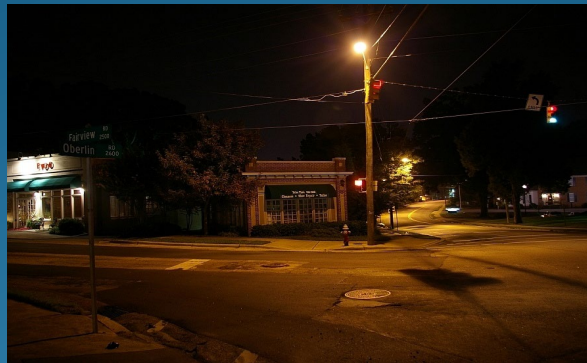




Safety Effects of Street Illuminance on Roadway Segments in Florida

Zhenyu Wang, Pei-Sung Lin, and Ping P. Hsu

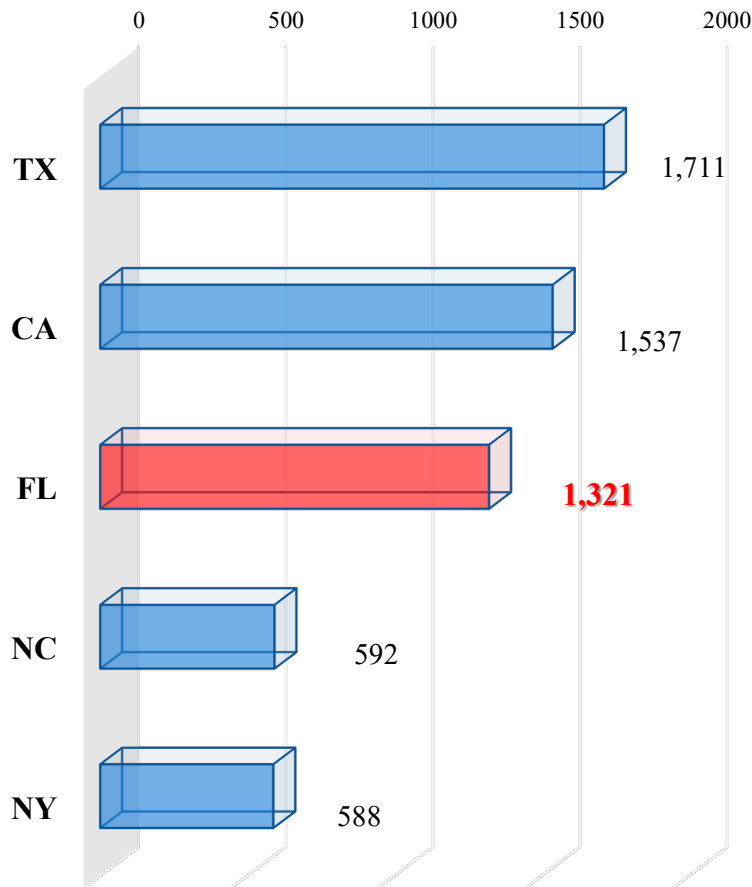


**Transportation Research Board
96th Annual Meeting**

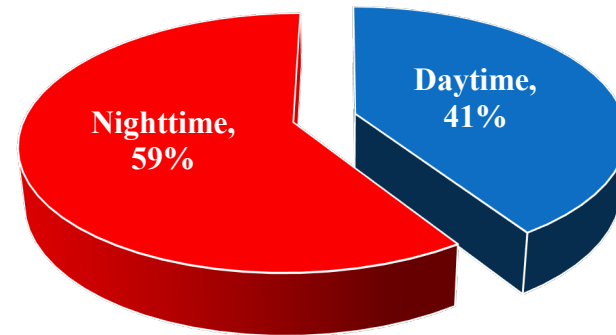
January 8–12, 2017 ■ Washington, D.C.

Nighttime Crash Facts in Florida

**Top Five States
in Nighttime Fatal Crashes, 2013**



**Percentage of Nighttime Fatal Crashes
in Florida, 2013**



Only **21-23%** of the vehicle miles traveled (VMT) occurred at night. (*Monsere and Fischer, 2008*)

Nighttime includes Dark, Dark w. Light Dusk, and Dawn

Street Lighting

- A safety countermeasure to reduce nighttime crashes.
 - Provide additional visibility to drivers
 - Significantly improve sight distance for hazard detection
 - Make roadside obstacles more noticeable to drivers

- FDOT Roadway Lighting Requirements

Road Classification	Illumination Level Average Initial Horizontal Foot Candle (HFC)	Uniformity Ratios	
		Avg/ Min	Max/Min
Interstates, Expressways, Freeways, and Major Arterials	1.5	4:1 or less	10:1 or less
All other Roadways	1.0	4:1 or less	10:1 or less
Pedestrian Ways and Bicycle Lanes	2.5	4:1 or less	10:1 or less

Past Studies

- Most studies considered the presence of roadway lighting
- Limited studies assessed safety effects of photometric measures (horizontal illuminance, horizontal luminance, STV) of street lighting
 - Inconsistent, even counterintuitive conclusions
 - Few studies considered uniformity
 - Outdated lighting and crash data

Research Objectives

- To address the effects of street lighting measures (illuminance mean and uniformity) on nighttime crash occurrence using latest data collected in Florida's roadway segments
 - nighttime crash frequency
 - night-to-day crash ratio
- To develop crash modification factors (CMFs) of street illuminance for roadway segments

Advanced Lighting Measurement System



Current version: 2.1

Up to 6 lighting meter inputs

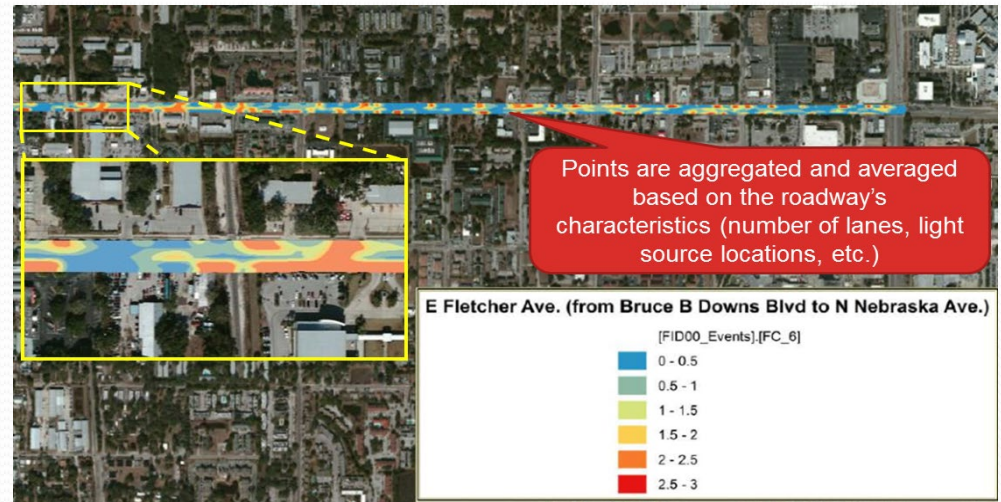
Horizontal illumination

High accuracy

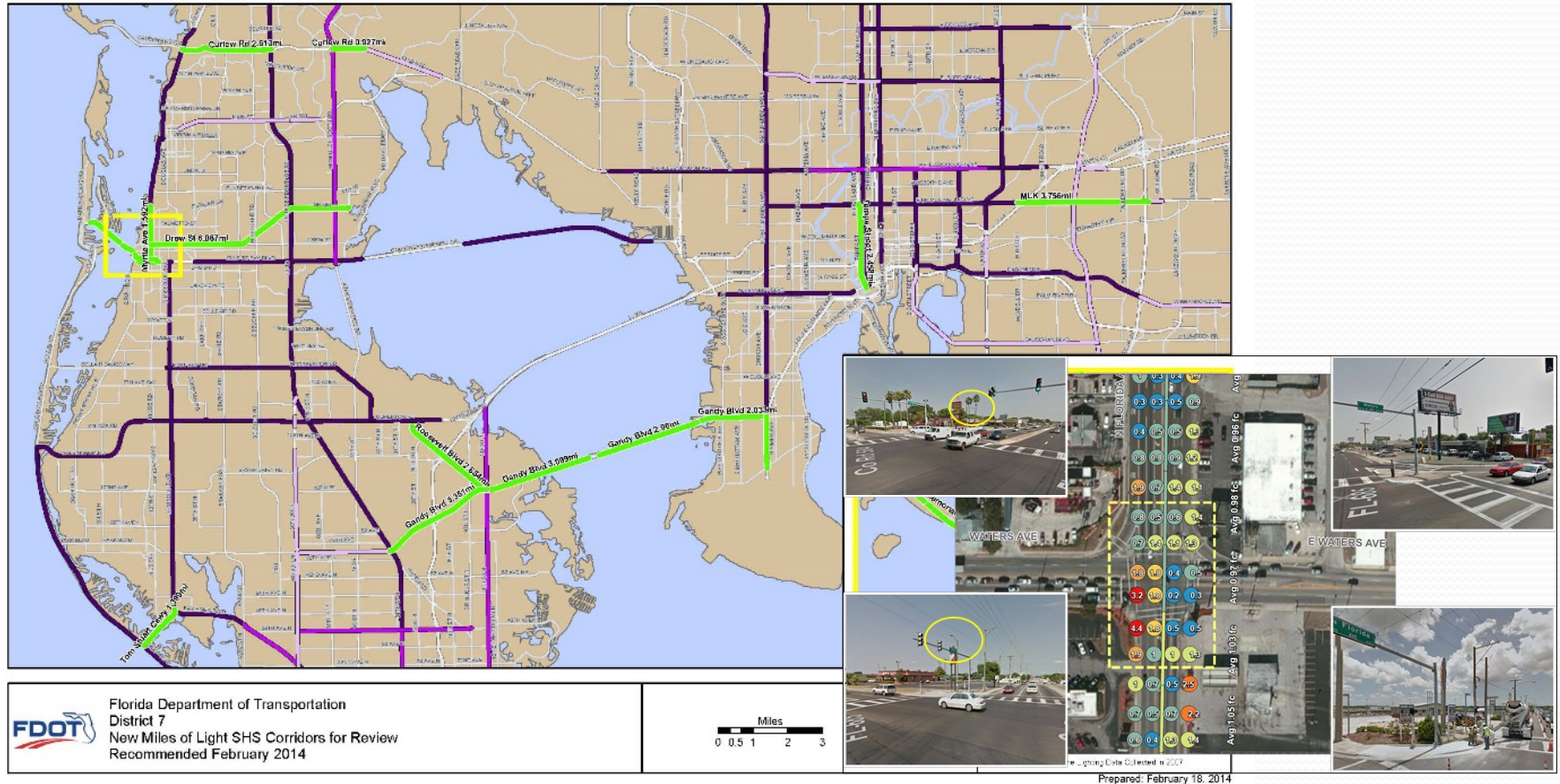
Resolution: 2 points per 10 feet

Speed: = 30 mph

Special event logger



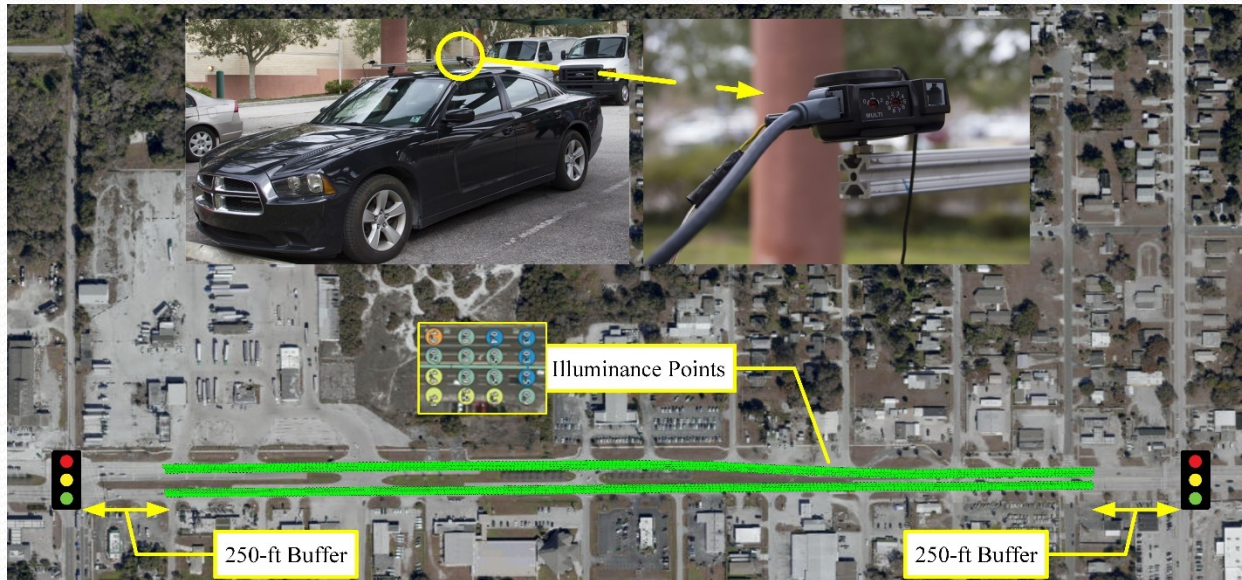
Lighting Data Collection



- Completed data collection for **300+ centerline miles** in Tampa Bay
- 2012 - 2014

Site Selection

- A total of 403 roadway segments with street lights were selected
 - Between two successive signals
 - 500 feet or longer
 - High Pressure Sodium (HPS)
 - No upgrade in past four years
- A 250-ft buffer was subtracted from two ends



Illuminance Measures

- Average Illuminance

$$MI = Mean(FC_i)$$

$$LMI = \ln(MI)$$

$$MLI = Mean(\ln(FC_i))$$

- Uniformity

$$MMR = \frac{\text{Max}(FC_i)}{\text{Min}(FC_i)} = \frac{\text{95th Percentile of } FC_i}{\text{5th Percentile of } FC_i}$$

$$SDLI = \sqrt{\text{Var}(\ln(FC_i))}$$

FC_i is illuminance (at foot-candle) at measure point i

Variable Description (number of observations: 403)	Mean	Standard Deviation	Max.	Min.
Crash Variables				
Number of nighttime crashes (four years, 2011–2014)	5.486	9.885	148	0
Number of daylight crashes (four years, 2011–2014)	16.655	24.844	311	0
Traffic Variables				
Annual average daily traffic (AADT)	30,466	16,763	84,750	4,350
Log (AADT)	10.13	0.687	11.35	8.38
Geometric Variables				
Length of roadway segment (mi)	0.502	0.595	6.566	0.095
Access density (number of access points per mi)	11.764	8.968	44.872	0
Average Illuminance Variables				
Mean illuminance (MI) at foot-candle (fc)	0.678	0.320	1.432	0.019
Log (Mean illuminance) (LMI)	-0.612	0.844	0.359	-3.968
Mean of Logarithm of illuminance (MLI)	-1.053	1.008	0.212	-5.224
Illuminance Uniformity Variables				
Good uniformity indicator (1 if max/min ≤ 6 , 0 otherwise)	0.149	0.356	1	0
Standard deviation of logarithm of illuminance (SDLI)	1.307	0.452	3.760	0.508

Modeling Methods

- Zero-Inflated Negative Binomial (ZINB) Model
 - Expected nighttime crash frequency (N)
 - Expected daytime crash frequency (D)
- Night-to-day crash ratio
 - N/D
 - Eliminate influence of confounding factors
- Night-to-day crash ratio change (Lighting Condition A to B)

$$P_{A \rightarrow B} = \frac{\frac{N_B}{D_B} - \frac{N_A}{D_A}}{\frac{N_A}{D_A}} \times 100\% = \left(\frac{N_B}{N_A} \times \frac{D_A}{D_B} - 1 \right) \times 100\%$$

Fitted ZINB Model

Variable	Coefficient (t-statistics)	
	Nighttime Model	Daylight Model
Count Equation		
Constant	-5.468 (-6.28)	-6.091 (-7.50)
Log (AADT)	0.756 (9.31)	0.936 (12.40)
Access density	0.038 (7.09)	0.037 (7.14)
Log (mean illuminance) (LMI)	-0.1068 (-2.09)	-0.0295 (-0.59)
Good uniformity indicator (1 if max/min ≤ 6 , 0 otherwise)	-0.283 (-2.54)	-0.259 (-2.54)
Logarithm of over-dispersion parameter, $\log(\alpha)$	-1.345 (-8.59)	-1.039 (-10.19)
Inflation Equation		
Constant	0.435 (1.49)	0.607 (2.39)
AADT: multiples of 10,000	-0.490 (-5.02)	-0.553 (-6.29)
Model Statistics		
Number of observations	403	403
Zero observations	138	282
Log likelihood	-930.733	-1279.41
Pseudo R ²	0.130	0.095
AIC	1877.466	2574.820
BIC	1909.457	2606.812
Vuong statistics	5.01	9.16

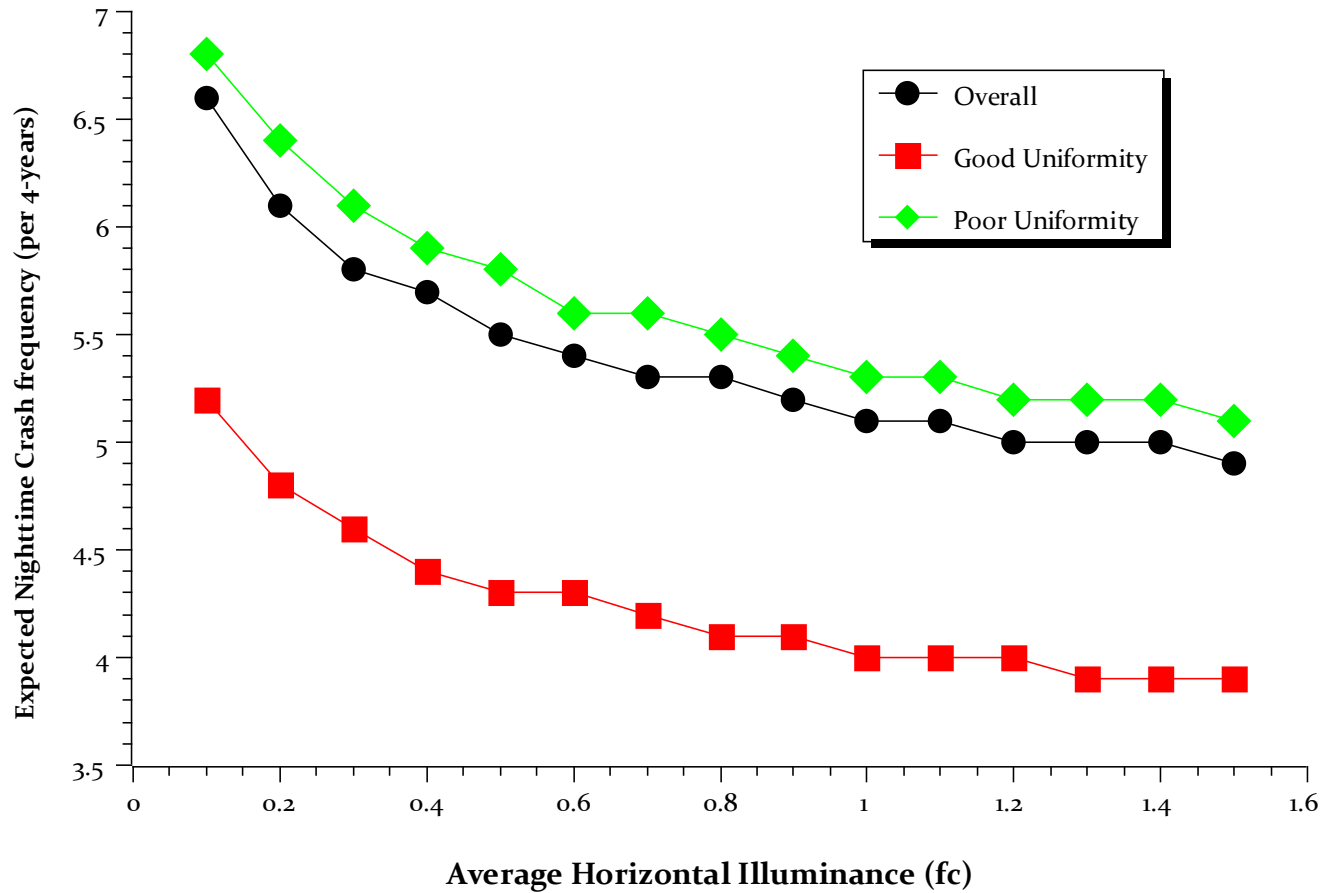
Average Illuminance

- A unit increase in the logarithm of mean illuminance will reduce 0.6 expected nighttime crashes per 4 years.
 - Night time model: -0.1068 (-2.09)
 - Daytime model: -0.0295 (-0.59)
- Impacts of confounding variables cannot be ignored
 - AADT and LMI is positively correlated
 - (*Pearson coefficient = 0.224, p-value = 0.000*)
 - High illumination associates with high-level geometric design, safety treatments, ...

Illuminance Uniformity

- Good uniformity ($\text{max/min} < 6$) significantly decreases the expected nighttime crash frequency by 1.6 crashes (per 4 years)
 - frequent changes of contrasting high- and low-lit patterns may result in drivers' weakened vision.
- Significance in Daytime Model (cof. = -0.259, p-value = -2.54)
 - Confounding impacts
 - High uniformity associates with high-level geometric design, safety treatments, ...

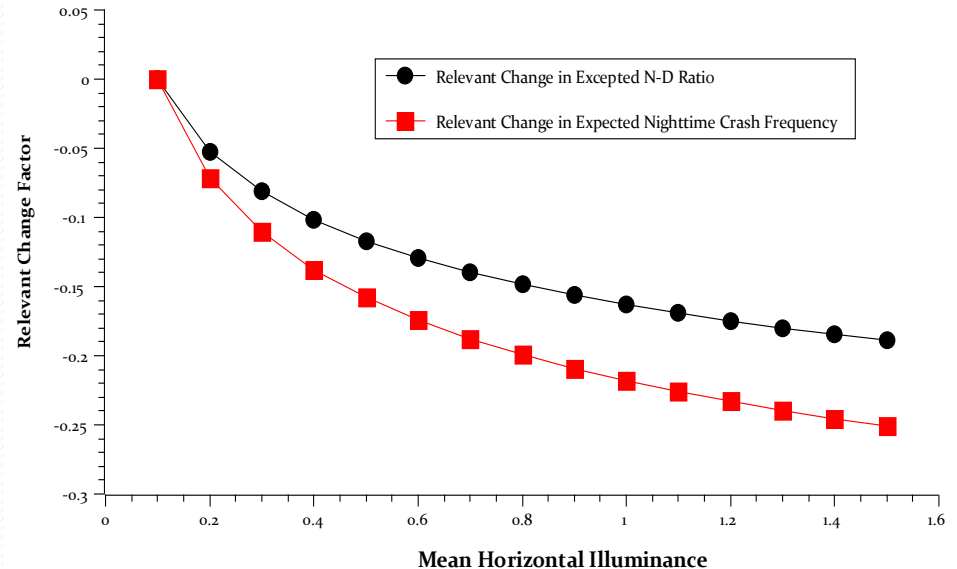
Expected Nighttime Crash Frequency



Expected Night-to-Day Crash Ratio

- Average Illuminance

$$P_{0.1fc \rightarrow x} = \left[\left(\frac{x}{0.1} \right)^{(-0.0733)} - 1 \right] \times 100\%$$



- Uniformity

$$P_{P \rightarrow G} = \{EXP(-0.2825 + 0.2594) - 1\} \times 100\% = -2.3\%$$

$$-CRF = [EXP(-0.283) - 1] \times 100\% = -24.6\%$$

Crash Modification Factors

- Average Horizontal Illuminance

$$CMF_{NF} = x^{-0.1068} \times 100\% \quad \text{based on expected nighttime crash frequency}$$

$$CMF_{N-D} = x^{-0.0773} \times 100\% \quad \text{based on expected N-D ratio}$$

- Uniformity (Good over Poor)

$$CMF_N = 1 + [EXP(-0.283) - 1] \times 100\% = 75.4\%$$

$$CMF_{N-D} = 1 + \{EXP(-0.2825 + 0.2594) - 1\} \times 100\% = 97.7\%$$

Conclusions

- An increase in horizontal illuminance significantly decreases either expected nighttime crash frequency or expected night-to-day crash ratio on roadway segments.
 - The logarithm of average illuminance was superior to average illuminance and average logarithm of illuminance in crash modeling to represent the average street lighting level.
 - Night-to-day crash ratio-based CMF is preferred since night-to-day crash ratio can hedge the influence from the confounding variables

$$CMF_{N-D} = x^{-0.0773} \times 100\%$$

- Good illuminance uniformity ($\max/\min < 6$) can significantly reduce expected nighttime crash frequency.
 - Night-to-day crash ratio-based CMF is preferred, 97.7%
 - A new measure for illuminance uniformity is needed

