National Center for Rural Road Safety

A Federal Highway Administration Center for Excellence

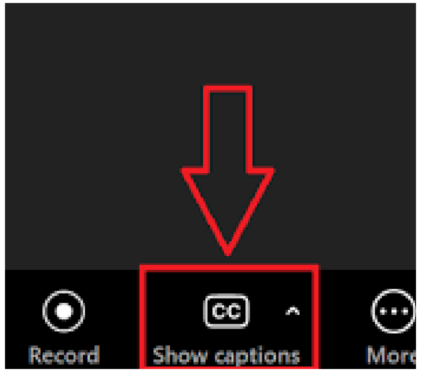
Session 3: Safer Roads in the Rural Context

Applying the Safe System Approach for Rural

½ Day Virtual, Mini-Conference

January 28, 2026

Webinar Logistics



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Safe System Design Hierarchy for the Rural Context

Applying the Safe System Approach for Rural Virtual, Mini-Conference

Session 3: Safer Roads in the Rural Context

January 28, 2026 – Jaime Sullivan

SSA Lens to Implementation of Safer Rural Roads

- Holistic and iterative
- Opportunity for collaborations
- All elements of SSA tie together

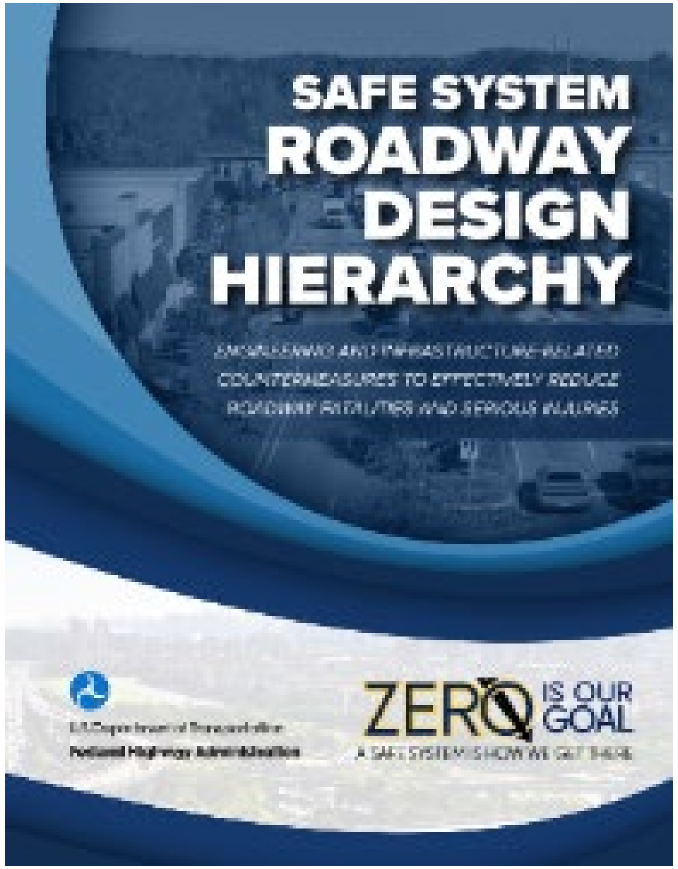
Graphic Source: FHWA

Rural Countermeasures

FHWA's Proven Safety Countermeasures in Rural Communities

NHTSA's Traffic Safety Countermeasures that Work in Rural Communities

Safe System Roadway Design Hierarchy

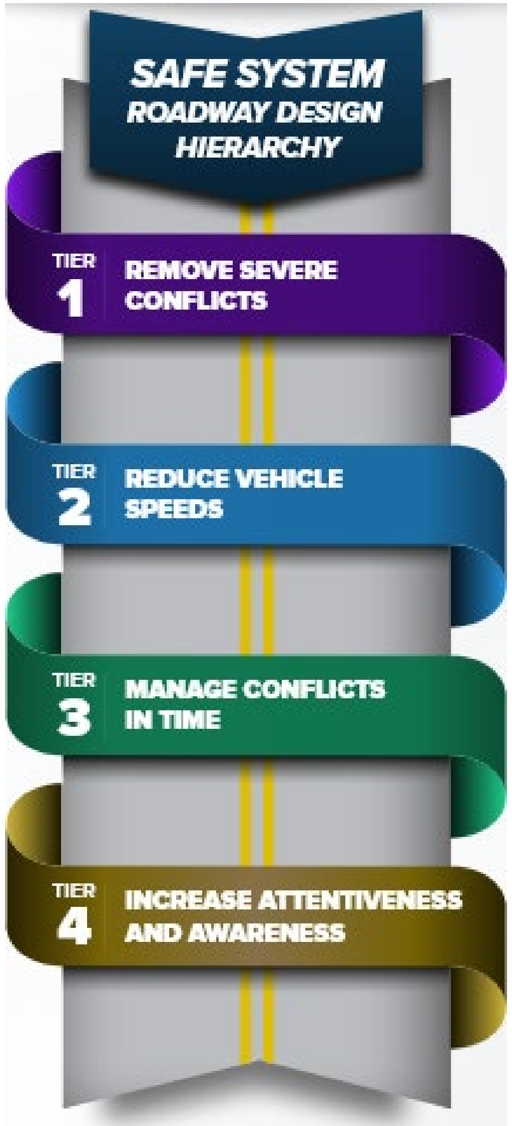


What is the Hierarchy?

- Framework for evaluating countermeasures and strategies based on SSA alignment
  - Dependent on context, classification, location, and users of the facility
  - Same countermeasure can be applied for SSA alignment in different contexts in different ways
- Supplement to other tools for identifying, selecting and prioritizing countermeasures

Hierarchy Tiers

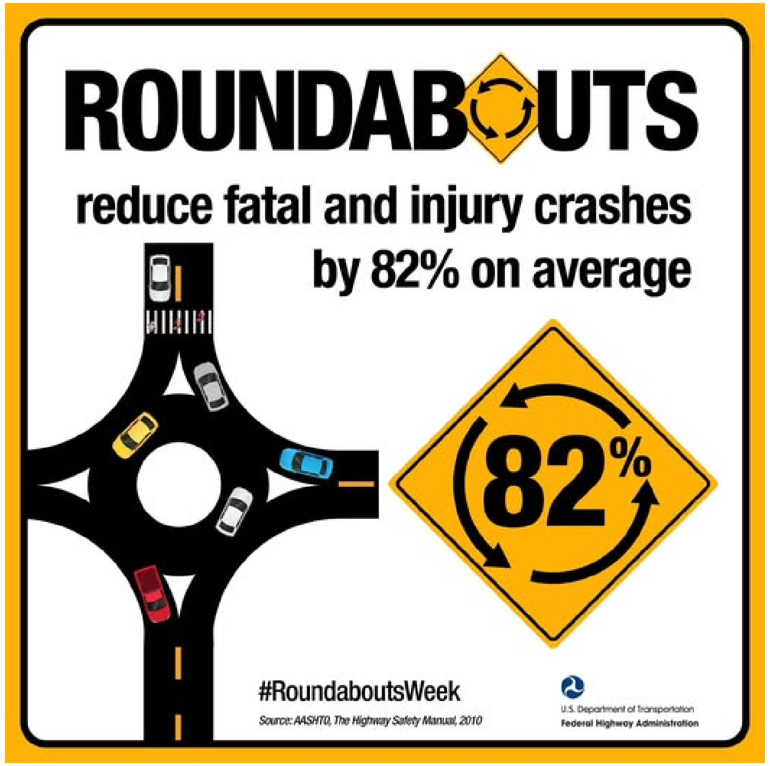
- Tier 1: Remove Severe Conflicts
- Tier 2: Reduce Vehicle Speeds
- Tier 3: Manage Conflicts in Time
- Tier 4: Increase Attentiveness & Awareness



Graphic Source: FHWA

Tier 1: Remove Severe Conflicts

- Strategies that minimize conflicts
- Separating road users moving at different speeds or in different directions in space
- Examples:
  - Roadside design improvements at curves
  - Roundabouts
  - Walkways



Graphic Source: FHWA

Tier 2: Reduce Vehicle Speeds

- Design features and speed management strategies
- Reduces kinetic energy if a crash occurs
- Examples:
  - Variable speed limits
  - Gateway treatments
  - Self-enforcing roads

Photo Source: Colorado DOT

Tier 3: Manage Conflicts in Time

- When users occupy same physical space
- Use traffic control devices to minimize conflicts
- Examples:
  - Left-turn phasing
  - Emergency vehicle preemption
  - Pedestrian hybrid beacons

Photo Source: Neil Hetherington, WTI

Tier 4: Increase Attentiveness & Awareness

- Alerting roadway users to certain conflicts
- Appropriate actions consistent with SSA
- Examples
  - Wider edge lines
  - Rumble strips/stripes
  - Systemic application of multiple low-cost countermeasures at stop-controlled intersections

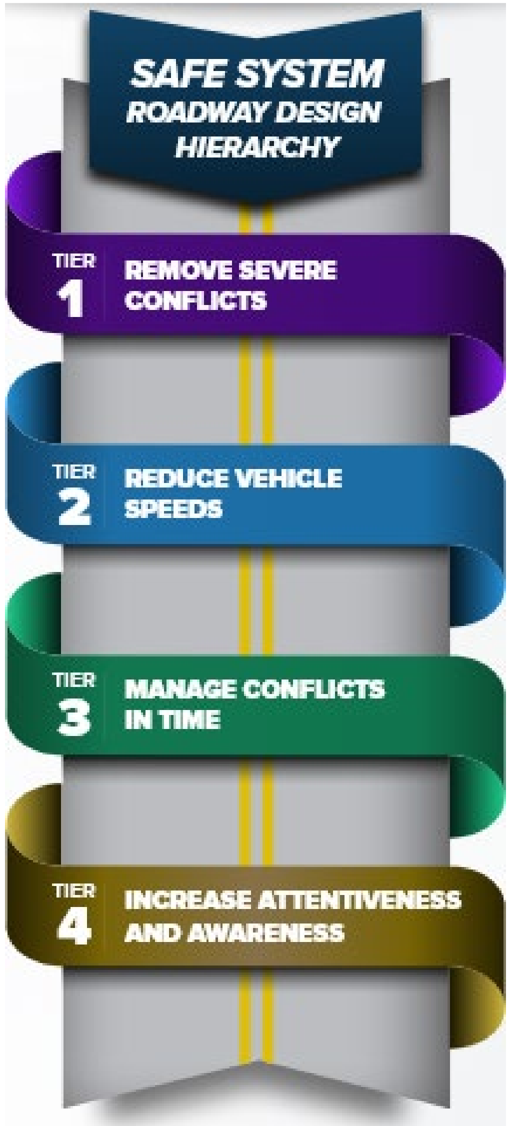
Average Benefit/Cost Ratio

12:1

Graphic Source: FWHA

How to Use the Hierarchy

- Framework for evaluating countermeasures for SSA alignment
  - Project based, site assessment tool
  - Planning phase for prioritization criteria
- Consider Tier 1 first
- Then subsequent tiers – alone or in combination
- Some countermeasures cross-cut multiple tiers
- Incremental approach



Graphic Source: FHWA

Proven Safety Countermeasure	Tier 1 Remove Severe Conflicts	Tier 2 Reduce Vehicle Speeds	Tier 3 Manage Conflicts in Time	Tier 4 Increase Attentiveness and Awareness
Roadway Departure (continued)				
Roadside Design Improvements at Curves	✓			
SafetyEdge℠	✓			
Wider Edge Lines				✓
Intersections				
Backplates with Reflective Borders				✓
Corridor Access Management	✓			
Dedicated Left and Right Turn Lanes at Intersections	✓			
Reduced Left Turn Conflict Intersections	✓			
Roundabouts	✓	✓		
Systemic Application of Multiple Low-Cost Countermeasures at Stop-Controlled Intersections				✓
Yellow Change Intervals			✓	
Crosscutting				
Lighting				✓
Local Road Safety Plans	✓	✓	✓	✓
Pavement Friction Management	✓	✓		
Road Safety Audit	✓	✓	✓	✓

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Questions?

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Self-Explaining Roads and Rural Speed Management

Applying the Safe System Approach for Rural

Session 3: Safer Roads in the Rural Context

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January 28, 2026

Objectives

- Define self-explaining roads.
- Examine human behavior.
- Explain the role of roadway design in driver speed selection.
- Design a self-explaining road.

Introduction

- What is a self-explaining road?
- A road that aligns roadway design with an intuitive understanding of appropriate driving.
- In other words, a self-explaining road should guide users to an appropriate speed (and other driver behavior) without the need for enforcement or extraneous signage.

Introduction

- Theeuwes (2021) identified three characteristics of self-explaining roads:
  - *Easily Recognizable:* Roads that have the same function, the same speed profile, the same type of road users should look similar.
  - *Easily Distinguishable*: Roads of different categories should look differently. In other words, there should be clear differences in appearance and layout between roads that belong to different road categories.
  - *Easily Interpretable*: It should be clear from the design what the desired behavior should be on that route. The road characteristics should induce this type of behavior.

Thought exercise: Think of a roadway near you. Is it self-explaining? Why or why not?

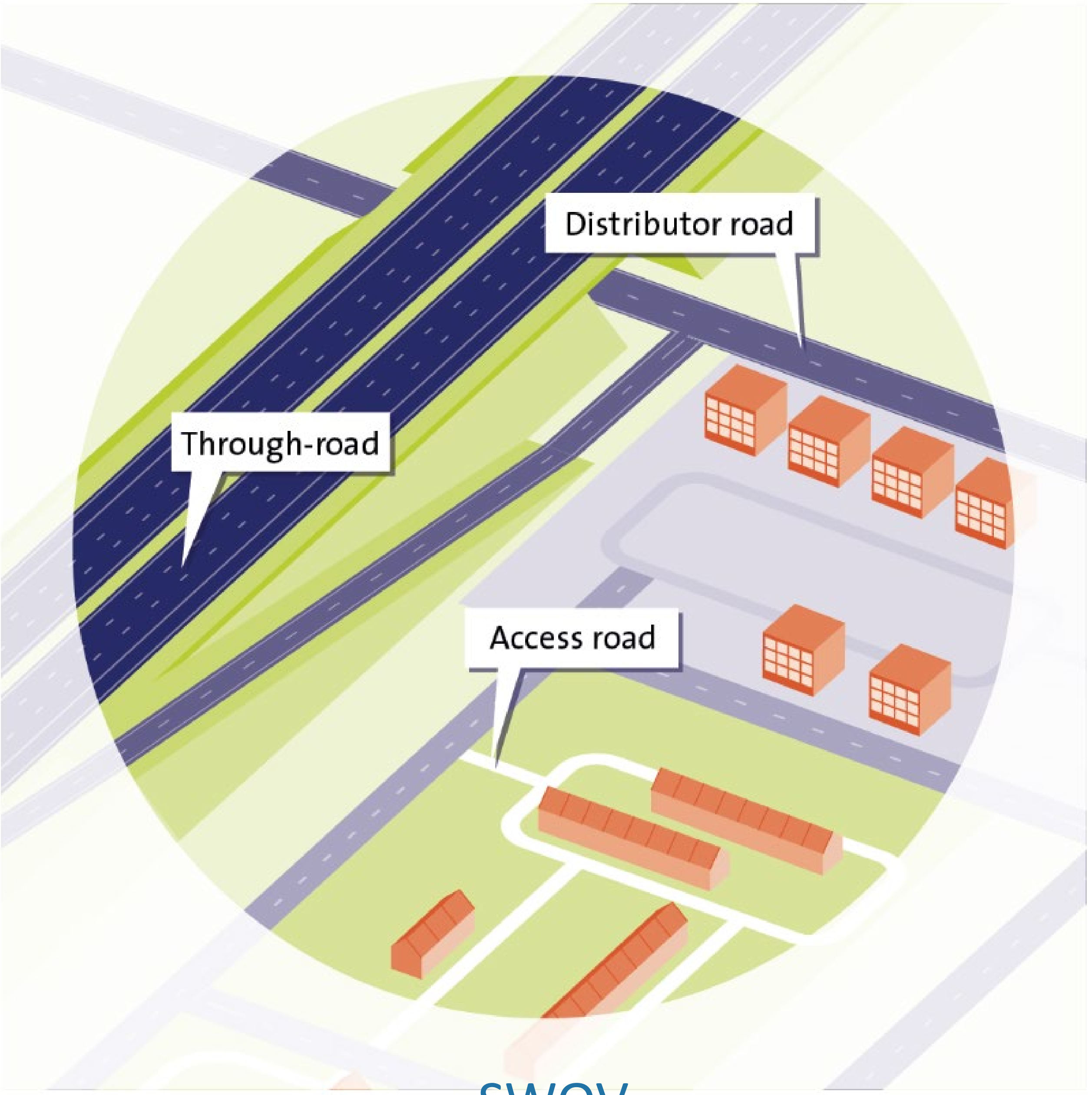
Self-Explaining Road Examples

Do you think this road is self-explaining?

- Is it easily recognizable?
  - Whom does this road serve? Pedestrians, bicyclists, drivers?
- Is it easily distinguishable?
  - How wide is it? How much traffic does it carry?
- Is it easily interpretable?
  - What speed should I go?
- What speed limit do you think it has?
  - 25 mph

Self-Explaining Roads

- Semler et al., 2023 argue that self-explaining roads should generally fit into three categories:
  - Through roads (i.e., freeways) – highest mobility, limited access
  - Distributor roads (i.e., collectors) – mix of mobility and access **at intersections**.
  - Access roads (i.e., local roads) – limited ability, door-to-door access.
- Does this sound like what we generally have in the U.S.?
- Where does an arterial fit in here?
- What about rural transition zones?

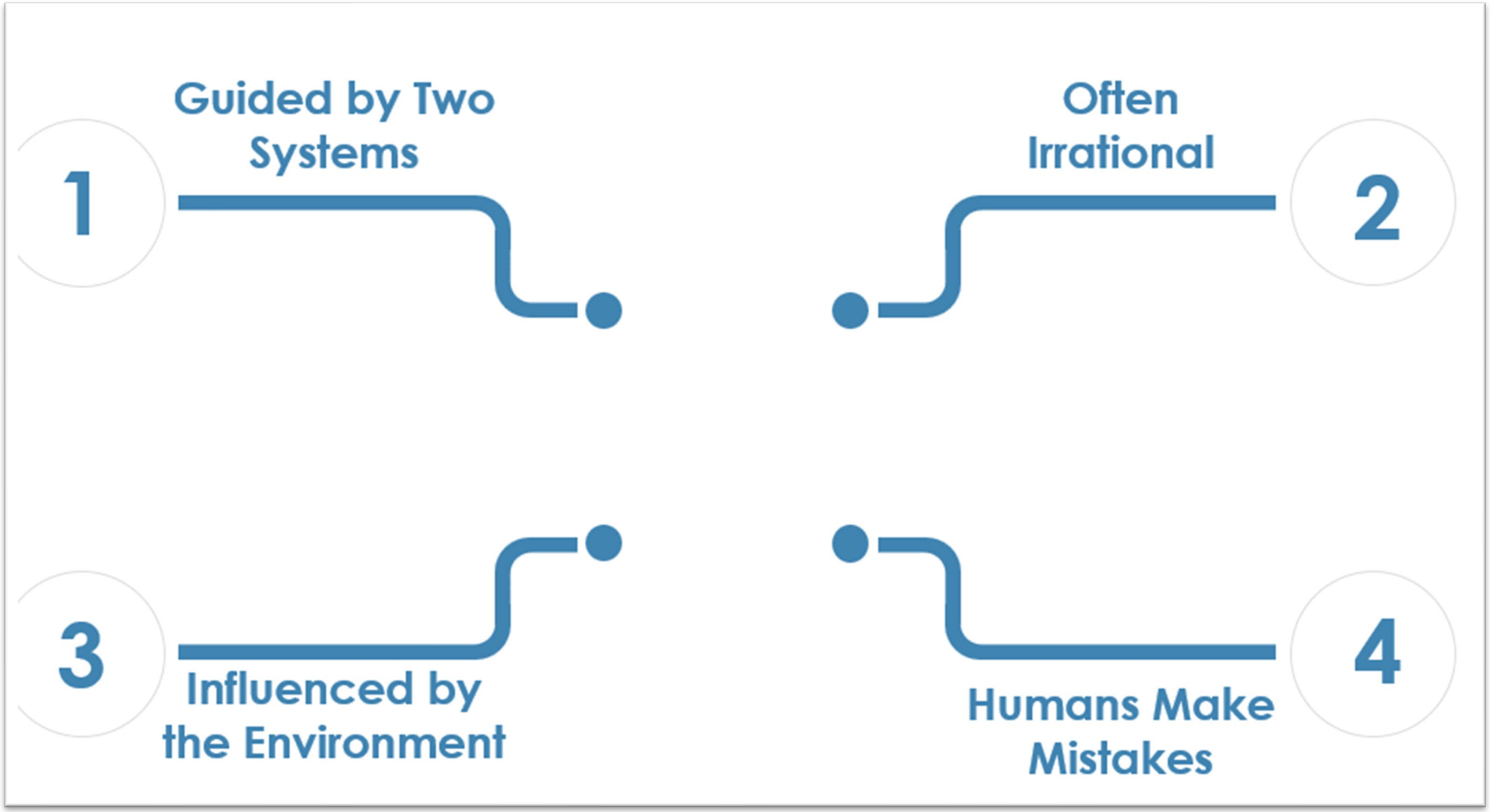


SWOV

Human Behavior

- Let's take another look at how we defined a self-explaining road.
- A road that aligns roadway design with an **intuitive** understanding of appropriate driving.
- What does it mean for a roadway to be intuitive?
- We need to examine how human beings make decisions.

Human Behavior



Human Behavior

Are our decisions deliberative or intuitive?

DELIBERATIVE

- Conscious system
- Consideration of all available information
- Decision made using rational thought, logic, and reasoning
- Examples:
  - Route planning
  - Purchasing a vehicle

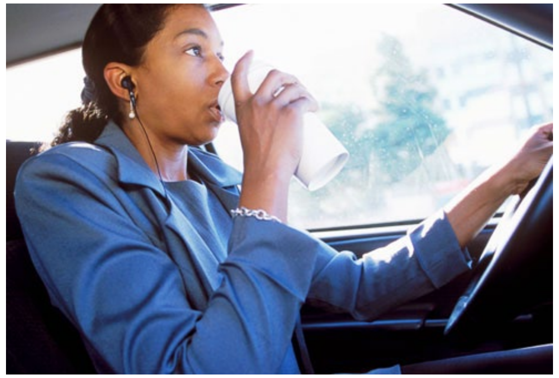
INTUITIVE

- Implicit and unconscious
- Decisions made instantaneously
- "Gut instinct"
- Examples:
  - Reacting to animal running into road
  - Turning left across oncoming traffic

Human Behavior

We assume that drivers are rational decision-makers:

INFORMATION



DESIRED BEHAVIOR

…and that speed limits appeal to the deliberative (rather than intuitive) system

Human Behavior

- Our roadway is designed for rational, deliberate decision-making by “reasonable and prudent” road users (FHWA, 2009).

05 *The actions required of road users to obey regulatory devices should be specified by State statute, or in cases not covered by State statute, by local ordinance or resolution. Such statutes, ordinances, and resolutions should be consistent with the “Uniform Vehicle Code” (see Section 1A.11).*

06 *The proper use of traffic control devices should provide the reasonable and prudent road user with the information necessary to efficiently and lawfully use the streets, highways, pedestrian facilities, and bikeways.*

Support:

07 Uniformity of the meaning of traffic control devices is vital to their effectiveness. The meanings ascribed to devices in this Manual are in general accord with the publications mentioned in Section 1A.11.

Section 1A.03 Design of Traffic Control Devices

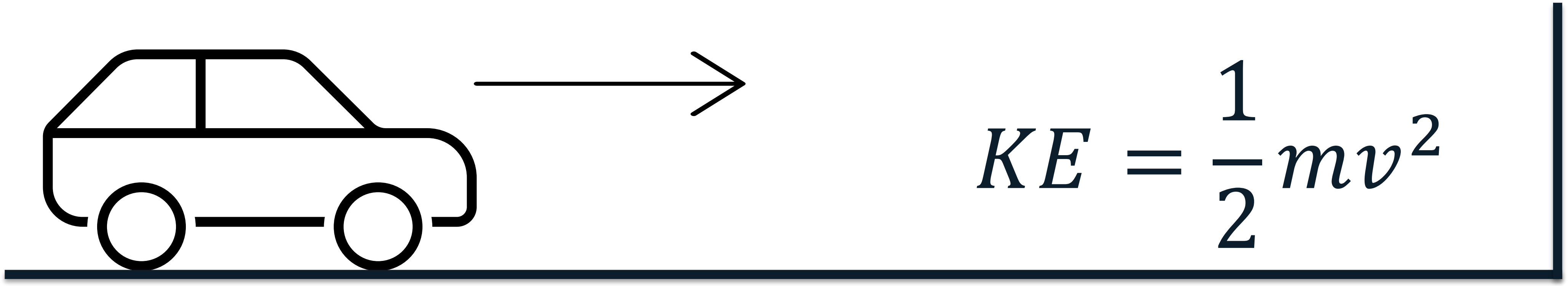
Guidance:

01 *Devices should be designed so that features such as size, shape, color, composition, lighting or retroreflection, and contrast are combined to draw attention to the devices; that size, shape, color, and simplicity of message combine to produce a clear meaning; that legibility and size combine with placement to permit adequate time for response; and that uniformity, size, legibility, and reasonableness of the message combine to command respect.*

02 *Aspects of a device’s standard design should be modified only if there is a demonstrated need.*

Speed and Safety

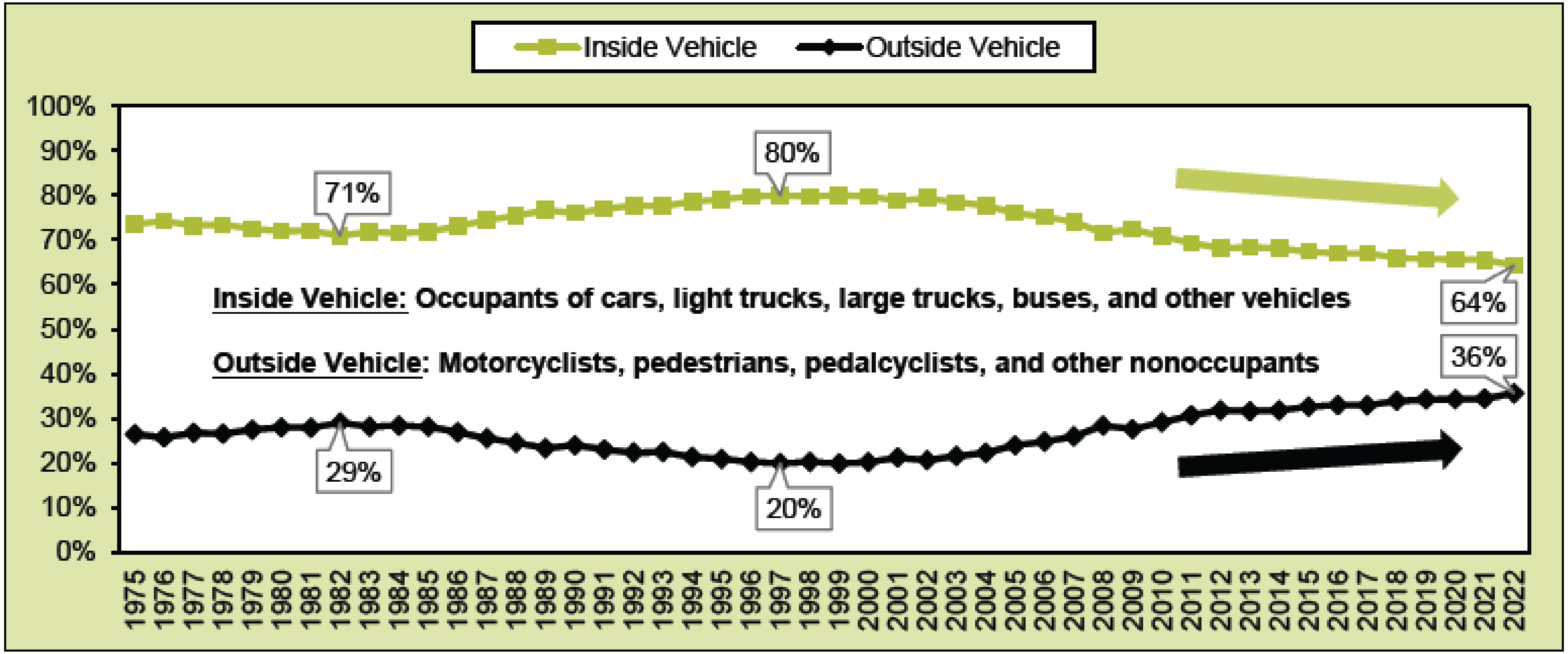
- So why is it so important to make sure we have matched our roadway design to our context to promote **intuitive** use?
- Simply put, speed kills.
- Velocity is the major determinant of the kinetic energy released in a crash.



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

Speed and Safety

Figure 3. Proportion of Traffic Fatalities Inside/Outside Vehicles, 1975-2022



Source: FARS 1975-2021 Final File, 2022 ARF

Occupants & Nonoccupants in Traffic Crashes

Table 4. Occupants and Nonoccupants Killed and Injured in Traffic Crashes, 2021-2022

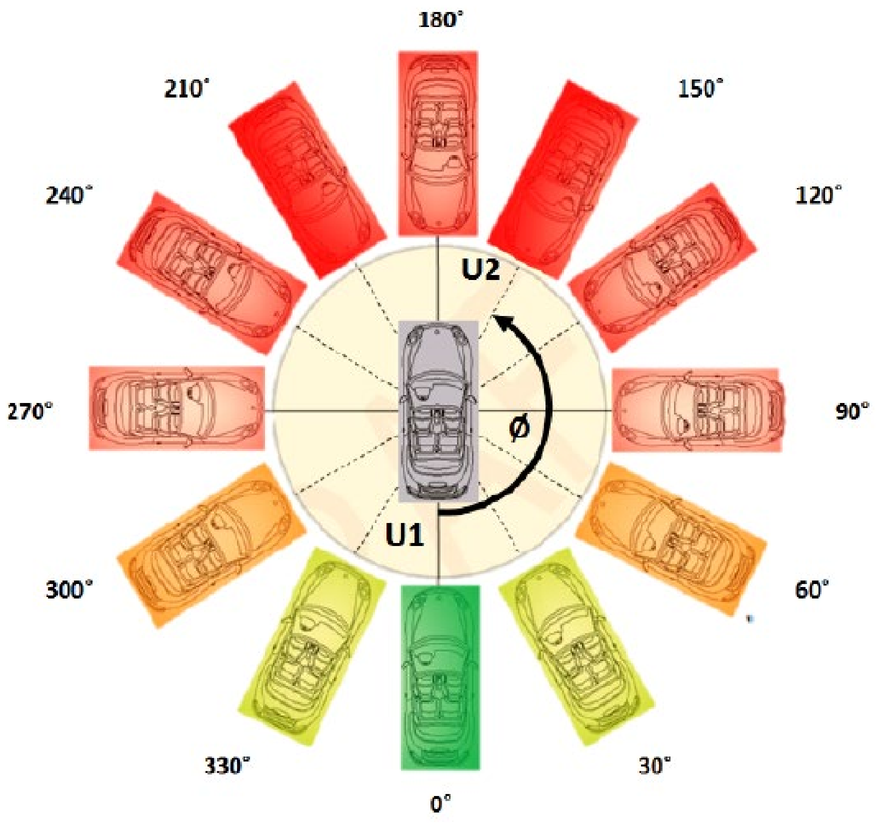
Description	Killed				Injured			
	2021	2022	Change	% Change	2021	2022	Change	% Change
Total	**43,230**	**42,514**	**-716**	**-1.7%**	**2,497,869**	**2,382,771**	**-115,098**	**-4.6%**
Occupants								
Total Occupants**	**28,339**	**27,344**	**-995**	**-3.5%**	**2,295,884**	**2,169,123**	**-126,761**	**-5.5%***
Passenger Vehicles	26,465	25,420	-1,045	-3.9%	2,092,743	1,900,539	-192,204	-9.2%*
Passenger Cars	13,618	12,691	-927	-6.8%	1,108,839	969,791	-139,048	-13%*
Light Trucks***	12,847	12,729	-118	-0.9%	983,904	930,748	-53,156	-5.4%*
SUVs	6,990	7,103	+113	+1.6%	659,903	624,227	-35,676	-5.4%*
Pickups	4,770	4,572	-198	-4.2%	228,002	218,974	-9,028	-4.0%
Vans	1,084	1,047	-37	-3.4%	95,997	87,351	-8,646	-9.0%
Large Trucks	1,011	1,097	+86	+8.5%	42,169	41,874	-295	-0.7%
Motorcyclists								
Motorcyclists	6,143	6,218	+75	+1.2%	84,898	82,687	-2,211	-2.6%
Nonoccupants								
Total Nonoccupants****	**8,748**	**8,952**	**+204**	**+2.3%**	**117,087**	**130,961**	**+13,874**	**+12%***
Pedestrians	7,470	7,522	+52	+0.7%	60,579	67,336	+6,757	+11%*
Pedalcyclists†	976	1,105	+129	+13%	41,615	46,195	+4,580	+11%

Sources: FARS 2021 Final File, 2022 ARF; CRSS 2021-2022
*These estimates are statistically significant at the α=.05 level of significance.
**Includes occupants of buses and other/unknown vehicle types.
***Includes occupants of other/unknown light-truck vehicle types.
****Includes other/unknown nonoccupants.
†Due to a change in motorized bicycles, the 2022 and later year data are not comparable to 2021 and earlier years.
Note: Changes in fatalities are not tested for statistical significance because they are from a census.

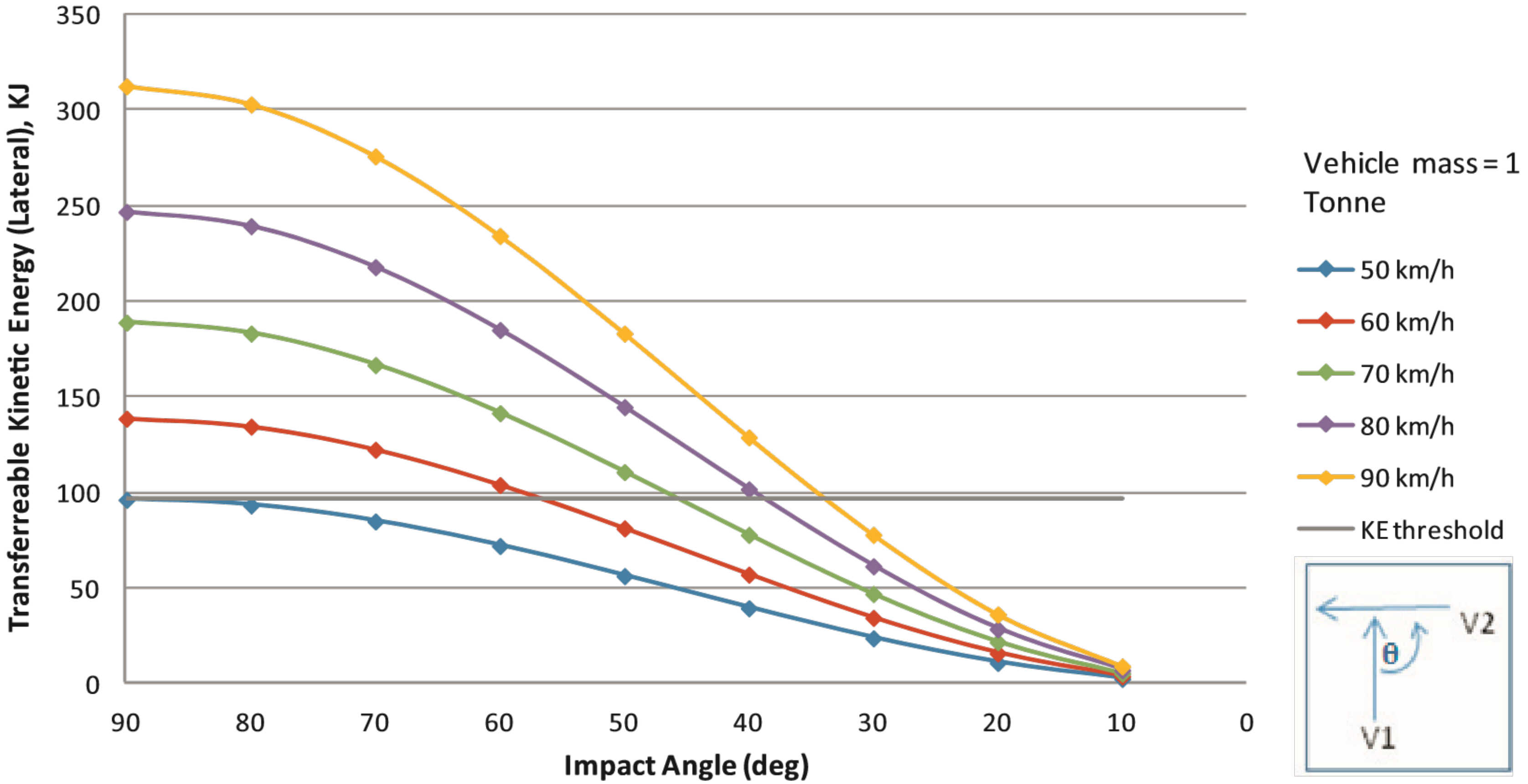
Source: National Center for Statistics and Analysis, 2024

Motor Vehicle Occupants

For motor vehicle occupants, kinetic energy can also depend on the angle of collision.



Source: Jurewicz et al., 2017



Source: Candappa et al., 2015

Safe Kinetic Energy

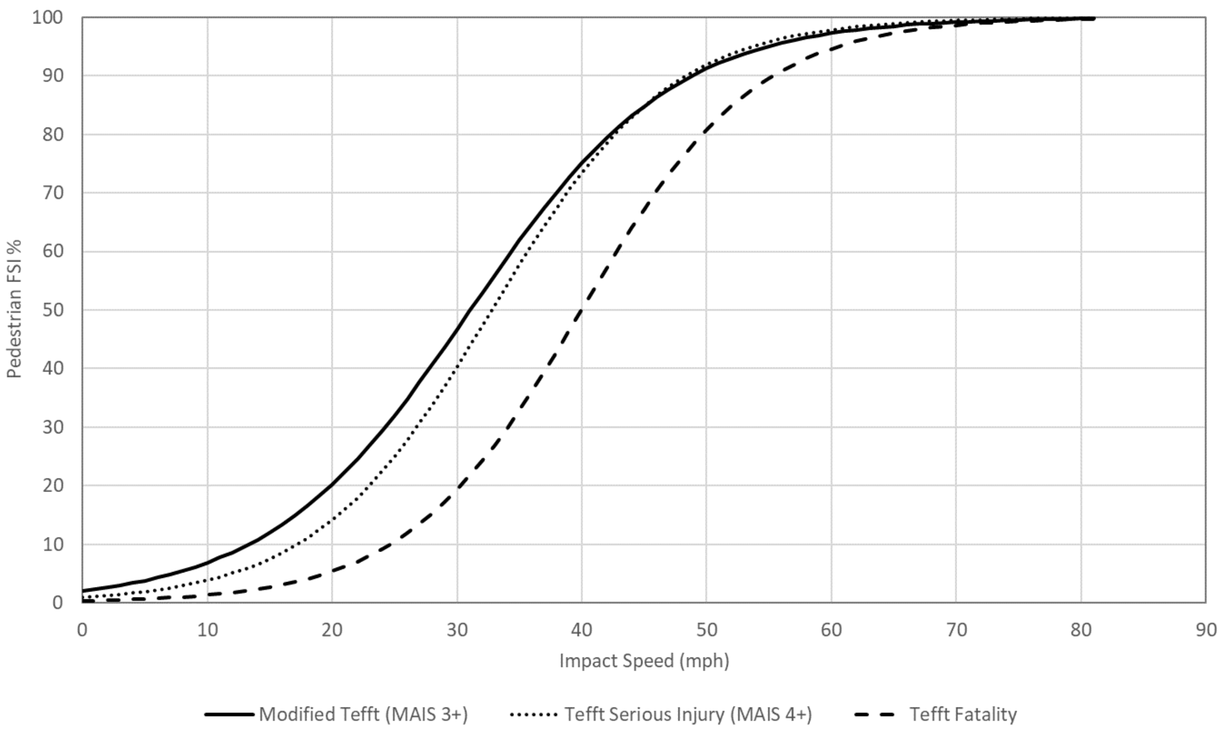
Candappa et al. (2015) uses a cutoff of ~100 kilojules (KJ) for safe kinetic energy.

Table 1
Speed and angle combinations that produce Safe System compatible levels of KE (KJ) (green highlight).

Speed (Mph)	Impact Angle (degrees)							
	90	80	70	60	50	40	30	20
62	385.8	374.2	340.7	289.4	226.4	159.4	96.5	45.1
56	312.5	303.1	275.9	234.4	183.4	129.1	78.1	36.6
50	246.9	239.5	218.0	185.2	144.9	102.0	61.7	28.9
43	189.0	183.3	166.9	141.8	110.9	78.1	47.3	22.1
37	138.9	134.7	122.6	104.2	81.5	57.4	34.7	16.2
31	96.5	93.5	85.2	72.3	56.6	39.9	24.1	11.3

Pedestrians and Bicyclists

For pedestrians and bicyclists, bumper height and vehicle mass are critical.



Source: Porter et al., 2021

Table 1 Fatality Probability and Vehicle Impact Speed[x xi xii xiii].

Crash Type	Driver Speed (10% Fatal Injury Risk)
Pedestrian or Bicyclist/vehicle crash	20[xiv] – 25[xv] MPH
Side impact crash vehicle/vehicle (typically at intersections)	30 MPH
Head-on vehicle/vehicle (typically no median barriers)	30[xvi] - 45[xvii] MPH
Rear-end vehicle/vehicle	35[xviii] – 70[xix] MPH

Notes: Speed limits from kilometers per hour have been converted to miles per hour. Speed limits are rounded to the nearest US speed limit. Ranges vary due to the different research study results.

Table 2 Severe Injury Probability and Vehicle Impact Speed[xx, xxi]

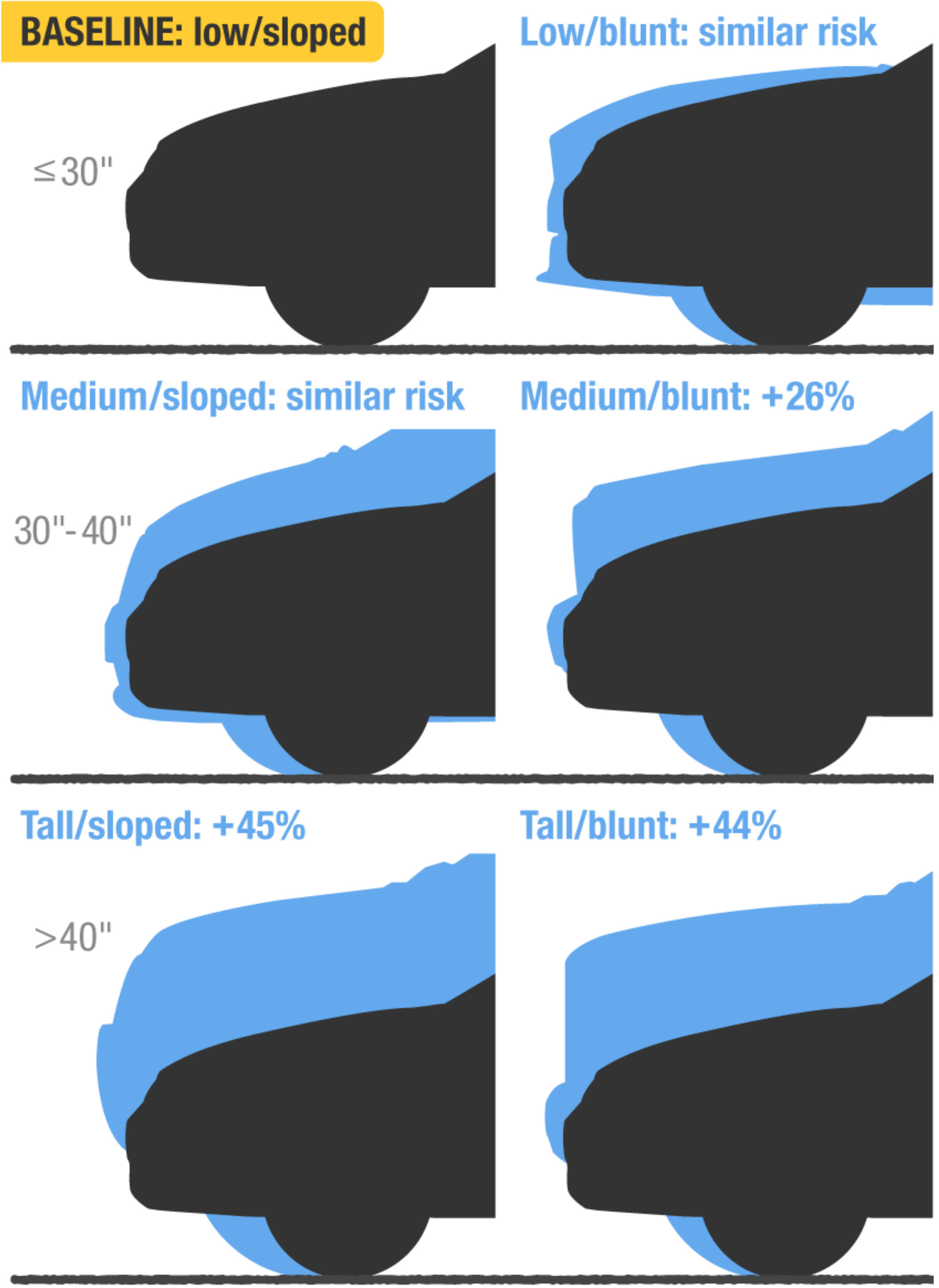
Crash Type	Driver Speed (10% Severe Injury Risk)
Pedestrian/vehicle crash	10 – 20 MPH
Side impact crash vehicle/vehicle (typically at intersections)	20 MPH
Head-on vehicle/vehicle (typically no median barriers)	20 MPH
Rear-end vehicle/vehicle	35 MPH

Notes: Speed limits from kilometers per hour have been converted to miles per hour. Speed limits are rounded to the nearest US speed limit. Ranges vary due to the different research study results.

Source: Washington Injury Minimization and Speed Management Policy and Guidelines Workgroup, 2020

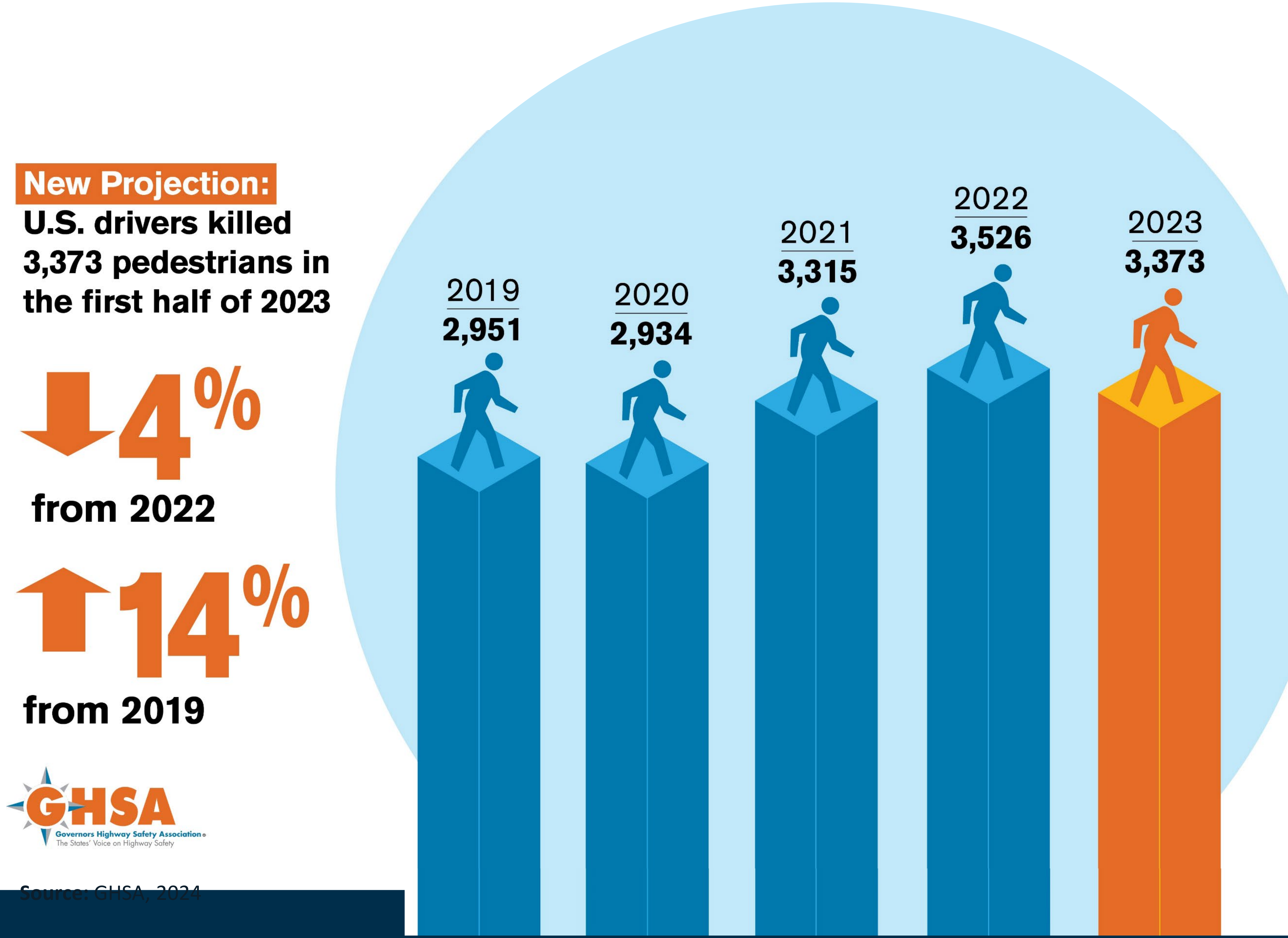
Pedestrian Risk

- IIHS (2023) showed that pedestrians are at greater risk because of vehicle design
- Over the past 30 years, vehicles in the U.S. have gotten:
  - 4 inches wider
  - 10 inches longer
  - 8 inches taller
  - 1,000 pounds heavier



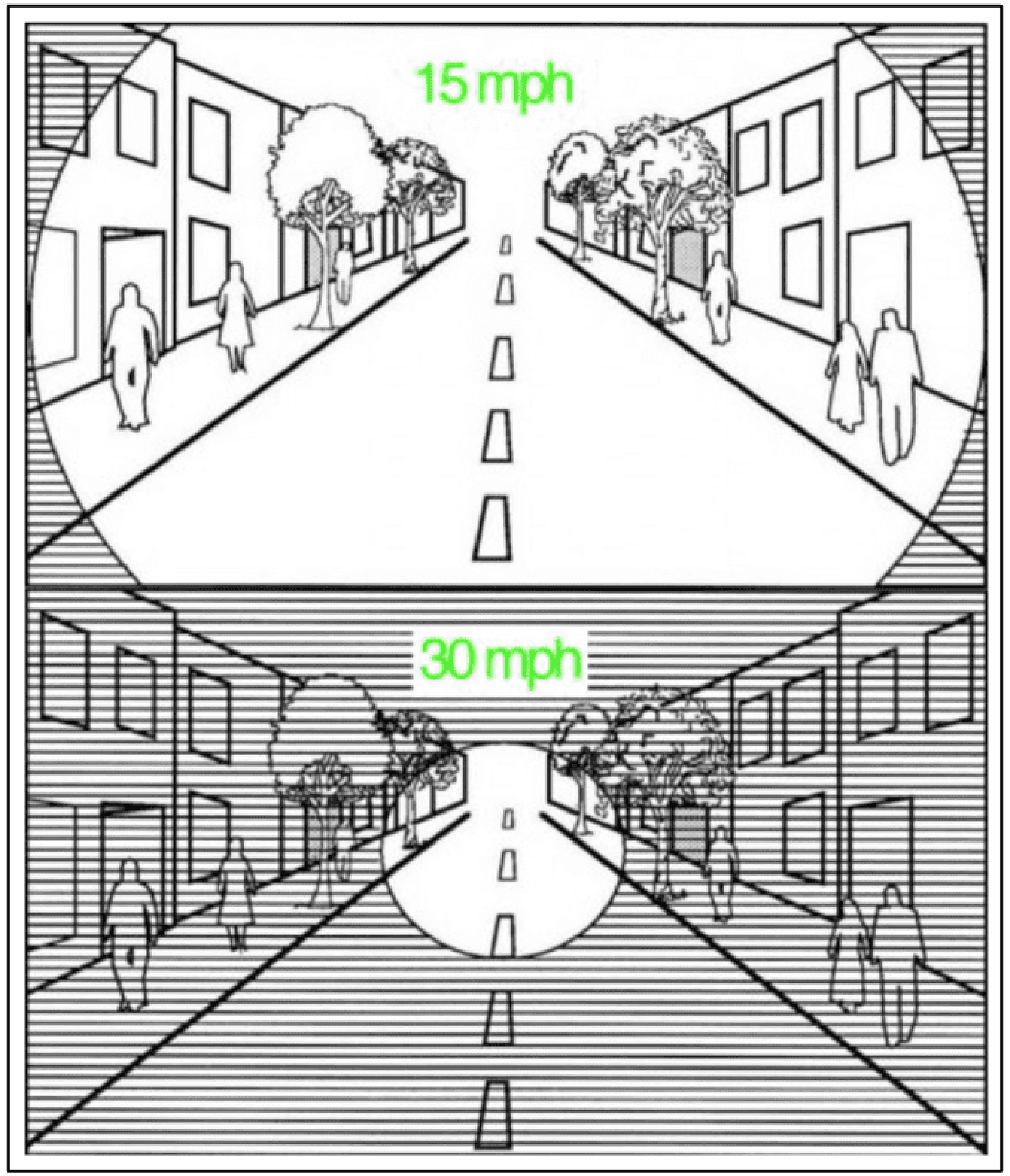
Disproportionate Burden of Injury

Recent statistics show people outside vehicles bear a disproportionate burden of injury.

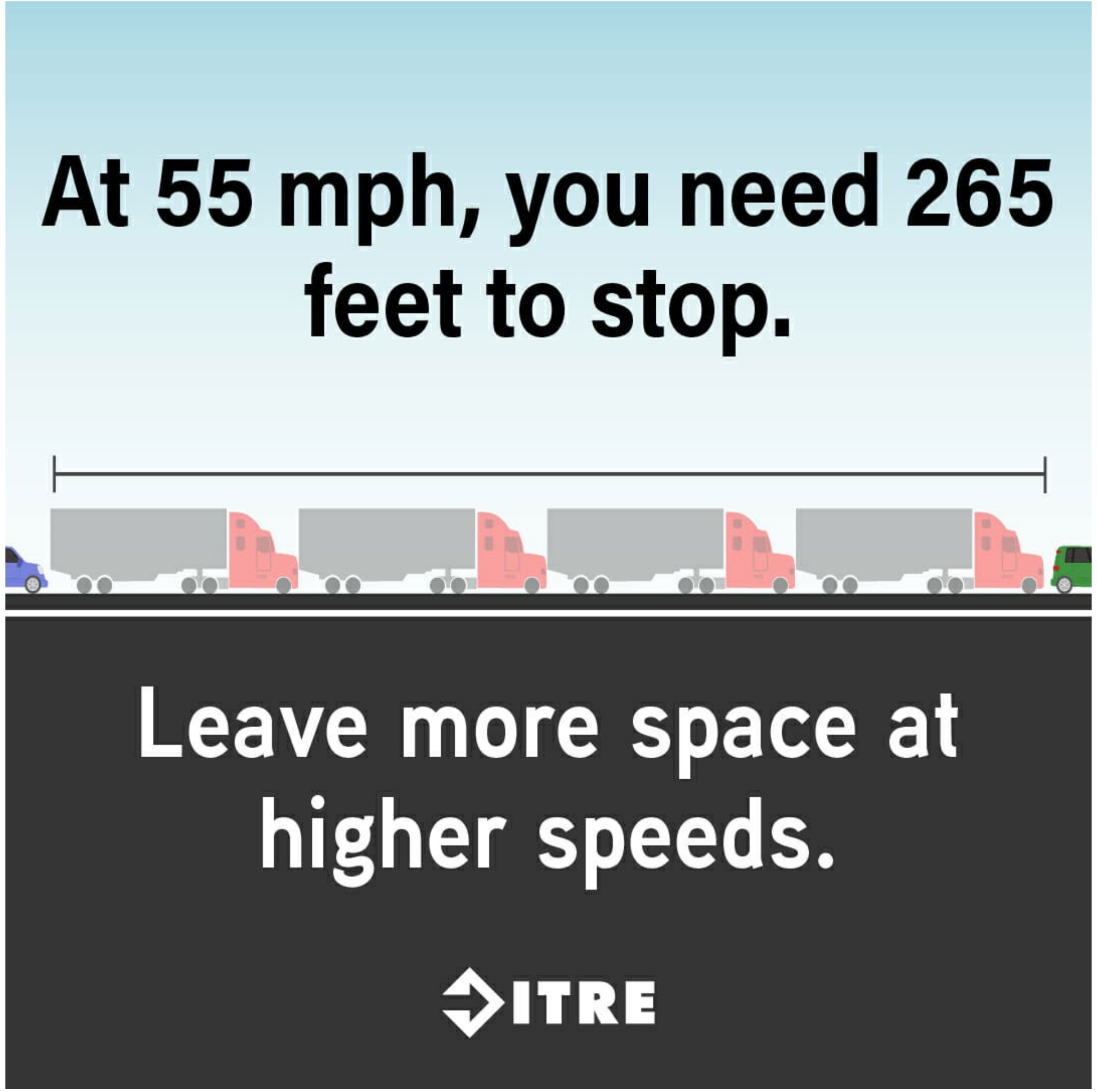


Source: GHSA, 2024

Speed and Human Factors



Source: Thomas, 2022



Source: ITRE

So should we be concerned about speed or speeding?

Speeding-Related Traffic Fatalities and Injuries

Table 1. People Killed and Injured in Traffic Crashes, by Speeding Involvement, 2014–2023

Year	Speeding Involvement				Total	
	Speeding-Related		Not Speeding-Related			
	Number	Percent	Number	Percent	Number	Percent
Killed						
2014	9,283	28%	23,461	72%	32,744	100%
2015	9,723	27%	25,761	73%	35,484	100%
2016	10,291	27%	27,515	73%	37,806	100%
2017	9,947	27%	27,526	73%	37,473	100%
2018	9,579	26%	27,256	74%	36,835	100%
2019	9,592	26%	26,763	74%	36,355	100%
2020	11,428	29%	27,579	71%	39,007	100%
2021	12,498	29%	30,732	71%	43,230	100%
2022	12,157	28%	30,564	72%	42,721	100%
2023	11,775	29%	29,126	71%	40,901	100%

Speeding as a Risk Factor

Year	Speeding Involvement				Total	
	Speeding-Related		Not Speeding-Related			
	Number	Percent	Number	Percent	Number	Percent
Injured						
2014†	339,189	14%	2,003,432	86%	2,342,621	100%
2015†	348,160	14%	2,106,619	86%	2,454,778	100%
2016	376,914	12%	2,684,971	88%	3,061,885	100%
2017	361,950	13%	2,383,317	87%	2,745,268	100%
2018	358,924	13%	2,351,134	87%	2,710,059	100%
2019	326,554	12%	2,413,587	88%	2,740,141	100%
2020	308,133	14%	1,974,076	86%	2,282,209	100%
2021	329,105	13%	2,168,763	87%	2,497,869	100%
2022	300,585	13%	2,082,248	87%	2,382,833	100%
2023	332,598	14%	2,109,982	86%	2,442,581	100%

Sources: FARS 2014–2022 Final File, 2023 Annual Report File (ARF); NASS GES 2014–2015; CRSS 2016–2023
†NASS GES estimates and CRSS estimates are not comparable due to different sample designs. Refer to end of report for more information about CRSS.
Note: Injury totals may not equal sum of components due to independent rounding.

Speed and Other Crash Factors

Safety Facts

11,775

SPEEDING-RELATED DEATHS IN 2023

Source

Safety Facts

51%

SPEEDING PASSENGER VEHICLE DRIVERS IN FATAL CRASHES IN 2023 WHO WERE NOT WEARING SEAT BELTS

Safety Facts

37%

MEN 15-20 YEARS OLD WHO WERE DRIVING, SPEEDING, AND INVOLVED IN FATAL CRASHES IN 2023

Source: National Highway Safety Administration (NHTSA)

Speed and Other Factors

Table 3. Drivers Involved in Fatal Traffic Crashes, by Age Group, Speeding Involvement, and Their BACs, 2023

Age Group	Speeding Involvement															
	Speeding								Not Speeding							
	No Alcohol (BAC= .00 g/dL)		BAC= .01+ g/dL		Alcohol-Impaired				No Alcohol (BAC=.00 g/dL)		BAC= .01+ g/dL		Alcohol-Impaired			
					BAC= .08+ g/dL		BAC= .15+ g/dL						BAC= .08+ g/dL		BAC= .15+ g/dL	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
<21	1,139	67%	565	33%	473	28%	255	15%	2,840	81%	682	19%	571	16%	326	9%
21–24	791	52%	716	48%	625	41%	404	27%	2,632	73%	962	27%	788	22%	500	14%
25–34	1,404	50%	1,394	50%	1,232	44%	842	30%	6,852	75%	2,266	25%	1,902	21%	1,252	14%
35–44	963	52%	901	48%	794	43%	547	29%	6,263	78%	1,749	22%	1,462	18%	967	12%
45–54	605	55%	500	45%	453	41%	325	29%	5,646	81%	1,366	19%	1,109	16%	744	11%
55–64	520	60%	345	40%	303	35%	211	24%	5,560	83%	1,135	17%	912	14%	581	9%
65–74	344	74%	122	26%	102	22%	73	16%	3,875	86%	613	14%	493	11%	319	7%
75+	203	83%	41	17%	34	14%	25	10%	2,942	92%	273	8%	225	7%	139	4%
Total*	**6,099**	**57%**	**4,640**	**43%**	**4,065**	**38%**	**2,706**	**25%**	**37,844**	**80%**	**9,356**	**20%**	**7,714**	**16%**	**4,954**	**10%**

Source: FARS 2023 ARF
*Includes drivers of unknown age.
Note: NHTSA estimates BACs when alcohol test results are unknown.

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Roadway Design

- So how do we make our roads intuitive?
- Make sure speed limit and context match and fit into the three categories.
- If they do not, apply speed countermeasures.

Roadway Design

- Example from FDOT design manual.

Table 6. FDOT Design Manual target speeds and speed management techniques.

Area Type	Context Classification	Target Speed (mph)	Strategies
Rural	C1-Natural (natural or wilderness lands)	55–70	N/A: Speed Management Strategies are not used on high-speed roadways
Rural	C2-Rural sparsely settled)	55–70	N/A: Speed Management Strategies are not used on high-speed roadways
Rural	C2T-Rural Town (small concentrations of developed areas surround by natural areas)	40–45	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, Rectangular Rapid Flashing Beacons (RRFB) and Pedestrian Hybrid Beacons (PHB)
		35	Techniques for 40–45 mph, plus On- street Parking, Street Trees, Short Blocks, Islands at Crossings, Road Diet, Bulb-outs,Terminated Vista
		30	Techniques for 35–45 mph, plus Chicanes, Islands in curved sections
		≤ 25	Techniques for 30–45 mph, plus Vertical Deflection
Suburban	C3R-Suburban (mostly residential within large blocks), C3C-Suburban Commercial (mostly non-residential with large building footprints)	50–55	Project-specific
		40–45	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, RRFB and PHB
		35	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, Islands in crossings, Road Diet, RRFB and PHB, Terminated Vista
Urban	C4-Urban general (mixed uses within small blocks)	40–45	Roundabout, Lane Narrowing, Horizontal Deflection, Speed Feedback Signs, RRFB and PHB
		35	Techniques for 40–45 mph plus On-Street Parking, Street Trees, Short Blocks, Islands at Crossings, Bulb-outs, Terminated Vista, Road Diet
		30	Techniques for 35–45 mph plus Chicanes, Islands in Curve Sections

Area Type	Context Classification	Target Speed (mph)	Strategies
Urban	C5-Urban Center (missed uses within small blocks, typically concentrated around a few blocks)	35	Roundabout, On-street Parking, Street Trees, Short Blocks, Speed Feedback Signs, Islands in Crossings, Road Diet, Bulb-outs, RRFB and HAWK, Terminated Vista
		30	Techniques for 35 mph plus Chicanes, Island in Curve Sections
		25	Techniques for 30–35 mph plus Vertical Deflection
Urban	C6-Urban Core (areas with highest density)	30	Roundabout, On-Street Parking, Horizontal Deflection, Street Trees, Islands in Curve Sections, Road Diet, Bulb-outs, Terminated Vista
		25	Techniques for 30 mph plus vertical deflection

Source: FDOT. (2022). FDOT Design Manual: Development and Processes. Tallahassee, FL: Florida Department of Transportation.

Rural Transition Zone

- Let's think about this rural transition zone on Hwy 84 into Slaton, TX.
- What would make this transition intuitive for divers?
  - Visual friction on the sides?
  - Maintain the barrier and reduce lanes?
  - Visible signs or gateway treatments?

Remember Human Behavior

Psychology has shown us that to change human behavior we need to both:

- Provide information
  - Media campaigns
  - Community engagement
  - Education

Source: NHTSA

- Change the environment
  - Infrastructure
  - Organizational practice
  - Social norms

Source: FHWA

Remember Human Behavior

- Speed is connected to roadway design both as a design element for designing specific geometric features and as an operational characteristic of a roadway that can be influenced by roadside features
  - Roadsides that provide visual friction can lower speeds and provide safer environments.
  - What reduces visual friction?
    - Wide setbacks, multiple lanes, wide clear zones, wide shoulders, straight roadways.
  - What increases visual friction?
    - Street trees, trash cans, flex posts, narrow lanes, dense development, other road users.
  - On higher speed roadways, horizontal and vertical curves, narrow cross-sections/lanes can all be used to lower speeds (AASHTO Green Book).

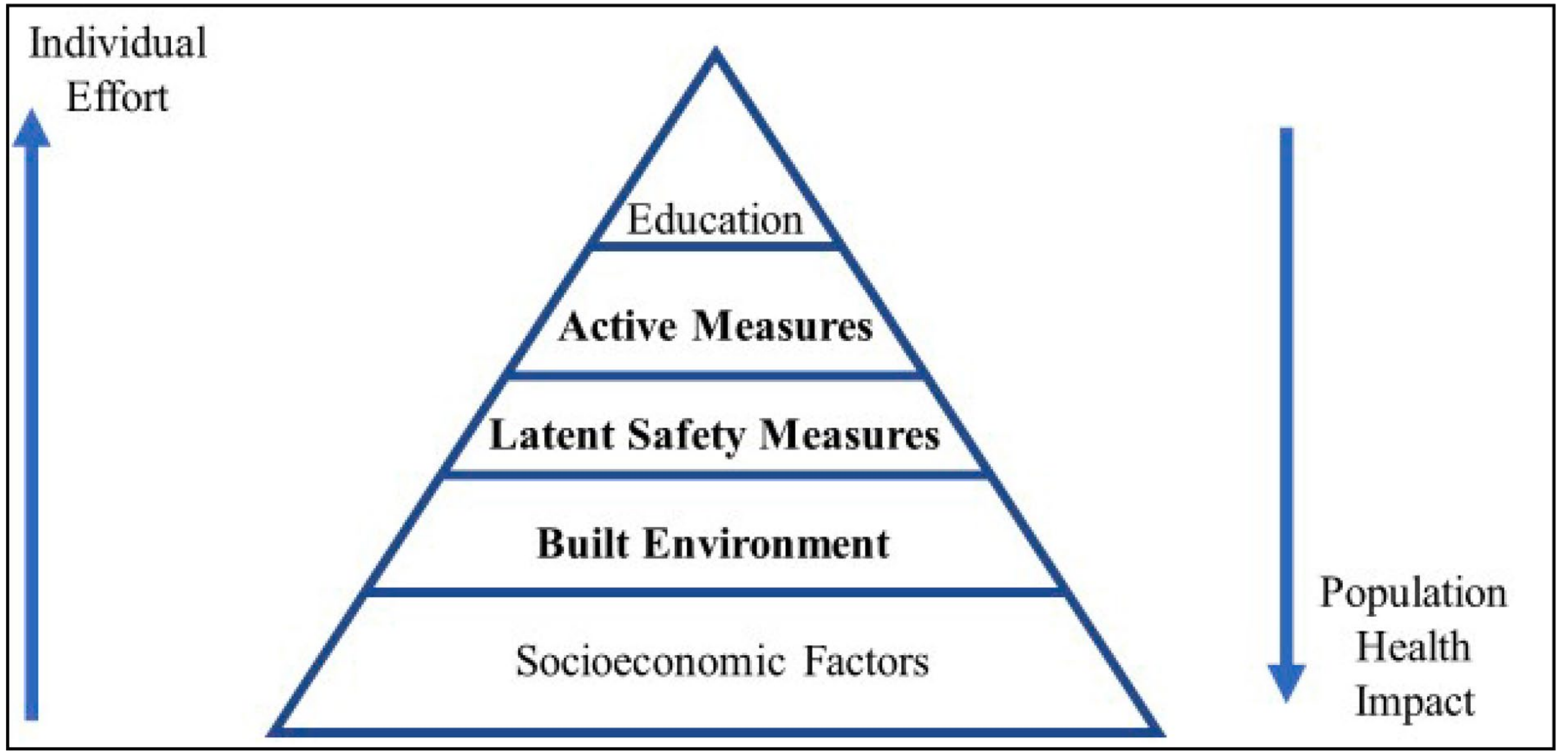
Proactively Prioritizing Locations for Speed Management

- When you've identified corridors that have speed problems, consider comprehensive approaches to change the environment and provide information.
- IIHS evaluated a comprehensive program in Bishopville, Maryland and found it was very effective.

IIHS, 2022 - https://www.iihs.org/news/detail/multipronged-anti-speeding-effort-succeeds-in-slowing-traffic

Speed and Safety

- Designing for speed helps us get to the bottom of the Safe System pyramid.



Ederer et al., 2023

Conclusions

- Our roadways are often not self-explaining.
- We overestimate how intuitive our roadway designs are.
- Because of this overestimation, we design roadways that lead to speeds that kill.
- We can address this problem by better understanding human behavior.
- Understanding the limitations of human behavior can help us design rural roads that are self-explaining and therefore safe.

Thanks!

You can contact me at Kumfer@hsrc.unc.edu

I’d also like to acknowledge my colleagues on the NCHRP 07-36 team, especially Seth LaJeunesse

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RESEARCH CENTER

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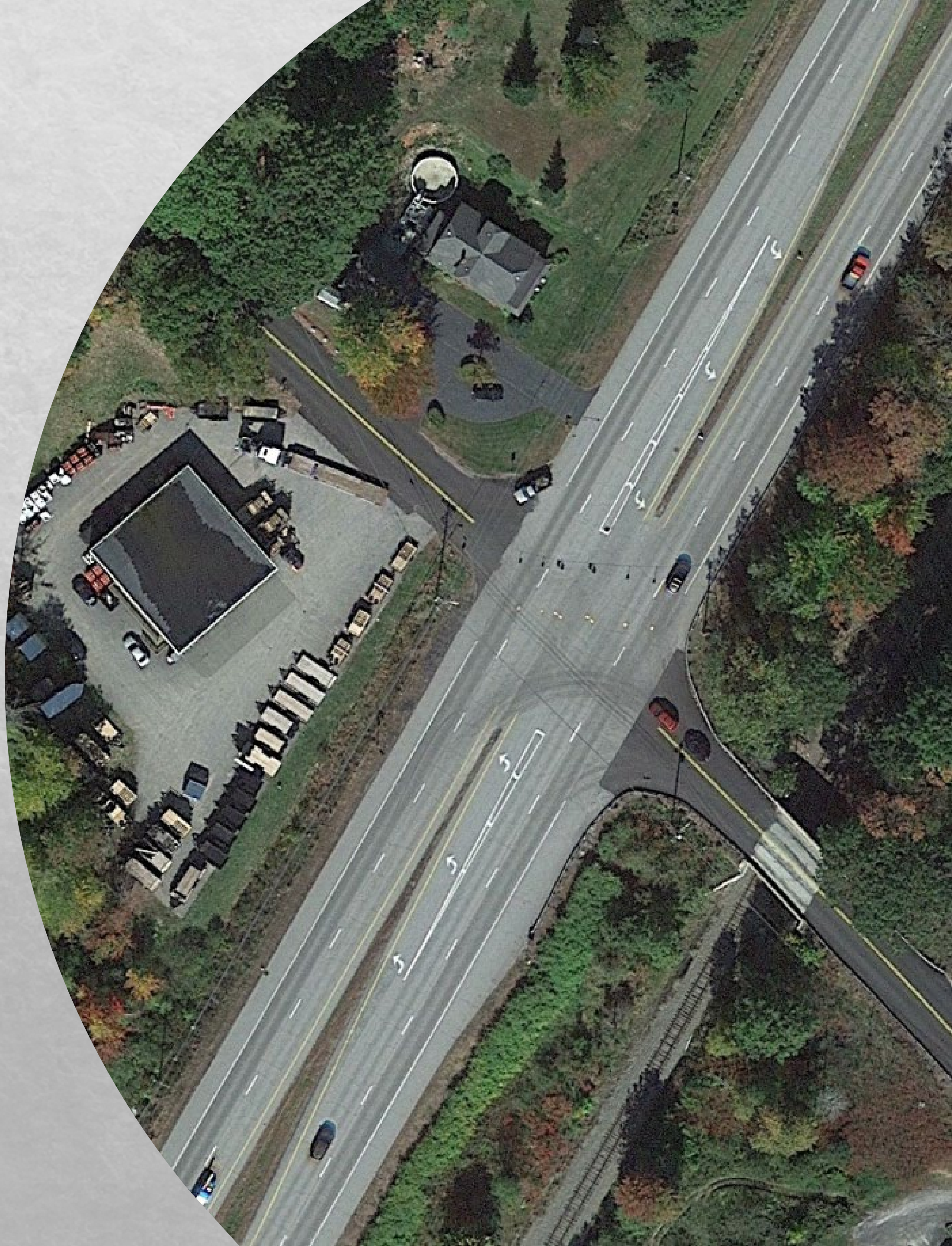
January 28, 2026

Ranking Maine Intersection Risk Based on Kinetic Energy

Jeff Pulver, MaineDOT

1/28/2026



Summary of What We Have Done

Created an evaluation and screening process that aligns closely with the Safe System Approach

incorporated principles of kinetic energy, using real Maine data

Rank intersections and prioritize them for improvement based on likelihood of fatal or serious injury crashes occurring

1

Share crash force and kinetic energy theories

2

Show how this information applies in real Maine scenarios

3

Explain the ranking process and associated tools we have developed

4

Share how our kinetic energy screening method has performed so far

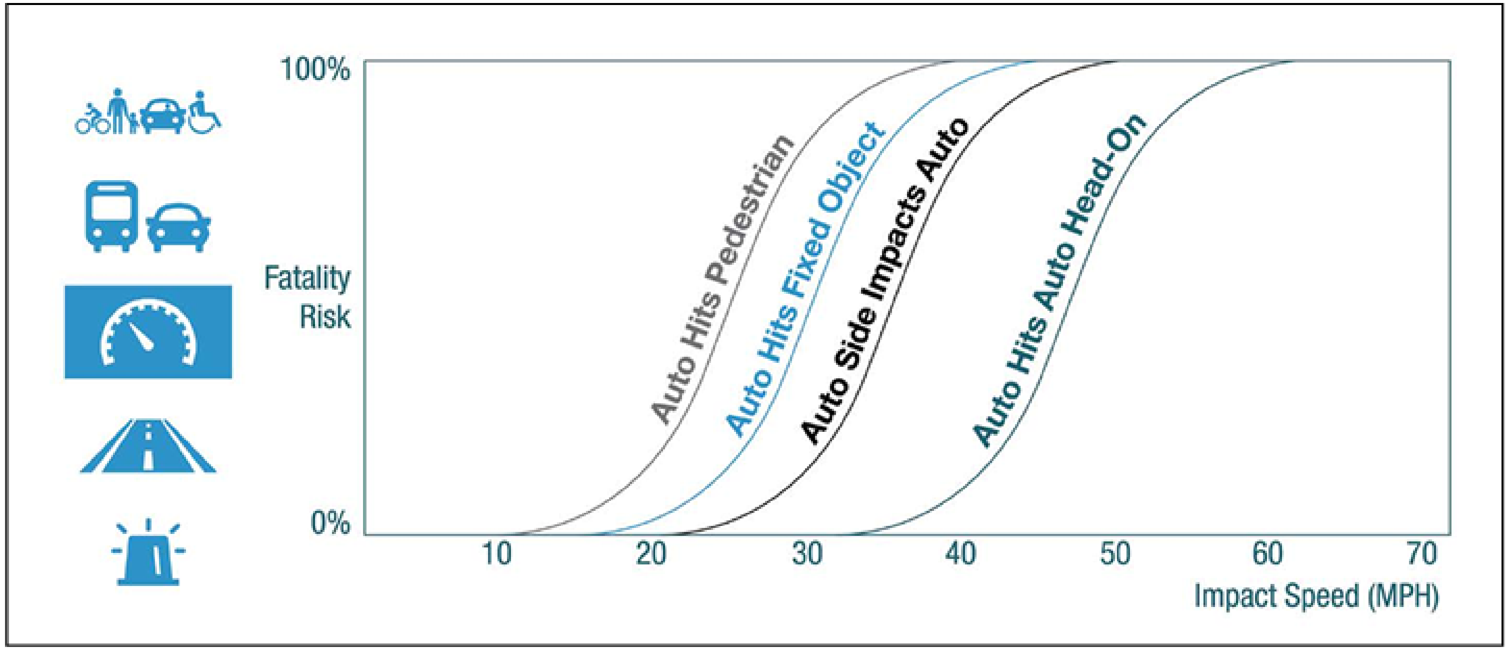


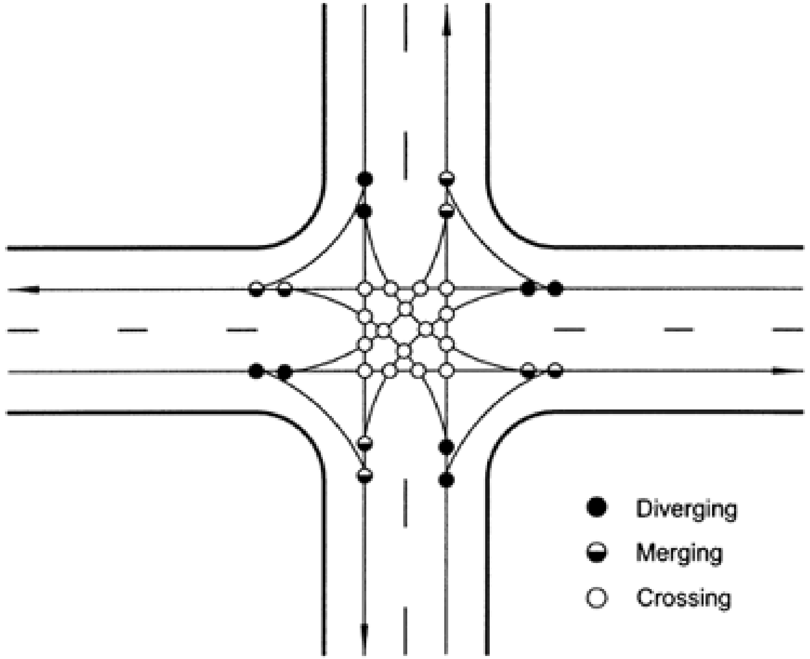
FIGURE 3 Crash types, speeds, and fatality risks. (Source: FHWA as adapted from Australian Roads and Traffic Authority of New South Wales.)

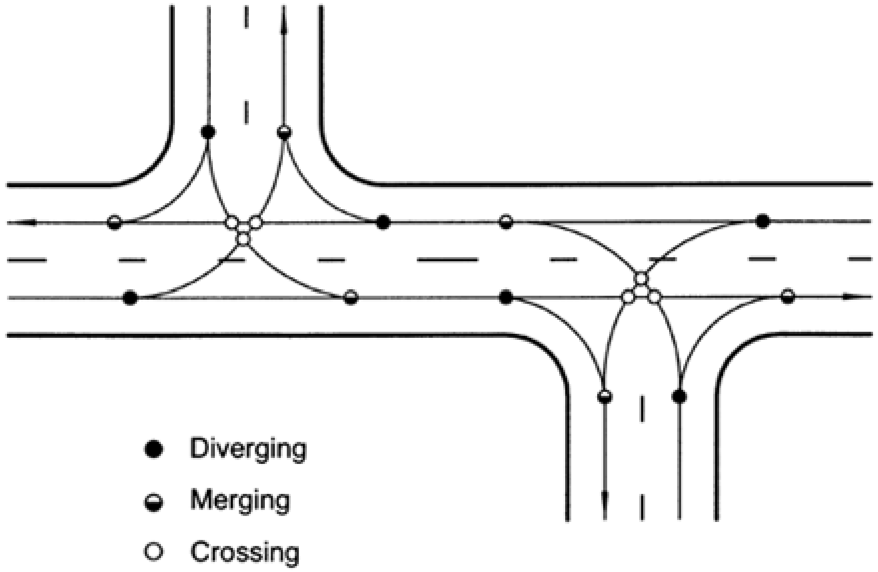
Safe System Approach to Crash Forces

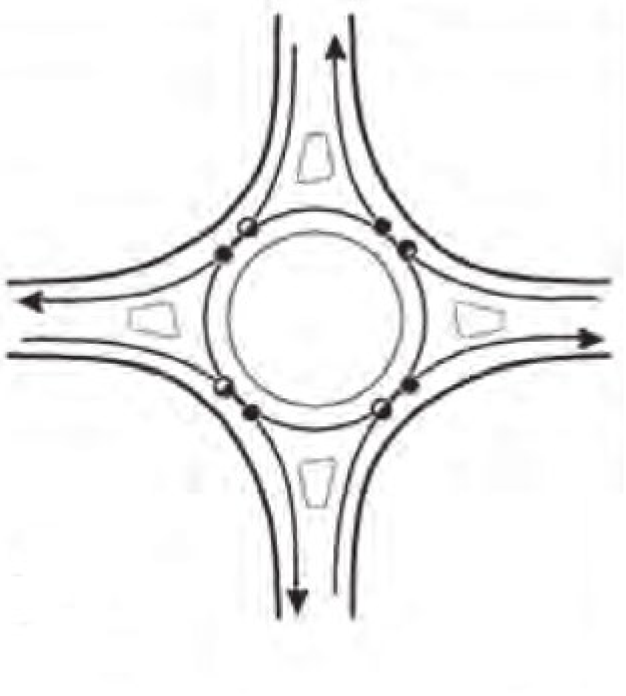
Humans have a limited tolerance to crash forces

Theory of Crash Forces

Intersection Conflict Point Diagrams



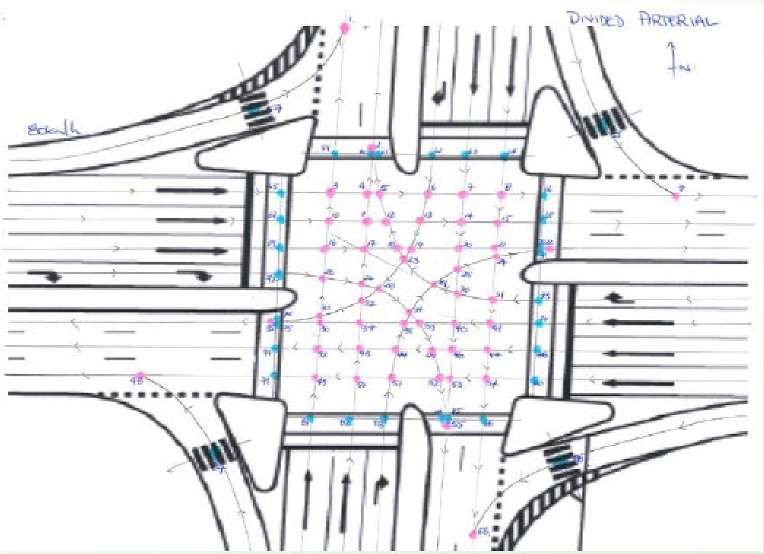


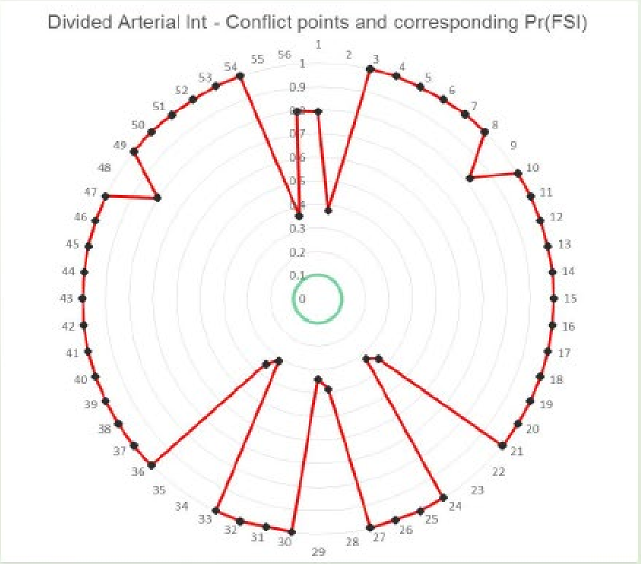


Intersection Energy Models

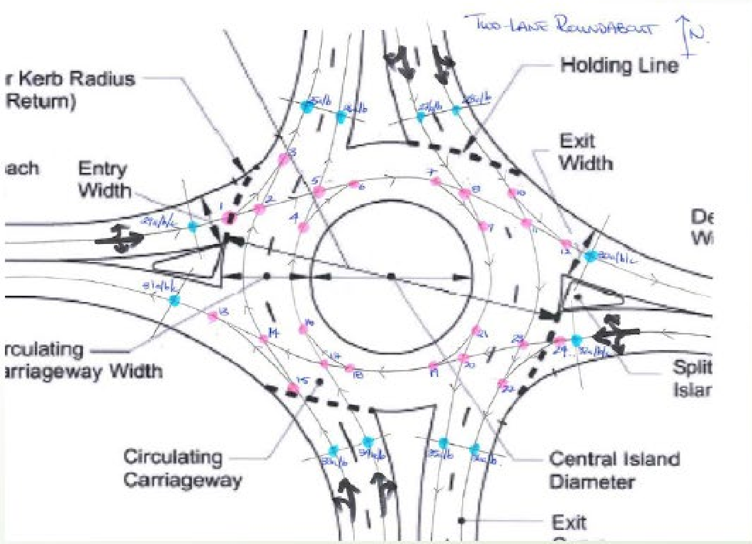
- Via Dr. Blair Turner from Australia
- Presented at the National Safety Engineer Peer Exchange in July 2019

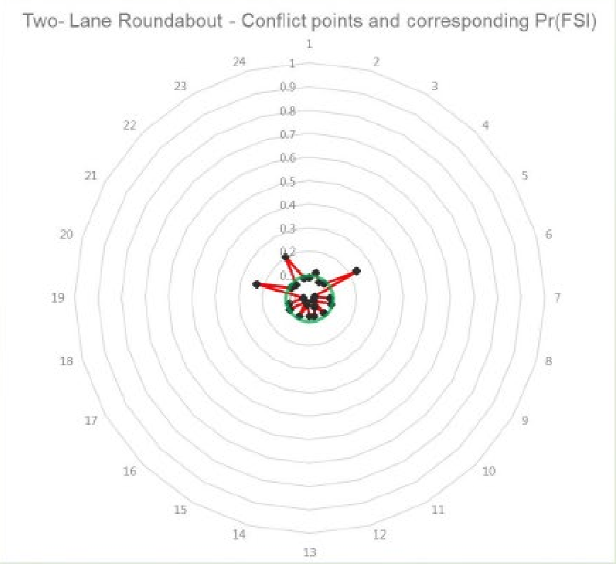
- Divided arterial signals - 80 km/h x 60 km/h





- Divided arterial roundabout - 80 km/h x 60 km/h





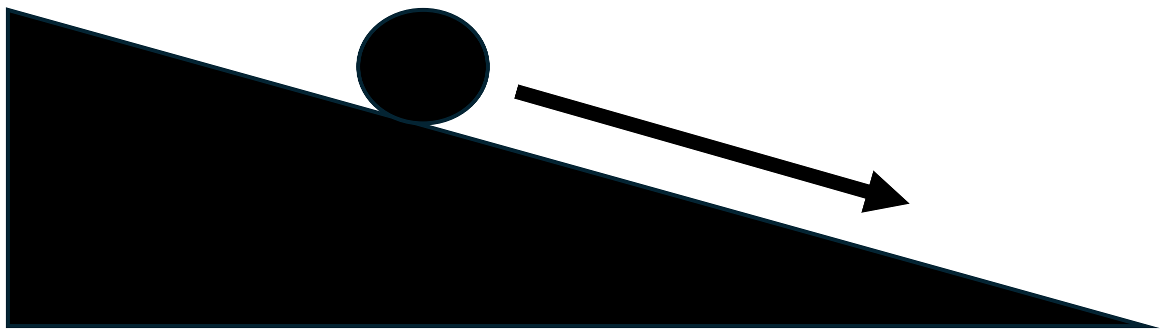
What Factors Impact Crash Forces?

- F=ma

- What Factors Impact Crash Forces
  - Vehicle/Object **Mass**
  - Acceleration
    - **Speed** vehicle is traveling before the crash
    - The **time** it takes for that vehicle to come to rest
    - **Deflection distance**

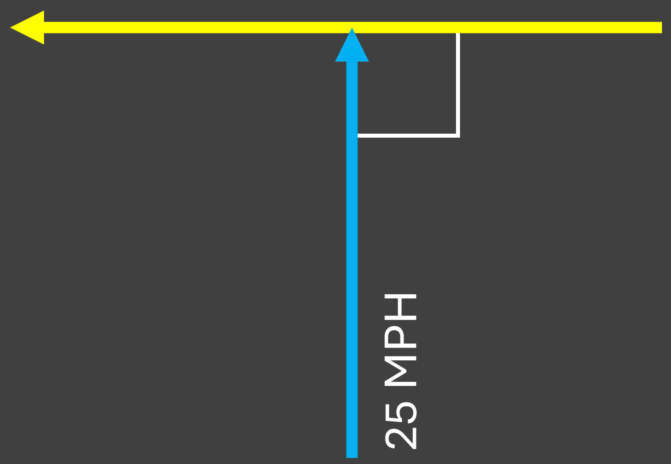
How Does Speed Impact Kinetic Energy

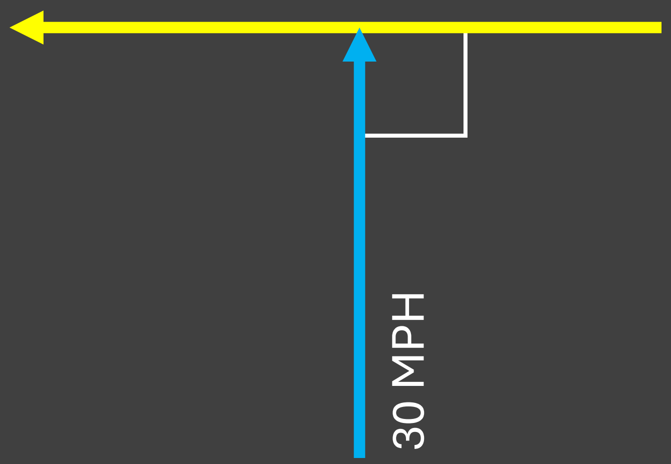
- The energy possessed by an object based on its motion
  - Depends on speed and mass of the object



- Kinetic Energy $= \frac{1}{2}mv^2$
  - Kinetic Energy increases with speed
  - Relationship is square instead of linear

How Crash Speed Impacts Kinetic Energy



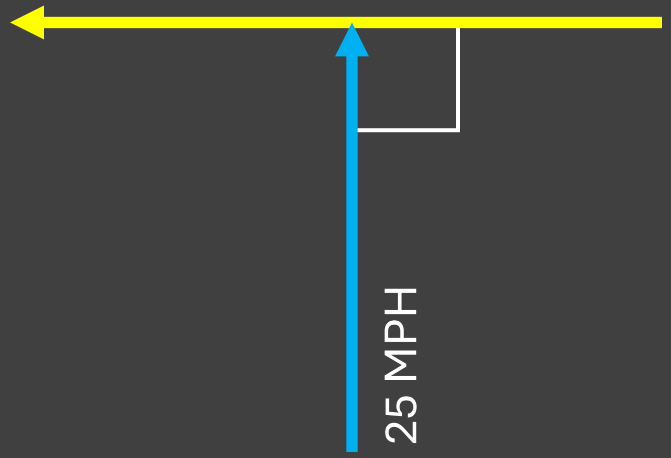


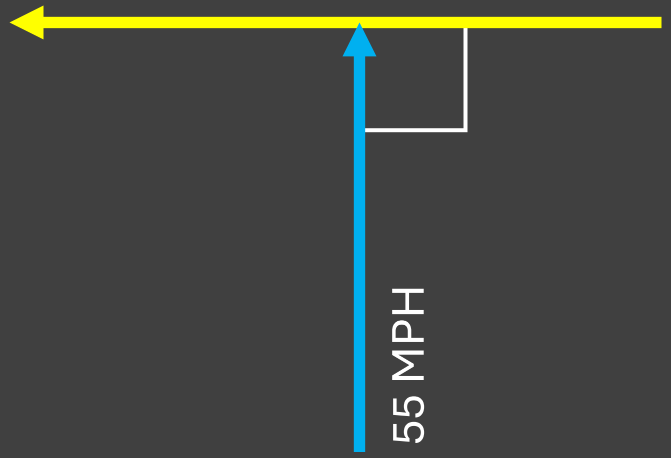
How Crash Speed Impacts Kinetic Energy

*Speed is **20%** higher

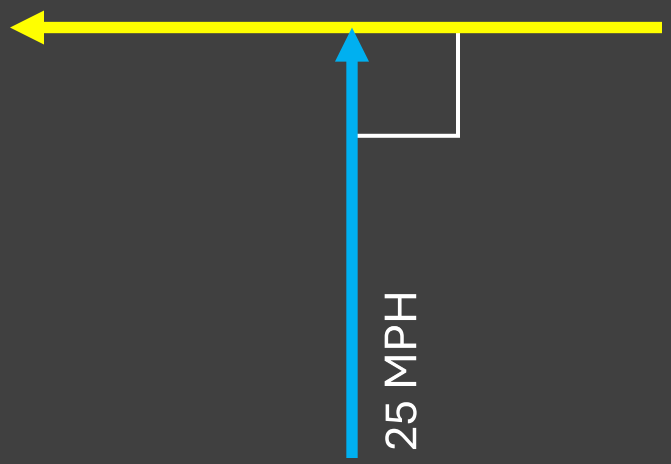
*Kinetic energy is **44%** higher

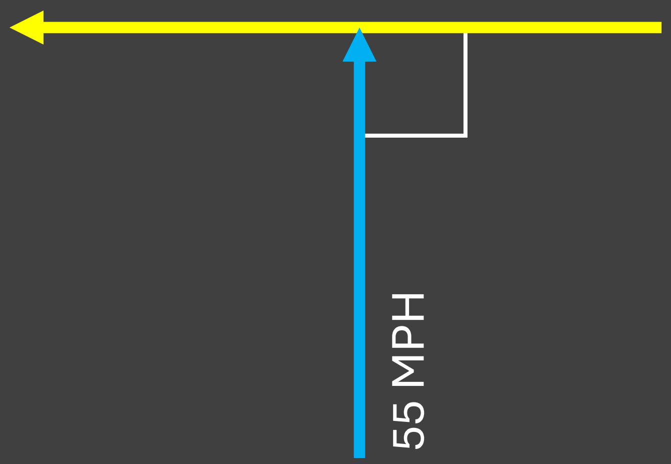
How Crash Speed Impacts Kinetic Energy





How Crash Speed Impacts Kinetic Energy





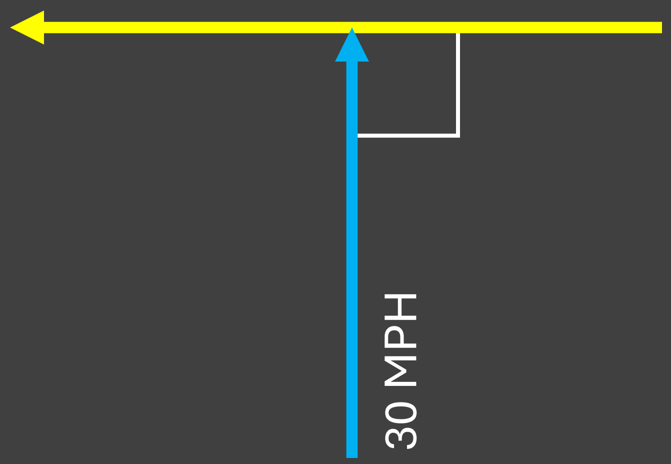
*Speed is **2.2** times higher

*Kinetic energy is **4.8** times higher

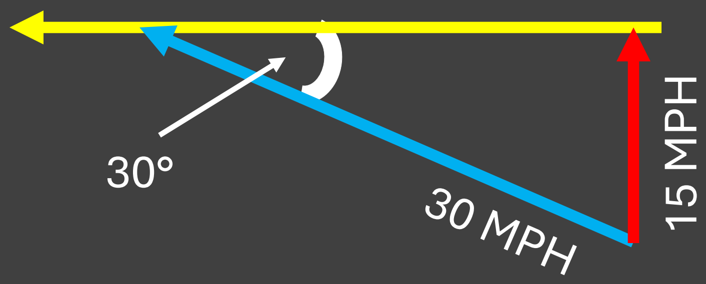
How Crash Angle Impacts Kinetic Energy

How Crash Angle Impacts Kinetic Energy

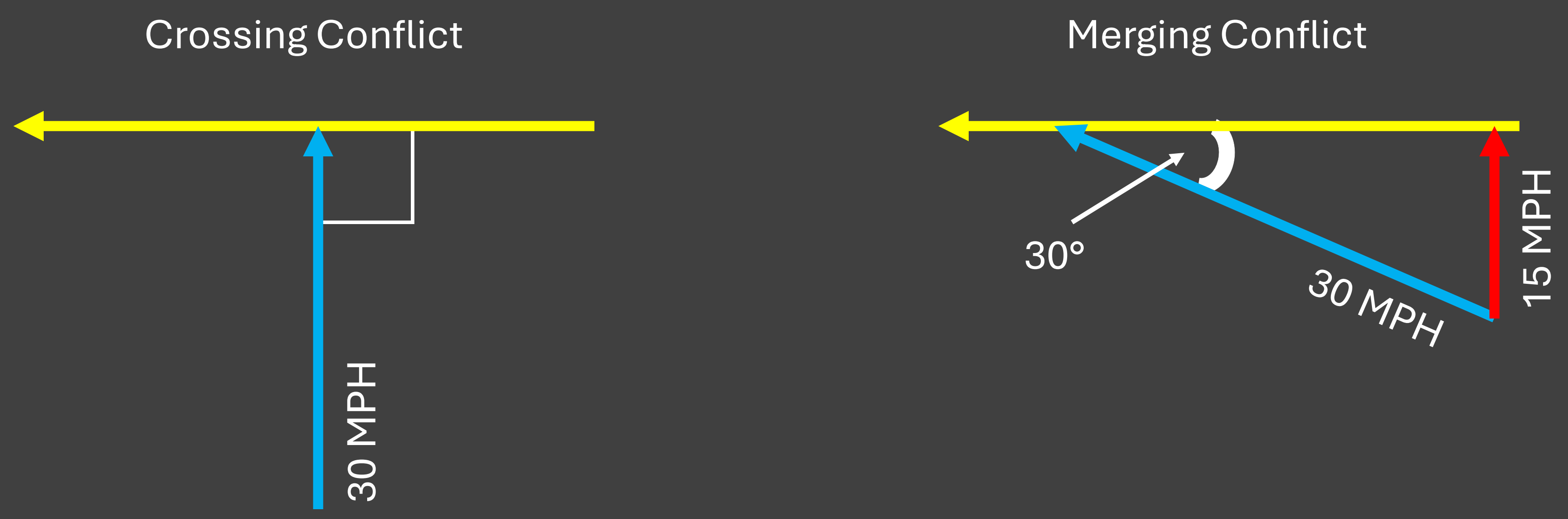
Crossing Conflict



Merging Conflict



How Crash Angle Impacts Kinetic Energy

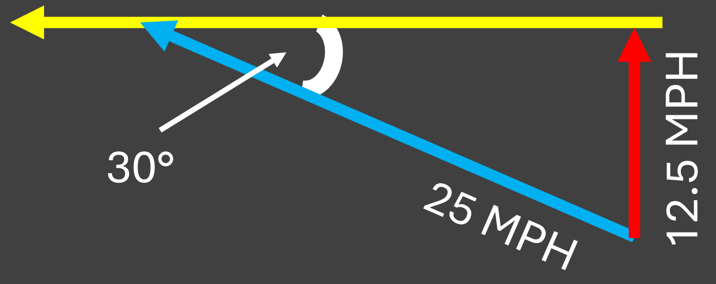


*Relative speed going into yellow vehicle is **2** times higher

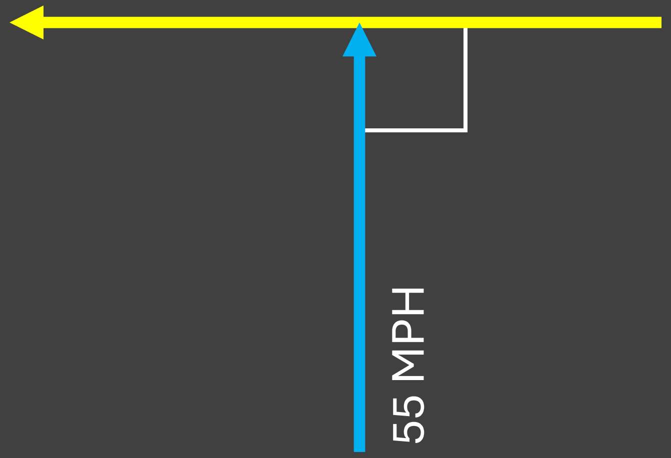
*Kinetic energy approaching yellow vehicle is **4** times higher

How Speed and Angle Impacts Kinetic Energy

Merging Conflict



Crossing Conflict



*Relative speed going into yellow vehicle is **4.4** times higher

*Kinetic energy approaching yellow vehicle is **19.4** times higher

Theory Applied to Maine Crash Data

Where did this start?

- Calculated Crash Severity for "Intersection Movement" angle crashes at intersections controlled for major road speed limit.

"Angle" Crash Severity By Intersection Speed Limit

	Injury %	K+A %	K+A+B %
25	25.96%	0.98%	6.30%
30	30.20%	1.49%	8.47%
35	31.65%	2.01%	9.53%
40	34.25%	2.53%	11.96%
45	40.68%	4.38%	15.82%
50	45.27%	5.55%	18.28%
55	49.42%	6.26%	22.74%

Does severity for other crashes change with speed?

How do these results change by intersection control?

How does the risk of compare across intersections with different crash patterns and speeds?

Connection Between Kinetic Energy and K+A Percentage

CALCULATED FATAL AND SERIOUS INJURY (K+A) PERCENTAGE FOR NUMEROUS INTERSECTION CRASH SCENARIOS

CORRECTED FOR SPEED, INTERSECTION CONTROL, CRASH TYPE, AND CRASH ANGLE

How to Account for Crash Angle in the Data?

- Intersection Movement Frontal Impact Adjustment
  - Reviewed different "most damaged area" data from police reports
  - Separated direct impact right angle crashes from intersection movement crashes happening at less severe angles
  - The K+A probability of a "frontal" angle crash is **3.7 times higher** than those without "frontal impact"

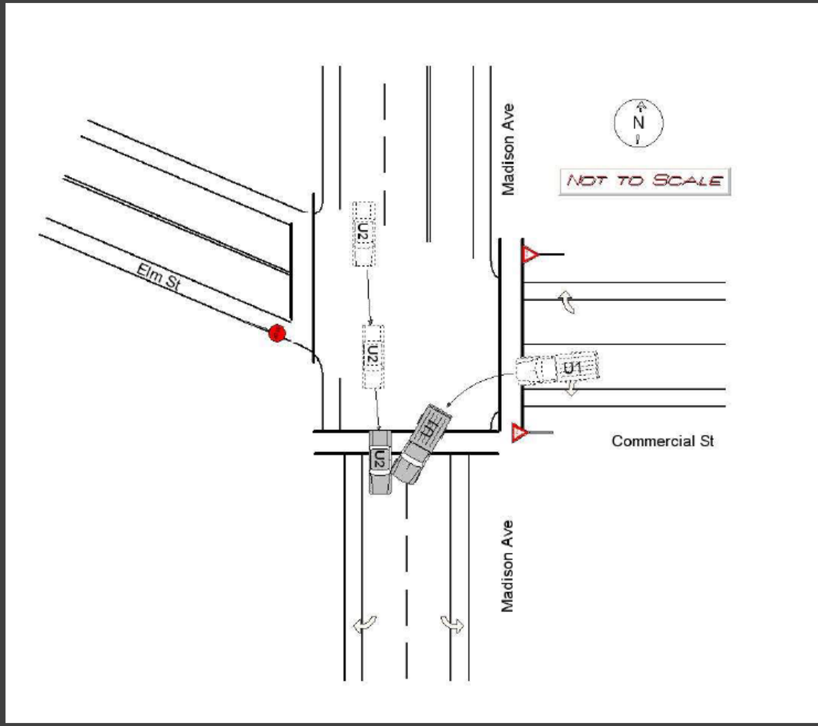
All-Way Stop Intersection Movement Ran Stop Sign Adjustment

- Running the stop sign is a big factor at all-way stop crashes
  - The K+A probability is **6.4 times higher** when a driver runs the stop sign

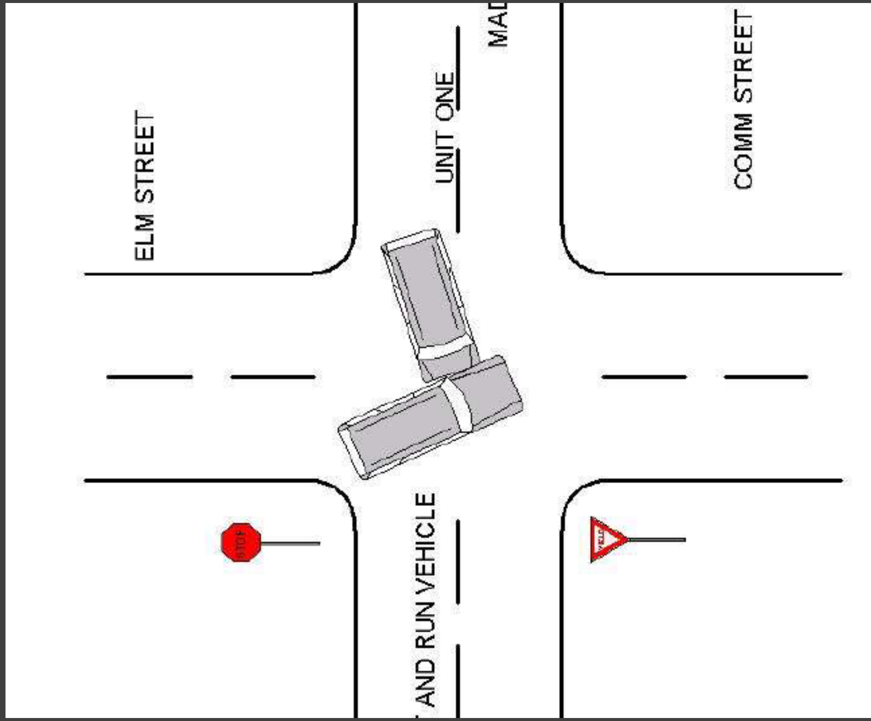
	All-Way Stop Intersection Movement Crashes	
	Non-Ran Stop Sign	Ran Stop Sign
% K+A	0.33%	2.10%

Example of Intersection Movement Severity Differences

Two intersection movement crashes at the **same intersection**: 25 MPH, Other Intersection Type



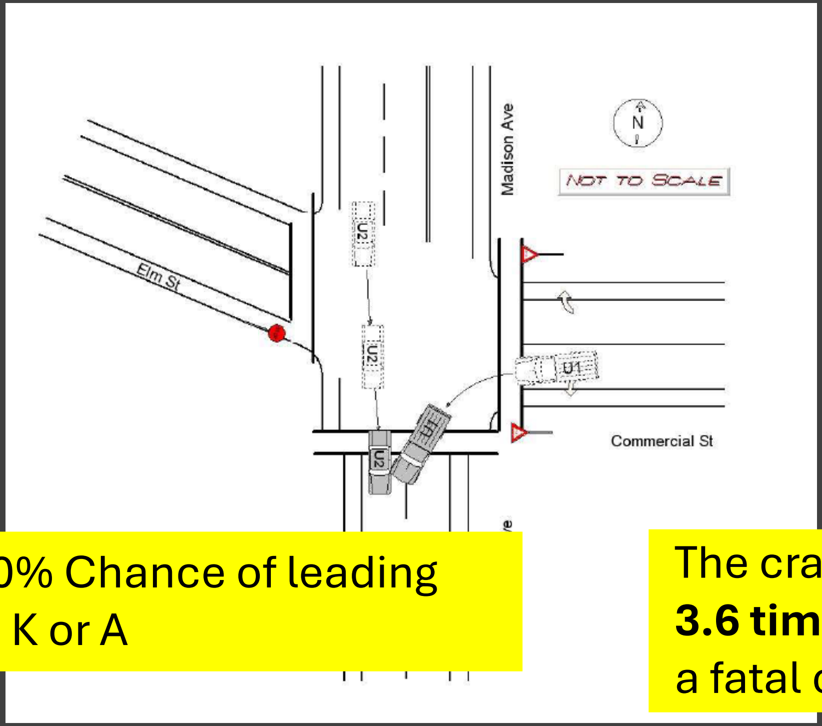
Non-frontal impact



Frontal Impact

Example of Intersection Movement Severity Differences

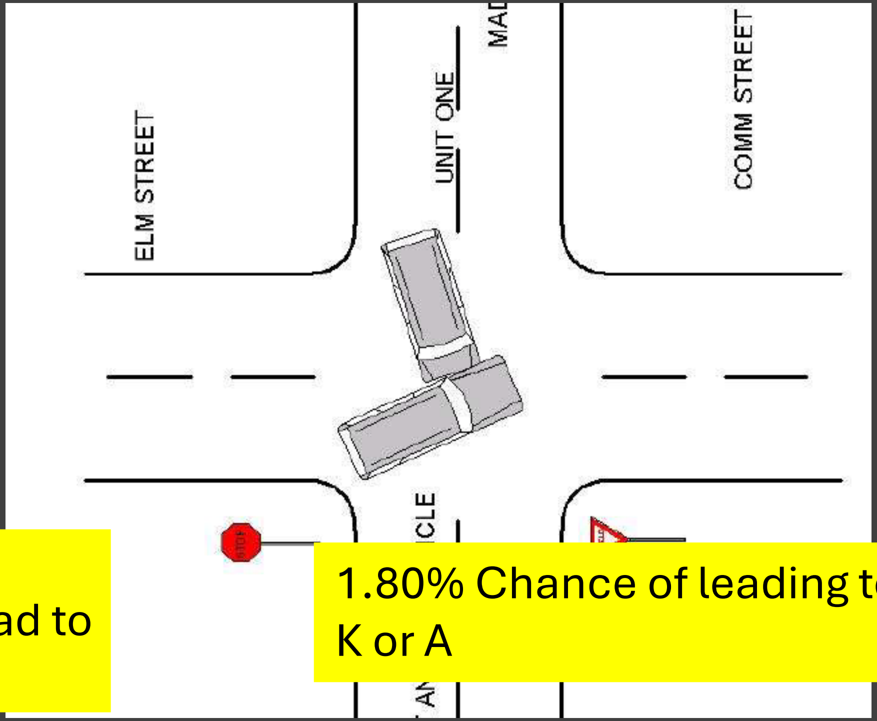
Two intersection movement crashes at the **same intersection**: 25 MPH, Other Intersection Type



0.50% Chance of leading to a K or A

Non-frontal impact

The crash on the right is **3.6 times** more likely to lead to a fatal or serious injury



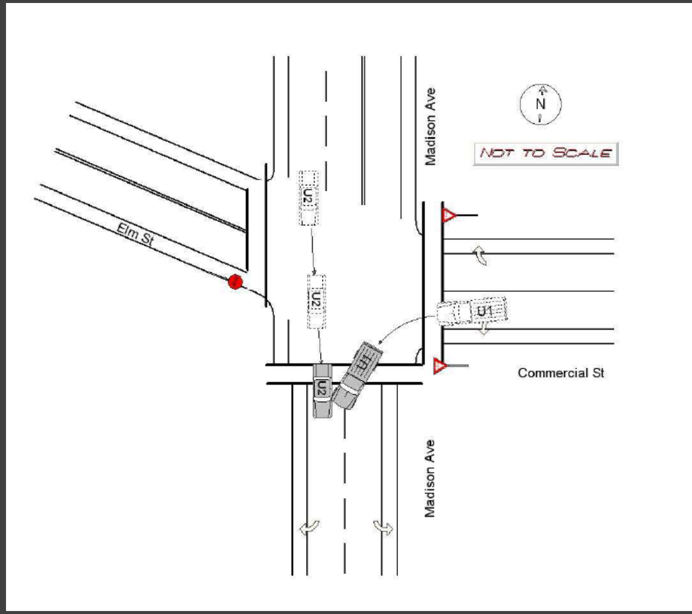
1.80% Chance of leading to a K or A

Frontal Impact

Example of Intersection Movement Severity Differences

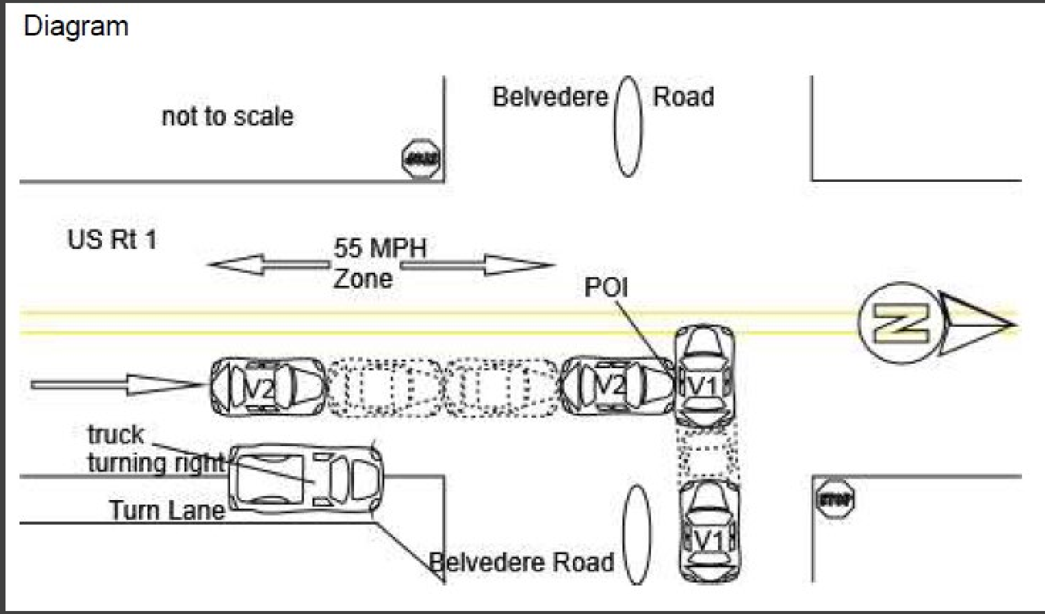
Two intersection movement crashes at **<u>different intersections</u>**

25 MPH, Other Intersection Type



Non-frontal impact

55 MPH, Other Intersection Type



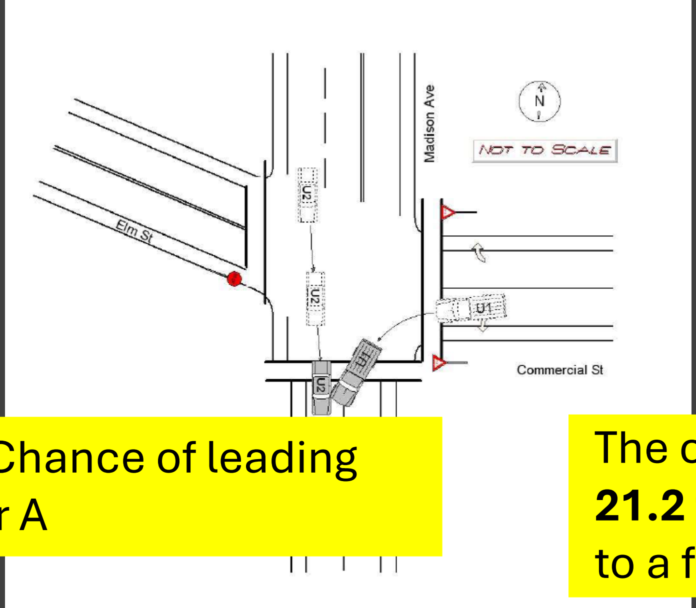
Frontal Impact

Example of Intersection Movement Severity Differences

Two intersection movement crashes at **<u>different intersections</u>**

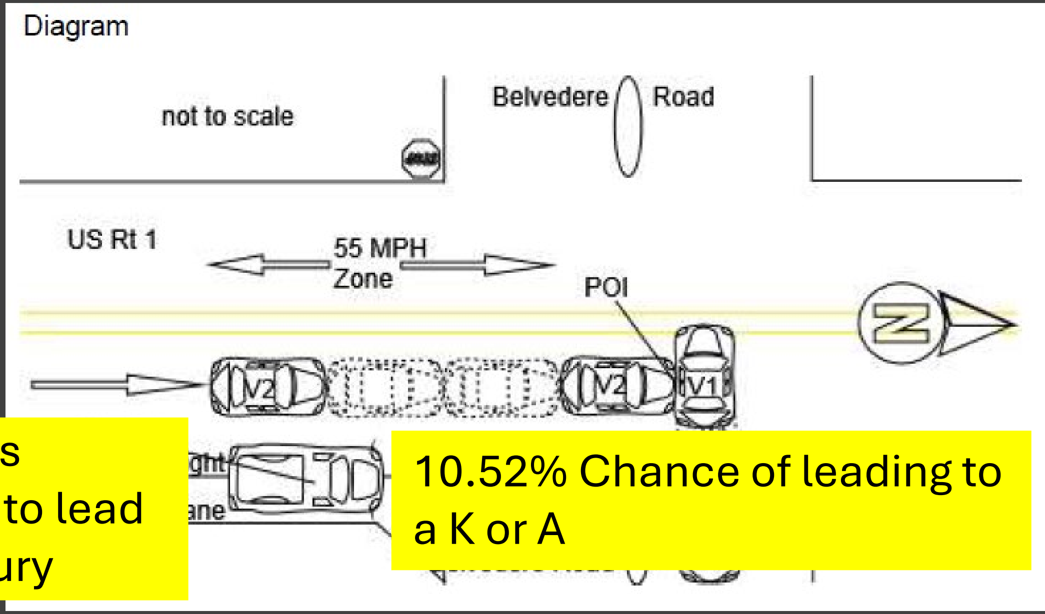
25 MPH, Other Intersection Type

55 MPH, Other Intersection Type



0.50% Chance of leading to a K or A

The crash on the right is **21.2 times** more likely to lead to a fatal or serious injury



10.52% Chance of leading to a K or A

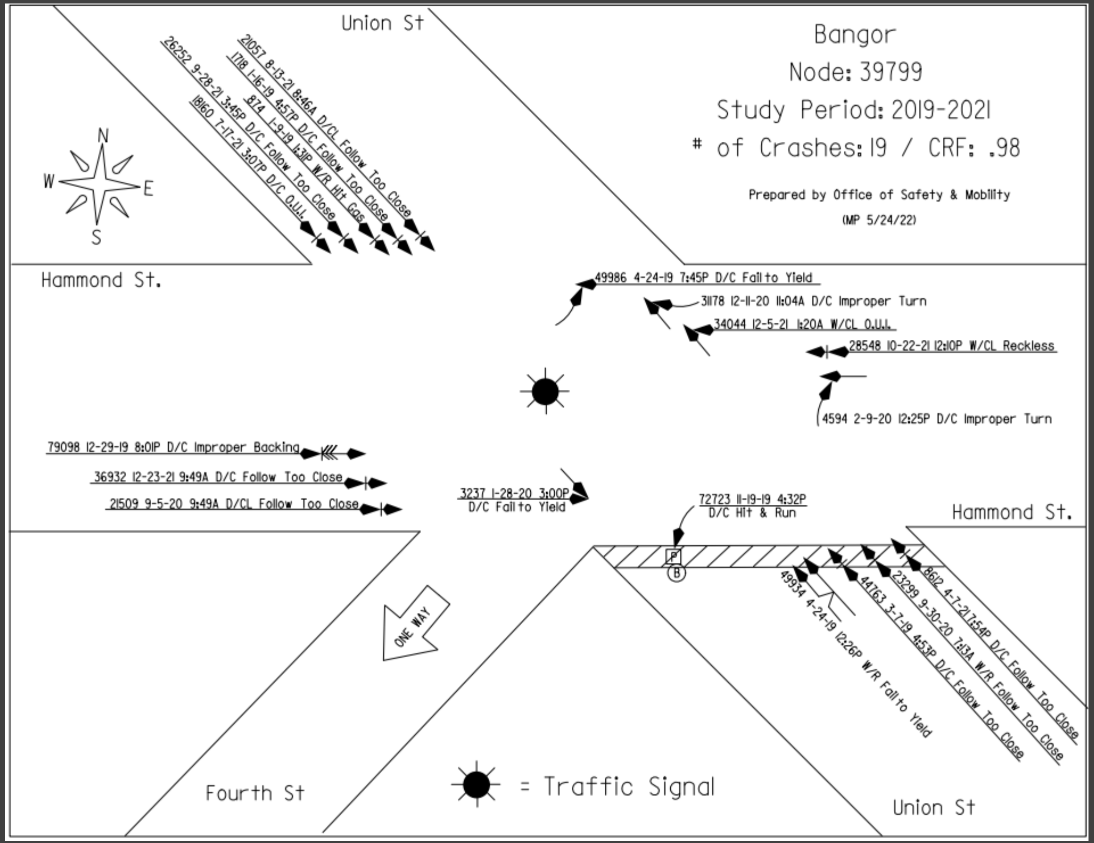
Non-frontal impact

Frontal Impact

Example of Crash Type Severity Differences

- Crash diagram shows **13 rear end / sideswipe** crashes and **1 pedestrian crash**
- The estimated K+A crashes from all the rear ends combined is 0.027
    - *13 crashes with a **0.21%** K+A Probability*
- The estimated K+A Crashes from the one pedestrian crash is 0.166
    - *1 crash with a **16.6%** K+A Probability*
- At this location, one pedestrian crash is **6.1 times** more likely to lead to a K or A than all the rear ends combined

25 MPH, Traffic Signal



K+A Potential

New MaineDOT Intersection Network Screening Process

Why Create Another Screening Method?

Maine's Existing Screening Methods

- High Crash Location rankings
- Highway Safety Manual Excess Cost
- These have limitations:
  - Do not always identify the most concerning intersections
  - Neither HCLs or our version of HSM screening account for observed crash severity, crash type, or speed
  - Only three years of data is considered
  - HSM models are often a poor fit for outlier intersections
    - → These are the locations where we want spot safety improvements
  - **We do not need to accept these limitations. We can build something better and more comprehensive.**

What is K+A Potential?

The number of K+A crashes we estimate will happen over the next 10 years if crash patterns continue.

Also, a ranking of intersections where fatal or serious injuries are most likely to occur.

What is K+A Potential based on?

At a basic level, this is based on two things:

- Crash patterns in recent years

- History of fatal and serious injury crashes at the location

How do you quantify crash patterns?

- Simple, statistically naive process
- **Sum the probability of a K or A occurring for every crash at an intersection**
    - Use 5-year crash history for most crashes and 10-year for ped/bike
- The value is converted to a per 10 years time frame, so values are shows at scales easier to understand

Calculating Crash Pattern Potential

Calculate K+A % for each type of intersection crash

Control for crash type, speed limit, intersection control, and crash angle (where appropriate)

- Angle (frontal) only considered for intersection movement crashes.
- Ran Stop Sign % considered at all-way stops

Determine how many of each crash type has occurred at every intersection

- Review 10-years of data for ped and bike crashes and 5-years for other crashes
- Convert the number of crashes to per 10 years values (multiply non-ped and bike crashes by 2)

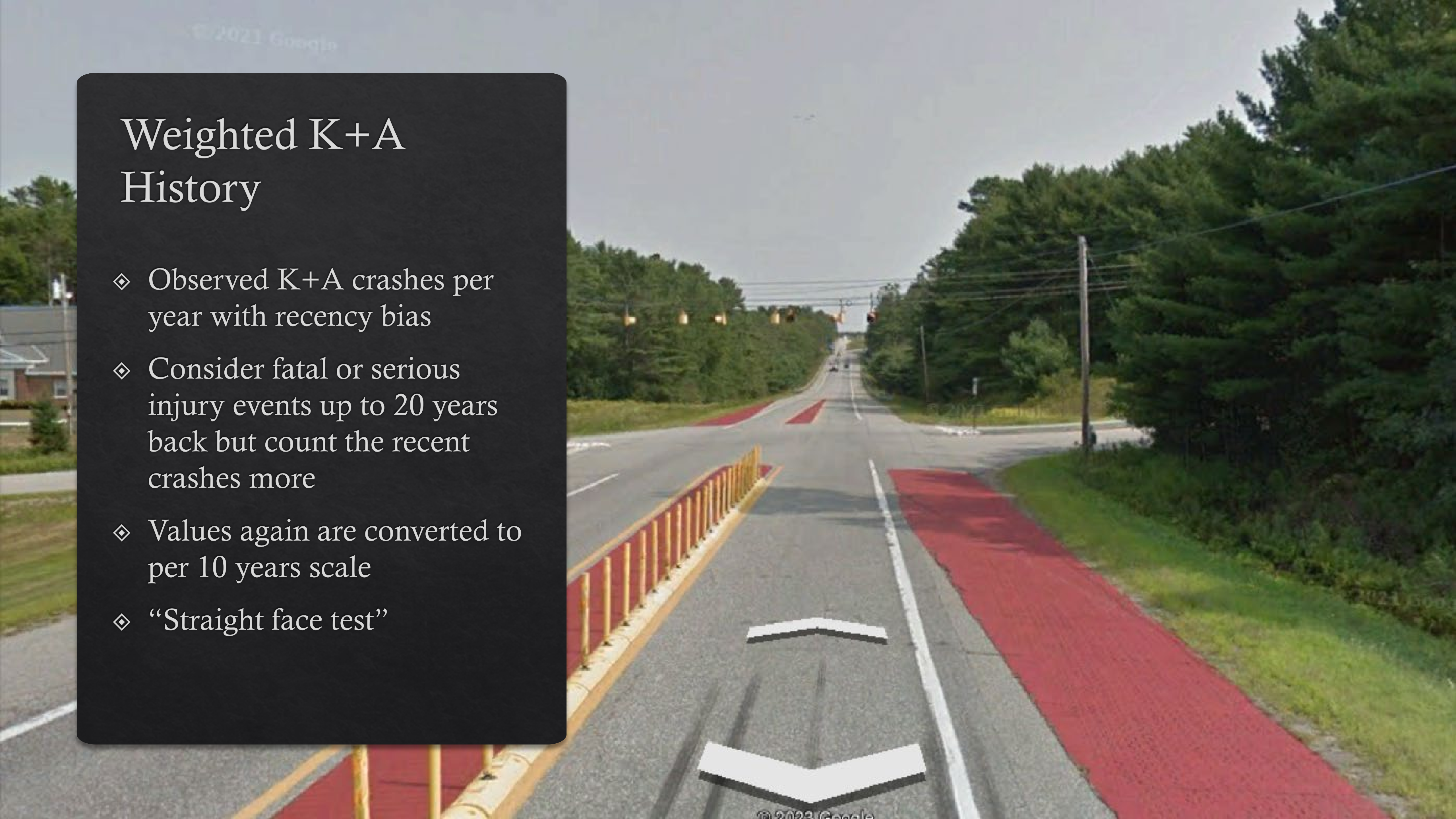
Multiply each observed crash frequency per 10 years by the associated K+A %

- Example: 2 crashes per 10 years and 5% K+A
- 2*0.05 = 0.10 K+A

Sum the results for all crash types to equal a total Crash Pattern Potential for each intersection

Weighted K+A History

- Observed K+A crashes per year with recency bias
- Consider fatal or serious injury events up to 20 years back but count the recent crashes more
- Values again are converted to per 10 years scale
- “Straight face test”



Considerations for Long-Term K+A Data

Maine Intersection Observed K+A Rankings

5-Year

Node	Town Name	5+ Year K+A Crashes
3380	LEWISTON	3
3538	LEWISTON	3
3704	TURNER	3
23885	ELLSWORTH	3
39819	BANGOR	3
1959	LEWISTON	2
3412	SABATTUS	2
3697	TURNER	2
4460	AUBURN	2
4580	AUBURN	2
9650	SOUTH PORTLAND	2
11001	GORHAM	2
11537	RAYMOND	2
14203	SOUTH PORTLAND	2
14816	STANDISH	2
15610	SCARBOROUGH	2
15615	SCARBOROUGH	2
15685	CASCO	2

10-year

Node	Town Name	10+ Year K+A Crashes
3704	TURNER	7
3538	LEWISTON	4
16602	SCARBOROUGH	4
17216	BRUNSWICK	4
39104	HERMON	4
60334	PORTLAND	4
10599	SCARBOROUGH	4
15048	WESTBROOK	4
15738	WINDHAM	4
25750	WATERVILLE	4
3380	LEWISTON	3
23885	ELLSWORTH	3
39819	BANGOR	3
4460	AUBURN	3
15685	CASCO	3
16780	PORTLAND	3
38885	BANGOR	3
39629	BANGOR	3

20-Year

Node	Town Name	20-Year K+A Crashes
15738	WINDHAM	11
3704	TURNER	8
30504	ROCKLAND	7
3538	LEWISTON	6
3391	LEWISTON	6
41304	BANGOR	6
3690	AUBURN	6
21275	WILTON	6
66505	GORHAM	6
60334	PORTLAND	5
15048	WESTBROOK	5
3380	LEWISTON	5
15685	CASCO	5
53268	ARUNDEL	5
3251	DURHAM	5
23847	ORLAND	5
56930	OLD ORCHARD BEACH	5
3412	SABATTUS	5

Observed K+A Crashes in the last 5 years count **1.5 X** more than 6-10 years ago and **2 X** more than 11+ years ago

Combine Crash Pattern with K+A History

- Currently, the crash pattern counts is **3 times** more than the observed K+A history
  - K+A Potential is **75%** Crash Pattern and **25%** Weighted K+A History
- React to K+A crashes without overreacting or "chasing fatals"
- Most top ranked intersections will have **both** K+A crashes in their history and a concerning crash pattern

Screening Process Location Types Identified

Screening Method	Rural Locations in Top 100	Traffic Signals in Top 100	Roundabouts in Top 100	45 MPH + Locations in Top 100	Ped or Bike Crash Locations in Top 100	45 MPH + or Ped/Bike Locations in Top 100
K+A Potential	43	39	2	52	49	91
Excess Cost	14	79	N/A	7	58	65
HCL CRF	42	0	9	27	29	55

How does this deviate from existing safety initiatives?

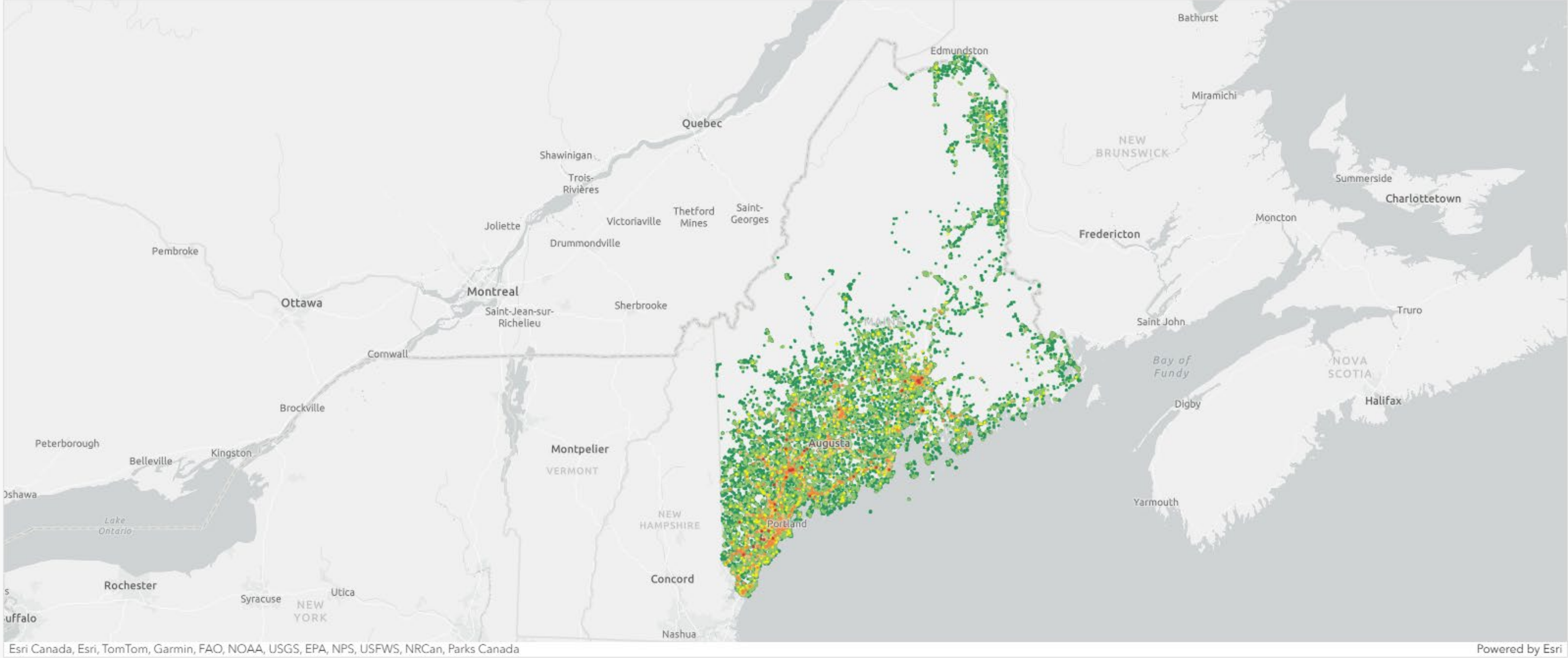
- Most research has been based on crash prediction models for all crash types combined.
- Since all crash types are combined, speed is often a minor factor in models if considered at all.
- Observed crash data used in prediction is often total crashes or property damage separated from all other injury severities.
- Most research and crash models only consider 3-5 years of observed data.
- Ultimately, most screenings are based on total crash frequency and theoretical severity based on facility type.

Tools and Resources We Use

Intersection Network Screening Ranking List

Ranking	Node	Town Name	Description	Primary Route	**K+A Potential**	Crash Pattern Potential	Weighted K+A History
2	3497	AUBURN	Int of BEECH HILL RD DANVILLE CORNER RD N WASHINGTON ST S WAS	0202X	**3.537**	4.115	1.800
3	10599	SCARBOROUGH	Int of BROADTURN RD BURNHAM RD	0500489	**2.825**	2.633	3.400
4	39629	BANGOR	Int of MAIN ST UNION ST	1910282	**2.808**	2.477	3.800
5	55829	SANFORD	Int of ALFRED RD ALUMNI BLVD JAGGER MILL RD	0004X	**2.711**	2.715	2.700
6	63225	PORTLAND	Int of CONGRESS ST FRANKLIN ST	0001A	**2.675**	2.667	2.700
7	55747	DAYTON	Int of HOLLIS RD NEW COUNTY RD RIVER RD	0005X	**2.672**	2.596	2.900
8	46653	PALMYRA	Int of ELL HILL RD ESTES AV MAIN ST	0002X	**2.652**	2.835	2.100
9	3704	TURNER	Int of AUBURN RD WESTON RD	0004X	**2.534**	1.912	4.400
10	16908	WINDHAM	Int of ALBION RD ROOSEVELT TRL	0302X	**2.495**	2.960	1.100
11	23847	ORLAND	Int of ACADIA HWY SCHOOL HOUSE RD UPPER FALLS RD	0001X	**2.469**	2.592	2.100
12	27882	MONMOUTH	Int of BLAISDELL RD MAIN ST US ROUTE 202	0202X	**2.465**	2.920	1.100
13	27880	MONMOUTH	Int of BLUE RD BOG RD US ROUTE 202	0202X	**2.448**	2.264	3.000
14	39104	HERMON	Int of ANNIS RD KLATT RD ROUTE 2	0002X	**2.366**	1.955	3.600
15	55866	BUXTON	Int of BREWSTER PL NARRAGANSETT TRL OLD ORCHARD RD	0202X	**2.364**	2.585	1.700
16	56874	ARUNDEL	Int of ALFRED RD LIMERICK RD	0111X	**2.357**	2.143	3.000
17	46726	MADISON	Int of LAKEWOOD RD WHITE SCHOOL HOUSE RD	0201X	**2.346**	3.094	0.100
18	28703	WINTHROP	Int of MAIN ST RAMP TO MAIN ST US 202	0202S	**2.319**	2.158	2.800
19	46360	MADISON	Int of MAIN ST OLD COUNTY RD WARD HILL RD WHITE SCHOOL HOUSE	0148X	**2.288**	2.450	1.800
20	39158	NEWBURGH	Int of CARMEL RD N WESTERN AV	0202X	**2.254**	2.372	1.900
21	27779	AUGUSTA	Int of MEMORIAL CIR WESTERN AV	0201S	**2.104**	2.806	0.000
22	39084	NEWPORT	Int of ELM ST ROUSSIN RD STETSON RD	0002X	**2.014**	2.286	1.200
23	35053	OXFORD	Int of MAIN ST OXFORD ST	0026X	**1.994**	2.359	0.900
24	30389	WARREN	Int of CAMDEN RD WESTERN RD	0090X	**1.943**	2.291	0.900
25	3472	LEWISTON	Int of BARTLETT ST PINE ST	0120024	**1.895**	1.859	2.000
26	3380	LEWISTON	Int of CONNECTOR RD RUSSELL ST SABATTUS ST	0126X	**1.886**	1.481	3.100
27	28712	WINSLOW	Int of AUGUSTA RD CARTER MEMORIAL DR	0201X	**1.855**	1.707	2.300
28	16765	PORTLAND	Int of CONGRESS ST ST JOHN ST	0022S	**1.841**	1.788	2.000
29	3412	SABATTUS	Int of PLEASANT HILL RD SABATTUS RD SABBATTUS RD WALES RD	0009X	**1.808**	1.644	2.300
30	15738	WINDHAM	Int of FALMOUTH RD GRAY RD	0202X	**1.800**	1.500	2.700
31	53245	KENNEBUNK	Int of WEBBER HILL RD WHITTEN RD	0099X	**1.797**	2.029	1.100
32	16412	SCARBOROUGH	Int of CUMMINGS RD PAYNE RD	0570485	**1.759**	1.745	1.800
33	3780	AUBURN	Int of HATCH RD MERROW RD MINOT AV	0011X	**1.732**	1.676	1.900
34	27892	WINTHROP	Int of HIGHLAND AV US 202	0202X	**1.693**	2.257	0.000
35	55742	SACO	Int of BOOM RD LOUDEN RD NEW COUNTY RD	0005X	**1.689**	1.919	1.000
36	66308	OLD ORCHARD BEACH	Int of OCEAN PARK RD SACO AV	0005X	**1.689**	1.885	1.100

Intersection KA Potential Dashboard 2024



Intersection KA Potential Rankings 2024

K_A_Potential

- > 1.48 - 3.208
- > 0.659 - 1.48
- > 0.446 - 0.659
- > 0.261 - 0.446
- > 0 - 0.261
- 0.000 - 0.000

Ranking	Node	Town_Name	Description	Primary_Route	K_A_Potential	Crash_Pattern_Potential	Weighted_K_A_History	Calculation_Speed_Limit	Speed_Limit	20_Year_K_A_Crashes	5_Year_K_A_
1	3497	AUBURN	Int of BEECH HILL RD DANVILLE CORNER RD N WASHINGTON ST S WASHINGTON ST	0202X	3.21	3.67	1.82	50	50	4	
2	21038	JAY	Int of CHESTERVILLE RD DEPOT ST FRANKLIN RD	0133X	2.87	3.16	2.00	40	35	5	
3	55829	SANFORD	Int of ALFRED RD ALUMNI BLVD JAGGER MILL RD	0004X	2.69	2.86	2.18	45	45	4	
4	46653	PALMYRA	Int of ELL HILL RD ESTES AV MAIN ST	0002X	2.62	2.70	2.36	45	45	5	
5	3712	TURNER	Int of AUBURN RD BEAR POND RD HOWES CORNER RD	0004X	2.50	2.79	1.64	45	45	3	
6	15738	WINDHAM	Int of FALMOUTH RD GRAY RD	0202X	2.37	1.52	4.91	50	50	11	

Kinetic Energy Location Lookup Tool

Enter Node Number Below:	Town Name	Intersection Description	Primary Route	Major Road Speed Limit	Speed Limit Used in Calculations	Intersection Control
27779	AUGUSTA	Int of MEMORIAL CIR WESTERN AV	0201S	25	25	Roundabout / Traffic Circle

	K+A Potential	Crash Pattern Potential	Weighted K+A History
Score	**2.01**	2.56	0.36
Statewide Ranking	***16***	*8*	*T-1602*

Known Recent or Future Safety Improvement Project?	Estimated Project Year
None known	None known

Highest Crash Pattern Contributors

Crash Pattern Impact Ranking	Crash Type	Crash Pattern Potential For Type	% of Total Crash Pattern Potential
1	Pedestrians	1.33	51.8%
2	Rear End / Sidewipe	0.65	25.3%
3	Went Off Road	0.35	13.6%
4	"Other" Crash Types Combined	0.10	4.0%
5	Bicycle	0.09	3.6%
6	Head-on / Sideswipe	0.05	1.8%
7	Intersection Movement	0.00	0.0%

	Totals	*Statewide Ranking*
20-Year K+A Crashes	1	*T-708*
K+A Crashes in the Last 10 Years	0	*T-1440*
K+A Crashes in the Last 5 Years	0	*T-743*
K+A+B Crashes in the Last 5 Years	2	*T-367*
Fatal crash in the last 20 years?	No	*N/A*

	5-Year Total Crashes	5-Year Intersection Movement Crashes	5-Year Right Angle Crashes (Int Mov Frontal)	10-Year Pedestrian Crashes	10-Year Bicycle Crashes	10-Year Non-Motorized Crashes
Totals	278	58	6	8	1	9
Statewide Ranking	*2*	*3*	*T-290*	*T-1*	*T-145*	*T-3*
Statewide Ranking for Roundabout / Traffic Circle and speed limit >= 25	*2*	*3*	*T-4*	*1*	*4*	*1*

Crash Severity Comparison Tool

MaineDOT Crash Severity Comparison Tool

Applicability: Results are only accurate when comparing crashes at intersections

Intructions: Add data from dropdown list wherever a red O is indicated. Unneccessary questions are colored black. These questions may uncover and become visible based on data entered in other fields.

Crash A	
Crash A Input (Choose From Dropdown List)	
Intersection Control	All Other Intersection Controls
Primary Road Speed Limit	40
Crash Type	Intersection Movement
Collision Angle	Right Angle (Frontal Impact)
Crash A Calculated Values	
Fatal and Serious Injury Probability	5.04%
Average Crash Cost Per Crash	$149,032.77

Crash B	
Crash B Input (Choose From Dropdown List)	
Intersection Control	Traffic Signal
Primary Road Speed Limit	30
Crash Type	Intersection Movement
Collision Angle	Other Crash Angle (Non-Frontal Impact)
Crash B Calculated Values	
Estimated Fatal and Serious Injury Probability	0.60%
Crash Cost Per Crash	$39,493.57

Crash Severity Comparison	
K+A Probability Comparison	Crash A is 8.5 times more likely to lead to a fatal or serious injury crash.
Theoretical Kinetic Energy Comparison	The kinetic energy for Crash A is 7.1 times higher.
Crash Cost Comparison	The crash cost for Crash A is 3.8 times higher.

Kinetic Energy Screening Performance

How is this working?
(Performance of Kinetic Energy Ranking System in 2023)

2023 Network Severity Performance

Sum of all Intersecttion 2023 K+A Potential / 10	180
# of Intersection K+A Crashes in 2023	170
Overprediction Percentage	5.9%

- Overall happy with this accuracy.
- Potential for calibration.

K+A Risk of Top Ranked Intesections

	Top Ranked Intersections from 2023 K+A Potential					
	Top 10	Top 25	Top 50	Top 100	Top 300	Top 2000
K+A Potential Predicted Share of K+A Risk	1.4%	3.0%	5.2%	9.0%	20.2%	61.8%
Percent of Actual K+A Crashes in 2023	1.8%	2.4%	4.1%	8.2%	17.6%	49.4%

- Very close distribution.
- K+A crashes are slightly more dispersed than crash history suggests

How is this working?
(Comparison to other methods identifying 2023 K+A crash locations)

- **Reviewed locations where K+A crashes occurred in 2023. Where did these locations rank in the different networks screening methods?**
  - Compared the following metrics for each method:
    - 10th percentile, First Quartile, Mean, Median, Third Quartile

- **How many K+A crashes occurred at locations which were highly ranked by screening methods?**
  - Counted how many K+A crashes occurred for the top ranked locations in each of the screening methods based on the following thresholds:
    - Top 10, Top 25, Top 50, Top 100, Top 300, Top 2000

- Did the same evaluations for K+A+B crashes
  - Increased sample size to evaluate (1,100 KAB crashes in 2023 vs. 170 KA crashes)
  - 22 total metrics to evaluate (11 K+A and 11 K+A+B)

How is this working?

(Comparison to other methods identifying 2023 K+A crash locations)

Cumulative Network Screening Performance

Ranking System	# of Metrics Won	# of Metrics in Top 2	Average Ranking	Rank Ranking
K+A Potential	21	22	1.05	1
HSM Excess Cost	1	13	2.59	3
HCL CRF Rank	0	6	3.18	4
HCL # of Times Rank	1	12	2.45	2

How is this working?

(Comparison to other methods identifying 2023 K+A crash locations)

Cumulative Network Screening Performance

Ranking System	# of Metrics Won	# of Metrics in Top 2	Average Ranking	Rank Ranking
K+A Potential	21	22	1.05	1
HSM Excess Cost	1	13	2.59	3
HCL CRF Rank	0	6	3.18	4
HCL # of Times Rank	1	12	2.45	2

This evaluation shows that detailed crash history is a good indication of future risk.

FHWA Video Effort

- Sent a video crew to Maine in August 2024 to highlight our effort
- Completed interviews with key stakeholders and traveled around the state to collect relevant footage
- Video is expected to be complete in 2026
- Will be posted on the FHWA YouTube site as part of the Data-Driven Safety Analysis channel

What is Next?

- Improve or automate data management / data maintenance
- Make information more accessible
- Figure out this info for road segments
- More research to come, likely from others…

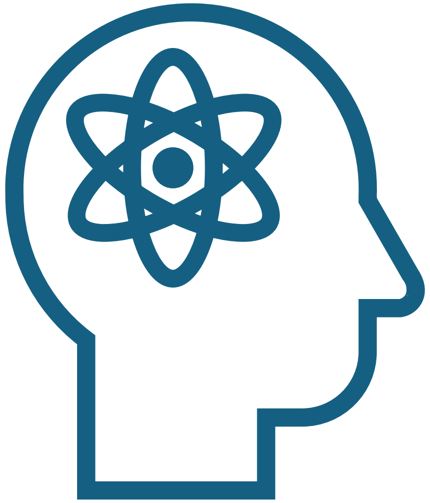
How can your state implement?

- Depending on data quality, Most work can be done in about a month, probably with internal staff.

- Don't let perfection get in the way of good / better.

- Crash angle is a big factor, but starting without it is still an improvement.

- Just start, don't overthink it.



Thank You

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