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Center for Transportation, Equity, Decisions and Dollars (CTEDD)
19-13

Development of Automated Roadway Lighting Diagnosis Tools for Nighttime Traffic Safety Improvement

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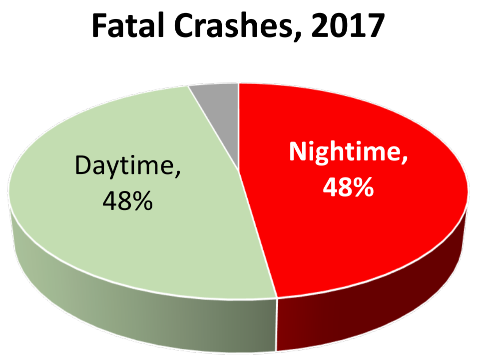
FDOT JMT

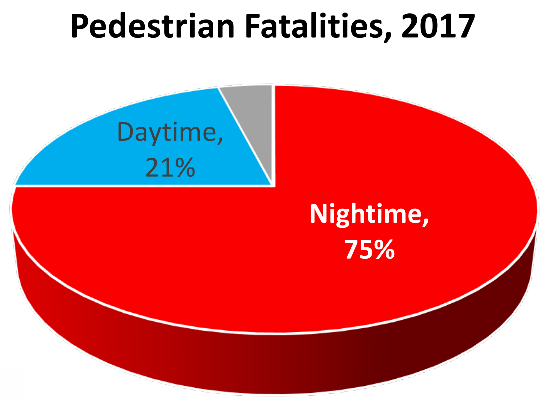
Outline

- Background
- Lighting Diagnosis
- Nighttime Safety Evaluation
- Development of Computer Tools
- Case Study
- Next Step

Background

- Nighttime crashes, <u>especially fatalities</u>, are overrepresented on the US roadway
  - Only <u>21-23%</u> of the vehicle miles traveled (VMT) occurred at night
- Primary contributing factors to nighttime safety
  - <u>**Reduced visibility in darkness**</u>
  - Drowsy and impaired driving
- Roadway lighting has been recognized as a vital countermeasure to prevent nighttime crashes
  - Improves the visibility of the roadway
  - Increases sight distance
  - Makes roadside obstacles more noticeable to the driver
  - Provides clear benefits of personal security for pedestrians, bicyclists, and transit users during nighttime





Source: NHTSA Traffic Safety Facts

- Ensuring adequate illumination is critical to improve nighttime safety and security for all road users
- Roadway lighting illumination performance may deteriorate over time
    - Reduced lighting level and poor uniformity
    - Does not satisfy DOT standards
- Possible causes
    - Natural bulb degradation and damage
    - Obstacles
    - External lighting resources
- A periodic lighting level checking is necessary

Street Lighting Metrics

- *AASHTO Roadway Lighting Design Guide*
- Adopted by state DOTs
- A good street lighting design requires
  - High average lighting level
  - Uniform distribution

Roadway Classification	Average Illuminance Level (foot-candle)		Illumination Uniformity Ratios		Veiling Luminance Ratio
	Horizontal	***Vertical***	***Avg./Min.***	***Max./Min.***	**$L_{v(max)}/L_{avg}$**
Conventional Roadway Lighting					
Freeway	1.5	N/A	≤ 4:1	≤ 10:1	≤ 0.3:1
Major Arterials	1.5				
Other	1.0				
High Mast Roadway Lighting					
All Roads	0.8 – 1.0	N/A	≤ 3:1	≤ 10:1	N/A
Signalized Intersection Lighting					
New Construction	3.0	2.3	≤ 4:1	≤ 10:1	N/A
Lighting Retrofit	1.5 (std.) 1.0 (min.)	1.5 (std.) 1.0 (min.)			
Midblock Crosswalk Lighting					
Low Ambient Luminance	N/A	2.3	N/A	N/A	N/A
Medium & High Ambient Luminance		3.0			

Source: FDOT Design Manual, Table 231.2.1

- Horizontal Illuminance
  - The amount of light that falls onto a horizontal surface
- Vertical Illuminance
  - The amount of illuminance that lands on a vertical surface
  - Pedestrian safety
- Uniformity
  - A long adaption procedure caused by nonuniformed lighting patterns
  - Reduced driver vision for detecting objects

Source: https://electricalnotes.wordpress.com/2019/06/01/how-to-design-efficient-street-lighting-part-4/

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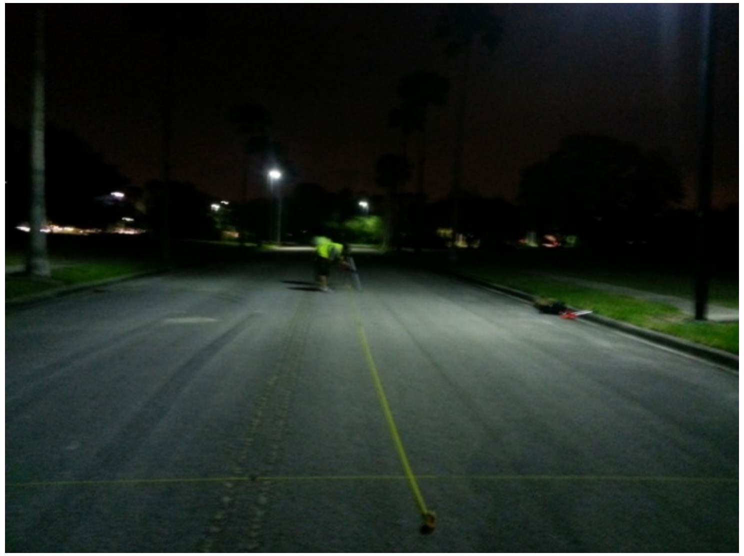
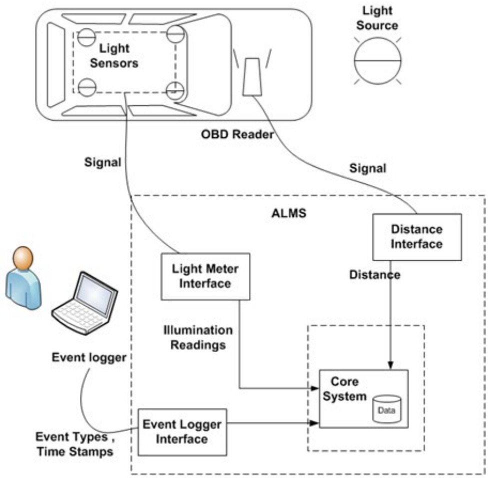
Advanced Lighting Measurement Technologies

- Traditional “manual” lighting measurement
  - Costly (**$5,000+/mile**)
  - Worker safety concerns
  - Driver safety concerns
  - Manpower
  - Accuracy/reliability

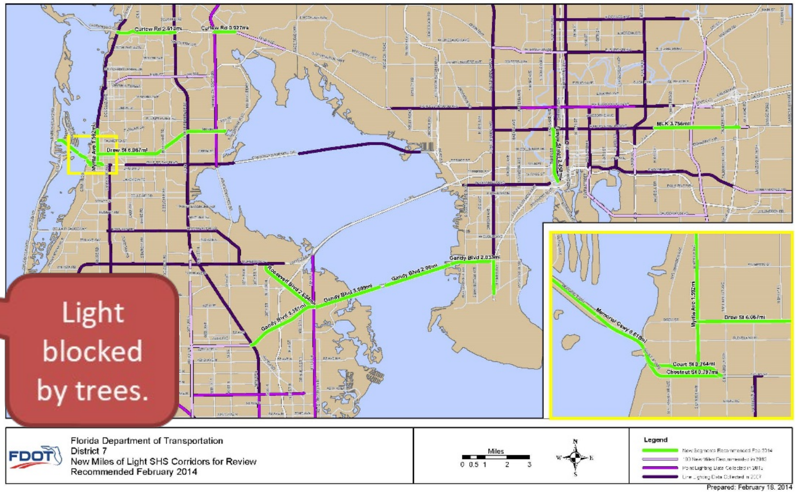


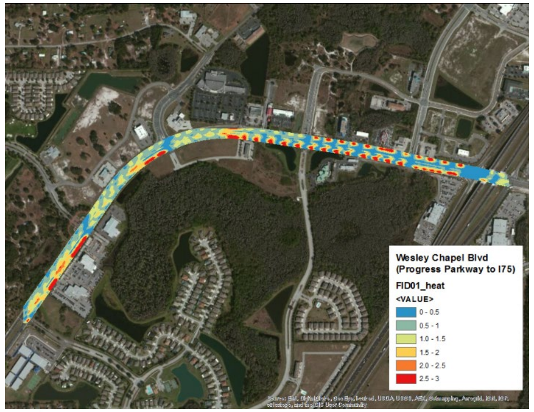
- Advanced lighting measurement System (ALMS)
  - Developed by CUTR
  - High-resolution (up to 2-4 readings per 10 feet per lane)
  - High efficiency (speed ≤ 80 mph)
  - Low cost ($300/mi)



ALMS Data and Applications

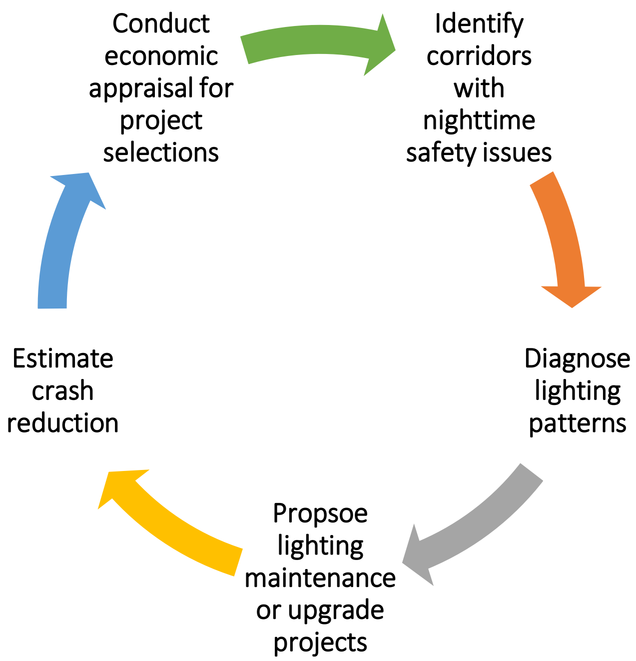
- The CUTR team collected lighting data in Tampa Bay since 2012
- “Big” lighting data Inventory
    - 400+ center-miles
    - **1.2 million lighting points**
- Has been used in FDOT D7 nighttime safety management
    - Lighting level check
    - Lighting retrofit validation
    - LED/HPS comparison
- How do we fully and efficiently use the ALMS data in nighttime safety management?





User Needs in Nighttime Safety Management

- Feedbacks from stakeholders (FDOT D7 and JMT, Inc.)
- Diagnose lighting patterns
  - Identify subsegments that do not meet FDOT lighting standards
- Predictive nighttime crash risk
  - Given lighting patterns and other factors
  - More reliable than historical crashes
- Estimate nighttime crash reduction due to a proposed lighting upgrade
  - Nighttime crash reduction
  - Decision-making support
- Visualize analysis results
  - GIS Map, Figures, Tables, …
- A computer tool



Research Objectives

- To develop innovative methods and tools that automatically and intelligently conduct nighttime safety management based on the ALMS data
    - Develop diagnosis algorithms that can effectively recognize lighting patterns and identify zones with poor lighting performance (e.g., do not meet standards).
    - Develop crash prediction models to predict nighttime crash risk associated with given lighting patterns and other factors.
    - Develop a prototype of computer tools for automatically processing and analyzing collected lighting data.
        - Realize the diagnosis and prediction models
        - Technology Readiness Level (TRL) is Level 7: Prototype Demonstrated in Operational Environment.
    - Implement the developed tools using Florida Department of Transportation (FDOT) lighting measurement projects as case studies.

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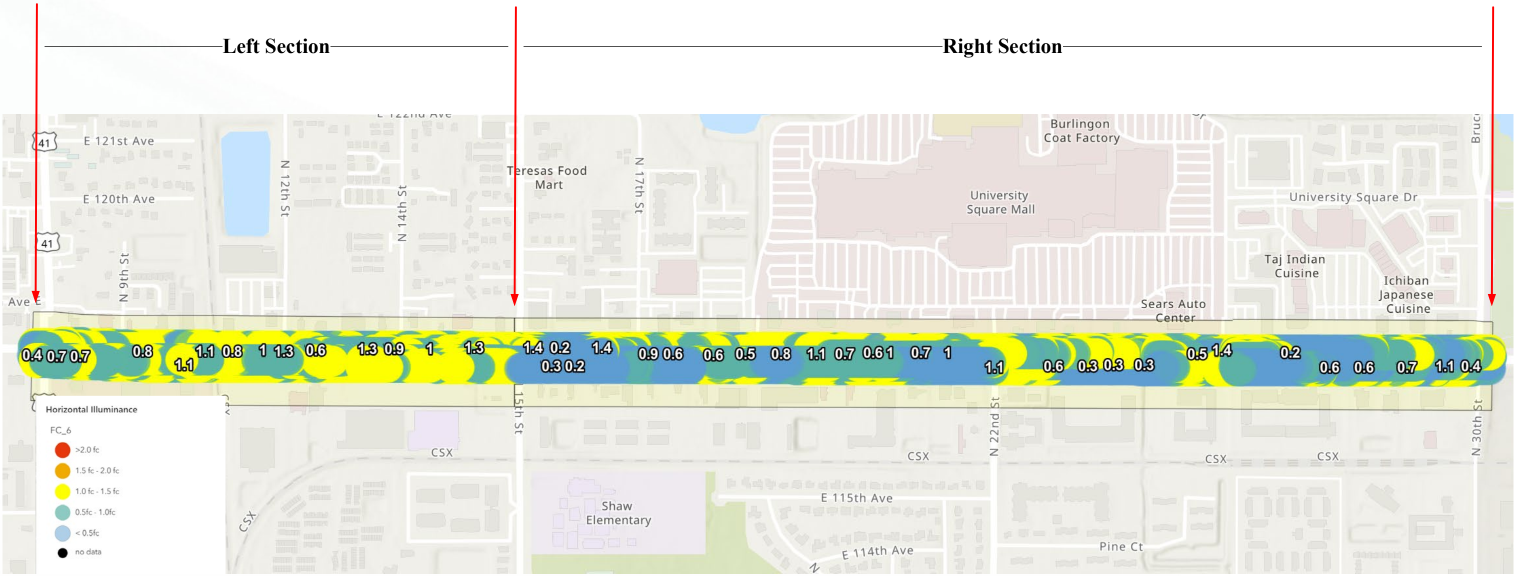
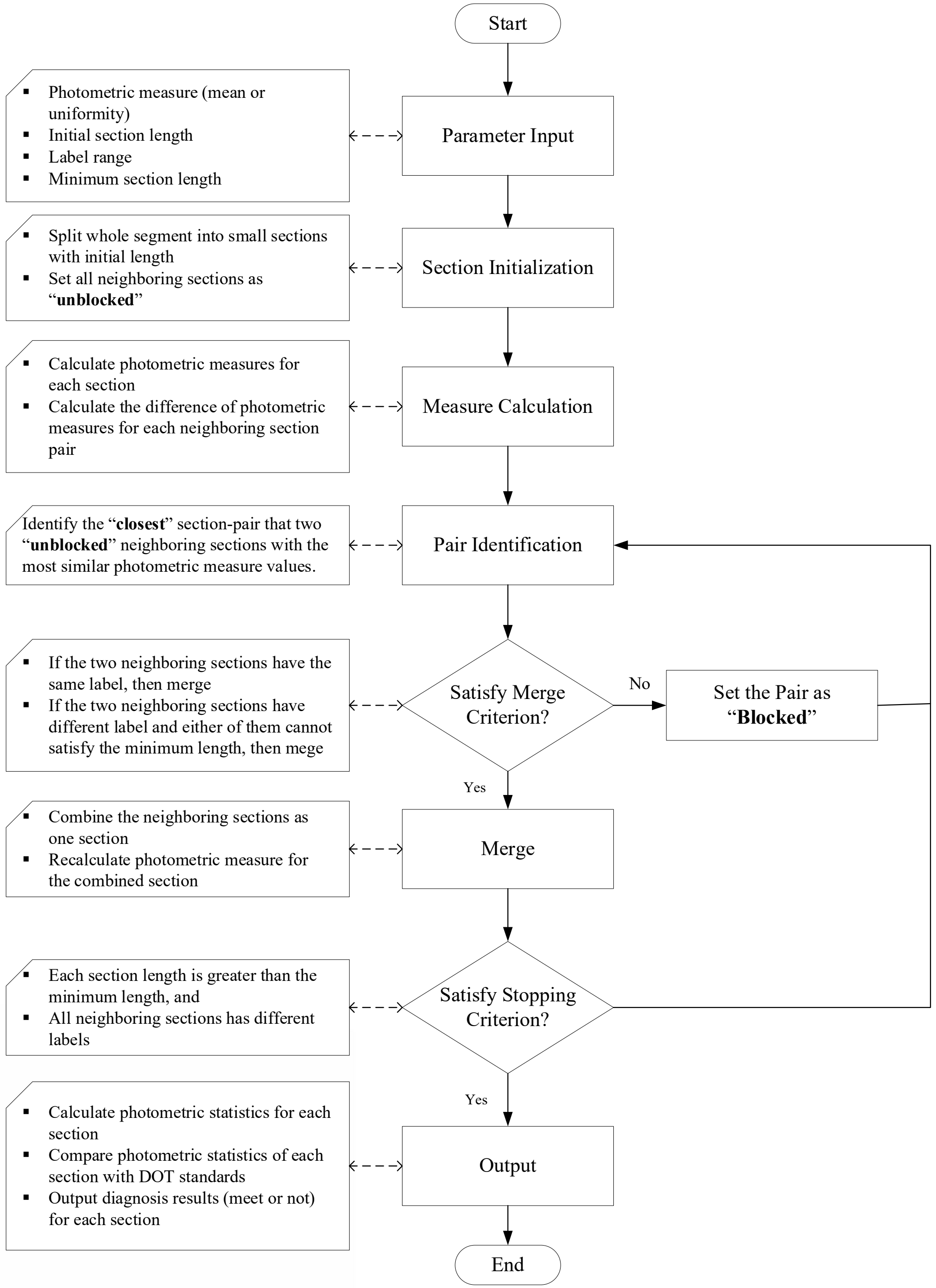
Lighting Diagnosis Algorithms

- Engineers need to check photometric statistics of roadway segments
  - Average lighting level - Mean of horizontal illuminance (Avg)
  - Uniformity – Max/Min, Avg/Min
- Example
  - Overall – Avg: 0.85 fc, Max/Min: 14.19, Avg/Min: 8.54
  - Cannot correctly address the diversity of lighting patterns in the two sections



- Hierarchical clustering methods
- Split the whole segment into small zones
- Calculate photometric statistics for each zone
- Combine the most “similar” neighboring zones as a new zone
- Repeat until satisfy the stopping criterions
  - Each zone ≥ the minimum zone length
  - Each neighboring zone pair are significant difference



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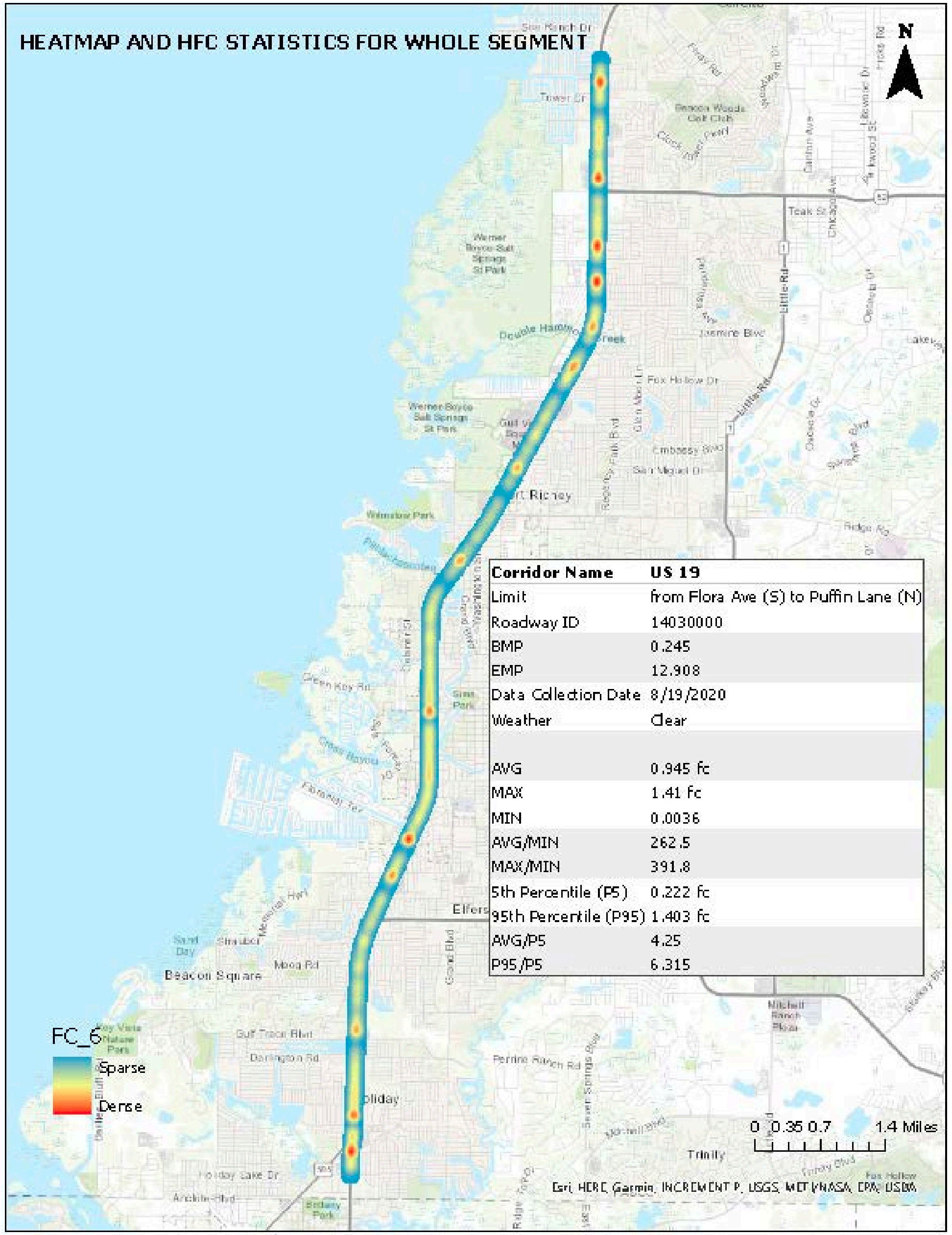

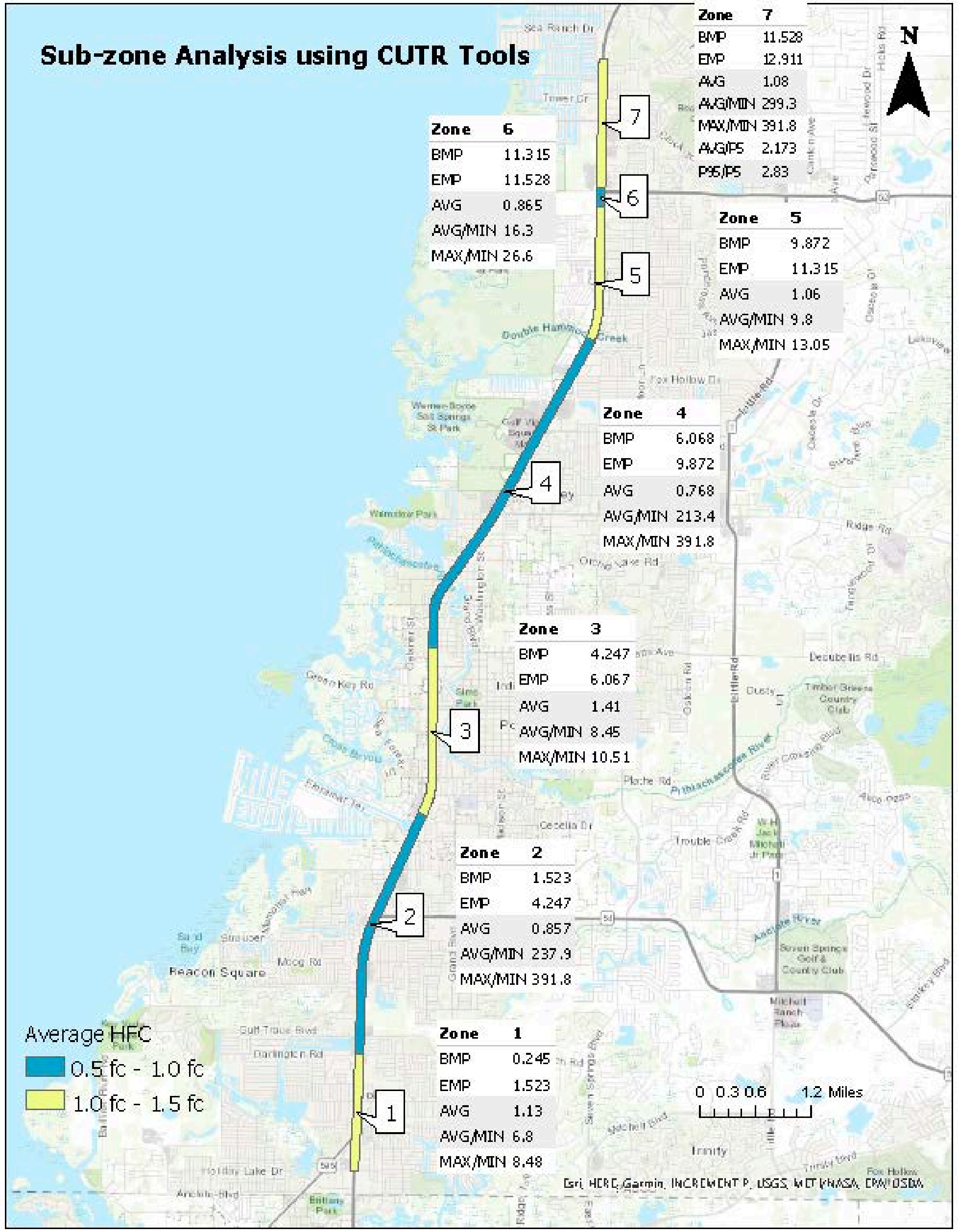

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Safety Performance Function for Lighting Patterns along A Corridor

- *Safety effects of street lighting on roadway segments: Development of a crash modification function*
  - https://doi.org/10.1080/15389588.2019.1573317
  - Random Parameter Negative Binomial Regression

$$\begin{aligned}&\text{Yearly Nightime Crash Frequency}\\&= \exp(-4.969 - 0.42 \cdot \textbf{Mean of HFC} + 0.769 \cdot \textbf{SD of HFC}\\&+ 0.526 \cdot \text{LNAADT} + 0.236 \cdot \text{High HV\%} + 1.161 \cdot \text{Length}\\&+0.036 \cdot \text{Access Density} + 0.456 \cdot \text{Undivided} + 0.283 \cdot \text{Urban})/4\end{aligned}$$

  - Empirical Bayesian (EB) Model to combine Predictive and Historical Nighttime crash data

$$\begin{aligned}&\text{Expected Nighttime Crash Freqeucy}\\&= (1 - \text{w}) \cdot \text{Historical Crash frequency} + \text{w} \cdot \text{Predicted crash freequency}\end{aligned}$$

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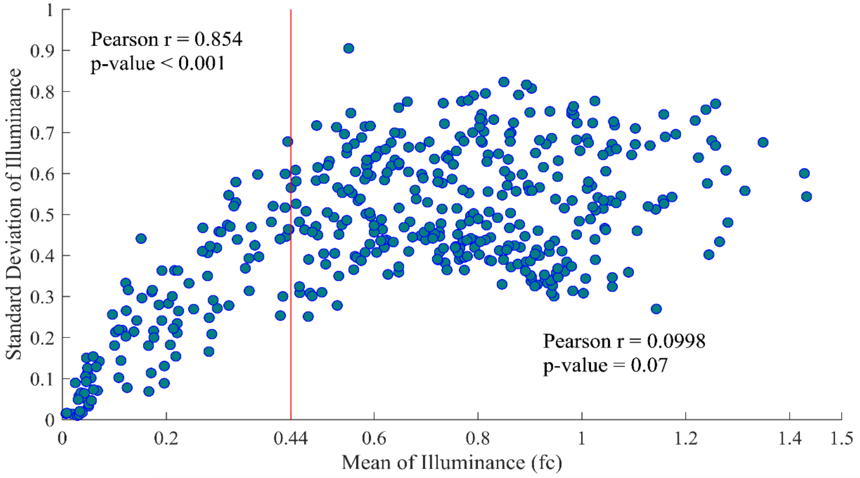
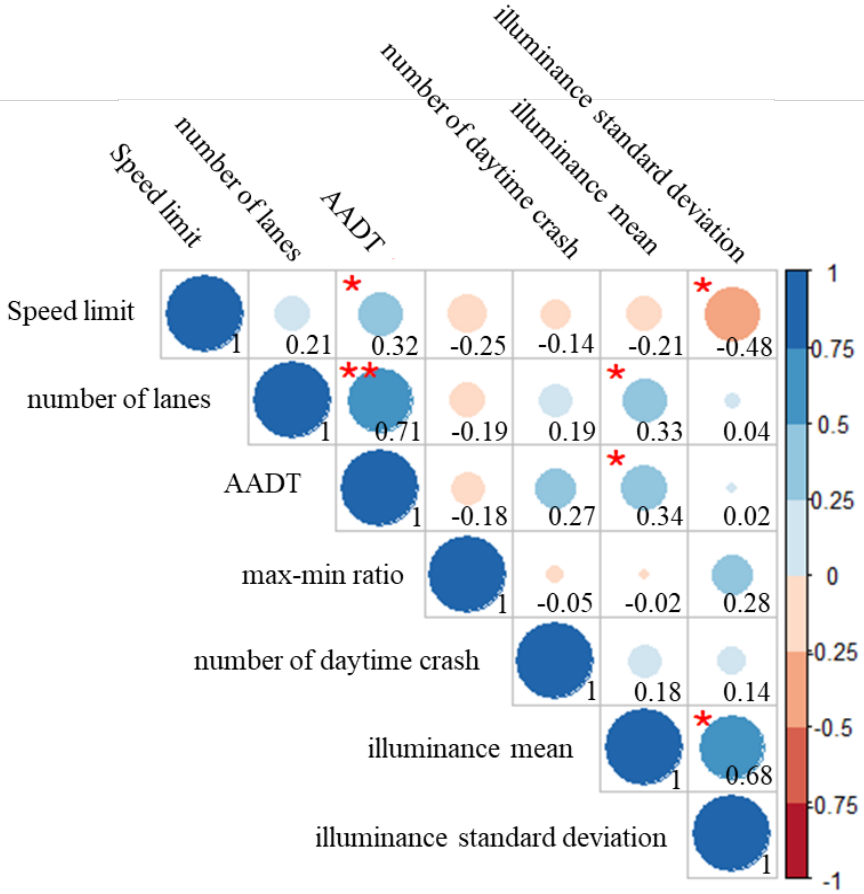
Crash Modification Factors for Lighting Patterns

- No reliable CMFs for lighting patterns were found in previous studies
- Technical challenges
  - To isolate the effects of lighting pattern factors from confounders
  - High lighting level ↔ high level roads ↔ high AADT





Pearson's correlation statistics

Matched Case-Control Method

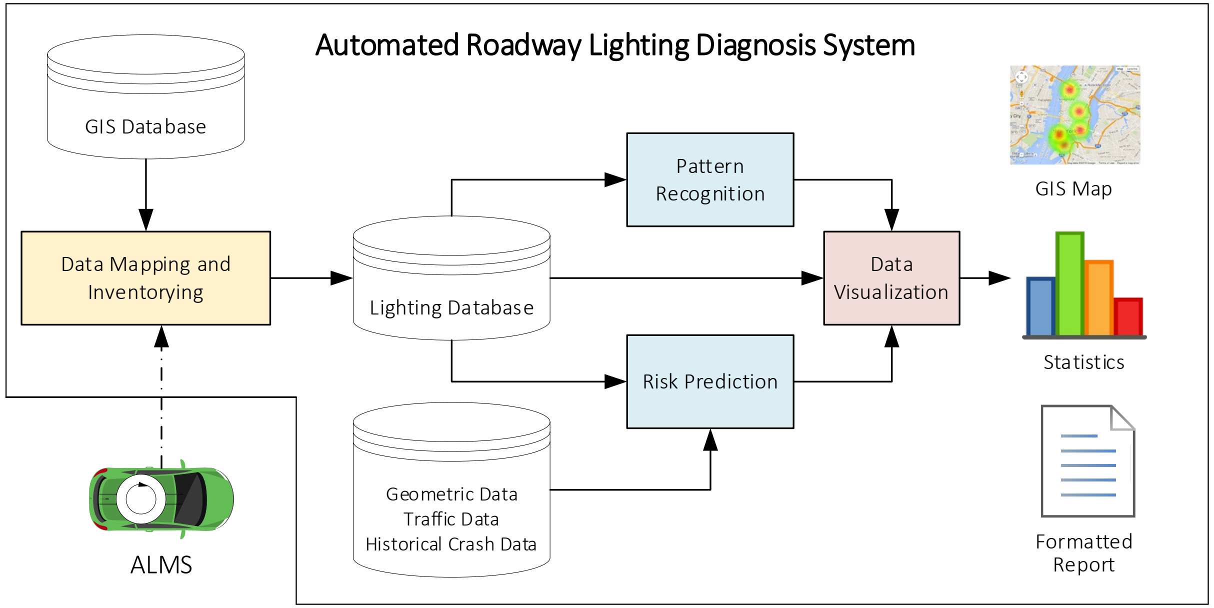
- 2,440 segments with a uniform length of 1,200 ft and ALMS data
- Case: a segment with nighttime data
- Control: a segment without nighttime data
- Randomly match one case to one control as a stratum
    - Values for matching variables: **AADT** and **SD of illuminance** are in the same categories for each stratum
    - Eliminate the influence from two confounders
- Conditional Logistic Model
    - Odds Ratios

CMFs for Lighting Patterns on Corridors
from a matched case-control study

Lighting Statistics	Change	CMF	95% CI for CMF
Mean of horizontal illuminance (fc)	< 0.5 fc → (0.5 fc, 1.0 fc)	**0.679**	[0.468, 0.984]
	< 0.5 fc → > 1.0 fc	**0.581**	[0.367, 0.922]
Uniformity Max-Min Ratio	> 10 → < 10	**0.719**	[0.533, 0.970]

Development of Computer Tools

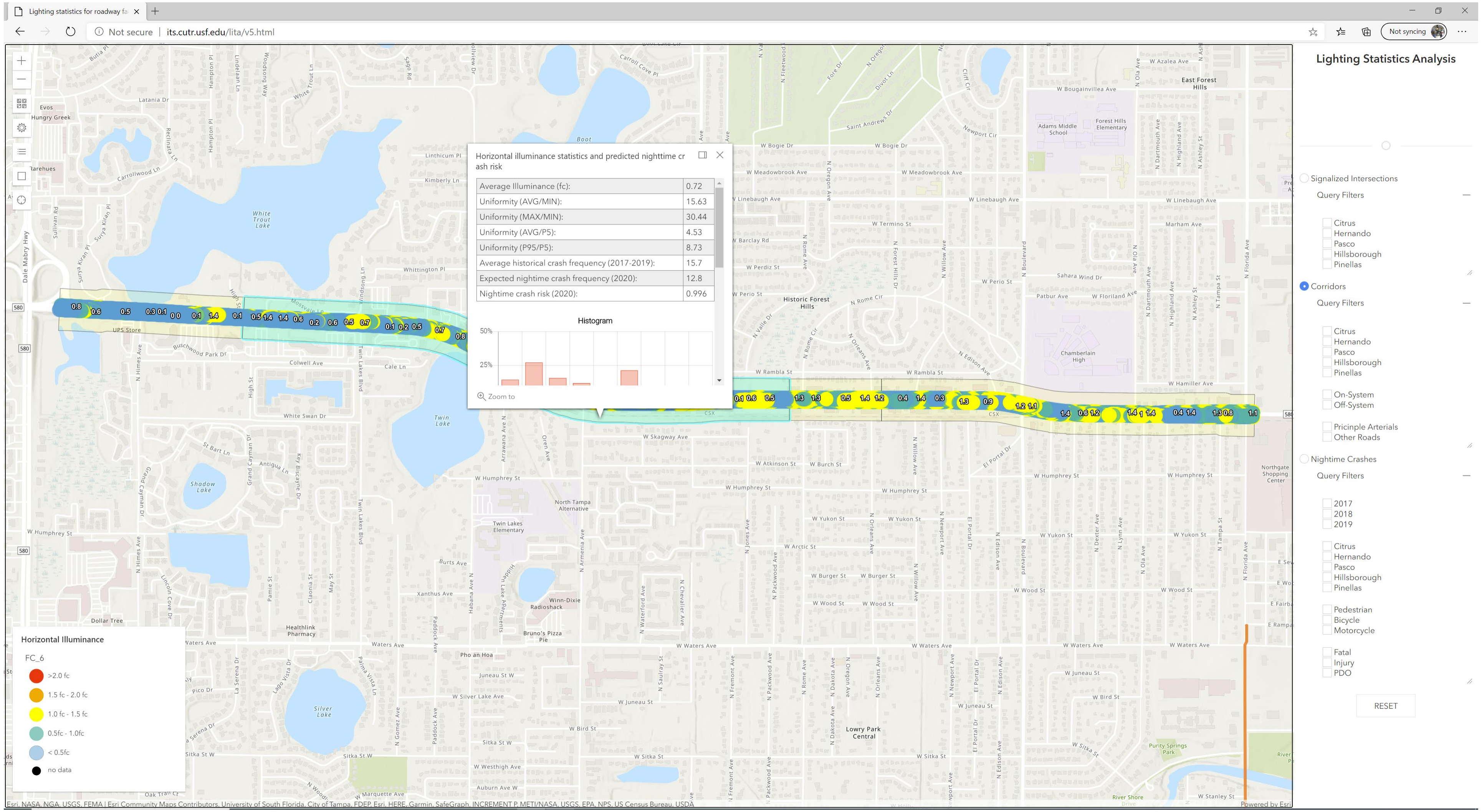
- Powered by Esri ArcGIS web-GIS technologies
- Web Service APIs
  - Can be called from web browsers and desktop apps
- http://its.cutr.usf.edu/lita
- ALMS: http://its.cutr.usf.edu/alms



System Component	Tool/Technology
Deployment – Server Side	
Web Server	Windows Server 2012 R2
GIS Server	ArcGIS Server 10.8
GIS Service	ArcGIS Geoprocessing Service
GIS Library	ArcPy, Numpy, Pandas
Deployment – Client Side	
Web Page	Browsers + ArcGIS API for JS
Desktop Apps	ArcGIS Pro / ArcGIS Map

Function	Algorithm/Technology	Description
Lighting Pattern Diagnosis	Hierarchical Clustering Model	Distinguish lighting patterns that do not satisfy FDOT standards
Crash Risk Prediction	• Safety Performance Function • Empirical Bayesian Model • CMF developed by Case-Control Study	• Predict nighttime crash frequency by lighting, traffic, and geometry conditions • Estimate nighttime crash reduction due to lighting pattern improvement
Data Visualization	Web-GIS	Present analysis results on GIS map

Demo – Lighting Diagnosis



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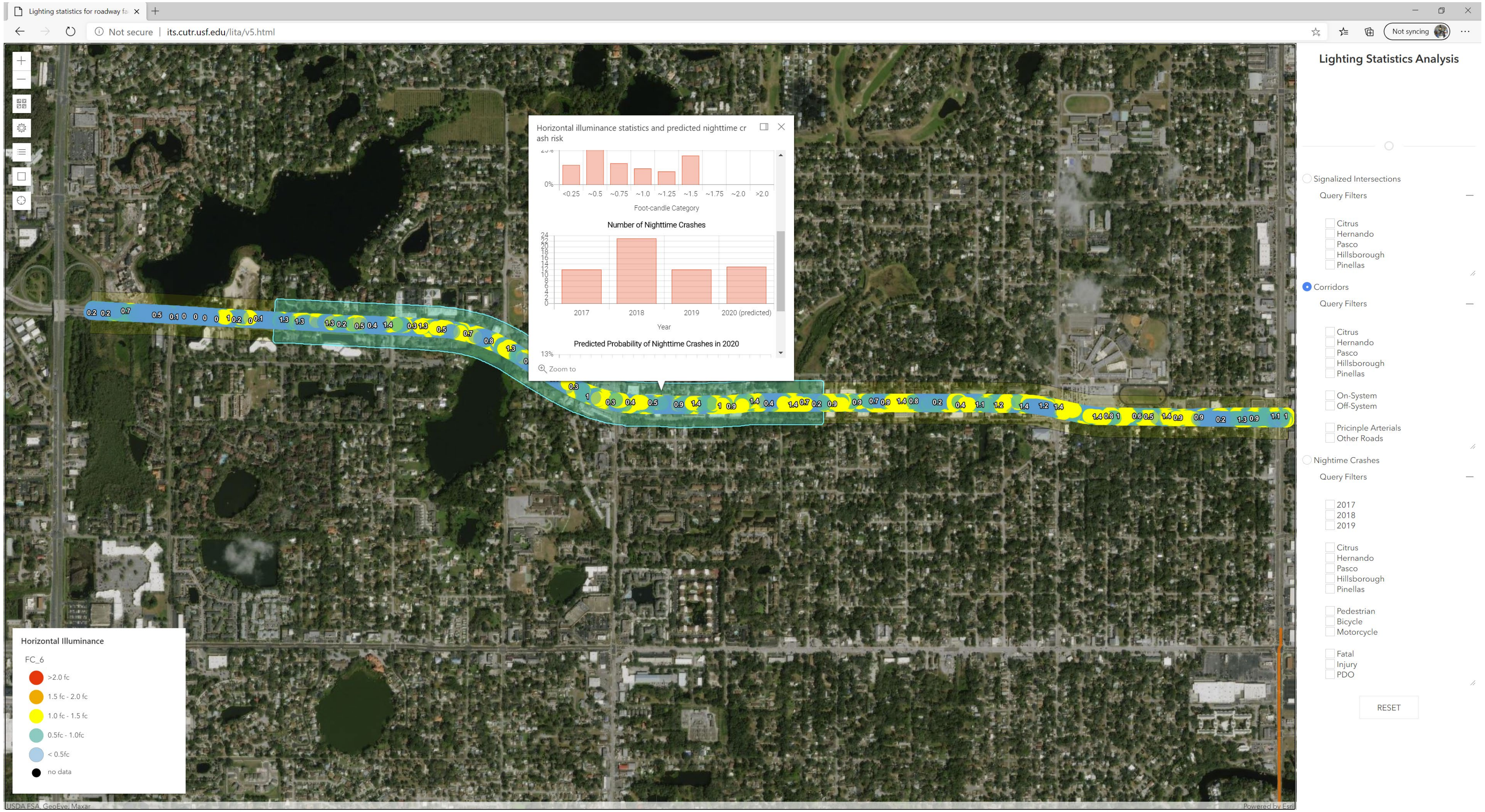
Demo – Lighting Diagnosis

Demo – Nighttime Crash Prediction



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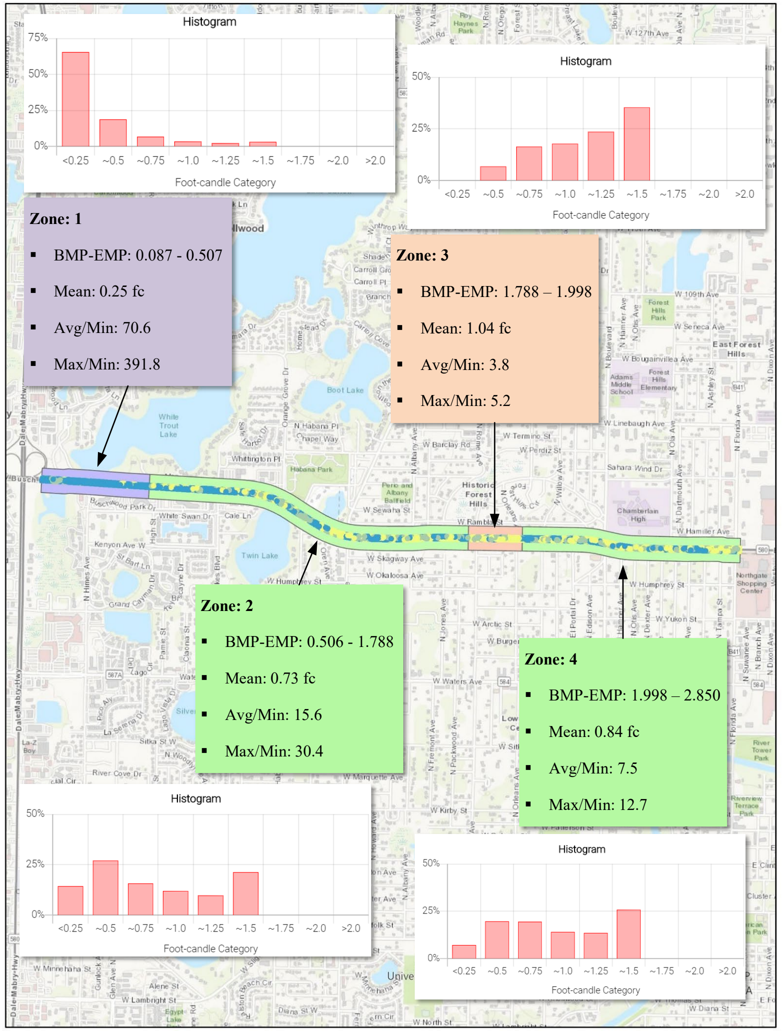
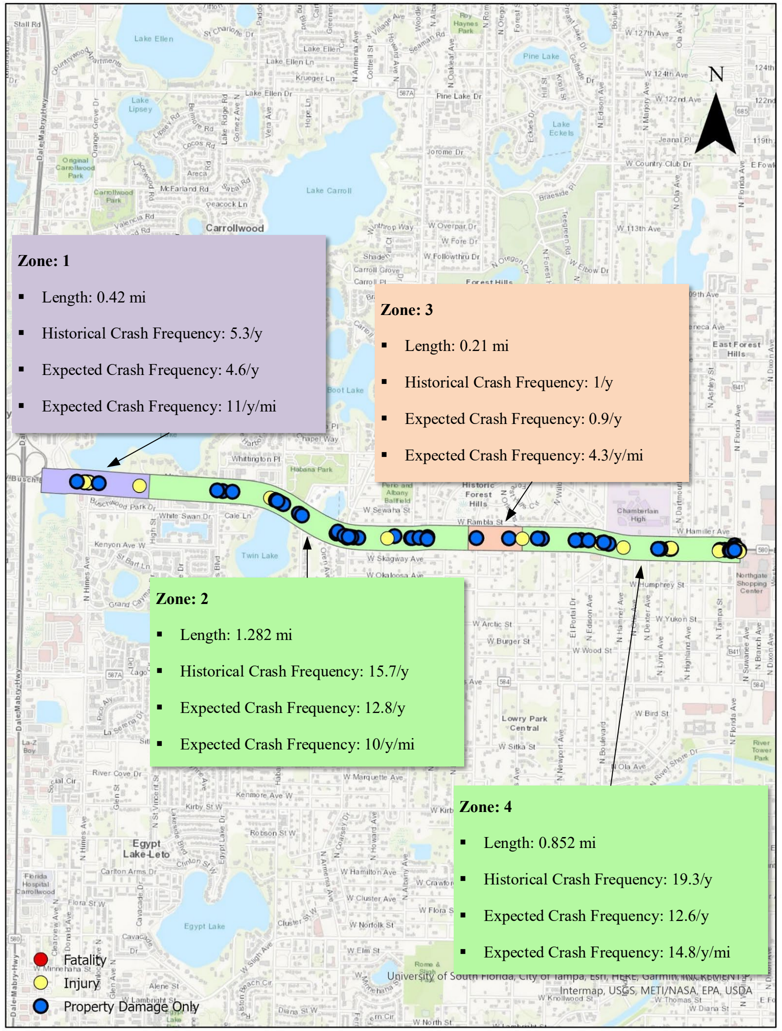
Case Study – W Busch Blvd, Tampa, Florida

Step – 1: Lighting Pattern Diagnosis



Step – 2: Nighttime Crash Risk Analysis



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Step – 3: Benefit Estimation for Proposed Lighting Upgrade

		Zone 1	Zone 2	Zone 3	Zone 4
Mean of Illuminance	Existing	0.25 fc	0.73 fc	1.04 fc	0.84 fc
	Proposed	1.5 fc	1.5 fc	1.5 fc	1.5 fc
	CMF_M	0.581	0.856	1	0.856
Max/Min	Existing	391.8	30.4	5.2	12.7
	Proposed	10	10	10	10
	CMF_U	0.718	0.718	1	0.718
Expected Nighttime Crash Frequency (per year)		4.6	12.8	0.9	12.6
$CMF_M \times CMF_U$		0.417	0.615	1	0.615
Crash Reduction Factor		0.583	0.385	0	0.385
Estimated Crash Reduction (per year)		2.7	4.9	0.0	4.9
Total Crash Reduction		12.5 crashes per year			

Next Step

- Enhance core functions
  - Lighting diagnosis algorithm based on multiple measures
  - SPFs and CMFs for pedestrians
  - SPFs and CMFs for LED technologies
  - User-friendly User Interface
- Improve the prototype to product
  - Implement and test the computer tools in current FDOT D7 lighting projects
  - Technology Readiness Level (TRL) Level 8: Technology Proven in Operational Environment

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