Effects of Intersection Right-Turn Lane Design

Illinois Transportation and Highway Engineering Conference (THE)

February 28, 2017

Dr. Kerrie Schattler, Professor
Dept. of Civil Engineering & Construction
Bradley University

Illinois Department of Transportation

ILLINOIS CENTER FOR TRANSPORTATION

BRADLEY University

Research Team

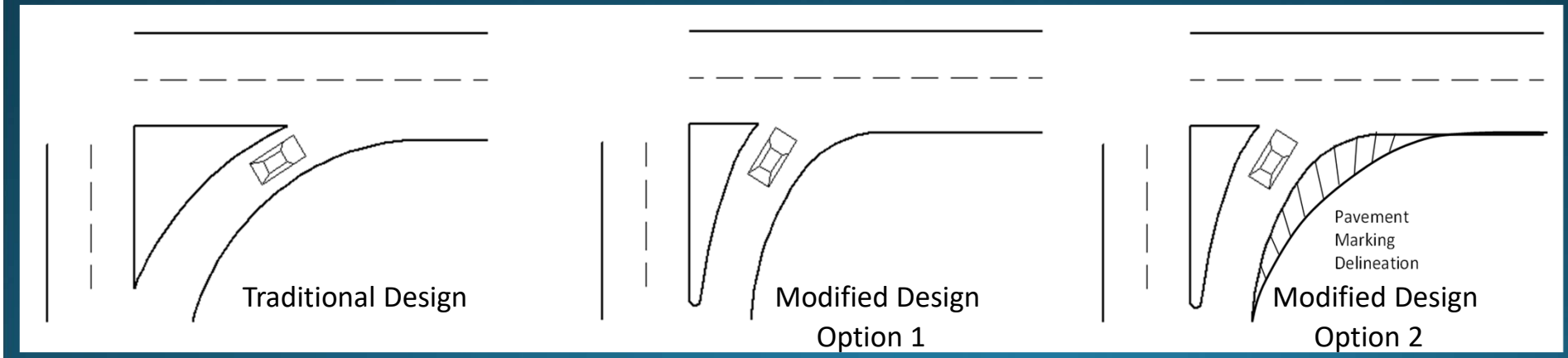
Principal Investigator (PI): Dr. Kerrie Schattler, Bradley University
Co-PI: Dr. Kris Maillacheruvu
Graduate Students:
Trevor Hanson, Travis Wallenfang, Akwasi Nketia, Mohammed Ali, Chandra Pulugulla, Marc Budzynski, Jessica Smith, Cody Gulla, Cliff Holly, Chandra Tummala
Undergraduate Students:
Brendan May, Beau Burdett, Nick Pitzen, Adam Shedor, David Green, Samantha Brothers

Original Research Project Chair - Sean Coyle, District 4
Current Project Chair - Dan Mlacnik, BDE
Technical Advisory Group Members:
Alan Ho, FHWA
Priscilla Tobias, BSPE
Juan Pava, BSPE
Filiberto Sotelo, BSPE
Kyle Armstrong, Operations
Randy Laninga, District 4 Operations

Project Description

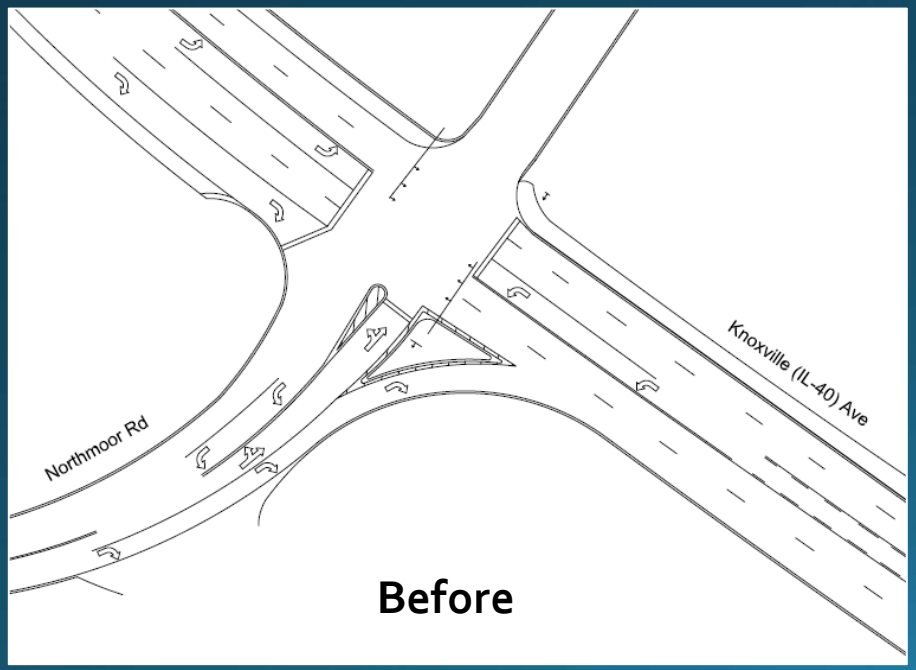
- From 2006 to 2014, 10 approaches in Peoria area were reconstructed/restriped with modified right turn lane

- Purpose ⇒ to improve the line of sight for passenger vehicles turning right, while still accommodating semi-tractor trailer trucks

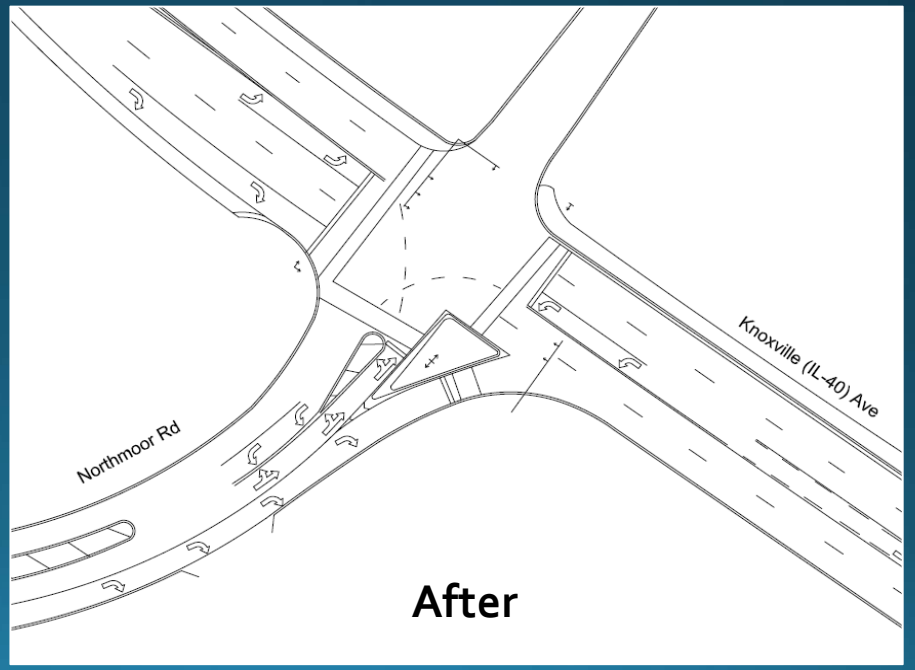


Modified Design

- Sharpen the typically flat approach angle
- Reduce the radius
- Adjust stop bar position
- Alter the corner island to improve the line of sight of approaching through traffic



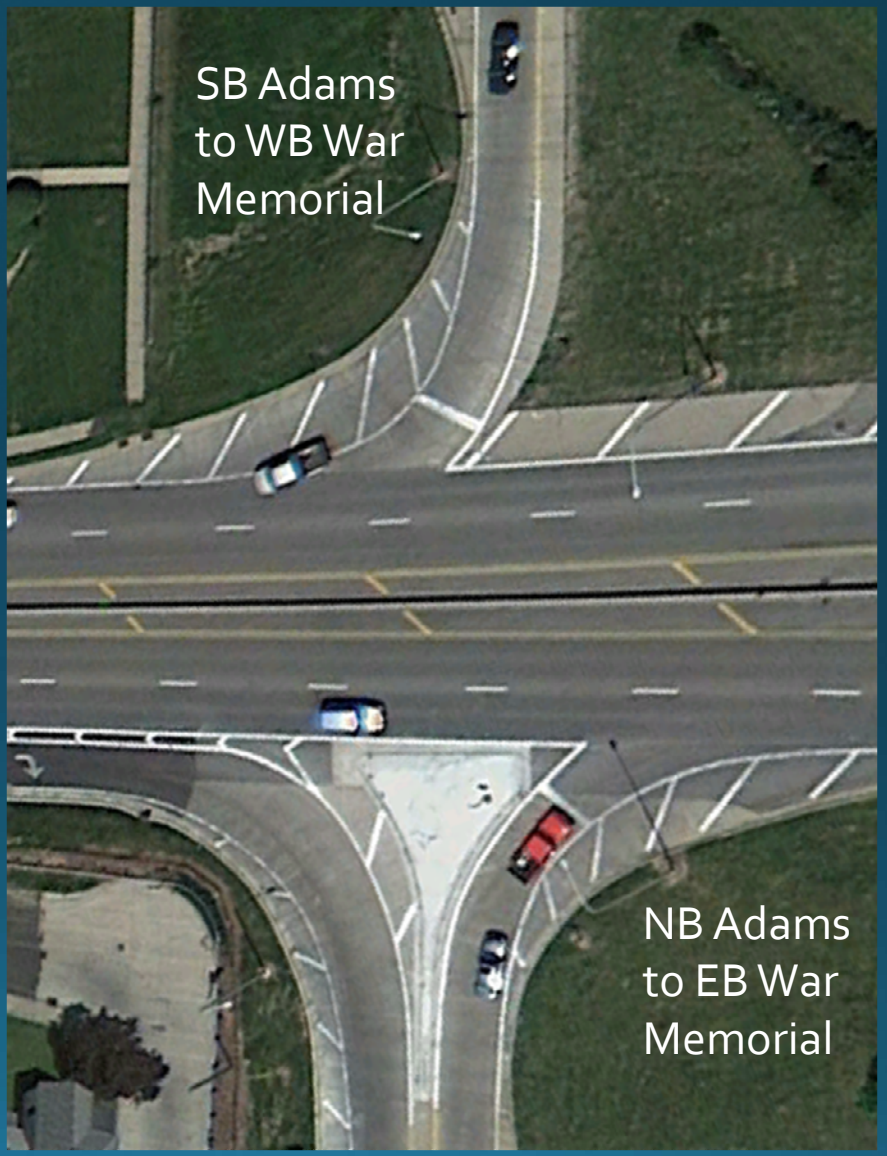
Before



After

Before & After Aerial Images

Before



After

Project Methodology

I. IDOT and ICT sponsored an effectiveness evaluation of redesigned right turn approaches
   - Driver behavior analysis of 10 approaches
   - Safety evaluation of crash experience at 7 approaches

- Expected outcome $\Rightarrow$ safety impact of modified design in terms crash modification factor (CMF)
  - Reduction in undesirable driver behavior
  - Reduction in right-turn crashes at subject approach

II. Crash causation analysis of right-turn crashes in Illinois

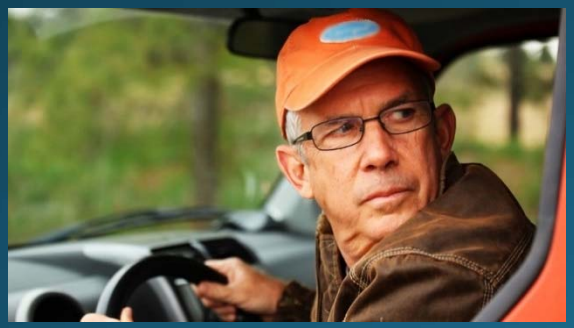
Re-Designed Test Approaches

No.	Intersection Name	City	Driver Behavior Analysis	Crash-Based Analysis
1	Prospect and Knoxville (IL 40)	Peoria	✓	✓
2	Northmoor and Knoxville (IL 40)	Peoria	✓	✓
3	Airport and IL 116	Peoria	✓	✓
4	Wesley and IL 29	Pekin	✓	✓
5	Douglas and IL 116	Metamora	✓	✓
6	Adams NB Ramp and War Memorial	Peoria	✓	✓
7	Adams SB Ramp and War Memorial	Peoria	✓	✓
8	I-155 SB Ramp and Broadway	Pekin/Morton	✓	
9	McCluggage and IL 8	Washington	✓	
10	Sterling and Farmington	Peoria	✓	

Research Results: Driver Behavior Evaluation

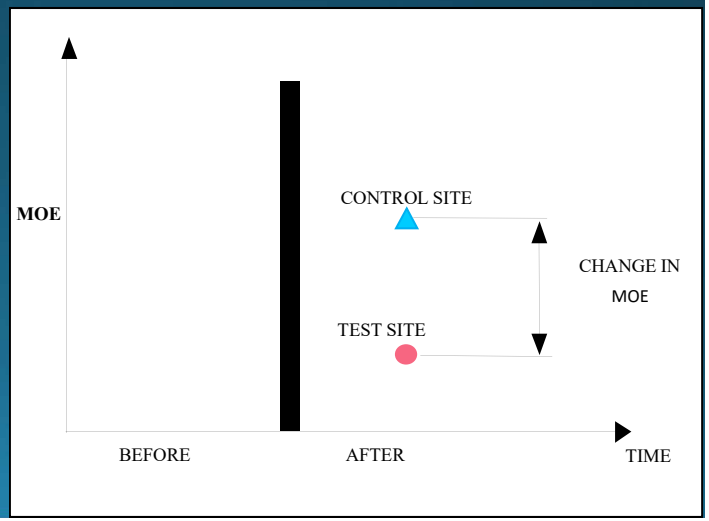
Driver Behavior Analysis

- To determine improvements in driver behavior based on four critical variables
  - *Exaggerated head turns*
  - *Inside/curbside lateral placement in the turn lane*
  - *Use of a roll & go stop (when a stop was required)*
  - *Stopping past the stop bar*



Driver Behavior Analysis

- Critical variable comparisons were made
  - Test approaches paired with "control" approaches
    - Control approaches had traditional right-turn lane design
  - Video data collected at 10 test and control pairs
  - Eight hours of data collected at each site
    - Total of 160 hours of data
    - 19,000 vehicles observed



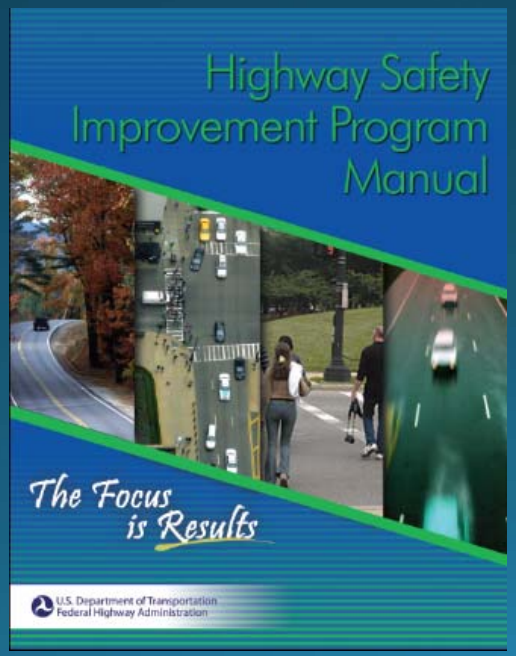
Driver Behavior Analysis

	No. Observations		Proportion		Z- statistic	p-Value	Significant at 95% LOC?*
	Control Sites	Test Sites	Control Sites	Test Sites			
Head Turn Behavior							
Exaggerated Head Turns	2,342	3,688	0.400	0.311	11.82	< 0.00001	Yes
Total Observed	5,852	11,869					
Lateral Placement							
Inside/ Curbside	783	4,864	0.134	0.410	-37.08	< 0.00001	Yes
Total Observed	5,852	11,869					
Stop Type							
Roll & Go	299	413	0.050	0.033	5.52	< 0.00001	Yes
Total Observed	5,948	12,358					
Stop Placement							
Past Stop Bar	1,937	1,310	0.547	0.196	36.20	< 0.00001	Yes
Total Observed	3,544	6,676					

*Based on Z-test for proportions at 95% LOC

- Compared to control sites (traditional design)
  - Exaggerated head-turns occurred **less at test sites** (modified design)
  - Roll and go stops occurred **less as test sites**
  - Drivers stopped past the stop bar **less at test sites**

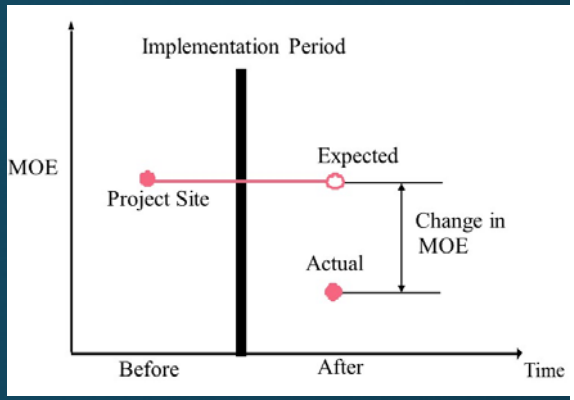
Research Results: Crash-Based Evaluation



Crash-Based Analysis

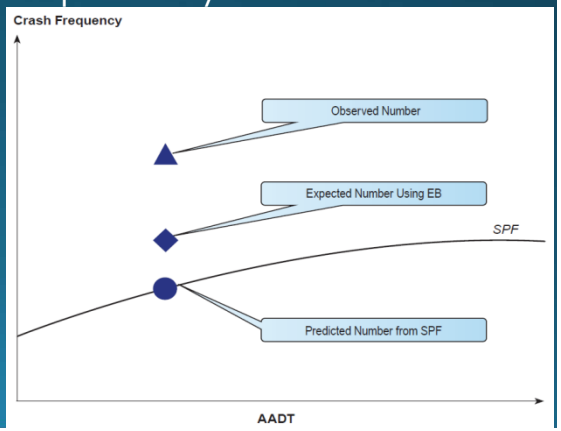
- Estimate the effects of the modified design on safety
- Site-specific evaluation methods:
  - Naïve Before & After
  - Empirical Bayes
    - Reduces regression-to-mean bias
- Comparison between actual and expected traffic crash experience at test approaches
  - 3 years before crash data
  - 3 years after crash data

Naïve Before & After



Regression-to-Mean

Empirical Bayes



Naïve Before & After

- Estimated crash experience is assumed to be equal to the before crash experience

Crash Type	Annual Average Crash Frequency Aggregated for 7 sites		
	Observed (After)	Naïve Before & After	
		Expected (Before)	Reduction
Total Intersection Crashes	53.67	91.33	41.2%*
Intersection Injury (K,A,B,C) Crashes	13.00	21.33	39.1%*
Subject Approach Crashes	21.67	57.33	62.2%*
RT Related Crashes at Subject Approach	15.00	53.67	72.0%*

* Denotes significant finding at 95% LOC

Naïve Before & After Younger & Older Drivers

Crash Type		Annual Average Crash Frequency Aggregated for 7 sites		
		Observed (After)	Naïve Before & After	
			Expected (Before)	Reduction
Older Drivers (65 yrs +)	Subject Approach Crashes	3.33	5.67	41.3%
	RT Related Crashes at Subject Approach	1.67	5.67	70.6%*
Younger Drivers (16-21 yrs)	Subject Approach Crashes	4.67	12.67	63.1%*
	RT Related Crashes at Subject Approach	3.67	11.00	66.6%*

* Denotes significant finding at 95% LOC

Empirical Bayes

- More precise estimation than Naïve Before & After
- Estimated crash experience is found using a crash prediction model-safety performance function (SPF)
- SPFs developed by Bradley University research team using 116 comparison approaches in Illinois to predict 4 crash types:
  - Total Intersection Crashes
  - Intersection Injury (K,A,B,C) Crashes
  - Subject Approach Crashes
  - Right-Turn Related Crashes at Subject Approach

Safety Performance Functions

- Models developed
  - Assuming Poisson/negative binomial distribution
  - Variables with statistically significant relationship with crashes

$$\mu_{Total} = e^{\alpha} \times e^{\beta_1 * RTappADT} \times e^{\beta_2 * INTRSappADT}$$

$$\mu_{Injury} = e^{\alpha} \times e^{\beta_1 * RTappADT} \times e^{\beta_2 * INTRSappADT}$$

$$\mu_{SubjectApp} = e^{\alpha} \times e^{\beta_1 * RTappADT} \times e^{\beta_2 * RTappSpeedLimit}$$

$$\mu_{RT} = e^{\beta_1 * HeadTurnAngle} \times e^{\beta_2 * RT\ Radius}$$

Empirical Bayes

- Summary of methodology
  - Observed crash frequency
  - Predicted crash frequency using SPFs
  - Expected crash frequency
  - Weighting factors as a function of overdispersion factor, k
  - Unbiased estimate of effectiveness (θ), CMF
    - Variance of θ, Standard error of θ
  - Unbiased safety effectiveness (percent reduction, crash reduction factor)
    - Variance, Standard Error
  - Statistical Significance
  - Confidence Interval of CMF

Empirical Bayes

Crash Type	Annual Average Crash Frequency Aggregated for 7 sites		
	Observed (After)	EB Method with BU Developed SPFs	
		Expected	Reduction
Total Intersection Crashes	53.67	95.47	44.2%*
Intersection Injury (K,A,B,C) Crashes	13.00	22.93	43.6%*
Subject Approach Crashes	21.67	52.43	59.0%*
RT Related Crashes at Subject Approach	15.00	36.74	59.6%*

* Denotes significant finding at 95% LOC

- Reductions in right-turn related crashes are attributable to the modified right-turn design

Crash Modification Factors

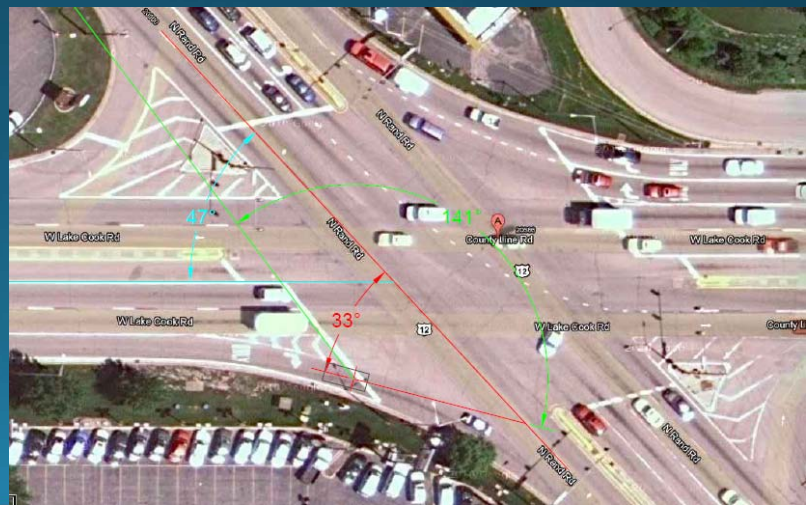
- Total intersection crashes
  - Percent Reduction = 44.2%
  - CMF = 0.558
  - 95% Confidence Interval = 0.383 to 0.734
- Intersection Injury (K, A, B, C) Crashes
  - Percent Reduction = 43.6%
  - CMF = 0.564
  - 95% Confidence Interval = 0.248 to 0.881
    - The above should be viewed with caution ⇒ at 2 test sites, improvements were made to the other approaches
- Subject approach crashes
  - Percent Reduction = 59.0%
  - CMF = 0.410
  - 95% Confidence Interval = 0.224 to 0.596
- Right-turn crashes at the subject approach
  - Percent Reduction = 59.6%
  - CMF = 0.404
  - 95% Confidence Interval = 0.183 to 0.625

Economic Analysis

- To determine economic effectiveness of modified right-turn lane design at 7 test sites
- Compared equivalent uniform annual benefits and costs
  - EUAB & EUAC in 2010 dollars
- Resulting benefit to cost ratio was **13.8** to 1.0
  - Accrued benefits of traffic crash reductions in dollar value exceeds the annualized cost of the modified right-turn lane design over a period of 15 years by a factor of nearly 14

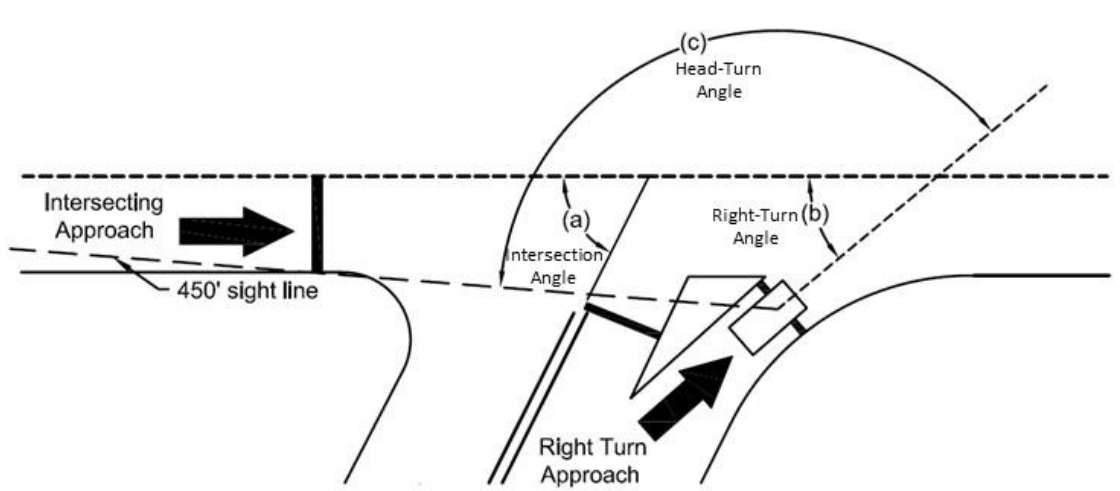
Crash Causation Analysis

- Area-wide investigation of right-turn crash causation was conducted at
  - 116 right-turn approaches
  - 3,174 right-turn crashes over a 4-year period
- Crash rates for right-turn crashes & injury crashes were calculated
- Geometric & volume data was obtained
- Statistical analyses performed to determine whether there was a significant difference in crashes among a series of 2-3 comparison groups



Crash Causation Analysis

- Comparison groups
  - Right-turn approach location
    - Acute quadrant vs. 90° intersection angle vs. obtuse quadrant
  - Intersection angle (a)
    - Intersection angle ≥ 75° vs. intersection angle < 75°
  - Right-turn angle (b)
    - Right-turn angle ≥ 45° vs. right-turn angle < 45°
  - Head-turn angle (c)
    - Head-turn angle ≤ 140° vs. head-turn angle > 140°



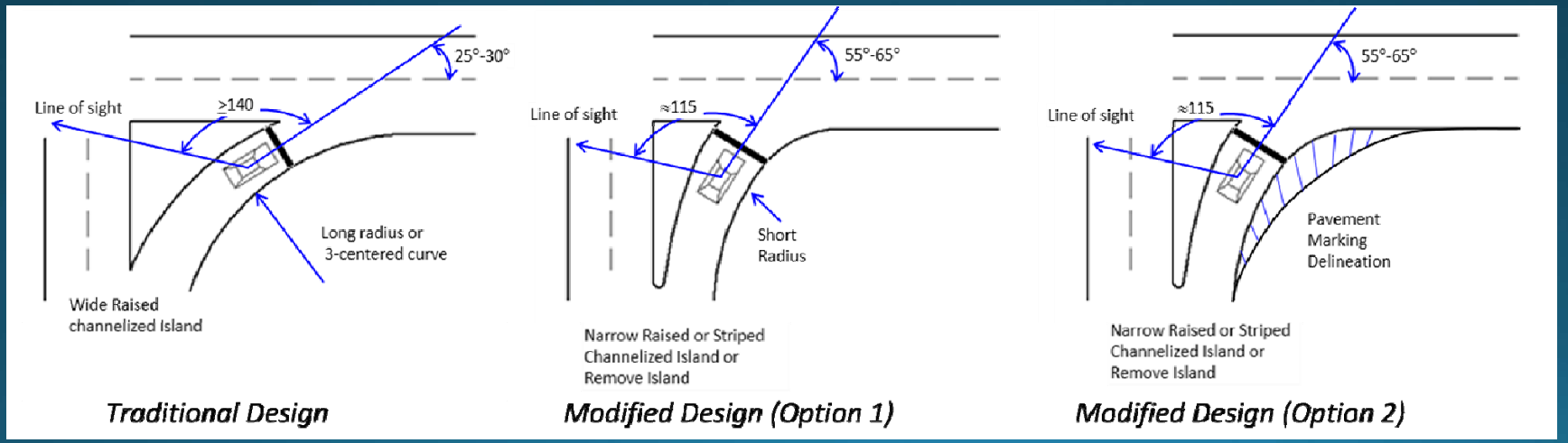
Crash Causation Analysis

- Results ⇒ Characteristics had significantly higher crash rates
  - Approaches with right-turn angles < 45°
  - Head-turn angles > 140°
  - Intersection angles <75°

- Through regression analysis
  - Variables that significantly impact right-turn crashes
    - Head-turn angle
    - Right-turn radius

Recommendations & Design Alternative

- Overall study findings demonstrate that modified right-turn lane design has significant safety benefits
- Modified design
  - Sharpening the flat approach angle
  - Reducing the radius
  - Adjusting the stop bar position
  - Modifying the corner island
    - Improve line of sight of approaching through traffic



Recommendations & Design Alternative

- Use of the modified design may be considered for intersections and right-turn approaches where ≥ 1 of the following characteristics exist because higher right-turn crash rates may result:
  - Channelized island present with large right-turn radius
  - Intersection angle < 75°
  - Right-turn angle 25° to 30°, or < 45°
  - Head-turn angle > 140°
  - Right-turning volume > 250 vph, or right-turn approach AADT > 3,125 vpd
  - Moderate truck volumes
  - ≥ 5 right-turn crashes at an approach per year
- It is recommended that IDOT promote the use of the modified right-turn lane design as an alternative to the current policy, thereby improving intersection safety for Illinois motorists

Any Questions ??