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A Matched Case-Control Safety Study of Street Lighting Uniformity along Urban Roadway Segments

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Background

- Street lighting uniformity is a critical factor that influences the nighttime crash risk.
- The frequent changes of contrasting high- and low-lit lighting patterns cause
  - Eye discomfort, stress, and tiredness
  - Adaption time to new lit condition
  - Objects to be invisible
  - Jeopardizing road safety
- Uniform lighting allows drivers to perceive roadway conditions continuously

Past Studies

- Some efforts investigated the safety effects of street lighting photometric characteristics
  - Most of them focused on the average lighting level
- Limited studies examined the uniformity

1. *Scott PP. The relationship between road lighting quality and accident frequency. Wokingham, Berkshire: Transport and Road Research Laboratory; 1980.*

2. *Zhao et al. Correlating the safety performance of urban arterials with lighting. Transportation Research Record. 2015; 2482(126–132).*

3. *Wang Z, et al. Safety effects of street illuminance on roadway segments in Florida. Presented in 96th Transportation Research Board Annual Meeting. Washington DC; 2017.*

- Disputed uniformity indicators
  - Uniformity ratios: max-min ratio (*Scott et al. 1980; Wang et al. 2017*)
  - standard deviation (*Zhao et al. 2015*)
- Inconsistent conclusions
  - No proved relationship with nighttime crash risk (*Scott et al. 1980*)
  - Significant connection with nighttime crash risk (*Zhao et al. 2015; Wang et al. 2017*)
- No reasonable CMFs of lighting uniformity on roadway segments

Challenges in Crash Modeling for Uniformity

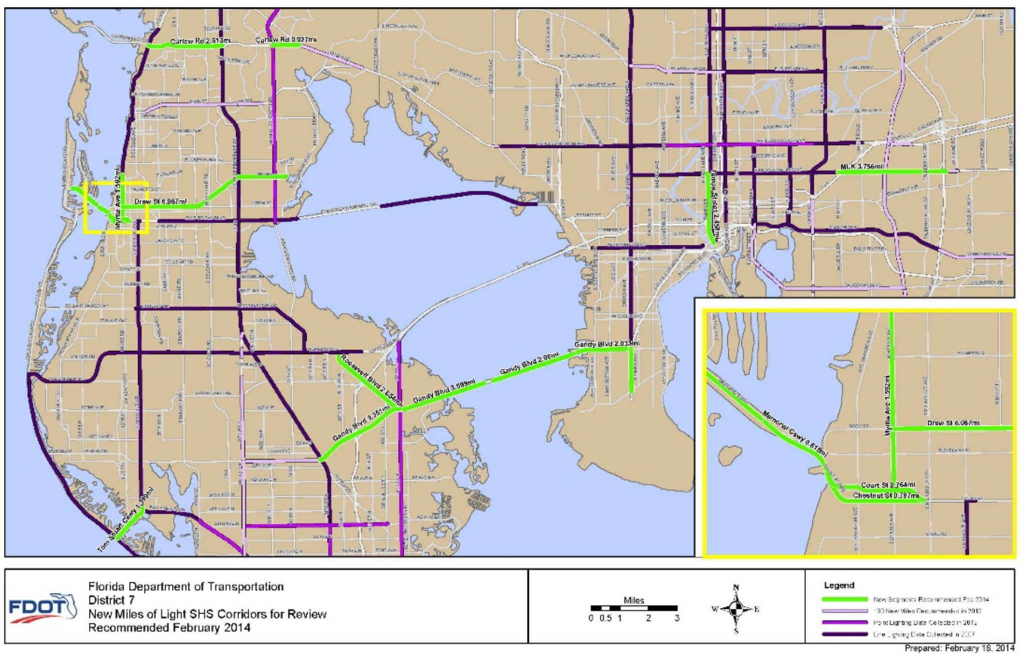
- Absence of a large scale lighting data
  - High cost for lighting data collection
  - Difficult to describe lighting patterns
- Excessive zero nighttime crash observations
  - Cannot be accommodated traditional count models
- Confounding factors
  - AADT, functional classification, safety design standards, …
  - N-D ratio partially addresses this issue
- Temporal heterogeneity

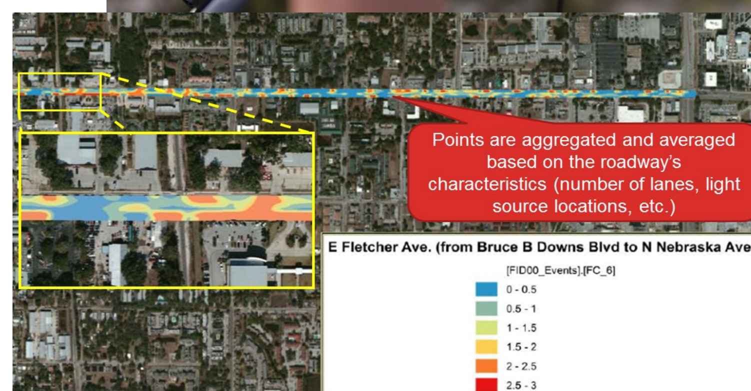
Research Objective

- To investigate the safety effects of street lighting uniformity on roadway segments
- To use proper data and statistical methods to address the critical issues
  - Excess zero crash observations
  - Confounding effects
  - Temporal heterogeneity
- To develop a CMF of uniformity for roadway segments

Data

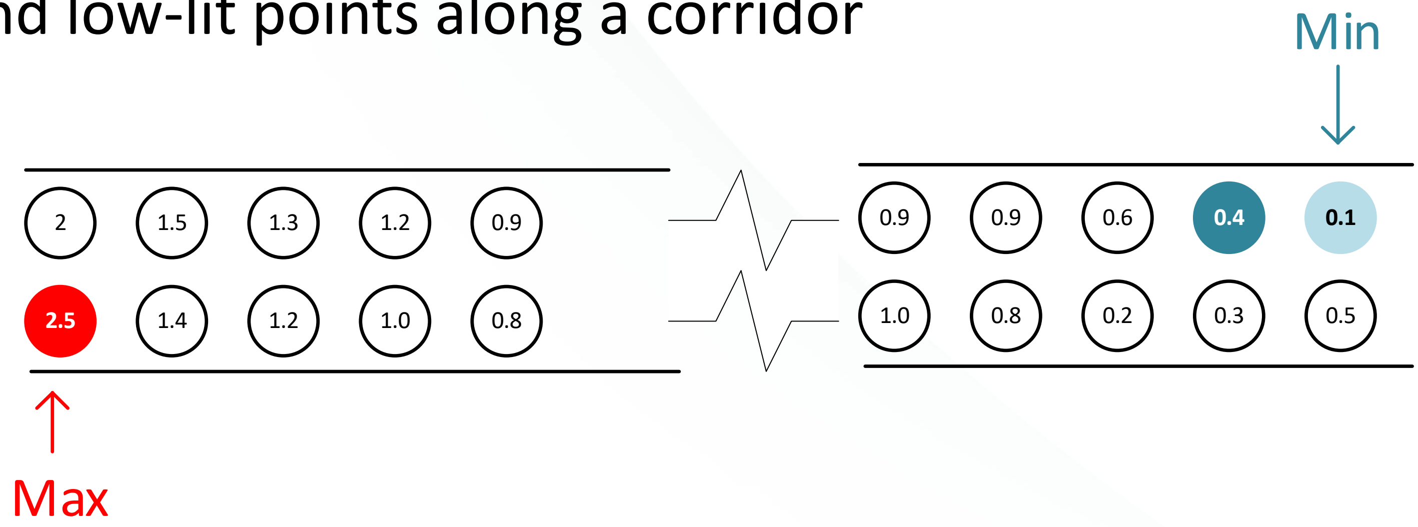
- Advanced Lighting Measurement System
- Two horizontal illuminance points per 10 feet per lane
- 400 centerline miles in Tampa Bay, 2012 - now



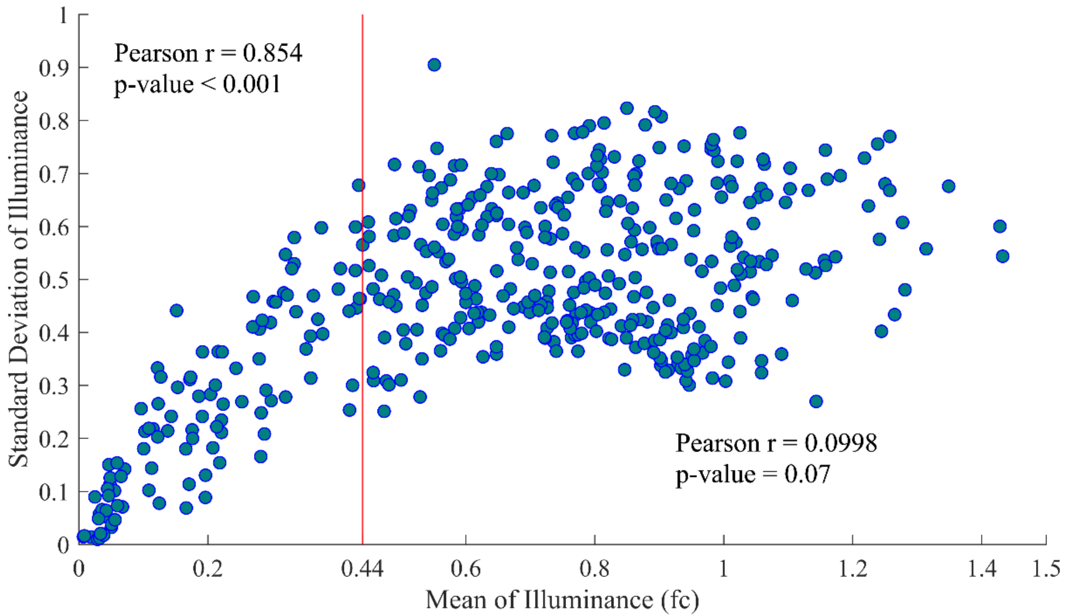


Uniformity Indicator

- Ratio-based indicator
  - Max/Min, Avg/Min
  - Applicable in a small space
  - Not necessarily to capture the spatial correlation of high- and low-lit points along a corridor



- Standard Deviation
  - Use the information of all lighting data
  - Superior to uniformity ratios for a corridor (*Zhao et al. 2015*)
  - Correlation with the average lighting level



Matched Case-Control Study

- Split segments into sub-segments with a uniform length
- Define Case and Control
  - Case – a segment with a each
  - Control – a segment without any crash
- Match confounding variables
  - Multiple controls are randomly matched to each case
  - Based on the similarity of confounding variables
- The conditional logistic model
  - To address the relative risk of unmatched risk factors

Case and Control

- 6,440 sub-segments with a uniform length of 600 ft
- Case – a sub-segment experienced nighttime crashes
- Control – a sub-segment experienced no crash

Year	Case Segments	Control Segments	Total Segments
2011	446	1,164	1,610
2012	442	1,168	1,610
2013	484	1,126	1,610
2014	518	1,092	1,610
Total	1,890	4,550	6,440

Confounder Matching

- One control are randomly matched to one case by year
- Based on the similarity of confounding variables
- To eliminate the influence of mean horizontal illuminance

Mean (fc)	Year								Total	
	2011		2012		2013		2014			
	Case	Control	Case	Control	Case	Control	Case	Control	Case	Control
0-0.4	122	368	127	363	145	345	124	366	518	1,442
0.4-0.8	153	388	149	392	153	388	189	352	644	1,520
0.8-1.0	98	253	104	247	113	238	114	237	429	975
>1.0	73	155	62	166	73	155	91	137	299	613
Total	446	1,164	442	1,168	484	1,126	518	1,092	1,890	4,550

Matched Data

Variable Description	Case (n=1,785)		Control (n=1,785)	
	Mean	Standard Deviation	Mean	Standard Deviation
Standard deviation ≤ 0.2 fc	0.162	0.136	0.357	0.230
0.2 fc < Standard deviation ≤ 0.57fc	0.577	0.244	0.580	0.244
0.57fc < standard deviation ≤ 0.7fc	0.169	0.140	0.169	0.140
Standard deviation > 0.7fc	0.092	0.083	0.056	0.053
AADT (in 10,000)	3.241	1.754	2.992	1.543
Divided roadway indicator (1 if roadway is physically divided or one-way, 0 otherwise)	0.315	0.148	0.347	0.476
Non access points indicator (1 if there is no access points in this segment , 0 otherwise)	0.601	0.240	0.760	0.183
One access point indicator (1 if there is one access point in this segment, 0 otherwise)	0.249	0.187	0.166	0.139
Multiple access points indicator (1 if there are more than one access points in the segment, 0 otherwise)	0.150	0.128	0.075	0.069
Commercial area indicator (1 if roadway is in the commercial area, 0 otherwise)	0.523	0.250	0.450	0.248
Multiple-lane indicator (1 if number of lanes is more than 6, 0 otherwise)	0.030	0.029	0.003	0.003
Narrow shoulder width (1 if shoulder width is less than 20ft; 0 otherwise)	0.657	0.225	0.582	0.243
Intermediate shoulder width (1 if shoulder width is between 20ft and 40 ft; 0 otherwise)	0.308	0.213	0.370	0.233
Wide shoulder width (1 if shoulder width is more than 40ft; 0 otherwise)	0.036	0.035	0.048	0.045

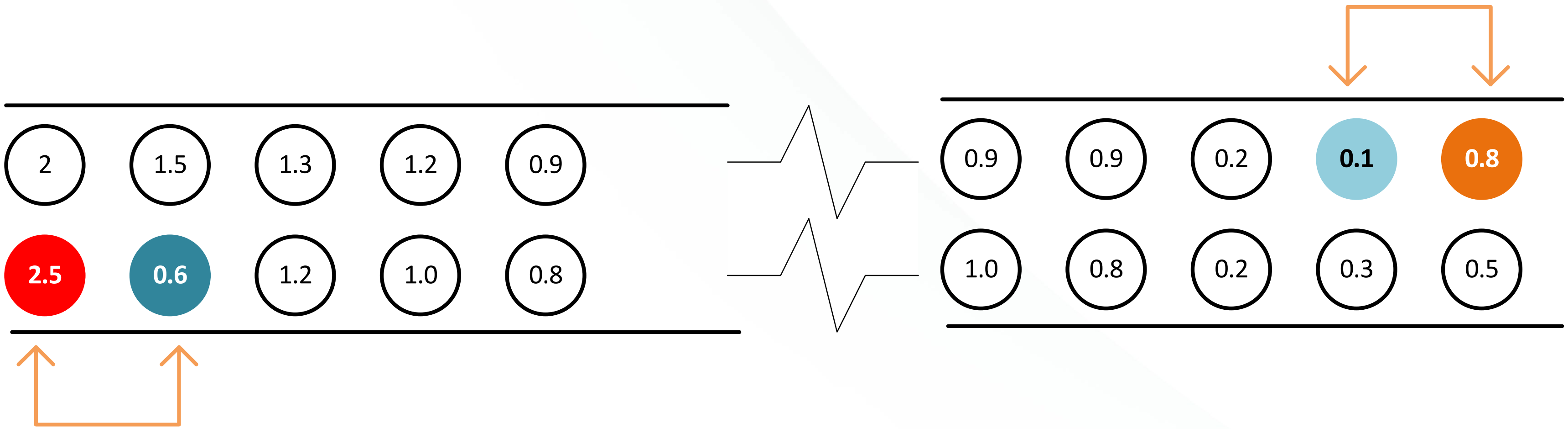
Fitted Conditional Logistic Model

Variable	Coefficient	z-statistics	*p*-value	OR	95% CI of OR
SD ≤ 0.2	Baseline				
0.2 < SD ≤ 0.57	0.268	1.97	0.049	**1.31**	**[1.00, 1.71]**
0.57 < SD ≤ 0.7	0.348	2.02	0.043	**1.42**	**[1.01, 1.98]**
SD > 0.7	0.885	4.29	0.000	**2.42**	**[1.62, 3.63]**
AADT (in 10,000)	0.189	6.63	0.000	1.02	[1.01, 1.02]
Divided roadway indicator	-0.245	-2.92	0.003	0.78	[0.66, 0.92]
No access points indicator	Baseline				
One access point indicator	0.677	6.96	0.000	1.97	[1.63, 2.38]
Multiple access points indicator	1.120	8.15	0.000	3.06	[2.34, 4.01]
Commercial area indicator	0.160	2.05	0.040	1.17	[1.01, 1.37]
Multiple-lane indicator	1.903	3.91	0.000	6.71	[2.58, 17.41]
Narrow shoulder width indicator	Baseline				
Intermediate shoulder width indicator	-0.177	-1.97	0.000	0.83	[0.70, 0.99]
Wide shoulder width indicator	-0.591	-3.01	0.000	0.55	[0.38, 0.81]

Discussion

- More reasonable than previous studies
- Wang et al. 2017
  - Cross-sectional study without any control on confounding
  - CMF = 98% if max/min < 6
  - Underestimate the effect of uniformity
- Zhao et al. 2015
  - Controlled the mean of horizontal illuminance
  - Not suitable for CMF development
    - Nighttime Crash – Daytime Crash

- Standard Deviation is still not a perfect indicator to capture the "true" uniformity pattern influencing driver's vision
  - The continuous changes of high- and low-lit along a travel route
- New photometric measures are needed



Thank You!

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