Principles of Work Zone Safety: The Safe System Approach

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Learning Objectives

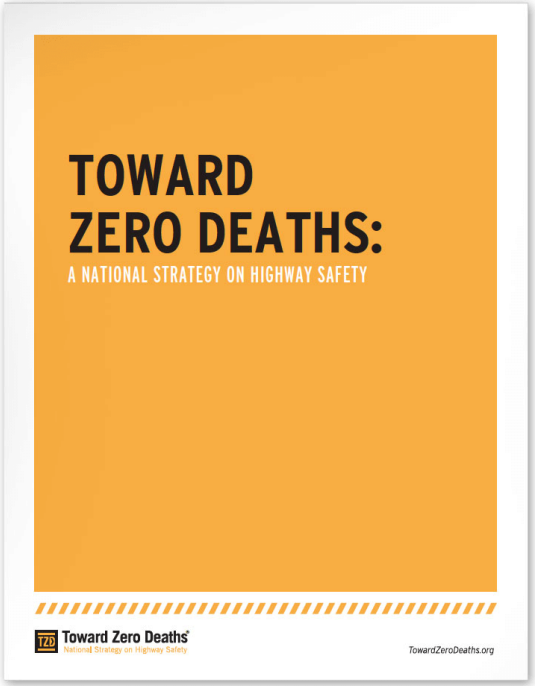
- Define work zone crashes and work zone characteristics
- Discuss SAFE system approach
- Discuss possible treatments as designers

Toward Zero Deaths

A National Strategy on Highway Safety (2014)

National Goal:

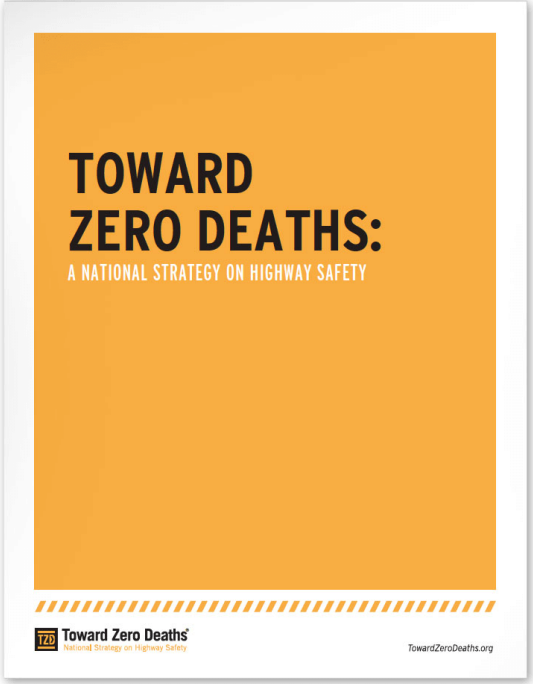
"A highway system free of fatalities through a sustained and even accelerated decline in transportation-related deaths and injuries."



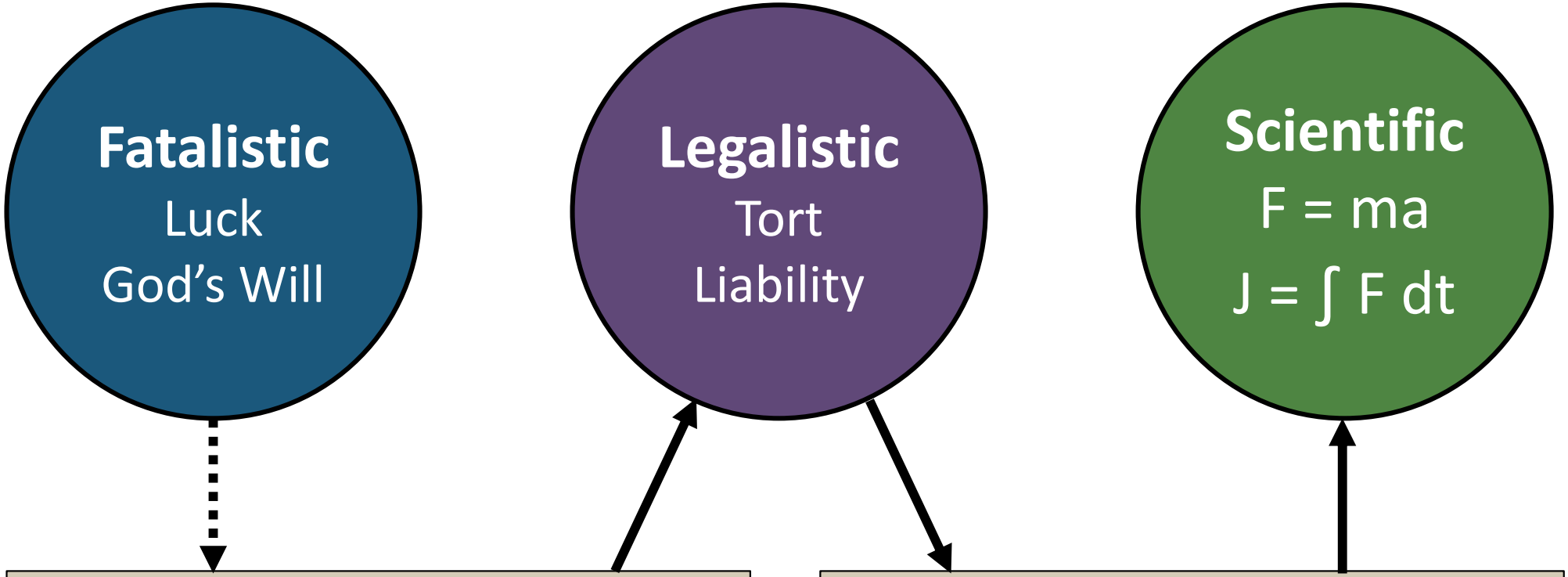
http://www.towardzerodeaths.org/wp-content/uploads/TZD_Strategy_12_1_2014.pdf

Toward Zero Deaths: Work-Zone Elements

- "Improve speed management and enforcement in work zones to reduce the risk of work zone fatalities."
- "Improve work zone design and operations."
- "Educate drivers on safer driving practices in work zones."
- "Educate workers on safety practices."
- "Educate judges, prosecutors and law enforcement on…risks related to work zones."
- "Enact legislation…including pervasive automated speed enforcement and applications for school and work zones."



Perspectives on Safety



"When you build a new house, make a parapet around your roof so that you may not bring the guilt of bloodshed on your house if someone falls from the roof."
--Deuteronomy 22:8, circa 700 BCE

"The gap between existing design and attainable safety has widened enormously… As these attainable levels of safety rise, so do the moral imperatives to use them.."
--Ralph Nader, 1965

Design Makes a Difference

Nissan Versa vs Nissan Tsuru

https://www.youtube.com/watch?v=85OysZ_4lp0

Performance Comparison

Tsuru: blue grease paint identifies where driver's head strikes the "A" pillar.

Versa: driver protected by airbags and crumple zones.

Class Discussion

Can you think of some products, companies, or organizations whose reputation was damaged by design flaws?

What could designers have done to prevent these problems?

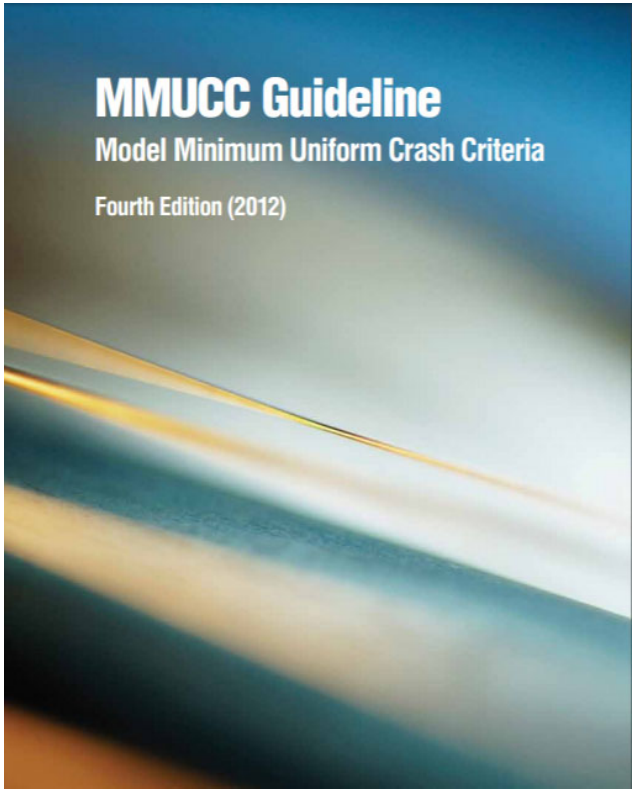
How does this relate to work zones?

Photo: Kim Scarborough/Wikimedia Commons

What is a “work zone crash”?

As defined by the Model Minimum Uniform Crash Criteria (MMUCC) standards, a WZ crash:

- *Is any crash that occurs in or is related to a construction, maintenance, or utility work zone, whether or not workers were actually present at the time of the crash*
- *Also includes any crash involving motor vehicles slowed or stopped because of a work zone, even if the first harmful event occurred before the first warning sign*



http://www.mmucc.us/sites/default/files/MMUCC_4th_Ed_0.pdf

Work Zone Characteristics

Photo: Wayne State University

Competing Road Space Demands

- Lane and shoulder closures
- Narrow lanes
- Obstacles near live lanes
- Reduced visibility

Complicated Driving Environment

- Driver comprehension / distraction
- Congestion
- Regular traffic mixing with slow-moving work vehicles

More collision risk than under ordinary conditions.

More crashes than usual per vehicle-mile traveled.

More hazards than under ordinary conditions.

How safe are we?

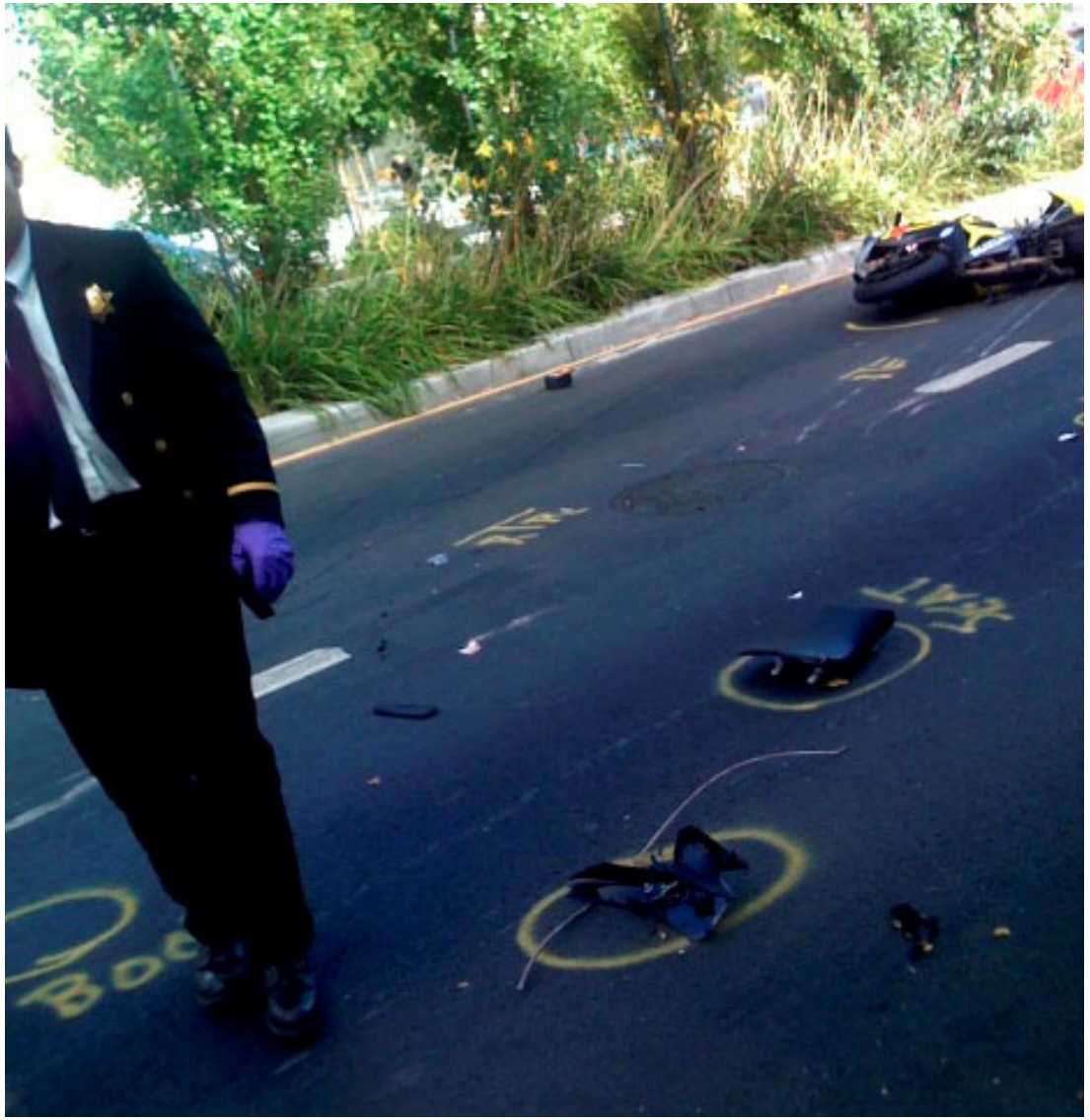
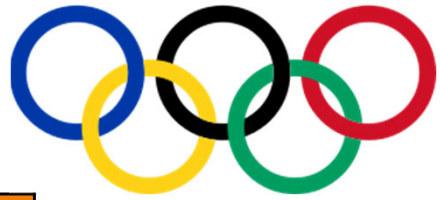


Photo: Todd Siegel/WkikMedia Commons

2020 Olympic Medal Count



Country	Medals		Country	Medals
Australia	46		Norway	8
Canada	24		Poland	14
France	33		Republic of Korea	20
Germany	37		Spain	17
Italy	40		Sweden	9
Japan	58		Switzerland	13
Netherlands	36		United Kingdom	65
New Zealand	20		**United States**	**113**

We're the best!

Source: NBC

Fatal Roadway Crashes per 100,000 People

Country	Rate		Country	Rate
Australia	6.1		Norway	4.3
Canada	6.8		Poland	11.8
France	6.4		South Korea	14.1
Germany	4.7		Spain	5.4
Italy	7.2		Sweden	3.0
Japan	5.2		Switzerland	4.3
Netherlands	3.9		United Kingdom	3.7
New Zealand	9.1		**United States**	**11.4**

Source: World Health Organization

Most of our peers are doing much better than us.

US Highway Safety: 2015 Results

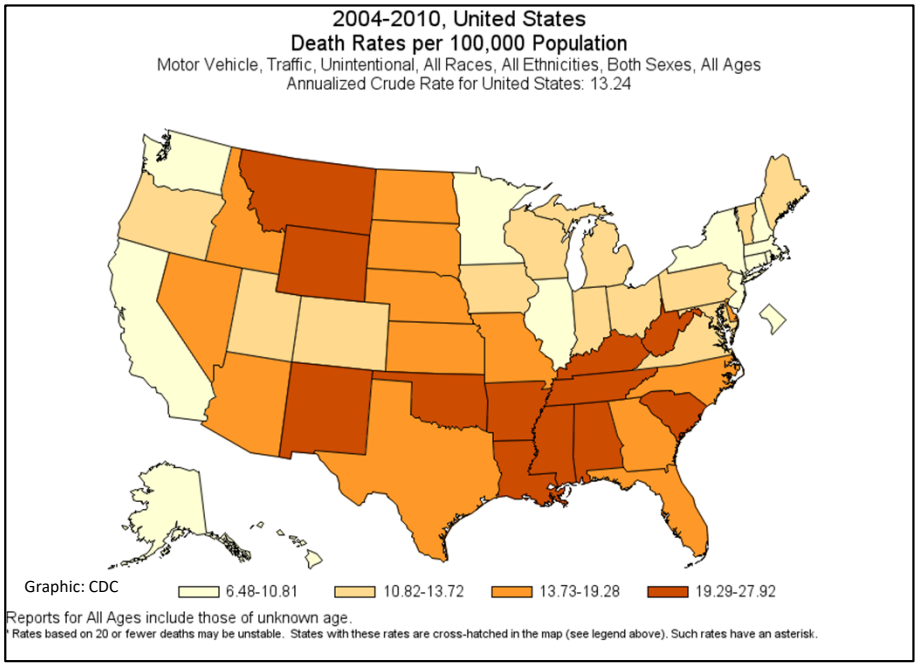
Roadways in general:

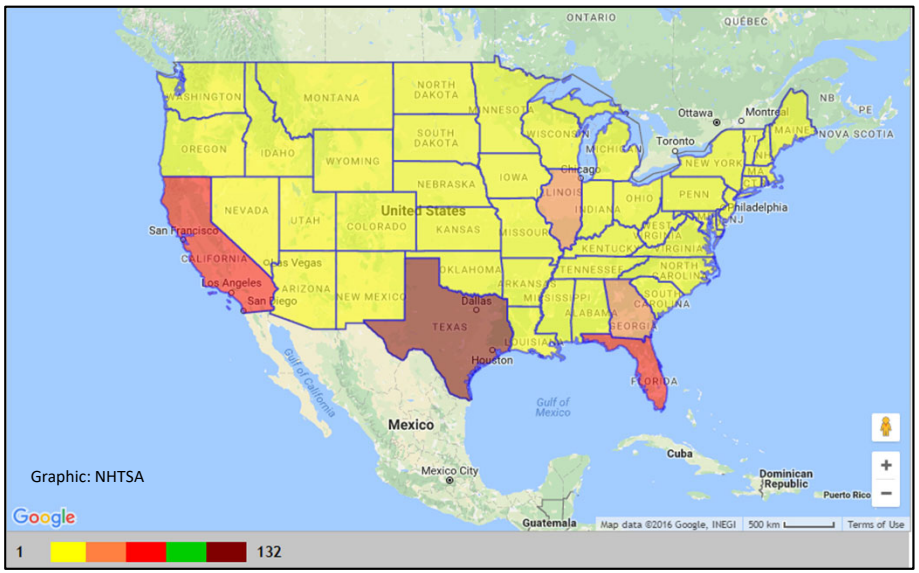
- 32,166 crashes killed 35,092 people
- 2.3 million injuries (2014)

Work Zones specifically:

- 642 crashes killed 700 people
- Every US state had at least one fatal crash in a work zone
- 62 fatal work zone crashes involved a child 12 or under

Source: NHTSA





Crashes in US Work Zones

Crash Severity

- Fatalities 0.6%
- Injuries 30%
- Property Damage 69%

→ Perhaps 50 injuries for every death.

→ Heavy trucks overrepresented in work zone fatalities.

Source: NHTSA 2010

Worker Fatalities

- About 19 workers/year killed by traffic in US work zones.
- At least 20% of worker deaths involve flaggers.

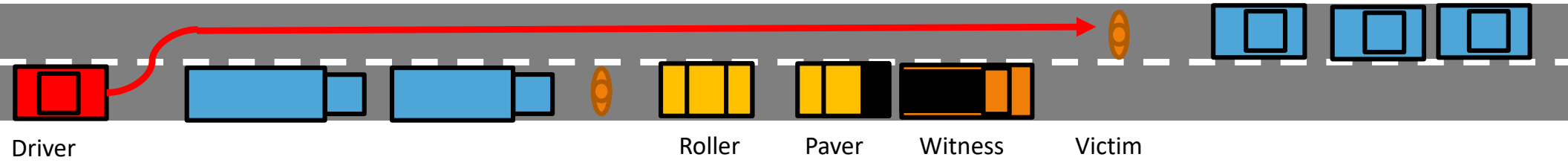
Source: BLS/Pegula 2013

What Goes Wrong?

Case Example: Worker Fatality in Saskatchewan

Facts & Circumstances

- Asphalt paving operation on flat, straight two-lane rural highway about 50 miles north of US border
- Statutory 60 km/h (35 mph) workers-present work zone limit
- Victim (age 18) a newly-trained flagger struck from behind and killed by vehicle driven by Driver (age 44)
- Victim's fiancée (paving crew) witnessed crash and interviewed by national media
- Driver told police he was distracted looking for a dropped paper
- Driver had three prior citations for minor traffic violations
- No evidence of alcohol/drug use
- Analysis showed 51-62 mph speed at time of impact
- Criminal justice process took more than 3 years



Case Example: Possible Contributing Factors

Driver:

- Distraction
- Excessive speed

Victim:

- Standing too close to open lane?
- Inexperience?

Roadway:

- Lowest statutory work zone speed limit in North America (35 mph). (Will drivers comply?)
- Lack of clarity about workers-present and workers-not-present speed limits

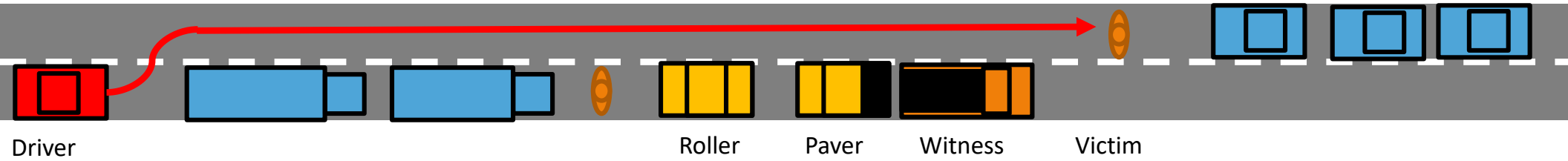
Case Example: Outcomes

Criminal Justice

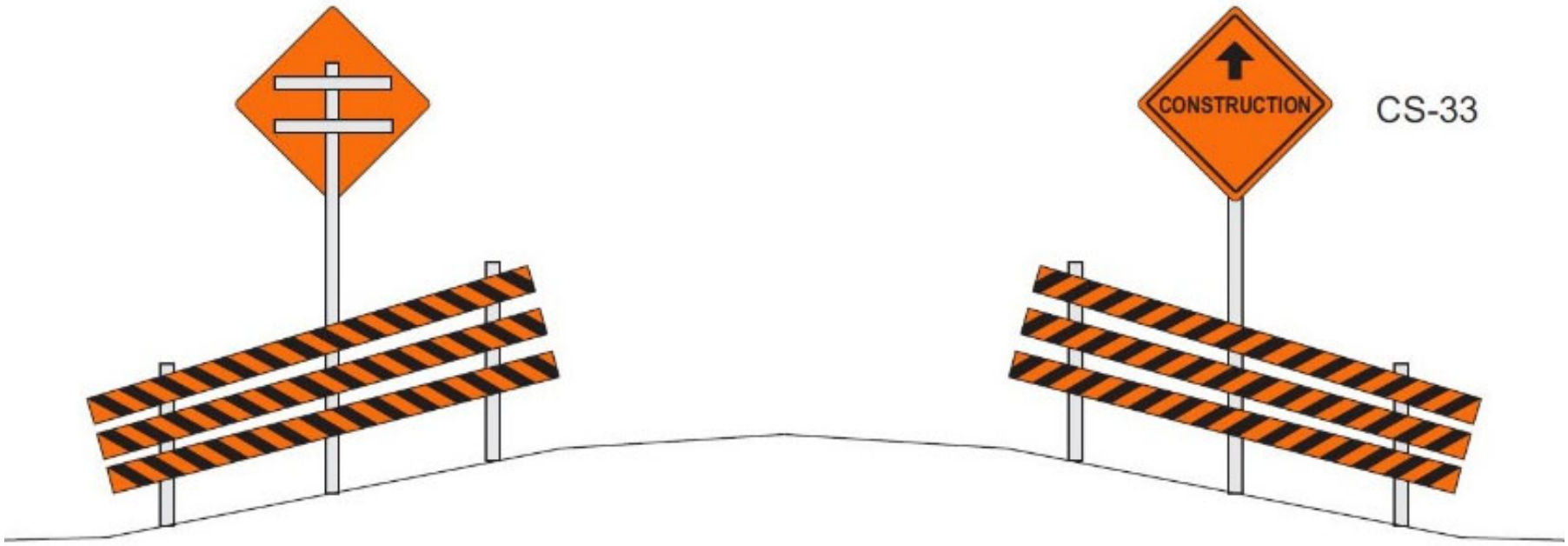
- Driver convicted of Dangerous Driving Causing Death and sentenced to two years imprisonment (currently under appeal) but acquitted of Criminal Negligence Causing Death.

Administrative & Legal

- Redesign of work zone approach signage
- Contractual changes to assure that 60 km/h (35 mph) speed limit signage is removed promptly when workforce leaves the site
- Increased use of rumble strips at flagger station approaches.
- Introduction of “gateway treatments” at work zone approaches
- Three-year pilot program for automated speed enforcement in work zones



Gateway Treatment

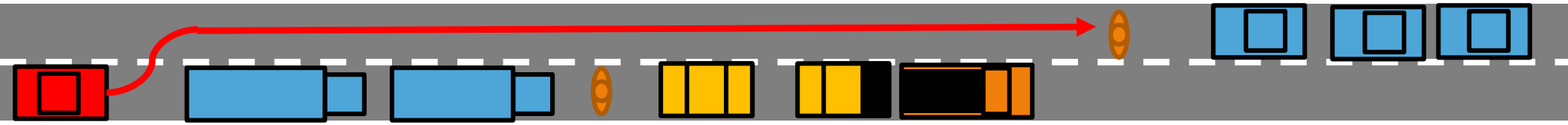


ENTERING A WORK ZONE

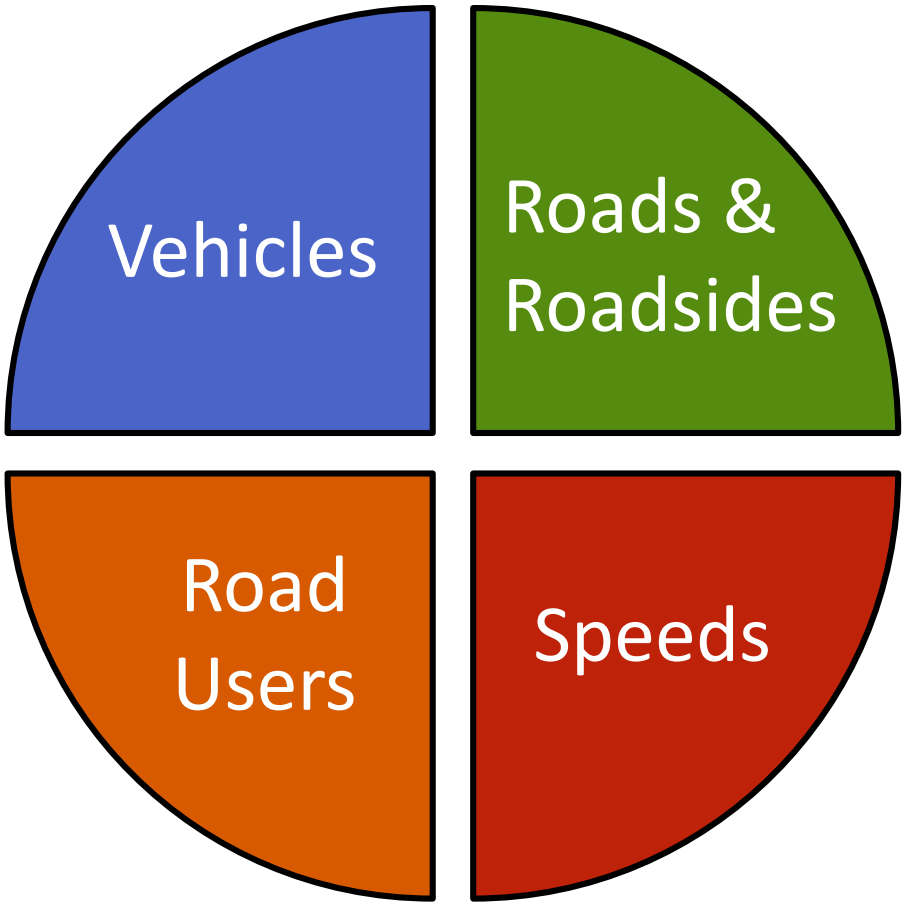
- The converging slanted boards are intended to make the roadway feel like it is suddenly getting narrower.
- The signage and colors shown above are consistent with the Canadian MUTCD and would require minor modification to meet the US MUTCD requirements.

Case Example: Human Impacts

- Driver: “I am truly, truly, truly sorry. I have a daughter about the same age and I can’t imagine.”
- Victim’s Manager at Company: “There are no winners. He could get 20 years and that’s not going to bring her back.”
- Witness / Fiancée : “I am depressed and considered suicide… I drink myself to sleep every night.”



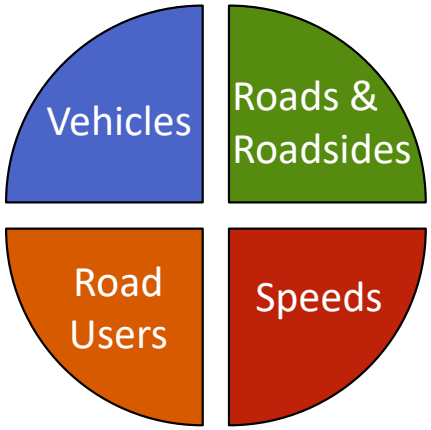
The Safe System Approach

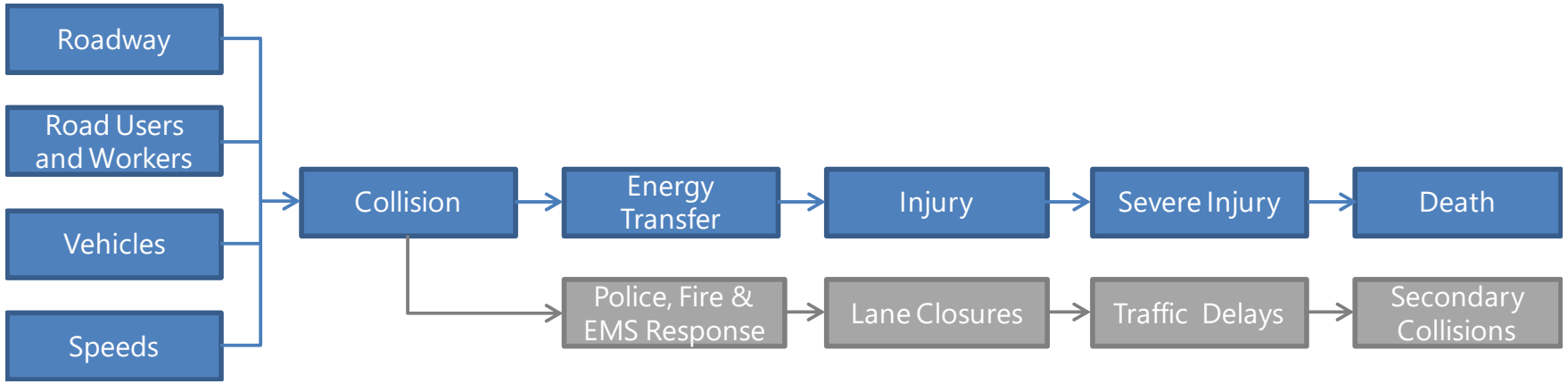


Source: FHWA Office of Safety

Making the Work Zone a "Safe System"

- Traffic crashes usually involve a chain of events: *Mistakes – Mishaps – Behaviors*
- **Primary Goal:** Break the chain before a mistake turns into a serious incident
- **Fallback Goal:** Reduce incident and injury severity





Trauma Chain for a Work Zone Fatality

100 Years of Vehicle Safety Engineering

World's Best-Selling Automobile 1916

Photo: Views of the Past

World's Best-Selling Automobile 2016

Photo: Car gurus

What safety features were standard in 1916? In 2016?

Traditional Approach: The 3 (or more) E's

"Every road safety problem can be solved by applying the 3Es"

Engineering • Education • Enforcement

Emergency Medical Services • Evaluation

Example • Encouragement • Everyone

- Developed circa 1915 and promoted by auto industry
- Works best for issues that involve a relatively small number of agencies and stakeholders
- Can be difficult to apply to problems that cut across professional disciplines or agency boundaries

Example of Difficulties with 3Es Approach

Single-vehicle run-off-the-road crashes involving fatigued drivers.

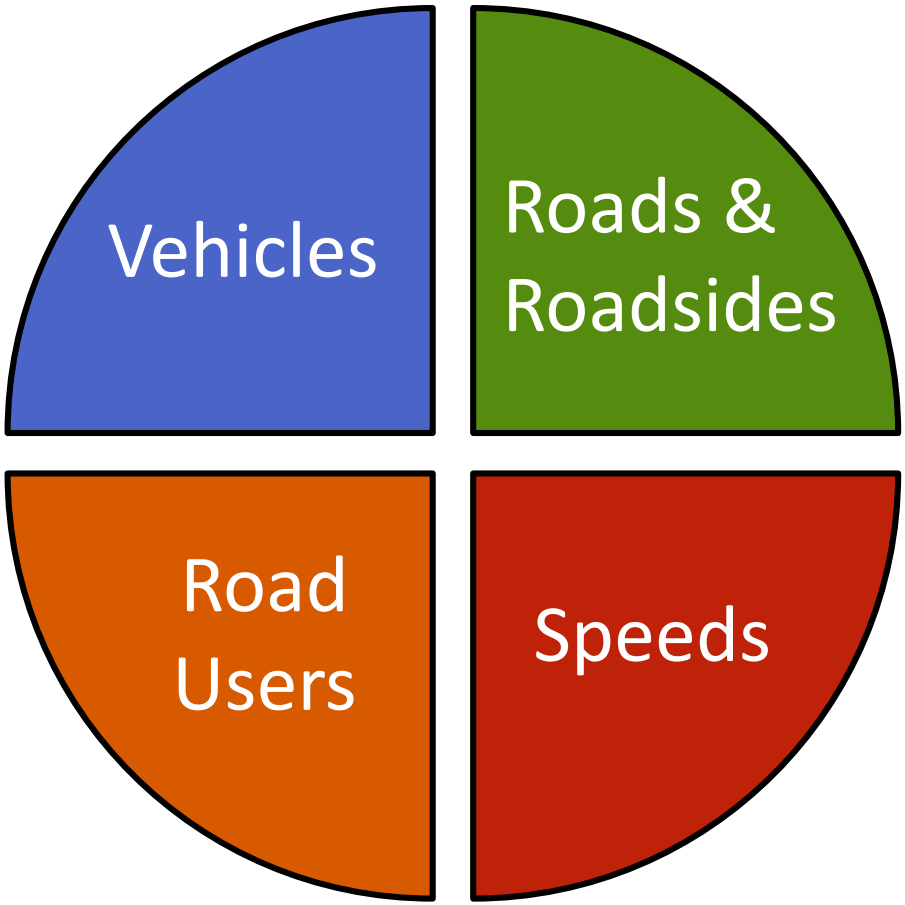
Engineering:
Not isolated to specific locations, roadway reconstruction expensive

Enforcement:
Unsuitable for targeted enforcement – can happen almost anywhere

Education:
Public outreach effectiveness limited

Photo: La Cara Salma/WikiMedia Commons

The Safe System Approach



Source: FHWA Office of Safety

Hazard vs Risk

- In everyday speech we often use these two words interchangeably.
- In Safety Science, there is a distinction:
  - **Hazard:** A condition which could result in a casualty (injury or death)
  - **Risk:** The likelihood and consequences of a hazard

Low Hazard, High Risk

Photo: Cikukiuna

High Hazard, Low Risk

Photo: Dcoetzee/WikiMedia Commons

Risk Matrix

Likelihood			Potential Consequences				
			L6	L5	L4	L3	L2
			Minor injuries or discomfort. No medical treatment or measureable physical effects.	Injuries or illness requiring medical treatment. Temporary impairment.	Injuries or illness requiring hospital admission.	Injury or illness resulting in permanent impairment.	Fatality
			Not Significant	**Minor**	**Moderate**	**Major**	**Severe**
	Expected to occur regularly under normal circumstances	**Almost Certain**	**Medium**	**High**	**Very High**	**Very High**	**Very High**
	Expected to occur at some time	**Likely**	**Medium**	**High**	**High**	**Very High**	**Very High**
	May occur at some time	**Possible**	**Low**	**Medium**	**High**	**High**	**Very High**
	Not likely to occur in normal circumstances	**Unlikely**	**Low**	**Low**	**Medium**	**Medium**	**High**
	Could happen, but probably never will	**Rare**	**Low**	**Low**	**Low**	**Low**	**Medium**

Image: University of Sydney

Discussion: Managing WZ Hazards and Risk

- Have you experienced unexpected hazards in a work zone?
- What could have been done to mitigate the hazards or reduce risk?

Hazard

Image: J. Samuel Burner/WikiMedia Commons

Partial Reduction of Risk

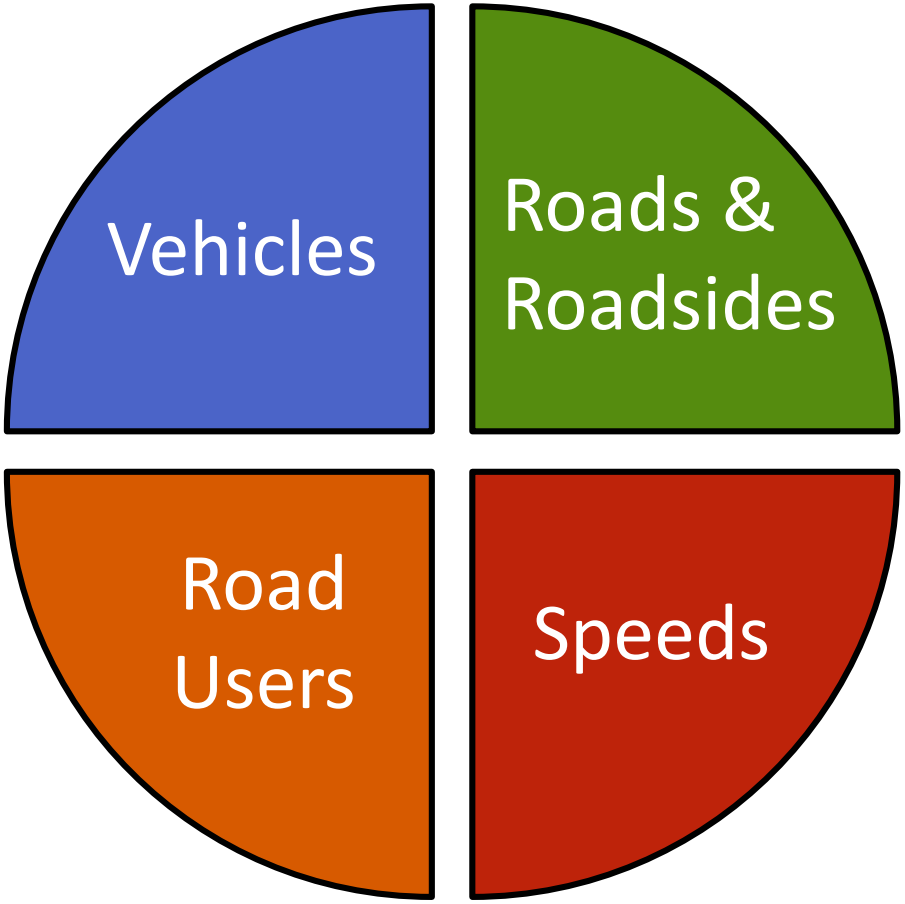
Image: JInfrogmation/WikiMedia Commons

Substantial Reduction of Risk

Image: Spielvogel/WikiMedia Commons Commons

Elements of a Safe System

Developed in 2008 by safety experts from 21 countries



Based on rigorous analysis of factors that cause crashes

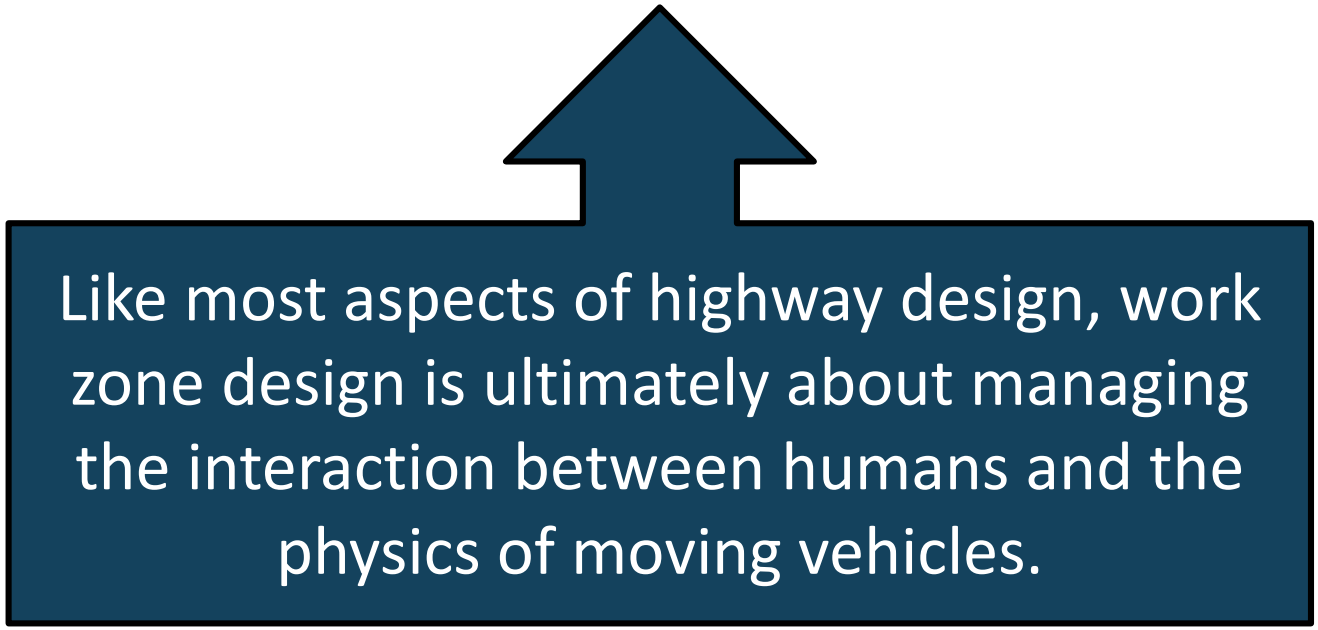
US represented by NHTSA, FHWA and FMCSA

Grounded in work by Dr. William Haddon, first NHTSA director.

If one element of the system fails, other elements help minimize the consequences of failure.

Safe System Principles

- Human bodies don’t withstand crash forces well.



Physics 101

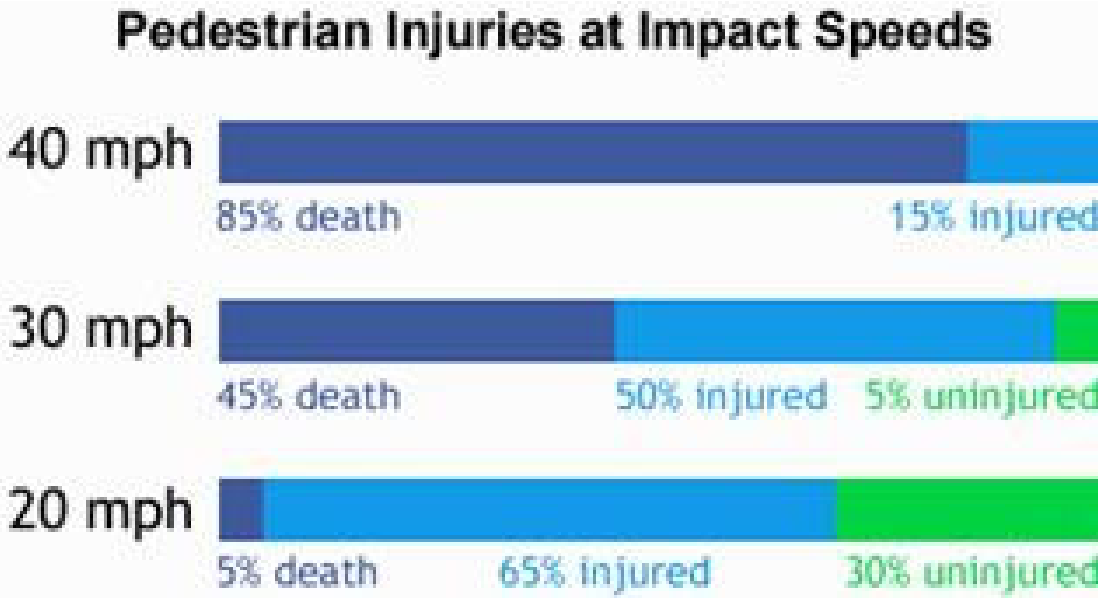
SUV
4400 lb
(2000 kg)

Kinetic Energy = ½mv²

At 20 mph (30 km/h): KE = 0.5 x 2000 x (30000/3600) ² = 70 kJ
At 30 mph (50 km/h): KE = 0.5 x 2000 x (50000/3600)² = 190 kJ
At 60 mph (100 km/h): KE = 0.5 x 2000 x (100000/3600)² = 770 kJ

Doubling speed quadruples kinetic energy

Pedestrian or Worker-On-Foot Struck by Car: Probability of Death



Graph: FHWA

Safe System Principles

- Human bodies don’t withstand crash forces well.
- Focus on preventing death and serious injury from crashes.
- Although some crashes involve an element of misbehavior, many are due to simple mistakes such as momentary inattention.

Drivers make mistakes.

Can we make our projects more forgiving of driver error?

Non-Forgiving Roadside

Photo: FHWA-SA-10-018

Evolution of Roadway Safety Engineering

Photo: Wikipedia

Safe System Principles

- Human bodies don't withstand crash forces well.
- Focus on preventing death and serious injury from crashes.
- Many crashes are due to simple mistakes such as momentary inattention.
- Strengthen all parts of the system: roads and roadsides, speeds, vehicles, and users.
- **System designers and system users must share responsibility for managing crash forces to a level that doesn't result in death or serious injury.**

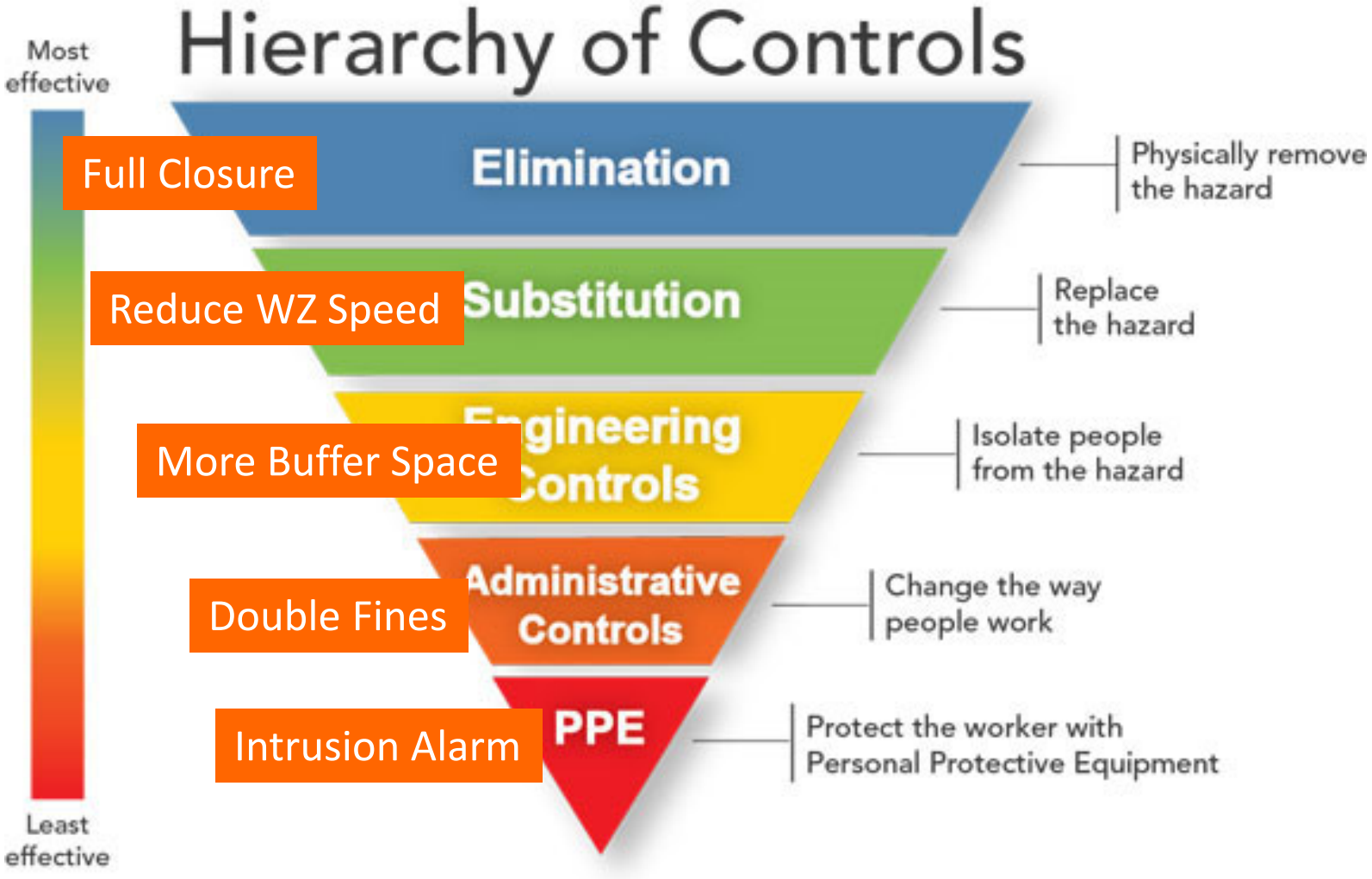
Ten Injury Prevention/Reduction Methods

(Haddon 1970)

#	Method	Work Zone Example
1	Prevent accumulation of energy that could result in an injury.	Close the work zone to all traffic.
2	Reduce amount of energy marshalled.	Reduce traffic speed through the work zone.
3	Prevent release of potential energy.	Install fences to keep pedestrians away from construction equipment, trenches, and open holes.
4	Modify energy release rate.	Install Truck-Mounted Attenuators on work vehicles.
5	Increase time or space between potential victims and hazards.	Increase lateral and longitudinal buffer space between vehicles and workers.
6	Place barriers between hazard and potential victims.	Install portable concrete barriers to separate travel lanes from work activity areas.
7	Modify contact surfaces to disperse impact energy in a less hazardous way.	Use temporary traffic control devices that have been tested for crashworthiness.
8	Strengthen structures and devices that might be damaged.	Use MASH Test Level 4 barriers instead of Test Level 3 barriers on corridors with high truck volumes.
9	Reduce casualties by detecting injuries rapidly.	Install and maintain remote video monitoring of work zone traffic during construction.
10	Expedite and improve post-crash medical treatment.	Begin medical treatment while victims are being transported to trauma center.

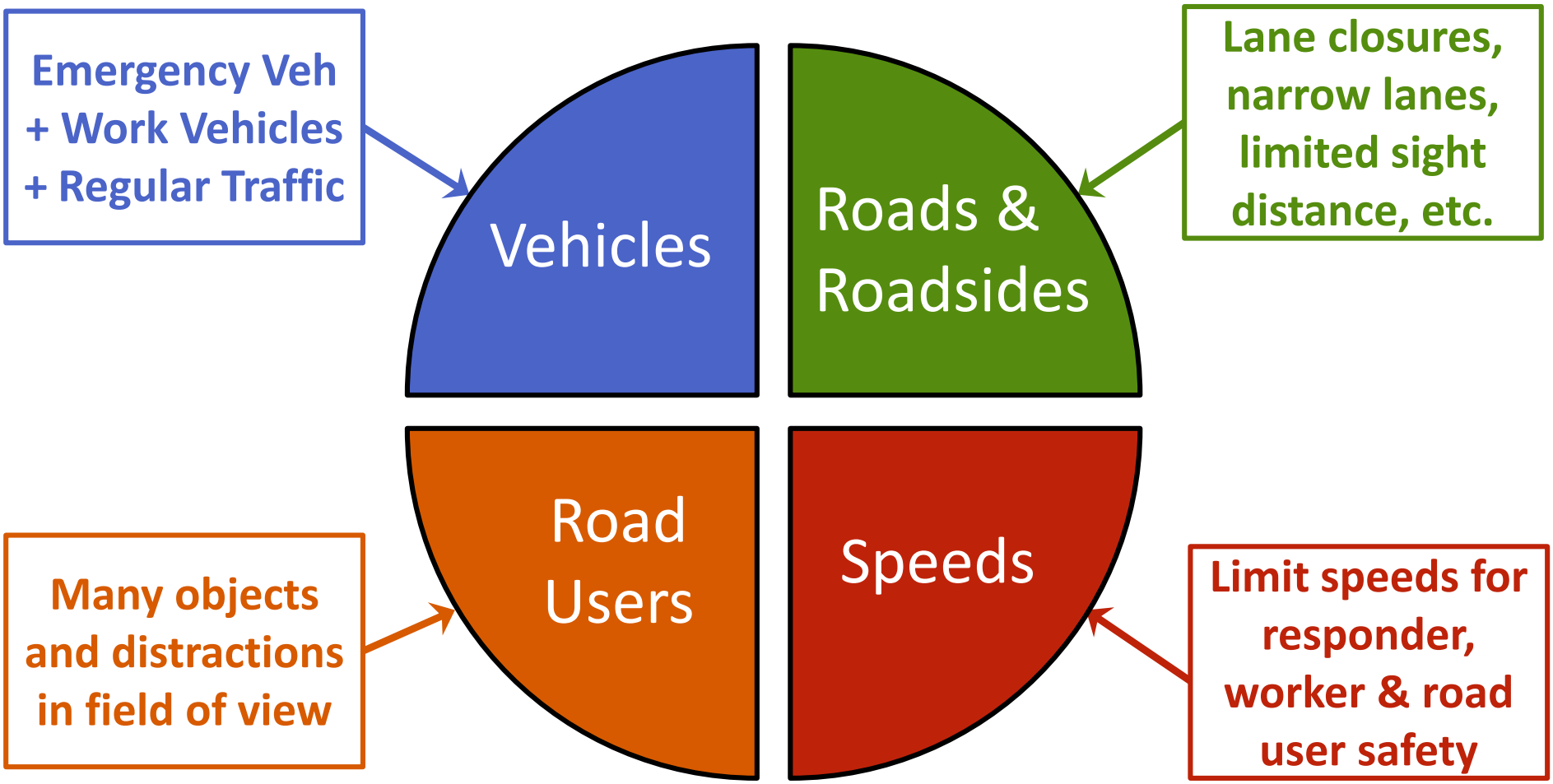
Effectiveness of Different Types of Controls

Examples



Source: CDC

The Safe System in Work Zone Incidents



Weakened performance of some elements needs to be compensated to maintain overall safety.

Safety Culture in Organizations

- **Pathological:** The organization thwarts changes that improve safety, even when the need is obvious and the payoff is rapid.
- **Reactive:** Changes accepted only in response to a significant incident/threat.
- **Calculative:** Potential improvements considered systematically as part of cost control and risk management.
- **Proactive:** Organization actively searches for ways to improve performance and reduce risks.
- **Generative:** Safety is an integral part of everything the organization does.

Applying These Principles

Class Discussion

Before Construction

Base Image: Google Maps

During Construction

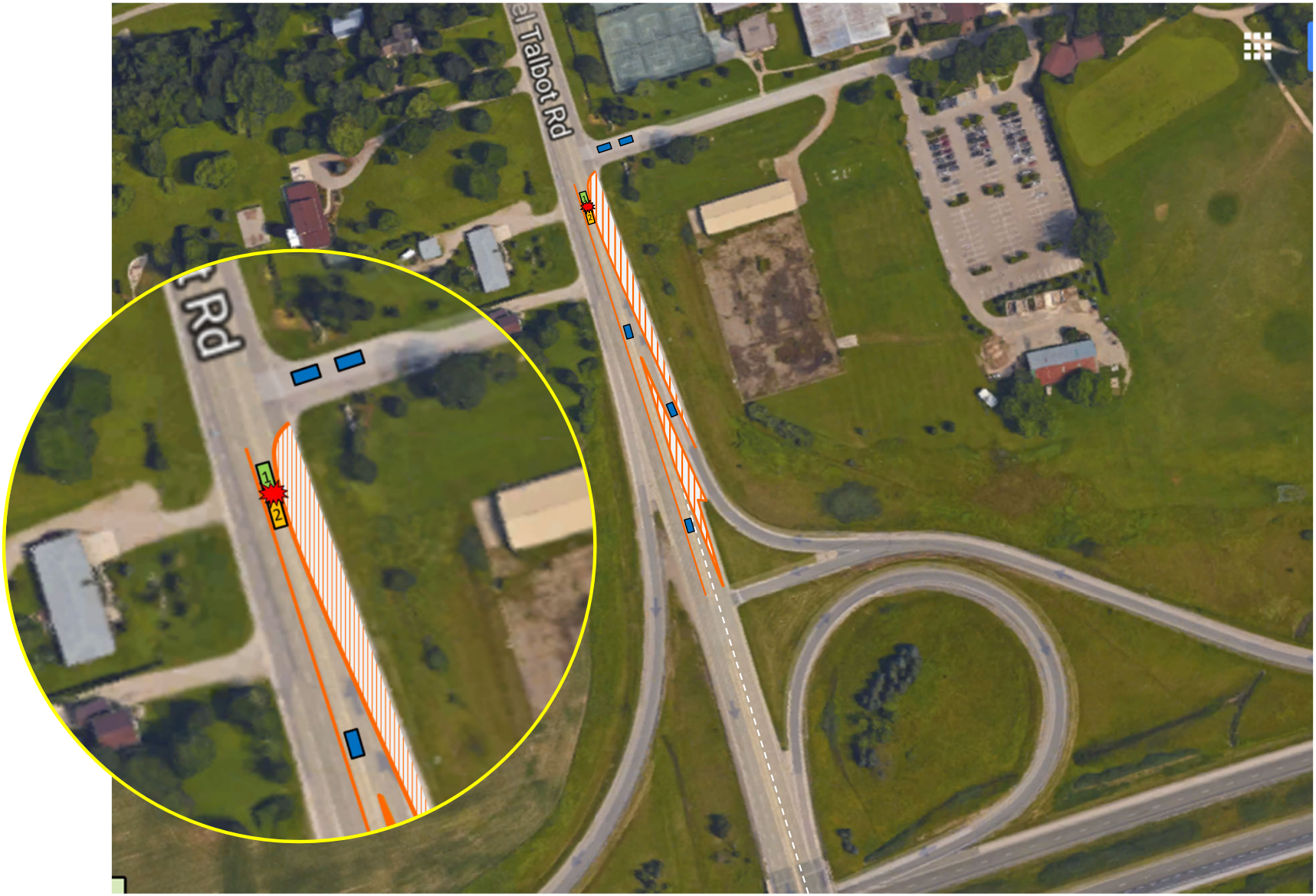
Base Image: Google Maps

Class Discussion Scenario

- During construction, the merging area at a freeway exit ramp leading to a signalized intersection is shorter than usual.
- Driver 1, a 74 year old female (green vehicle) approaches the intersection and stops when the light is near the end of the amber (caution) phase.
- Driver 2, a 16 year old male (yellow vehicle) drives through the merge section and rapidly approaches the intersection.
- Driver 2 assumes that Driver 1 will go through the intersection and rear-ends Driver 1.
- The headrest in Driver 1's vehicle is poorly positioned; she suffers whiplash. Driver 2 suffers a knee injury.

Discuss the factors that contributed to this incident.

During Construction



Base Image: Google Maps

Matrix for Class Discussion

Vehicles	Road/Roadside
Road Users	**Speed**

Matrix for Class Discussion

Vehicles	Road/Roadside
• Vehicle 1: Insufficient knee space during/after impact • Vehicle 2: Inadequate headrest geometry or materials	• Short transition from freeway to arterial geometrics • Possible visual distractions due to temporary traffic control and/or work operations • Signal clearance interval time possibly too short for one-lane operation • Vehicle detection loop possibly too close to stop bar
Road Users	**Speed**
• Driver 1 possibly indecisive • Driver 2 not attentive and/or presumptuous about Driver 1 behavior	• Driver 2's approach speed excessive • Driver 2 probably acclimated to high-speed freeway driving

We're In This Together

All work zone partners have shared responsibility to prepare for potential work zone crashes by:

1. Arranging the work zone to minimize the chances of a crash
2. Making efforts to ensure that crash severity and crash consequences are minimized
3. Being ready to respond quickly and efficiently if a crash occurs