









 "For all types of highway projects, clear zones should be determined or identified and forgiving roadsides established."

- Highway Safety Design and Operations Guide, 1997

- "Through decades of experience and research, the application of the forgiving roadside concept has been refined to the point where roadside design is an integral part of transportation design criteria."
 Roadside Design Guide, 2002
- "The wider the clear zone, the safer it will be." - Transportation Research Board, 2004



Highway Safety Hearings of 1966

 "What we must do is to operate the 90% or more of our surface streets just as we do our freeways... [converting] the surface highway and street network to freeway road and roadside conditions."

- Kenneth A. Stonex, 1966

The Passive Safety Approach



"Highways built with high design standards put the traveler in an environment which is fundamentally safer because it is more likely to compensate for the driving errors he <u>will</u> eventually make."

- AASHTO, 1974

Passive Safety and the "Green Book"



"Every effort should be made to use as high a design speed as practical to attain a desired degree of safety."

- AASHTO, 2001

Considering the Evidence

- Surprisingly, there is very little research examining roadside safety in <u>urban</u> environments.
 - Most existing studies focus predominantly on rural areas.
 - Most credible studies report anomalous findings:
 - Wider shoulders have a mixed effect on roadside crashes, and generally increases midblock crashes.
 - Wider clear zones decrease crashes in rural environments, but are found to be associated with increases in crashes in urban ones.







Two-Tiered Research Approach Negative Binomial Regression Models of Crash Performance. Field Analysis of Individual Crash Locations.

Model: Dependent Variables

- Total and Injurious Roadside Crashes
- Total and Injurious Midblock Crashes
 - A "safe" roadside treatment should reduce both roadside and midblock crashes.
 - Reductions in roadside crashes should not be offset by increases in midblock ones.
 - Fatal crashed could not be considered because no fatalities occurred on livable sections.



Model Results: Paved Shoulders

Wider shoulders are consistently associated with <u>increases</u> (though not at statistically-significant levels) in roadside and midblock crashes.

Measure	Coefficient	Z	95% Confide	ence Interval
Total Roadside Crashes	0.055	0.85	-0.072	0.181
Injurious Roadside Crashes	0.081	0.92	-0.092	0.253
Total Midblock Crashes	0.004	0.09	-0.07	0.076
Injurious Midblock Crashes	0.055	1.39	-0.023	0.132

Model Results: Object Offsets

Wider fixed object offsets are associated with <u>decreases</u> in fixed-object crashes, but have <u>no effect</u> on midblock crashes.

Measure	Coefficient	Z	95% Confide	ence Interval
Total Roadside				
Crashes	-0.038	-1.51	-0.088	0.011
Injurious Roadside				
Crashes	-0.053	-1.65	-0.118	0.011
Total Midblock				
Crashes	0.003	0.24	-0.024	0.031
Injurious Midblock				
Crashes	0.001	-0.05	-0.029	0.028

Model Results: Livable Streets

Livable street treatments are consistently associated with <u>decreases</u> in both fixed-object and midblock crashes.

Measure	Coefficient	Z	95% Confidence Inte	
Total Roadside				
Crashes	-1.533	-2.33	-2.824	-0.241
Injurious Roadside				
Crashes	-2.020	-1.75	-4.285	0.245
Total Midblock				
Crashes	-0.650	-1.66	-1.416	0.116
Injurious Midblock				
Crashes	-0.526	-1.28	-1.329	0.278

Comparative Safety Performance

		Fixed-Object	Fixed-Object Crashes per 100 MVMT				
		Urban (All) Livable Only Differe					
SR 15	Total	7.1	3.2	-55.0%			
	Injurious	4.0	0.0	-100.0%			
SR 44	Total	11.4	6.1	-46.3%			
	Injurious	5.8	0.0	-100.0%			
SR 40	Total	15.0	15.7	4.0%			
	Injurious	9.2	0.0	-100.0%			
Average	Total	10.1	3.3	-67.3%			
	Injurious	5.7	0.0	100.0%			

Considering the Results...

- While these results are consistent with most recent research, there has been almost no elaboration on the implications of these findings:
 - Where are roadside crashes occurring?
 - Why do roadside crashes occur?
 - Are there identifiable patterns in roadside crashes that might account for these anomalous findings?
 - What are the implications of these findings for design practice?



Field Investigation Methodology



Unidentified Tree Crash Location

- Conducted field examinations of all tree and pole crashes on candidate roadways:
 - 51 total crashes.
 - 40 (78%) were located.
 - Remaining 11 objects could not be identified because:
 - Multiple trees present, preventing the ability to locate the offending object.
 - Tree or pole not at reported location.





The Nature of Roadside Crashes



Representative Urban Fixed-Object Crash

- <u>83%</u> of identified tree and pole crashes occurred behind an intersection or driveway.
 - <u>65%</u> of total whether identified or not.
- Suggests that many roadside crashes are <u>systematic</u>, rather than the product of random encroachments.

Anatomy of an Urban Roadside Crash



Representative Urban Fixed-Object Crash

Systematic Pattern:

- Higher operating speeds along primary arterial
- Attempt to turn onto a driveway or side street
- Higher-speed turn results in vehicle leaving the travelway behind the side street.



Random vs. Systematic Error

- <u>Random Error</u> is error that naturally occurs as a result of human fallibility.
 - Humans will err, and a roadway should be "forgiving" when they do.
 - Assumes error is constant and fixed.
 - Strives for a single, "fail-safe" design solution.
- <u>Systematic Error</u> is a design problem that results from mismatches in the interaction between people and their environment.
 - Recognizes that designs may produce error.
 - Systematic error occurs when a roadway encourages inappropriate expectations regarding safe operating behavior.
 - Focuses on understanding and addressing unsafe driver behavior, rather than attempting to engineer "fail-safe" designs.



- A safe design is one that eliminates systematic error while simultaneously reducing the consequences of random error.
- Two strategies for addressing urban roadside safety:
 - 1. The Interstate Approach
 - 2. The Livable Street Approach

1. The Interstate Approach



- Random error addressed through "forgiving" design.
- Systematic error minimized by design:
 - Limited access, with few opportunities for turning maneuvers.
 - Where turns permitted, they are accompanied by ramps that allow for gradual deceleration.

1. The Interstate Approach

- Similar design solution appropriate on urban roadways where accessmanagement principles are fully applied.
- Similar characteristics:
 - Higher speeds
 - Few driveways and side streets.
 - Deceleration lanes.



Effective Access Management

1. The Interstate Approach



Speed + Access = Systematic Error

- "Forgiving" design is less effective along roadways where driveways and side streets are present:
 - Can lead to higher and inappropriate operating speeds.
 - Produces higher rates of roadside and multiple-vehicle crashes.

2. The Livable Street Approach



- "Unforgiving" by design:
 - Roadside hazards are obvious and expected, resulting in behavioral compensations.
- Systematic error substantially reduced:
 - Turning movements safely accommodated because of lower operating speeds.
- Minimizes the consequences of random error:
 - Lower speeds result in less severe crashes when they occur.
 - Lower speeds equate to reduced stopping sight distance, and thus reduced crash frequency.

2. The Livable Street Approach

Case Illustration: Woodland Blvd





<u>5-Year Totals:</u> • 0 Roadside Crashes • 4 Injurious Midblock Crashes

0 Fatalities



Implications

- <u>There is no "one-size fits all" safety solution</u>
 - Context and environment appear to influence the expectations and behavior of drivers, and thus safety.
 - Unless access and turning movements are reduced, lower speed, less forgiving designs may be desirable for safety.
- <u>Safety research (and practice) must better account for</u> both systematic and random error.
 - Specifically needed is guidance that links design and safety to a roadway's environmental context.
- Context-Sensitive Solutions may yield important safety results.
 - Concrete, context-specific safety recommendations and countermeasures are needed.

Research Needs

- Must move beyond hypothetical crash scenarios to consider the behaviors that result in crashes:
 - How do specific designs relate to <u>schemata</u> (expectations about hazards) and <u>scripts</u> (expectations about appropriate behavior)?
 - <u>Methods</u>: field analysis, crash reconstruction, and simulation
 - Secondary data sources are inadequate for meaningfully explaining crash frequency or severity.

2. The Livable Street Approach

- Why livable streets appear to be safer than conventional urban roadside treatments:
 - Condition that produces systematic error (i.e., expectation that the roadway will accommodate high speeds) are eliminated.
 - Roadside "hazards" are <u>apparent</u> and <u>expected</u>, leading to behavioral adjustments that minimize crash exposure.
 - Consequences of random error reduced because operating speeds are lower.
 - Total crashes are reduced because designs encourage contextually-appropriate driver behavior.





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Positive Design

- Focused on the <u>communicative</u> and <u>behavioral</u> aspects of a roadway's design.
 - Drivers "read" information from the roadway environment and adjust their behavior to <u>expected</u> hazards.
 - Where hazards are present, but unexpected, drivers have a false sense of security, thereby encouraging them to adopt unsafe behaviors.

Positive	Design:	Examp	le 2
FUSILIVE	Design.	слаттр	

	A O	"Suburbar range Blos	n" Arte som ⊺	erial: Trail
		Crashes	; per 100 N	AVMT
A CONTRACTOR		Livable Streets (Avg)	OBT	Ratio OBT/Livable
	Total Roadside	3.3	12.1	3.7
	Injurious Roadside	0	5.3	NA
	Total Midblock	23.1	102.2	4.4
	Injurious Midblock	18.1	64.6	3.6

Positive Design: Example 2





Conclusions

- "Forgiving" designs may enhance, have no effect, or even be detrimental to safety
 - Appropriateness of specific designs are dependent on developmental context
 - Forgiving designs are appropriate for limited-access roadways.
 - Forgiving designs are highly undesirable on roadways where land access or pedestrian activity is present because they encourage unsafe operating behaviors.

Positive Design: Implications

 Roadway classifications and corresponding design applications must be better linked to their respective developmental contexts, rather than focusing solely on vehicle access or mobility.



Three Urban Minor Arterials

An Illustration: European Design



- Environmental Reference Speed
- Urban design speeds capped at 30 MPH (50 km/h)
- Because of its context, Orange Blossom Trail would have been designed for lower speeds (CIV), or explicitly flagged as "problematic" (CII)

Conclusions

Livable streets are not less safe than their conventional counterparts:



- The weight of the evidence suggests that they *enhance* safety because they encourage contextuallyappropriate behavior
- If safety is to be addressed, road design must be linked to developmental context and corresponding road use

Future Research: Near Term

- Must move beyond hypothetical crash scenarios to consider the behaviors that result in crashes:
 - How do specific designs relate to <u>schemata</u> (expectations about hazards) and <u>scripts</u> (expectations about appropriate behavior)?
 - Methods: field analysis, crash reconstruction, and simulation
 - Why do crashes occur?
 - Identify precipitating actions and behaviors that lead to crashes
 - Develop design countermeasures to eliminate unsafe behavior



- Designs guidance used by engineers should correspond to the information and behavior needs of roadway users
 - A "design vocabulary" that is linked to safe design in a variety of operating contexts
 - Positive design provides a much-needed safety input into ongoing context-specific design guidance currently being developed by ITE and CNU

Reconsidering Livable Streets

- How do livable streets perform when compared against baseline roadway averages?
 - On average, are they more or less safe then one would expect when compared to the overall performance of urban roadways?
 - Normalized by crashes per 100 MVMT

Livable Streets: Roadside Crashes

		Crashes Per 100 MVMT		
		Urban (All)	Livable Only	Difference (%)
SR 15	Total Roadside	7.1	3.2	-55.0%
	Injurious Roadside	4	0	-100.0%
SR 44	Total Roadside	11.4	6.1	-46.3%
	Injurious Roadside	5.8	0	-100.0%
SR 40	Total Roadside	15	15.7	4.0%
	Injurious Roadside	9.2	0	-100.0%
Averages	Total Roadside	10.1	3.3	-67.3%
	Injurious Roadside	5.7	0	-100.0%

_ivable	Streets:	Midblock	Crashes

		Crashes Per 100 MVMT		
		Urban (All)	Livable Only	Difference (%)
SR 15	Total Midblock	31.9	28.6	-10.5%
	Injurious Midblock	22.7	22.2	-2.2%
SR 44	Total Midblock	37.1	18.3	-50.7%
	Injurious Midblock	27.7	18.3	-33.9%
SR 40	Total Midblock	42.0	15.7	-62.8%
	Injurious Midblock	25.7	7.8	-69.5%
Averages	Total Midblock	38.3	23.1	-39.7%
	Injurious Midblock	25.1	18.1	-27.7%

Rejecting Passive Safety

- Passive safety assumptions are not supported by the empirical evidence
 - Shoulders generally increase crashes
 - Object offsets decrease roadside crashes, but have (at best) no effect on midblock crashes
 - Livable streets decrease both roadside and midblock crashes

Positive Design: A Behavior-Based Approach Linking the Random error may occur spontaneously during the course of driving "3 E's" A Holistic Approach to Driving Behavior Transportation Driver-Related Factors Driving Experience Operation System Safety Speed Position Education Target Comfort Experience Individual Characteristics Risk Placement Control

⋪

Security

Safety

Motivation

Systematic error occurs when there is a mismatch between *safety* and *security*

Conflict



Applying Positive Design – 3 Steps

- 1. Determine current and <u>future</u> developmental context of the road.
- 2. Identify the uses and users associated with the design environment.
- 3. Design the roadway to encourage safe and contextually-appropriate operating behavior.

Positive Design

- Addressing systematic error requires a more solid understanding of the behavior of the driver:
 - Risk Homeostasis Theory (Wilde)
 - Drivers attempt to maintain static exposure to harm or injury
 - Safety vs. Security (Hauer)
 - Safety: empirical measure of crashes or injury
 - Security: perception of exposure to harm or injury













Recent Research...

Ivan, Pasupathy and Ossenbruggen (1999)

- Widening shoulders decreases roadside crashes, but increases multiple vehicle crashes.
- Lee and Mannering (1999; 2001)
 - Trees and other fixed objects adjacent to the ROW decreases fixed object crash frequency in rural areas, but has the opposite effect in urban environments.

• Ossenbruggen, Pendharkar, and Ivan (2001)

- "Urban village" streetscape treatments report fewer crashes than suburban treatments.
- Naderi (2003)
 - Aesthetic streetscape improvements reduce midblock crashes.
- Noland and Oh (2004)
 - Widening shoulders decreases total crashes, but increases fatal crashes.

Reconsidering Livable Streets

Livable Street Treatments:

- None of the livable street segments had shoulders.
- Fixed objects offset 4' from travelway or less.
- Nevertheless:
 - Not a single injurious roadside crash on any of the livable street treatments.
 - Not a single fatality occurred on any of these roadways.





Random vs. Systematic Error

Random Error:

- Concept emerged in the 1960's out of the general observations of Interstate roadways reported fewer crashes (including roadside) than other roadway classes.
- Presumed cause was that higher-speed designs, wider lanes, shoulders, and shoulders found on Interstates were more "forgiving" to random error.
- Idea is that humans are fallible, therefore a roadway should be designed to minimize the consequences of "worstcase scenarios."
- Results in current assertion that most crashes are attributable to "driver failure."



Presumed Roadside Encroachment Pattern

Random vs. Systematic Error

Systematic error is error that is structurally encoded into a roadway's design



- Concept comes from Ergonomics.
- Involves a disparity between an environment or object and its actual use.
- High operating speeds combined with an environment that produces turning movements leads to a condition that results in systematic error.





Empirical Evidence

- Most safety studies examine geometric design factors exclusively, without accounting for the built environment.
- Empirical safety studies find mixed results on design strategies assumed to be beneficial.

Adding Lanes

 Studies consistently find that adding lanes <u>increases</u> crashes, while eliminating lanes though "road diet" projects decreases crashes.



Sources: Dumbaugh, 2005; Harwood, 1986; Harwood, 1990; Huang, Stewart, and Zegeer, 2001; Knapp and Giese, 2001; Milton and Mannering, 1998; Noland and Oh, 2004; Sawalha and Sayed (2001); Vitalano and Held 1991.

Lane Width

- Studies on lane widths report <u>mixed results</u>, with some studies finding wider lanes are safer, and other finding wider lanes are more dangerous.
- In general, lane widths appear to have a "U" shaped relationship with crash performance, with crashes decreasing until lane widths reach roughly 11.5 feet, and increasing thereafter.

Sources: Clark, 1985; Dumbaugh, 2005; Farouki and Nixon, 1976; Fitzpatrick et al., 2001; Gattis and Watts, 1999; Harwood, 1990; Hauer, 1999; Heimbach et al., 1983; Lee and Mannering, 1999; Noland and Oh, 2004; Zegeer, Deen and Mayes, 1981.

Shoulder Width

 Studies consistently find that wider paved shoulders <u>increase</u> crashes in urban environments, while they reduce crashes in rural areas.



Sources: Dumbaugh, 2005; Ivan Pasupathy and Ossenbruggen,1999; Ivan, Wang and Bernardo, 2000; Lee and Mannering, 1999; Milton and Mannering, 1998; Noland and Oh, 2004.

Roadside Fixed-Object Offsets

 The presence of roadside objects generally <u>reduces</u> crashes on nonfreeway urban roadways, while they increase crashes in rural environments.



Sources: Dumbaugh, 2005; Ossenbruggen, Pendharkar and Ivan, 2001; Lee and Mannering, 1999; Naderi, 2001.



The Passive Safety Paradigm

Highway Safety Hearings of 1966

- Emerged in Response to Nader's Unsafe at Any Speed (1965).
- Early safety analyses found that Interstates reported fewer crashes than other roadway types.
- Interstate safety performance attributed to the use of high design values.
 - "Forgiving to error"
- Resulted in the conclusion that the use of high design values for design speeds, offsets and clear zones enhances safety.



• "What we must do is to operate the 90% or more of our surface streets just as we do our freeways... [converting] the surface highway and street network to freeway road and roadside conditions."

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