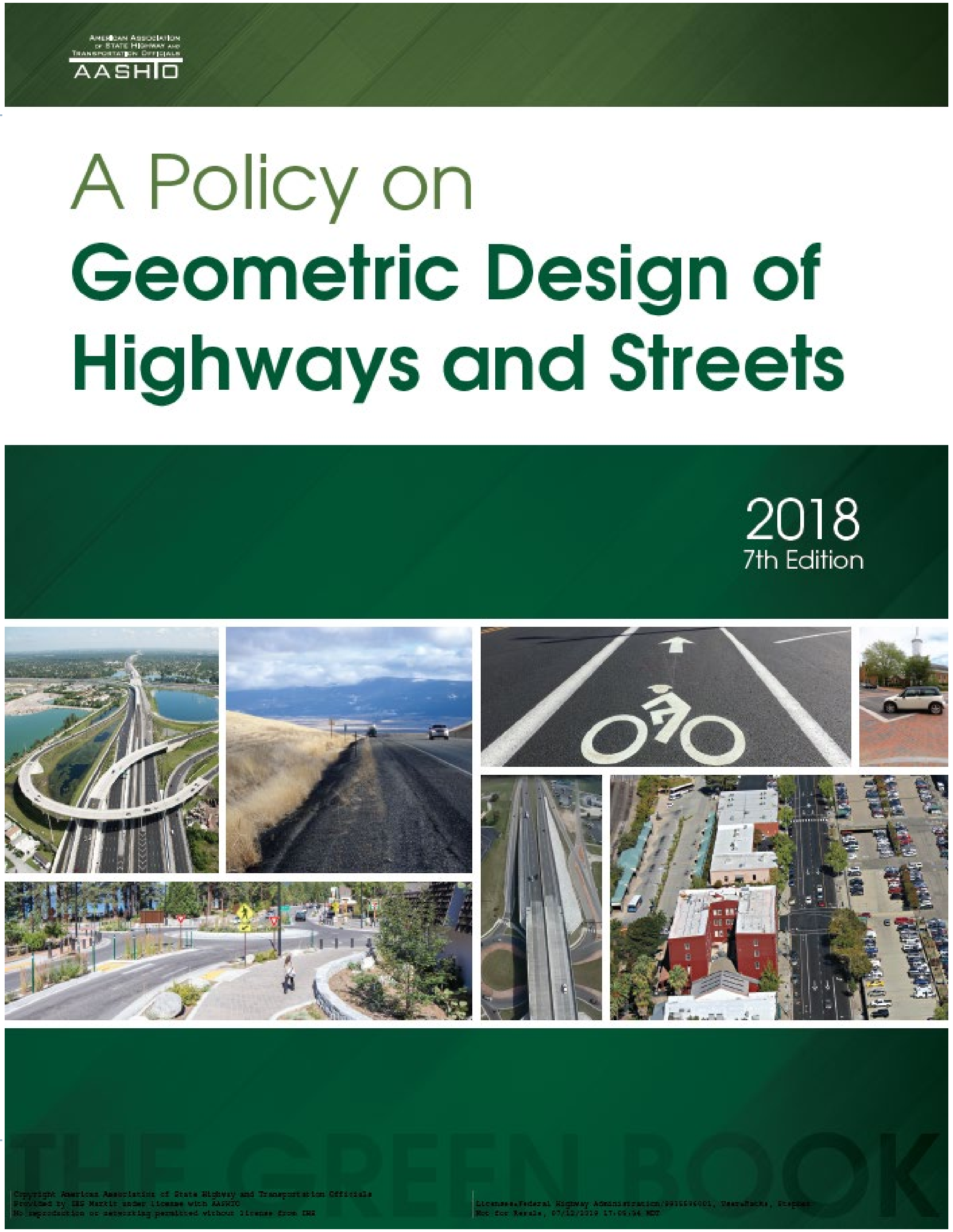
Roadway Type	Land-Use Context: Rural	Suburban	Urban	Urban Core
Freeways	High	High	High	High
Principal Arterial	High	Intermediate / High	Low / Intermediate	Low
Minor Arterial	High	Low/ Intermediate	Low / Intermediate	Low
Collector	Low/ Intermediate	Low/ Intermediate	Low	Low
Local	Low/ Intermediate	Low	Low	Low

*Definitions of low, intermediate, high speeds DO NOT match across documents

https://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1103.pdf

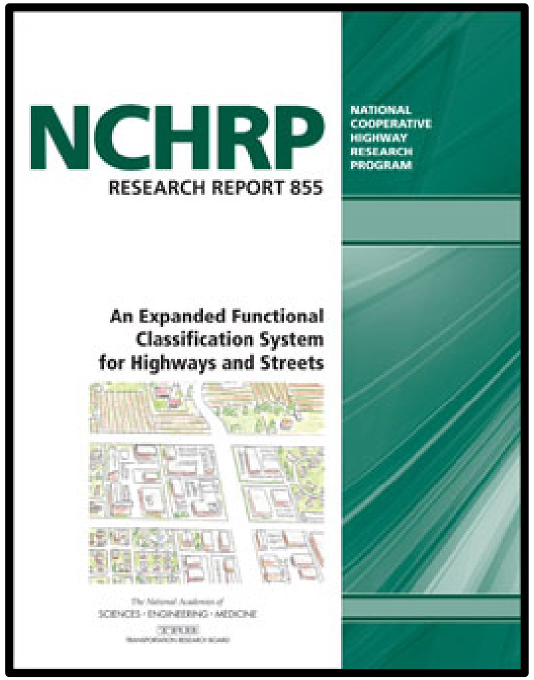
AASHTO Green Book

- 2018, 7th Edition
- Has yet to be formally adopted by FHWA
- Many changes to the document
  - Performance based when possible
  - Movement of people over vehicles only
  - Revised functional class and context
  - Speed management
    - Away from "higher is better"
  - Alternative intersections
  - New construction vs. projects on existing roads



Chapter 1 - New Context Classifications

(based on NCHRP 855)



<u>Two Rural:</u>

Rural and Rural Town

<u>Three Urban:</u>

Urban, Urban Core and Suburban

"Rural" Context Classes

Rural Context

Rural Town Context

"Suburban" Context Class

Suburban Context

FHWA

“Urban” Context Classes

Urban Context | **Urban Core Context**

Projects on Existing roads

- Old Way: Vehicle speeds and LOS based
- New Way: Based on project purpose and need

Purpose / Need	Potential Performance Measure
Mobility / Speed	v/c ratio, delay, LOS
Safety Performance	Crash rate
Surface Condition	IRI / Roughness
Freight Movement	Travel Time Reliability
Economic Development	Job Creation
Bike, Ped and Transit	LOS

General Design Changes

- High speed to low speed transition zones
- "Right Sizing" elements
  - Urban Street lane guidance
  - Rural shoulder width guidance
- Ranges of design speeds within each context
- "Alternative" intersections
  - Turn lanes
  - Reduced conflict intersections
    - RCUT/Superstreet
    - Roundabouts

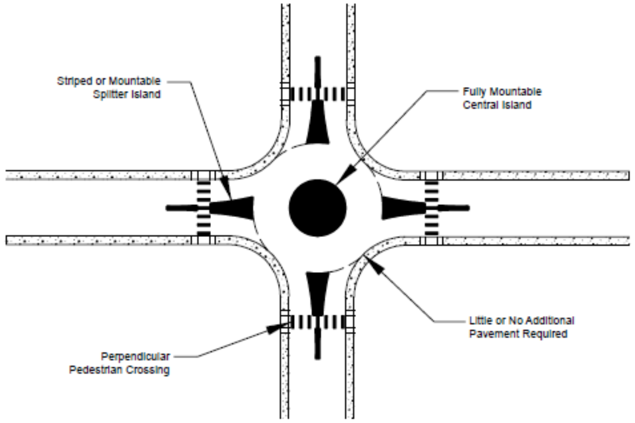
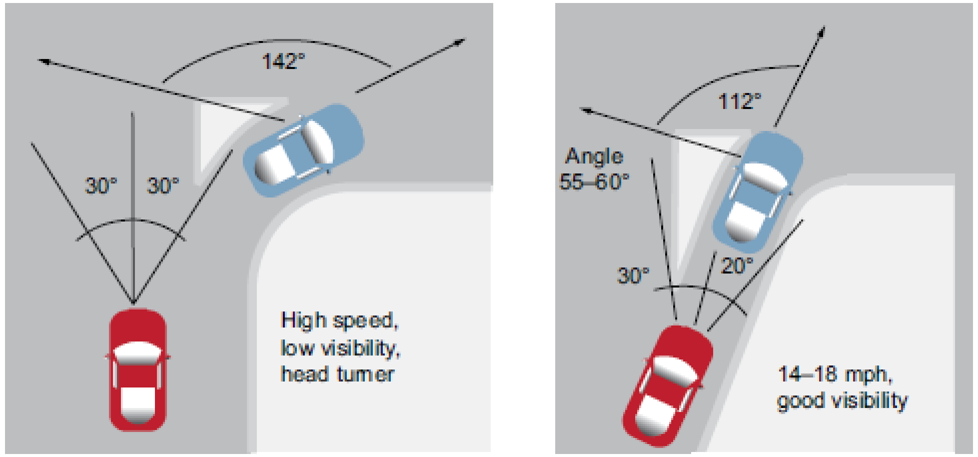


Figure 9-12. Typical Mini-Roundabout



Source: FHWA PEDSAFE http://www.pedbikesafe.org/PEDSAFE/cm_images/ImpRig31.jpg

Figure 9-19. Channelized Right-Turn Lanes

Future Green Book Editions?

NCHRP Report 839: A Performance-based Highway Geometric Design Process

Objectives: (1) develop a comprehensive, flexible design process to meet the needs of geometric designers in the future and (2) update AASHTO's Guidelines for Geometric Design of Very Low-Volume Roads.

The design process must consider:

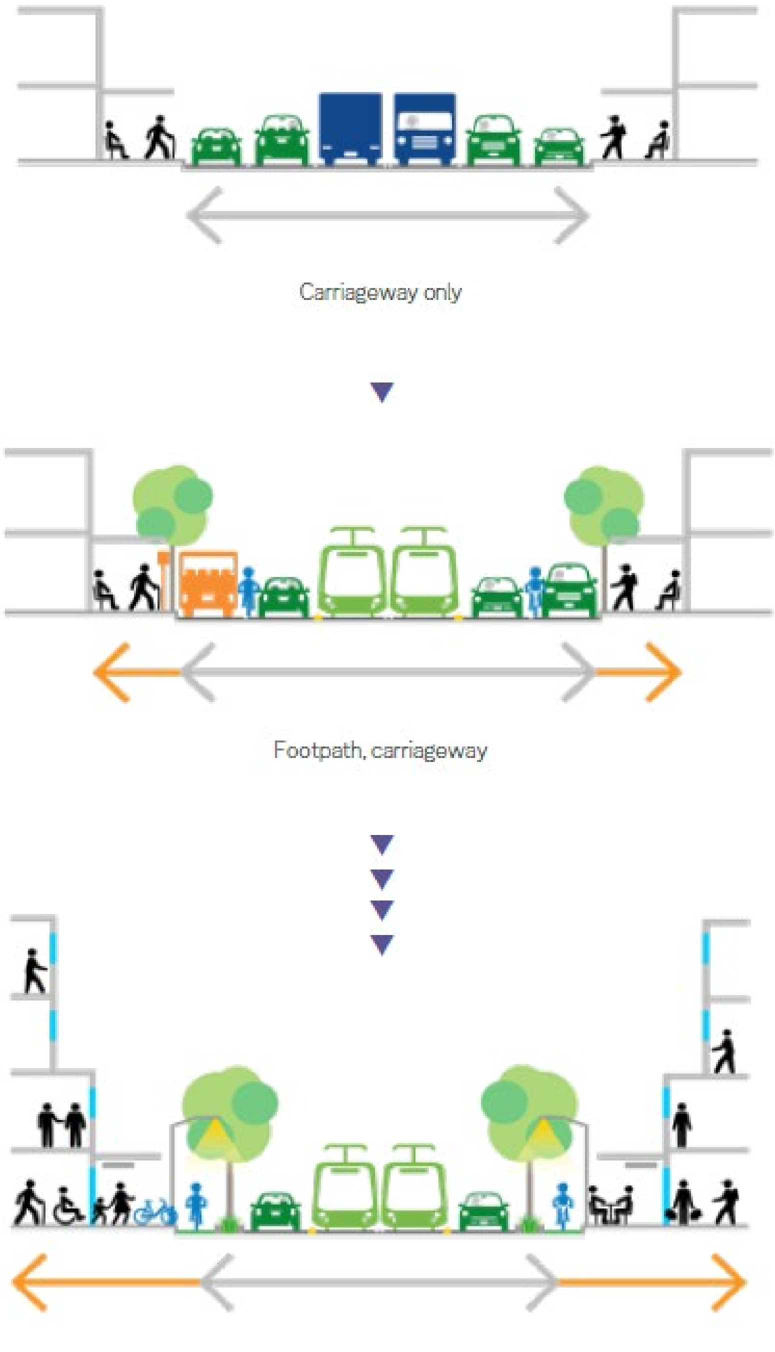
- **Context** setting of the facility
- Desired performance outcomes for the facility for the **various modes**
- Methods for evaluating **tradeoffs** associated with design alternatives
- **Flexibility** to address issues from stakeholder involvement

Fewer standards, more focus on performance

Movement and Place

- What is Movement and Place?
- Fundamental to movement and place thinking is recognizing that streets perform multiple functions. Transport links not only move people from A to B, they also serve as key places and destinations in their own right.

Image: NACTO



Source: Victoria (Australia) Department of Transport

New and Emerging Designs for Speed Management and Safety

Roundabouts

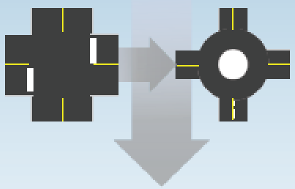
Safe Systems explains these results

U.S. Department of Transportation
Federal Highway Administration

PROVEN SAFETY COUNTERMEASURES

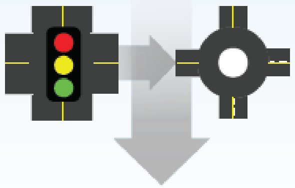
Roundabouts

TWO-WAY STOP-CONTROLLED INTERSECTION TO A ROUNDABOUT



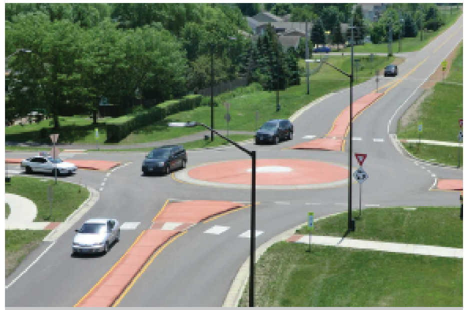
82%
Reduction in severe crashes

SIGNALIZED INTERSECTION TO A ROUNDABOUT



78%
Reduction in severe crashes

Source: *Highway Safety Manual*



Example of a single-lane roundabout.
Source: FHWA

The modern roundabout is a type of circular intersection configuration that safely and efficiently moves traffic through an intersection. Roundabouts feature channelized approaches and a center island that results in lower speeds and fewer conflict points. At roundabouts, entering traffic yields to vehicles already circulating, leading to improved operational performance.

Roundabouts provide substantial safety and operational benefits compared to other intersection types, most notably a reduction in severe crashes.

Roundabouts can be implemented in both urban and rural areas under a wide range of traffic conditions. They can replace signals, two-way stop controls, and all-way stop controls. Roundabouts are an effective option for managing speed and transitioning traffic from high-speed to low-speed environments, such as freeway interchange ramp terminals, and rural intersections along high-speed roads.

Example of a multi-lane roundabout.
Source: FHWA

FHWA encourages agencies to consider roundabouts during new construction and reconstruction projects as well as for existing intersections that have been identified as needing safety or operational improvements.

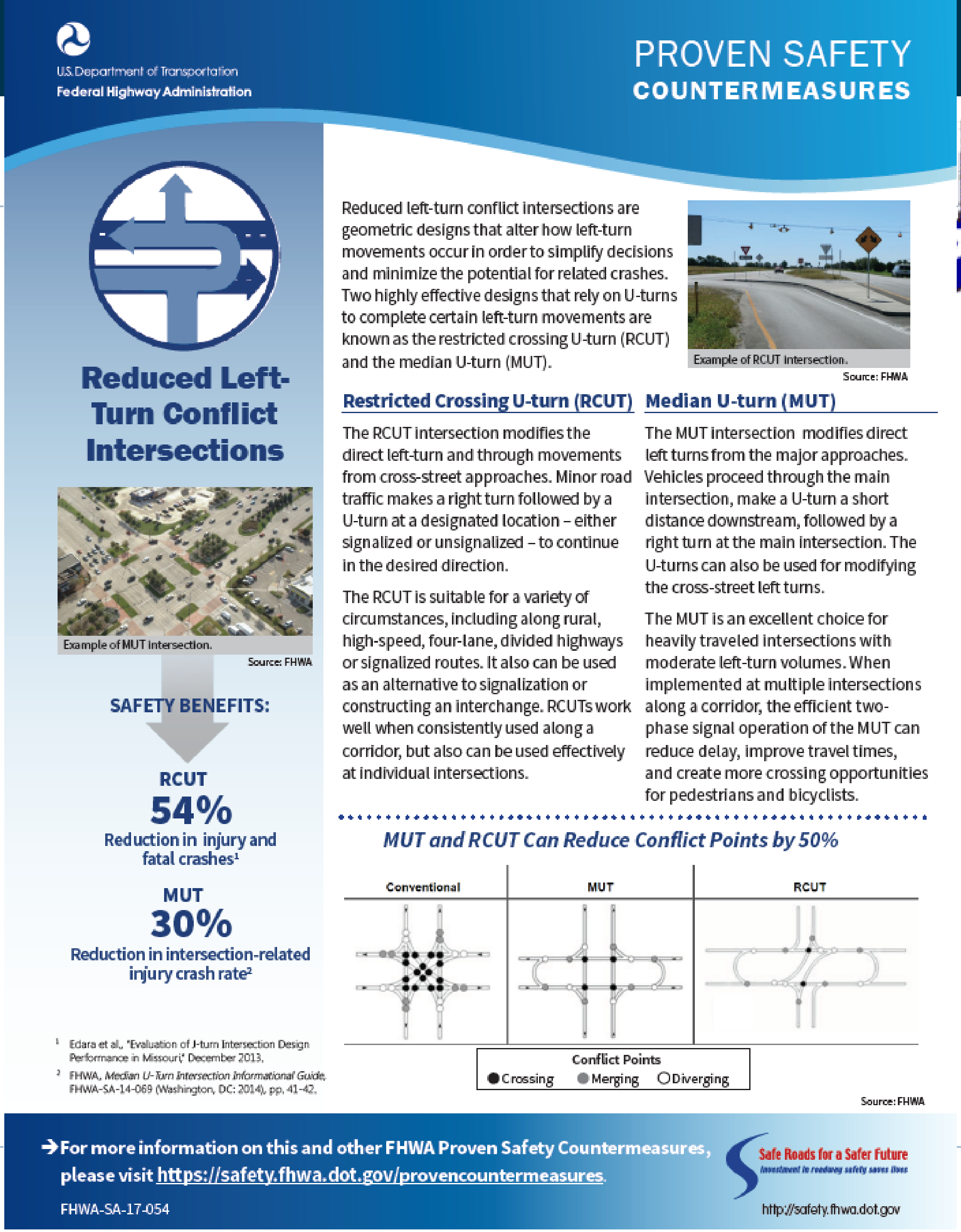
→ For more information on this and other FHWA Proven Safety Countermeasures, please visit https://safety.fhwa.dot.gov/provencountermeasures.

FHWA-SA-17-055

Safe Roads for a Safer Future
Investment in roadway safety saves lives
http://safety.fhwa.dot.gov

FHWA

Reduced Left-turn Conflict Intersections



U.S. Department of Transportation
Federal Highway Administration

PROVEN SAFETY COUNTERMEASURES

Reduced Left-Turn Conflict Intersections

Example of MUT intersection.
Source: FHWA

SAFETY BENEFITS:

RCUT
54%
Reduction in injury and fatal crashes[1]

MUT
30%
Reduction in intersection-related injury crash rate[2]

Reduced left-turn conflict intersections are geometric designs that alter how left-turn movements occur in order to simplify decisions and minimize the potential for related crashes. Two highly effective designs that rely on U-turns to complete certain left-turn movements are known as the restricted crossing U-turn (RCUT) and the median U-turn (MUT).

Example of RCUT intersection.
Source: FHWA

Restricted Crossing U-turn (RCUT)

The RCUT intersection modifies the direct left-turn and through movements from cross-street approaches. Minor road traffic makes a right turn followed by a U-turn at a designated location – either signalized or unsignalized – to continue in the desired direction.

The RCUT is suitable for a variety of circumstances, including along rural, high-speed, four-lane, divided highways or signalized routes. It also can be used as an alternative to signalization or constructing an interchange. RCUTs work well when consistently used along a corridor, but also can be used effectively at individual intersections.

Median U-turn (MUT)

The MUT intersection modifies direct left turns from the major approaches. Vehicles proceed through the main intersection, make a U-turn a short distance downstream, followed by a right turn at the main intersection. The U-turns can also be used for modifying the cross-street left turns.

The MUT is an excellent choice for heavily traveled intersections with moderate left-turn volumes. When implemented at multiple intersections along a corridor, the efficient two-phase signal operation of the MUT can reduce delay, improve travel times, and create more crossing opportunities for pedestrians and bicyclists.

MUT and RCUT Can Reduce Conflict Points by 50%

Conventional | MUT | RCUT

Conflict Points: Crossing, Merging, Diverging

Source: FHWA

1 Edara et al., "Evaluation of J-turn Intersection Design Performance in Missouri," December 2013.
2 FHWA, *Median U-Turn Intersection Informational Guide*, FHWA-SA-14-069 (Washington, DC: 2014), pp. 41-42.

→ For more information on this and other FHWA Proven Safety Countermeasures, please visit https://safety.fhwa.dot.gov/provencountermeasures.

Safe Roads for a Safer Future
Investment in roadway safety saves lives
http://safety.fhwa.dot.gov

FHWA-SA-17-054

A Safe Systems Approach to Intersection Planning & Design in the United States*

- Encompasses following elements
  - Combinations of intersection geometric characteristics and controls.
  - Exposure and conflict frequency (considering temporal variations in volumes).
  - Speed and conflict severity.
  - Modal and user vulnerability (considering higher-risk or non-motorized users).
  - Critical thresholds of collision kinetic energy (considering collision angles/types).
  - Other intersection collision risk factors.

Methodology Currently in Development
Scheduled Completion summer 2020

Type of Collision	Maximum Survivable Impact Speeds
Car/car (side impact)	50 km/hr
Car/car (head-on)	70 km/hr
Car/tree or pole	40 km/hr
Car/pedestrian	30 km/hr
Car/motorcyclist	30 km/hr
Source: Australian National Road Safety Strategy (2011-2020)	

Road Diets

U.S. Department of Transportation
Federal Highway Administration

PROVEN SAFETY
COUNTERMEASURES

Road Diets

(Roadway Reconfiguration)

A "Road Diet," or roadway reconfiguration, can improve safety, calm traffic, provide better mobility and access for all road users, and enhance overall quality of life.

SAFETY BENEFIT:

4-LANE →3-LANE ROAD DIET CONVERSIONS

19-47%

Reduction in total crashes

Source: *Evaluation of Lane Reduction "Road Diet" Measures on Crashes*, FHWA-HRT-10-053.

Before and after photos of a Road Diet project.

Source: City of Orlando, Florida

A Road Diet typically involves converting an existing four-lane undivided roadway to a three-lane roadway consisting of two through lanes and a center two-way left-turn lane (TWLTL).

Benefits of Road Diet installations may include:

- An overall crash reduction of 19 to 47 percent.
- Reduction of rear-end and left-turn crashes due to the dedicated left-turn lane.
- Reduced right-angle crashes as side street motorists cross three versus four travel lanes.
- Fewer lanes for pedestrians to cross.
- Opportunity to install pedestrian refuge islands, bicycle lanes, on-street parking, or transit stops.
- Traffic calming and more consistent speeds.
- A more community-focused, "Complete Streets" environment that better accommodates the needs of all road users.

A Road Diet can be a low-cost safety solution when planned in conjunction with a simple pavement overlay, and the reconfiguration can be accomplished at no additional cost.

Road Diet project in Honolulu, Hawaii.

Source: Leidos

→For more information on this and other FHWA Proven Safety Countermeasures, please visit https://safety.fhwa.dot.gov/provencountermeasures.

Safe Roads for a Safer Future
Investment in roadway safety saves lives

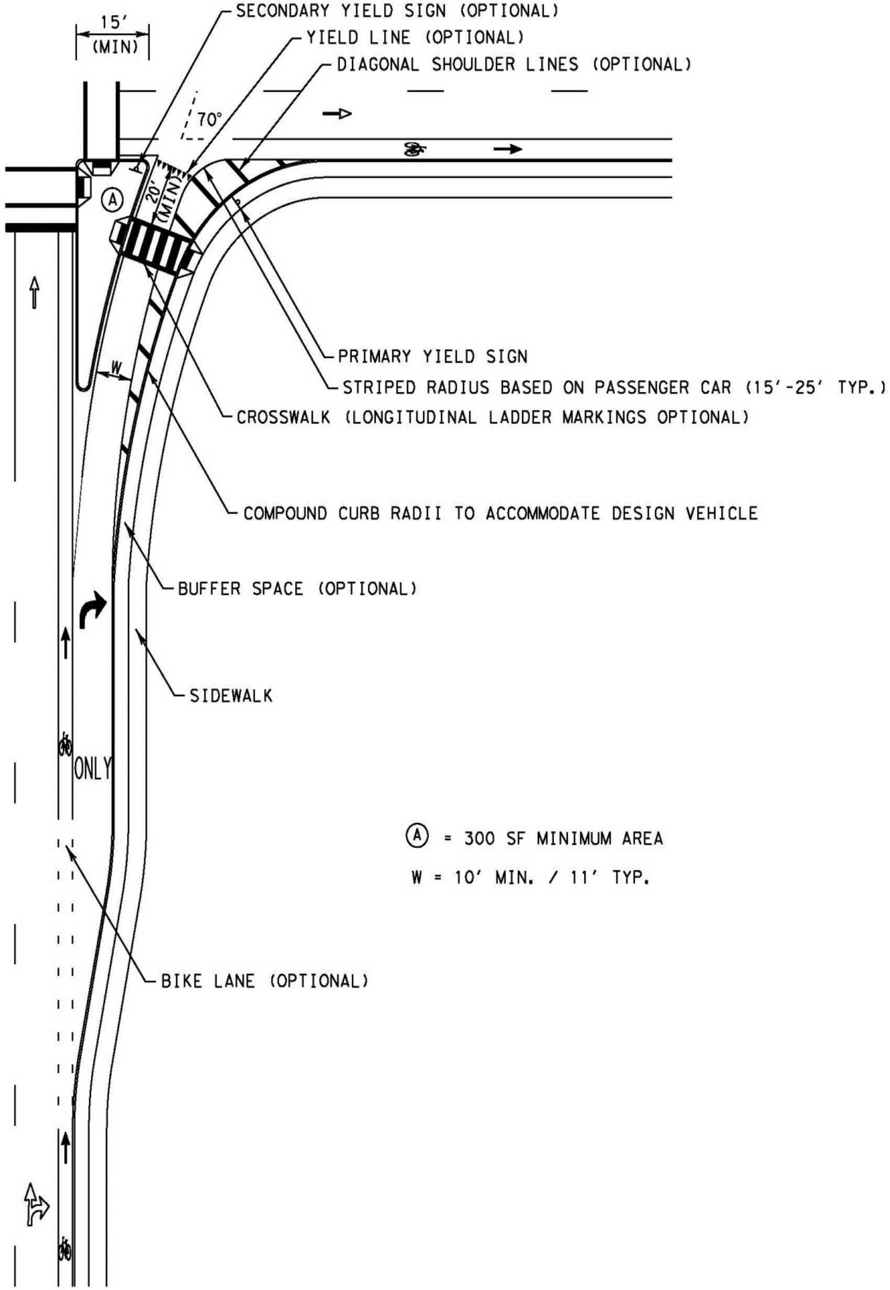
http://safety.fhwa.dot.gov

FHWA-SA-17-066

FHWA

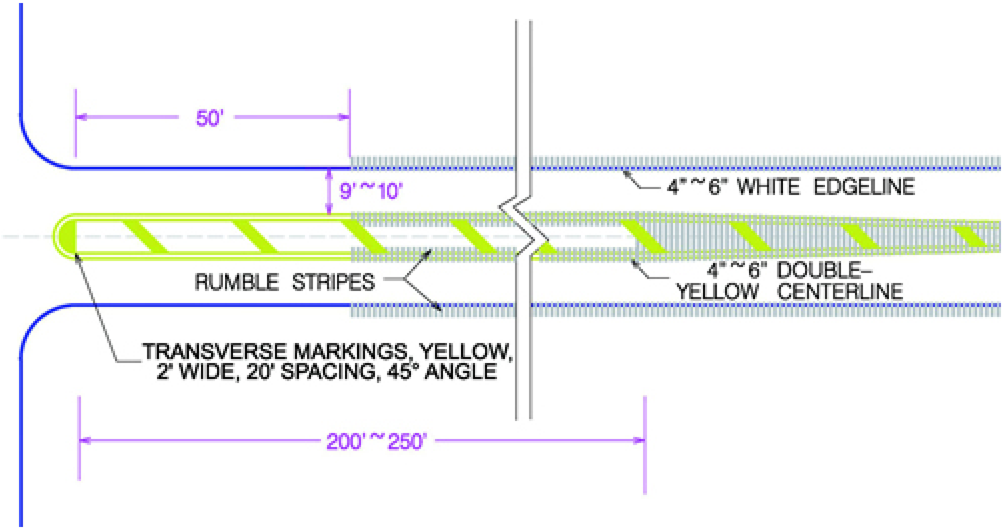
Right Turn Lane Design

- Draft TxDOT RDM Appendix
  - Curbs based on truck turning paths
  - Striping based on car turning paths
- Austin: Curb Aprons



Lane Narrowing with Rumble Strips at Two-Lane Rural Stop-Controlled Intersections

- 32% total crash reduction and 34% fatal and injury crash reduction



https://www.fhwa.dot.gov/publications/research/safety/10047/

FHWA Speed Management and Other Resources

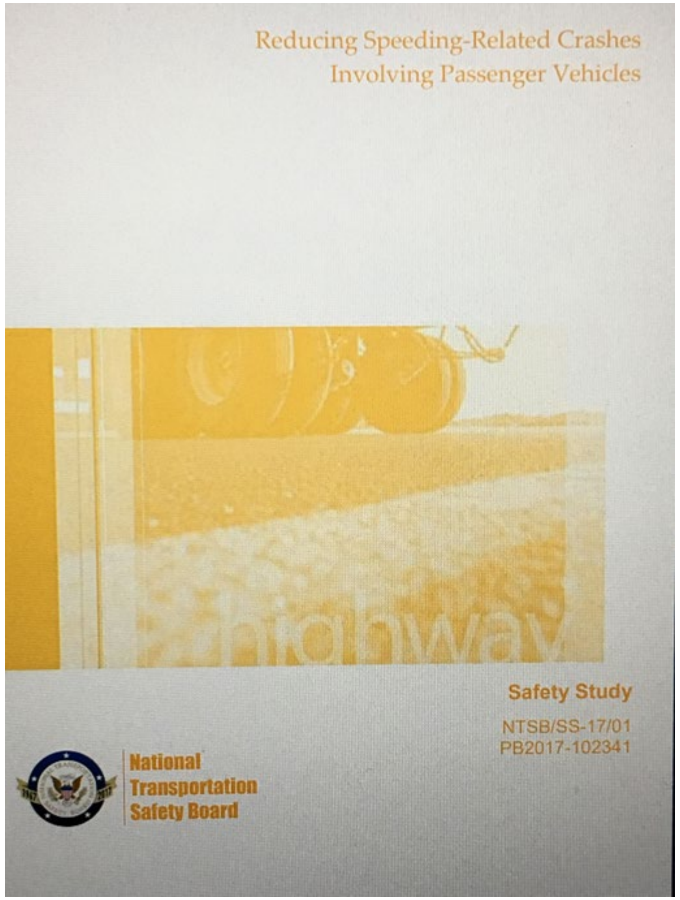
US DOT Speed Management

- FHWA, NHTSA, and FMCSA have a joint working group
- FHWA website: https://safety.fhwa.dot.gov/speedmgt/
- Guidance documents
  - Speed Concepts: Informational Guide: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa10001/#
  - Methods and Practices for Setting Speed Limits: An Informational Report: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa12004/
  - Guidelines for the Use of Variable Speed Limit Systems in Wet Weather: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa12022/

Reducing Speeding-Related Crashes Involving Passenger Vehicles - NTSB 2017

19 Recommendations focusing on:

- Speed limit
- Data-driven approach for speed Enforcement
- Automated Speed Enforcement
- Intelligent speed adaptation
- National leadership



NTSB Speeding-Related Crashes Study Recommendations

- One to USDOT Team – Update USDOT plan
- Four to FHWA
  - Revise MUTCD Section 2B.13 to require an expert system such as USLIMITS2 be used and remove 85^{th} percentile speed
  - Revised MUTCD to incorporate the safe system approach for urban roads
  - Update the Speed Enforcement Camera Systems Operational Guidelines
  - Assess the effectiveness of point-to-point speed enforcement in the United States and update the ASE guidelines accordingly

NTSB Speeding-Related Crashes Study Recommendations

- Seven to NHTSA
  - establish a consistent method for evaluating data-driven, high-visibility enforcement programs
  - communicate with law enforcement officers and the public about the effectiveness of data-driven, high-visibility enforcement programs
  - develop and implement Model Minimum Uniform Crash Criteria Guideline
  - increase public awareness of speeding as a national traffic safety issue.
  - Establish a program to incentivize state and local speed management activities

Other FHWA Technical Assistance

- **USLIMITS2** – Free technical assistance and training webinar upon request via help@uslimits.org.
- **FHWA Speed Management Training Course** - Course number: FHWA-NHI-380116 https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=FHWA-NHI-380116&sf=0&course_no=380116
- **Technical assistance to State and locals for developing and implementing speed management plans** - Work directly with State/Locals to identify speeding safety problems and locations, strategies and countermeasures, and implementation plan. https://safety.fhwa.dot.gov/speedmgt/ref_mats/docs/fhwa_speedmanagementpackage_final.pdf

FHWA

QUESTIONS