

FINAL REPORT

- Revised from original submittal -

Comparing Street Lighting Levels with Nighttime Crash Histories

-VOLUME I-

Submitted to:



**Florida Department of Transportation
District 7
11201 N Malcolm McKinley Drive
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Background

Limited visibility is commonly blamed as one of the major contributing factors for nighttime crashes. Previous studies showed that appropriate and adequate lighting conditions can result in minimizing potential crashes that occur at night by enhancing the visibility of roadway users, including pedestrians.

In Florida, each roadway segment has its own classification, and guidelines exist for each that require a standard average lighting level for the safety of users. For example, the Florida Department of Transportation's (FDOT's) "Plan Preparation Manual" establishes a standard average illumination level of 1.5 footcandle (fc) for interstate highways, expressways, and major arterials. The manual also requires a 4:1 or lower uniformity ratio average/minimum and 10:1 or lower uniformity ratio maximum/minimum. As can be seen in Table 1, for all other roadways, it requires 2.5 fc as the standard average illumination level for pedestrian ways and bicycle lanes, with the same uniformity ratio mentioned above.

Table 1 FDOT Conventional Roadway Lighting Requirements

ROADWAY CLASSIFICATIONS	ILLUMINATION LEVEL AVERAGE INITIAL HORIZONTAL FOOT CANDLE (H.F.C.)	UNIFORMITY RATIOS	
		AVG./MIN.	MAX./MIN.
INTERSTATE, EXPRESSWAY, FREEWAY & 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

Note: These values should be considered standard, but should be increased if necessary to maintain an acceptable uniformity ratio. The maximum value should be one and one-half values.

* This assumes a separate facility. Facilities adjacent to a vehicular roadway should use the levels for that roadway.

Source: "Plans Preparation Manual: Design Criteria and Process," Florida DOT

Currently, roadway lighting illuminance levels often are measured manually with handheld light meters. On a regional scale, this represents an enormous data collection task. This data collection method also would place the light meter operator in the middle of the roadway at night during low-light conditions, creating a safety concern for both data collection personnel and roadway users. Therefore, it is not practical to monitor and evaluate the performance of roadway lighting levels in a timely manner due to the difficulty of the data collection process.

To address these issues, an Advanced Lighting Measurement System (ALMS) was developed that can measure lighting illuminance levels from a moving vehicle using a combination of a laptop computer, a light meter, and a distance measurement instrument (DMI). The illuminance value recorded by the light meter is matched to the location data from the DMI.

Data Collection

The developed system was used to collect illuminance lighting levels on approximately 245 centerline miles length for FDOT District 7. The illuminance measurements were collected every 40 ft on the right (outside) side and left (inside) side lanes for each direction of the roadway, in most cases. The goal was to obtain the maximum and minimum illuminance values based on the fact that the lighting poles are placed on the outside shoulders in each direction in most cases. Figure 1 shows one of the segments selected for the study, a six-lane divided highway with lighting poles at both sides. The top left corner of Figure 1 shows the box that contains the DMI and the circuit used for the interface of the communication between the DMI and the laptop computer. The bottom left and right pictures show the light meter on top of the vehicle as it was used during the illuminance measurement process.

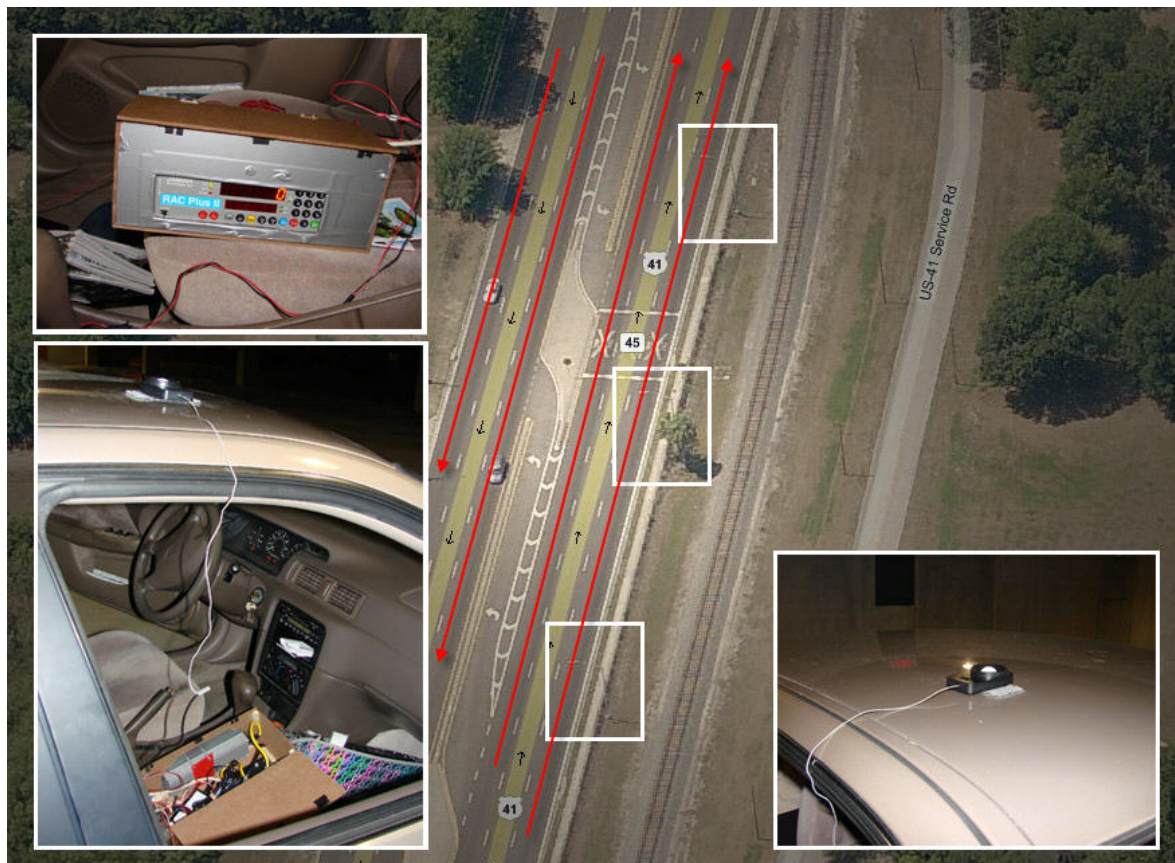


Figure 1 Example of Segment for Data Collection

Figure 2 shows an example of the illuminance levels measured using the ALMS on a one-mile corridor. It illustrates the change in the illuminance level along the corridor. For this particular segment, the data were collected for the inside and outside lanes in each traffic direction.

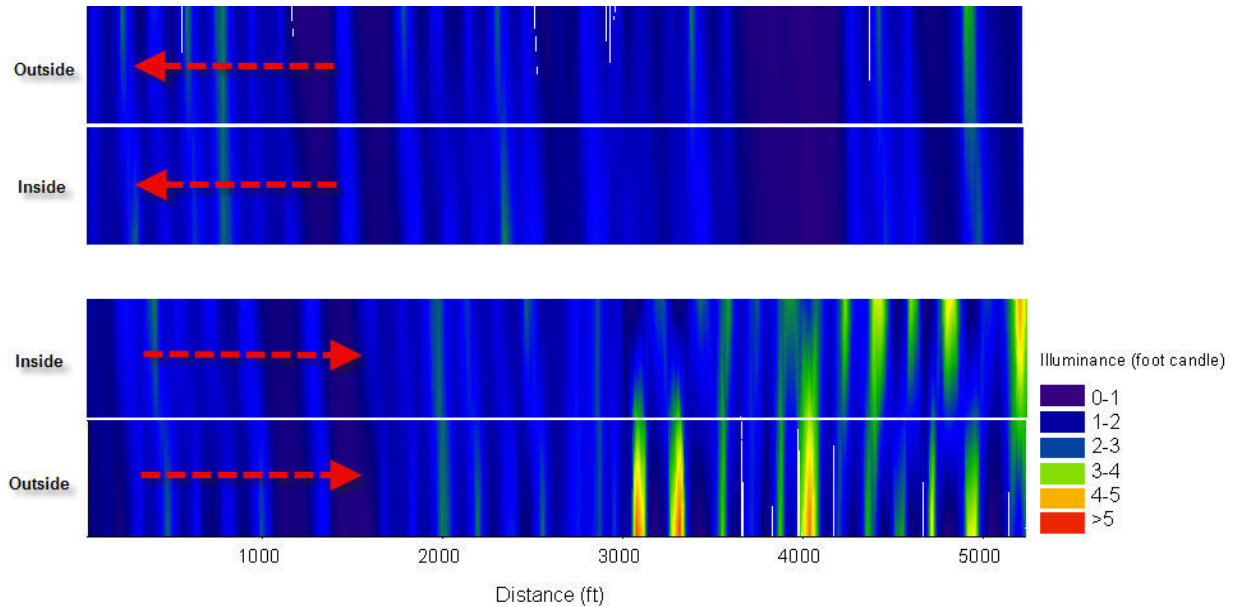


Figure 2 One-Mile Segment Example of Illuminance Data Measured Using the ALMS

The illuminance measurements were matched with the corresponding milepost based on the data obtained by the DMI unit. After collecting the data, the moving average technique was used to provide a better understanding of the conditions of the roadway lighting intensities. Therefore, the average, maximum, and minimum values for every milepost can be calculated. Table 2 shows the study area in FDOT District 7.

Table 2 Study Area Roadways, FDOT District 7

	Roadway ID	Road Name	Length (mile)	County	Begin-Street	End-Street
1	2010000	US 41/SR 44	1.5	Citrus	Relief St	Davidson Ave
2	2030000	US 19	3.211	Citrus	SE 8th Ave	NW 22nd St
3	8010000	US 41	3.386	Hernando	SR 50	Lakeside Dr
4	8040000	SR 50	2.556	Hernando	SR 50	US 98
5	10005000	40th St	2.845	Hillsborough	E Adamo Dr	E Hillsborough Ave
6	10020000	Florida Ave	11.211	Hillsborough	SR-60 Kennedy Blvd	Nebraska Ave
7	10030000	Hillsborough Ave	4.772	Hillsborough	Nebraska Ave	Orient Rd
8	10030000	US 92 Reynolds St	2.454	Hillsborough	Thonotosassa Rd	Park Rd
9	10030101	US 92 Baker St	1.782	Hillsborough	Reynolds St	Thonotosassa Rd
10	10040000	Nebraska Ave	8.164	Hillsborough	Kay St	142nd Ave
11	10060000	US 41	12.117	Hillsborough	1st St SW	Riverview Dr
12	10080000	Kennedy Blvd	1.686	Hillsborough	Henderson Blvd	Brevard Ave
13	10110000	E Frank Adamo Dr	6.97	Hillsborough	N 22nd St	I-75
14	10130000	Dale Mabry Hwy	7.181	Hillsborough	Gandy Blvd	Hillsborough Ave
15	10140000	Courtney Campbell Cswy	5.012	Hillsborough	Pinellas County Line	Rocky Point Dr
16	10150000	Hillsborough Ave	7.803	Hillsborough	Theresa Rd	Nebraska Ave
17	10160000	Dale Mabry Hwy	9.485	Hillsborough	Hillsborough Ave	Veteran Expressway
18	10250000	22nd St	2.782	Hillsborough	N21st St	Hillsborough Ave

19	10250101	21st St	0.622	Hillsborough	I-4	Adamo Dr
20	10270000	Kennedy Blvd	1.98	Hillsborough	Ward St	Henderson Blvd
21	10290000	Fowler Ave	5.454	Hillsborough	Florida Ave	Morris Bridge Rd
22	10310000	Busch Blvd	3.53	Hillsborough	Nebraska Ave	56th St
23	10330000	56th St	6.023	Hillsborough	E21st Ave	Fowler Ave
24	10340000	MLK Jr. Blvd	10.55	Hillsborough	Dale Mabry Hwy	Queen Palm Dr
25	14030000	US 19	11.105	Pasco	Pinellas County Line	Gulf Hwy Dr
26	15007000	S. Missouri Ave	3.041	Pinellas	East Bay Dr	Court St
27	15010000	5th Ave N	17.066	Pinellas	4th St N	East Bay Dr
28	15020000	Alt US 19	5.271	Pinellas	Myrtle Ave	Orange St
29	15030000	East Bay Dr	6.627	Pinellas	Seminole Blvd	Ulmerton Rd
30	15040000	Gulf to Bay Blvd	4.715	Pinellas	Highland Blvd	Damascus Rd
31	15050000	Drew St	6.792	Pinellas	N Myrtle Ave	Delaware St
32	15100000	Gulf Blvd	7.858	Pinellas	SR 682	SR 666
33	15110000	Passadena Ave	1.775	Pinellas	Blinds Pass Rd	Park St
34	15120000	Ulmerton Rd	11.828	Pinellas	Gulf Blvd	I-275
35	15140000	Gulf Blvd	6.752	Pinellas	SR 666	Walsingham Rd
36	15150000	US 19	30.962	Pinellas	54th Ave S	Live Oak St
37	15240000	Gandy Blvd/4th St	5.883	Pinellas	US 19	I-275

Lighting Data Summary

Table 3 shows the sample of collected raw data, which is measured every 40ft. The measured data were coded into the GIS system by Tindale-Oliver & Associates, Inc. and aggregated by portions of roadway segment (.05 mile) to investigate the relationship between illumination level and nighttime crashes. These specific details can be seen in Volume II.

Table 3 Collected Illumination Level (Raw Data-Sample)

Mile Post	<i>Illuminance (foot candle)</i>			<i>Illuminance (foot candle)</i>			<i>Both Directions</i>
	Left Outer	Left Inner	Left Average	Right Inner	Right Outer	Right Average	Average
7.841	0.09	0.13	0.11	0.14	0.08	0.11	0.11
7.848	0.11	0.14	0.12	0.09	0.07	0.08	0.10
7.856	0.16	0.16	0.16	0.08	0.08	0.08	0.12
7.864	0.20	0.20	0.20	0.09	0.09	0.09	0.15

A total of 97 percent of roadways on which lighting data were collected are “urban-principal arterial” or “urban-minor collector” in terms of functional classification; the cumulative inventory of illumination level for those roadways is illustrated in Figure 3. As can be seen, more than 60 percent of roadways have illumination levels below 1.0 fc, and 90 percent of principal arterials in urban area have illumination levels below 1.5 fc.

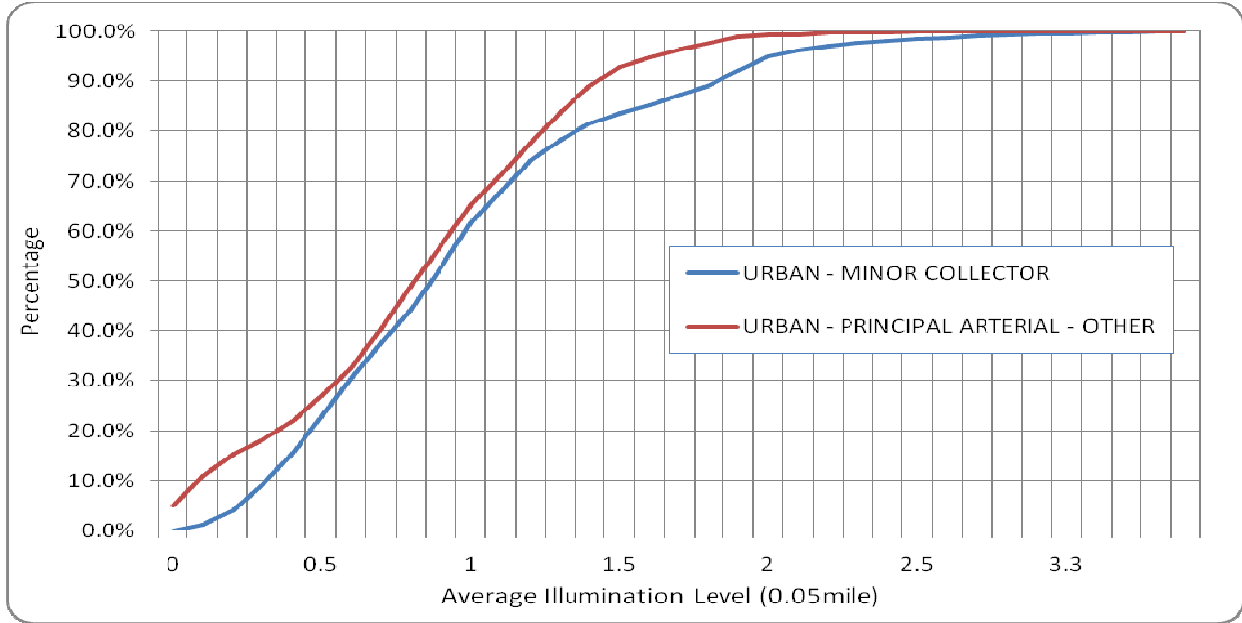


Figure 3 Cumulative Percentage of Illumination Levels on Roadways

Figure 4 shows the averaged illumination level by 0.05 mile segments in the Tampa Bay area. The darkest areas represent the locations where the illumination level is lower than 0.5 fc.

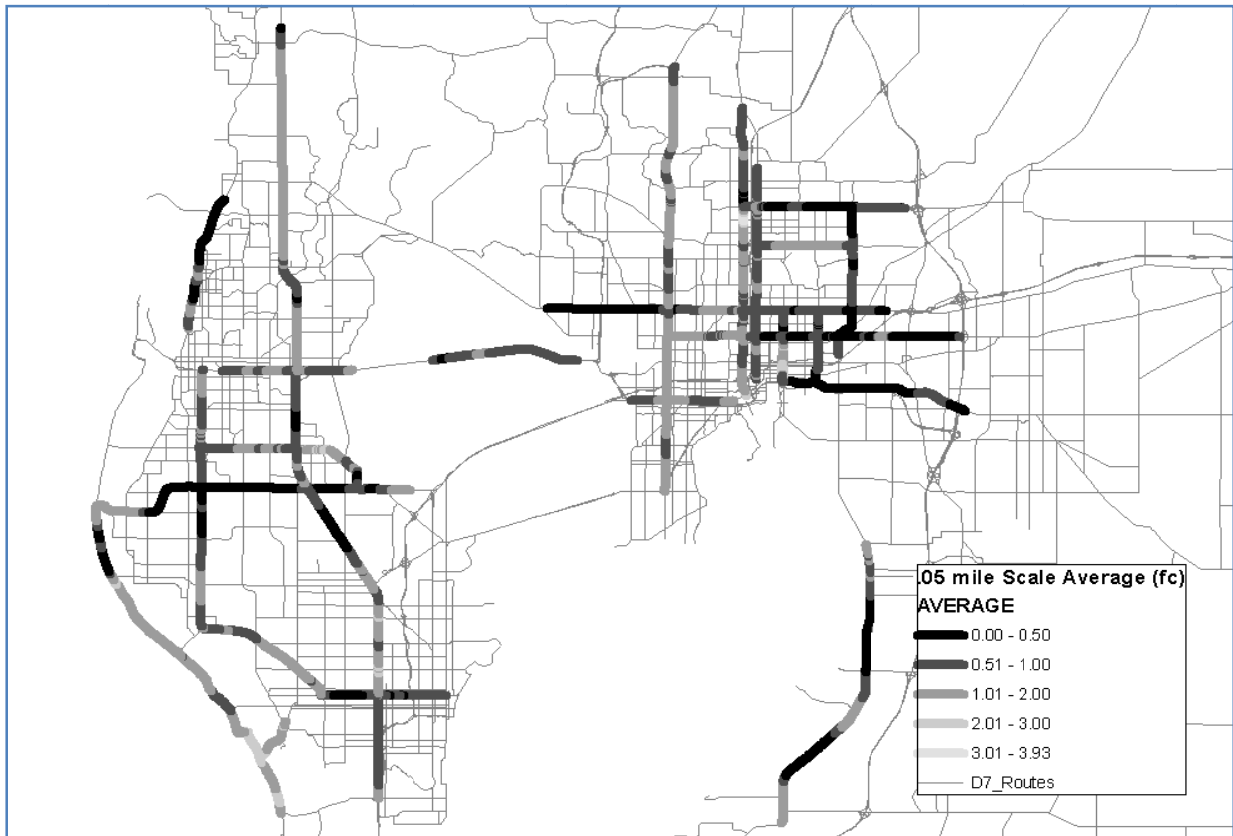


Figure 4 Average Illumination Level Map in Tampa Bay Area (0.05mile segments)

To evaluate the collected illumination levels effectively, random sampling was used. A total of 100 random samples of n consecutive (measured every 40 ft) lighting data points were drawn from each corridor segment dataset. The starting point of the n consecutive data points was randomly selected. The proposed sampling method with 100 trials assures the result with a 95 percent confidence interval. The collected response was the average lighting in both directions. For each sample, the following information was calculated:

- Average, Minimum, Maximum
- Ratio Average/Minimum
- Ratio Maximum/Minimum

The results of the analysis were plotted and compared to pre-established criteria for road lighting conditions evaluation. These criteria can be summarized as follows:

- the average lighting of the sample ≥ 1.5 fc or 1.0 fc
- the ratio of average/minimum ≤ 4.0
- the ratio of Maximum/Minimum ≤ 10

As can be seen in Figure 5, when the “0.05 mile” window (n=6) was used to calculate the average of illumination on the roadway, it appeared that most corridors in study area did not meet the illumination level recommended in the Plans Preparation Manual (Table 1). However, it is noted that FDOT’s criteria is for initial average illuminance levels. The measures in Figure 5 are the maintained illuminance levels. According to the “Roadway Lighting Design Guide” from AASHTO, output from the luminaire is reduced by 2-7% per year for various reasons.

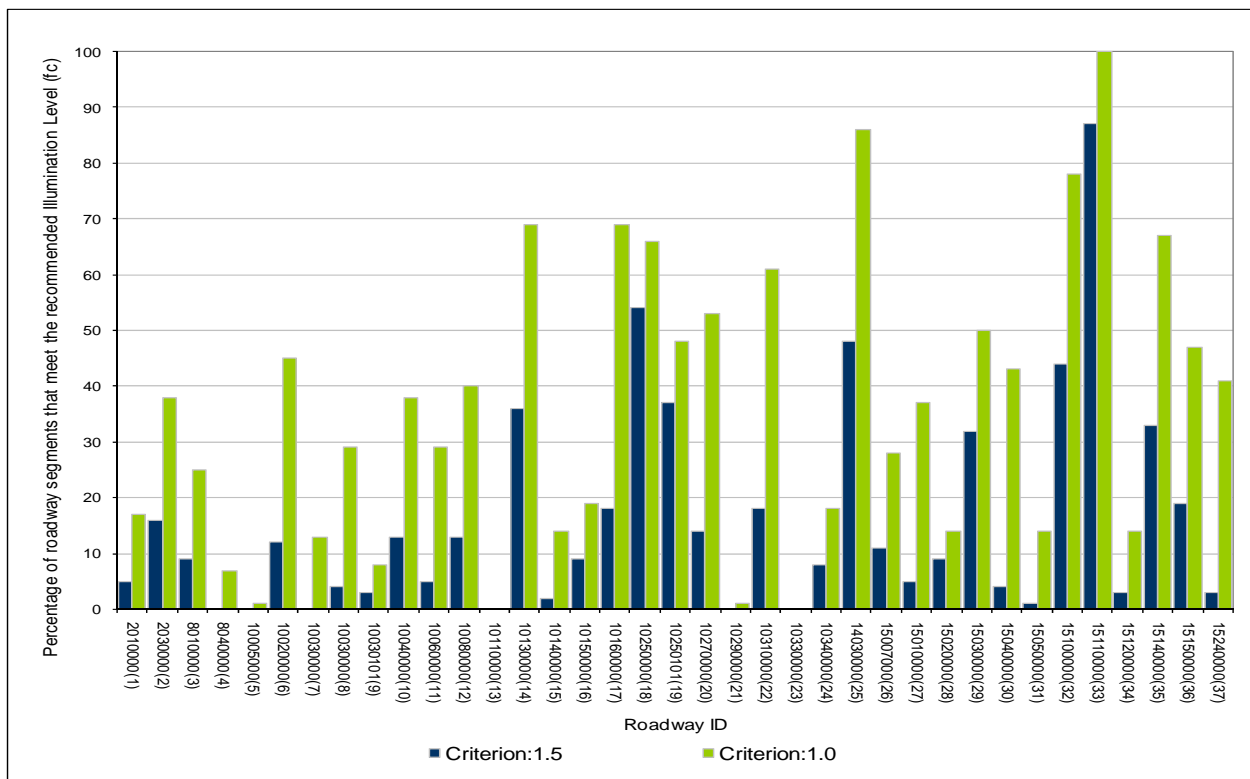


Figure 5 Percentage of Roadway Segments That Meet the FDOT-Recommended Illumination Level (fc)

Crash Data Summary

Crash data in FDOT District 7 between 2002 and 2007 were obtained and selected by lighting condition. A total of 1,743 crashes over the six-year period indicate that lighting conditions were reported as “Dark (No Street Lighting).” Considering that the number of nighttime crashes involving no lighting in the area has stayed essentially the same over the last six years, it can be assumed that street lighting conditions improved in FDOT District 7 between 2002 and 2007.

After initial efforts to analyze the crash data and illumination levels, it was found that the measured levels of illumination for intersections and mid-block locations is different in general. To conduct the study in an effective and efficient manner, the crashes were divided into four groups based on crash location (At Intersection, Influenced by Intersection, Not at Intersection/RRxing/Bridge, and Other) and treated separately throughout the study. Tables 4 and 5 summarize nighttime crashes for the four groups by years.

Table 4 Nighttime Crashes with No Street Lights

<i>Year</i>	<i>Site Location</i>				<i>Total</i>
	<i>At Intersection</i>	<i>Influenced by Intersection</i>	<i>Not At Intersection/ RRxing/Bridge</i>	<i>*Others</i>	
2002	175	31	134	30	370
2003	124	31	124	15	294
2004	185	23	112	24	344
2005	154	15	84	24	277
2006	106	17	97	24	244
2007	79	16	101	18	214
Total	823	133	652	135	1743

Table 5 Nighttime Crashes with Street Lights

<i>Year</i>	<i>Site Location</i>				<i>Total</i>
	<i>At Intersection</i>	<i>Influenced by Intersection</i>	<i>Not At Intersection/ RRxing/Bridge</i>	<i>*Others</i>	
2002	1476	159	624	224	2483
2003	1258	207	740	166	2371
2004	1525	235	668	152	2580
2005	1663	212	571	205	2651
2006	1641	200	586	209	2636
2007	1531	147	675	161	2514
Total	9094	1160	3864	1117	15235

*Other crashes include bridges, driveway access, entrance/exit ramps, public bus stop zones, and railroad crossings.

Figure 6 shows the distribution of nighttime crashes by time of day. In general, when traffic volume decreases, the number of nighttime crashes is reduced. A comprehensive analysis for each corridor can be found in Volume II.

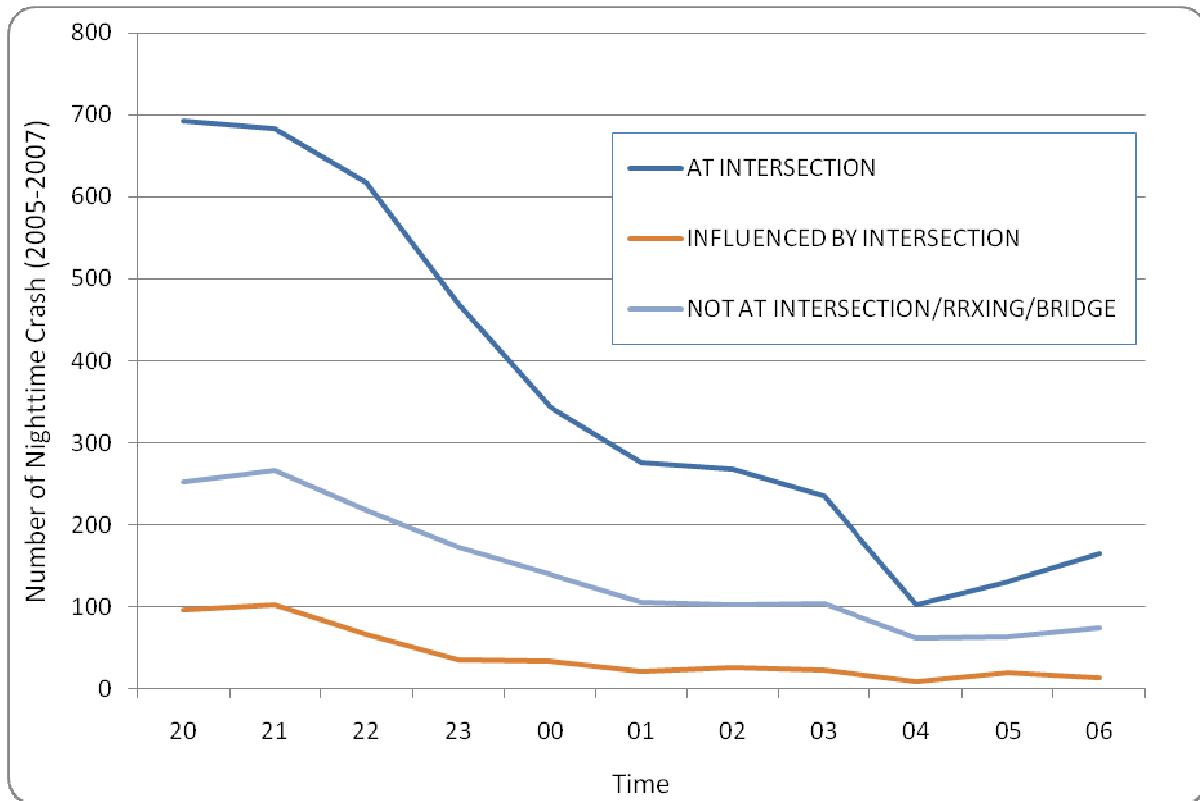


Figure 6 Number of Nighttime Crashes by Time of Day (2005-2007)

Data Analysis

1. Nighttime Crash Index

To understand the spatial distribution of nighttime crashes on roadways, two Nighttime Crash Index (NCI) methods were used. NCI1 calculates the ratio between nighttime crashes and daytime crashes as follows:

$$NCI1 = \frac{\frac{\text{Number of Nighttime Crashes}}{\text{Percentage Nighttime Traffic Volume}}}{\frac{\text{Number of Daytime Crashes}}{\text{Percentage Daytime Traffic Volume}}}$$

The ratio of traffic volume between daytime and nighttime for each corridor was calculated using AADT and 48-hour counts in FTI (Florida Traffic Information) data. NCI1 is intended to present a relative concentration of nighttime crashes compared to daytime crashes. The average of NCI1 in the study area was 2.0, which means twice the number of crashes occurred during nighttime compared to daytime within the selected segment. High NCI1, which is greater than

2.0, indicates that the roadway segment has a relatively higher risk for nighttime crashes compared to daytime on the roadway.

However, this indexing method is not appropriate for reflecting traffic volume difference between roadway segments. To address this, a second indexing method was developed, as follows:

$$NCI2 = \frac{\text{Number of Nighttime Crashes (per mile per 10,000 vehicles)}}{\text{Average Number of Nighttime Crashes (per mile per 10,000 vehicles)}}$$

NCI2 is intended to normalize the number of crashes by length of roadway and traffic volume. Also, the average number of nighttime crashes in the study area was used as a denominator. Therefore, if NCI2 is higher than 1, it means the roadway has a relatively higher risk for nighttime crashes compared to other roadway segments.

If a roadway segment meets both conditions, “NCI1 is higher than 2” and “NCI2 is higher than 1”, it is reasonable to say that the roadway segment requires further investigation for potential nighttime crashes.

NCI1 and NCI2 were calculated for a total of 35 corridors on which lighting data were collected and have available crash data. Table 6 shows a sample of NCI1 and NCI2 for a roadway. (For details, refer to Appendix A.)

Table 6 Sample NCI1 and NCI2 Calculations (Roadway ID: 02010000)

<i>Mile Post</i>			<i>AADT</i>	<i>2005</i>		<i>2006</i>		<i>2007</i>		<i>2005-2007</i>	
<i>Begin</i>	<i>End</i>	<i>Length</i>		<i>NCI1</i>	<i>NCI2</i>	<i>NCI1</i>	<i>NCI2</i>	<i>NCI1</i>	<i>NCI2</i>	<i>NCI1</i>	<i>NCI2</i>
9.027	11.381	2.354	16000	5.34	0.41	3.05	0.27	5.34	0.14	4.58	0.27
11.381	12.198	0.817	24000	0.00	0.00	7.79	0.76	0.00	0.00	2.60	0.25
12.198	12.502	0.304	29500	2.91	0.48	2.49	0.96	2.91	0.96	2.77	0.80
12.720	13.136	0.416	35000	0.00	0.00	1.89	0.31	6.28	0.63	2.72	0.31
13.136	14.654	1.518	18800	5.12	0.52	2.56	0.17	0.00	0.00	2.56	0.23
Roadway Average				2.67	0.28	3.56	0.50	2.91	0.34	3.04	0.37

As can be seen in Tables 7 and 8, NCI1 and NCI2 were calculated for 35 corridors, and the corridors were ranked to identify the roadways with high nighttime crash potential.

Table 7 Segments Ranked Using NCI1

<i>Roadway ID</i>	<i>NCI1</i>	<i>Rank by NCI1</i>	<i>NCI2</i>	<i>Average Illumination Level (fc)</i>
10030000	3.99	1	1.08	0.68
8010000	3.82	2	0.65	0.71
15007000	3.62	3	0.76	0.75
15040000	3.18	4	1.12	0.89

15100000	3.16	5	0.73	1.38
10140000	3.09	6	0.26	0.75
2010000	3.04	7	0.37	0.63
10060000	3.01	8	0.55	0.80
15030000	2.77	9	0.82	1.05
15140000	2.72	10	0.77	1.08
15120000	2.63	11	1.14	0.48
10080000	2.33	12	1.45	1.22
10110000	2.27	13	0.68	0.21
15020000	2.14	14	0.43	0.49
10270000	2.07	15	1.14	1.16

It was found that 15 segments among the 35 corridors have an NCI1 calculation greater than 2, which is the average for the study area. Using NCI2, since the average of the study area is used as a denominator in the indexing equation, values more than 1 represent the segments with more crashes by segment during nighttime periods. A total of 12 corridors were identified to have NCI2 greater than 1.

Table 8 Segments Ranked Using NCI2

Roadway ID	NCI2	Rank by NCI2	NCI1	Average Illumination Level (fc)
10250101	5.79	1	1.48	1.48
10250000	4.56	2	1.55	1.96
10040000	2.44	3	1.61	0.91
10080000	1.45	4	2.33	1.22
10020000	1.36	5	1.46	1.14
10340000	1.21	6	1.50	0.65
10270000	1.14	7	2.07	1.16
15120000	1.14	8	2.63	0.48
15040000	1.12	9	3.18	0.89
10005000	1.09	10	1.58	0.55
10030000	1.08	11	3.99	0.68
10290000	1.02	12	1.32	0.44
10030000	0.96	13	1.29	0.65
10150000	0.94	14	1.31	0.55
10030101	0.83	15	1.85	0.63

Table 9 presents the five segments that were ranked having an combined NCI1 and NCI2 of higher than the average of the study area.

Table 9 Segments with the Highest NCI

<i>Roadway ID</i>	<i>NCI1</i>	<i>Rank#</i>	<i>NCI2</i>	<i>Rank#</i>	<i>Average Illumination Level (fc)</i>
10030000	3.99	1	1.08	11	0.68
10080000	2.33	12	1.45	4	1.22

10270000	2.07	15	1.14	7	1.16
15040000	3.18	4	1.12	9	0.89
15120000	2.63	11	1.14	8	0.48

Figure 7 shows the cumulative percentage of crashes by illumination level. It is noted that a much higher percentage of nighttime crashes occurred in areas with no street lighting compared to the roadway illumination level inventory. However, nighttime crashes that occurred in areas with street lighting have almost same cumulative distribution as the actual roadway illumination level inventory.

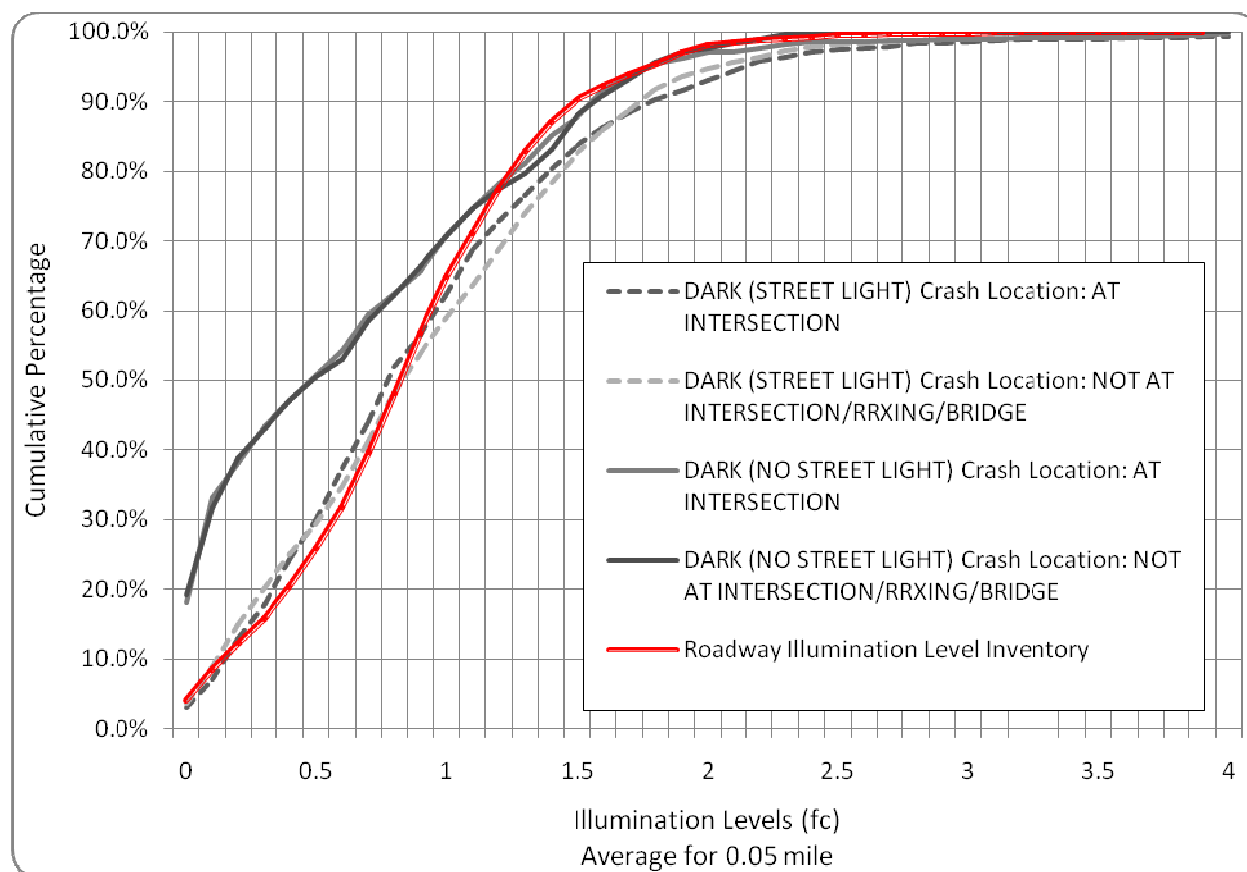


Figure 7 Cumulative Percentage of Crashes by Illumination Level (With/Without Street Lighting)

2. Nighttime Crash Models

To understand the relationship between nighttime crashes and illumination levels, the illumination data were averaged for each 0.05-mile segment, and crash data were aggregated for each 0.05-mile segment. Since information on the illumination levels for those periods was limited, and actual lighting measurements were conducted only in 2007, three years (2005-2007) of crash data were adopted for further analysis to minimize errors due to changes in the illumination environment over the years. The average number of crashes was calculated per 0.05-mile segment for three years (2005-2007) and compared with the illumination levels of the segments. Intersection crashes and non-intersection crashes were analyzed separately according

to the findings from initial data analysis effort. Figure 8 illustrates the total number of crashes per 0.05-mile segment based on illumination levels.

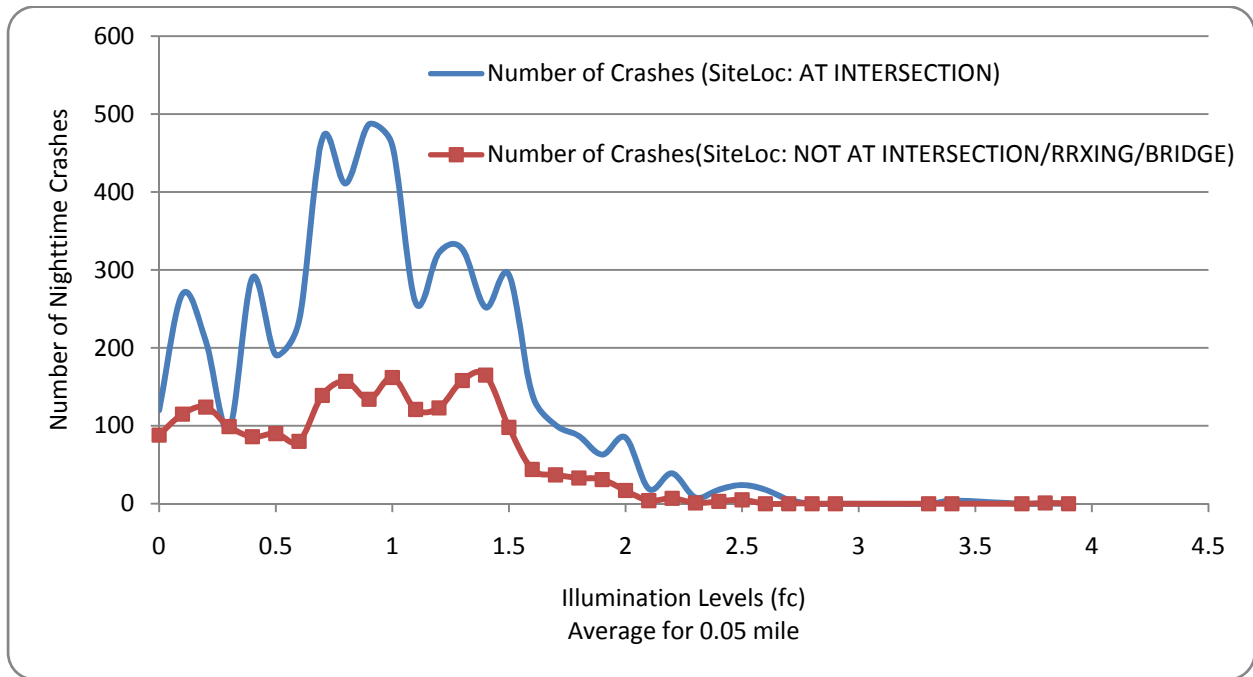


Figure 8 Number of Nighttime Crashes by Illumination Level (fc)

A simple linear regression model was applied to determine a relationship between nighttime crashes and illumination levels. As can be seen in Figure 9, non-intersection nighttime crashes reveal significant statistical association with illumination levels. However, it is noted that there are very limited data (less than 2 % of entire roadways; refer to Table 4) for illumination levels ≥ 2.5 fc.

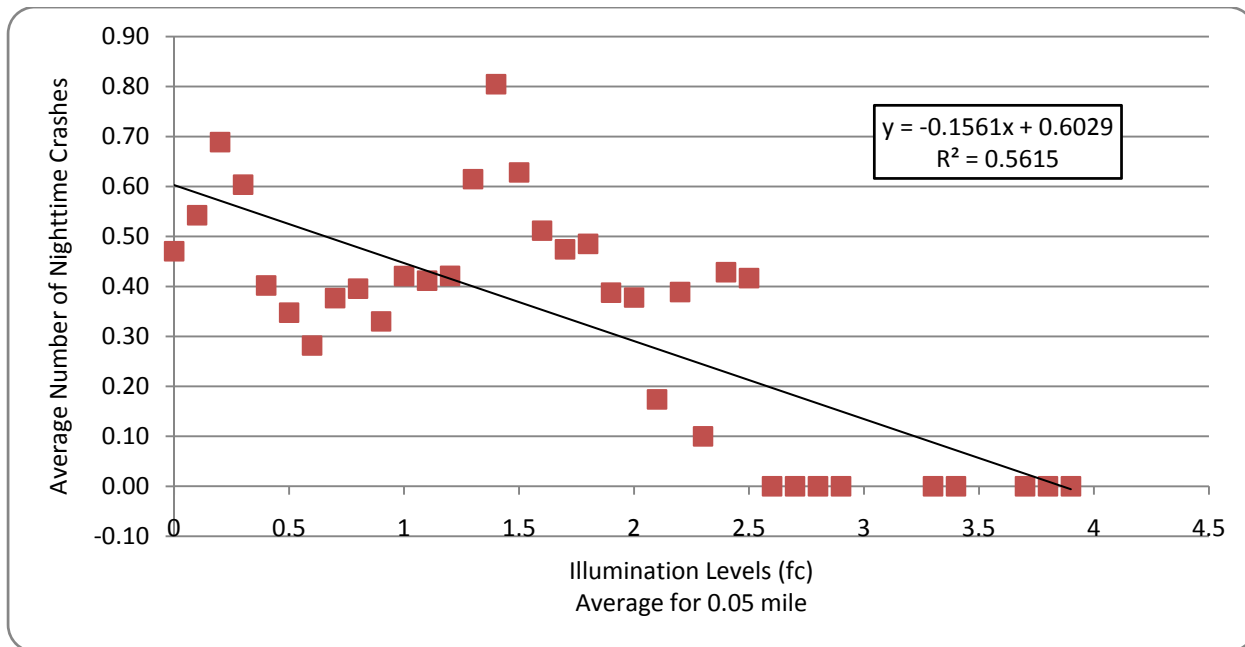


Figure 9 Average Number of Crashes Not at Intersection/RRxing/Bridge

If the model includes only the data for which the illumination level is below 2.0 fc, the explanatory power model is significantly reduced. The revised model has $R^2 = 0.09$, which means that only 10 percent of the dataset can be explained by the regression line. This implies that it is desirable to develop models by using a piecewise linear regression approach.

To construct a better model, the data range was divided, and a separate model was proposed for the roadways where the illumination level is less than or equal to 1.0 fc. This includes 65 percent of the study area. As can be seen in Figure 10, the developed model shows that an increase in illumination levels will result in a reduction in the number of nighttime crashes in non-intersection areas.

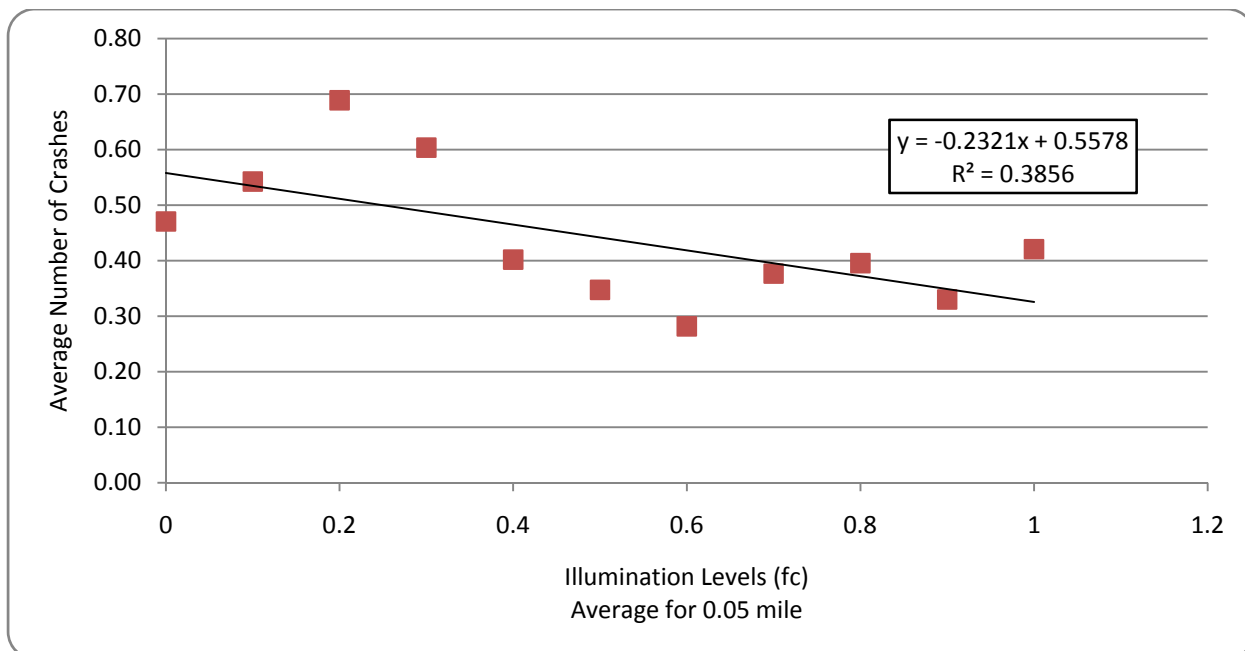


Figure 10 Average Number of Crashes Not at Intersection/RRxing/Bridge (fc < 1.0)

However, nighttime crashes at intersections do not reveal a clear relationship with illumination levels. Figure 11 illustrates the relationship between average nighttime crashes at intersections and illumination levels. Intuitively, it is assumed that this is due to other contributing factors, such as multiple conflict points and various lighting conditions.

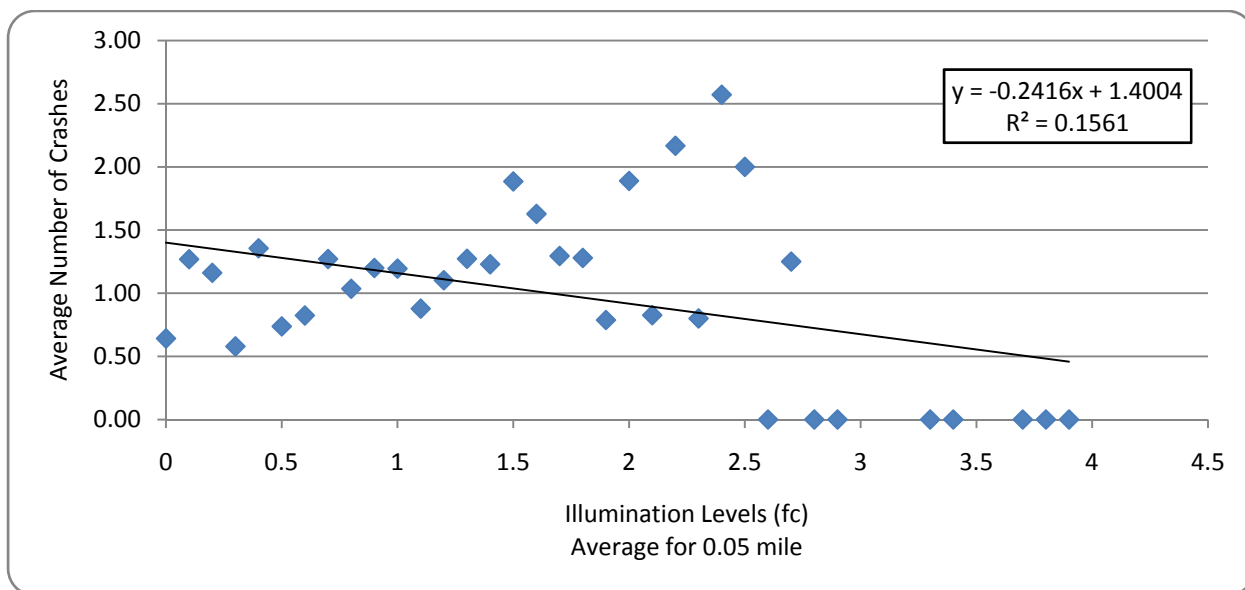


Figure 11 Average Number of Crashes at Intersections

Rigorous efforts were made to identify other contributing factors of nighttime crashes at the intersections, including the relationship with illumination levels, by using advanced multivariate regression tree methods, but the efforts were limited by several unknown factors, such as the various sources of illumination along with roadways and information on nighttime activities.

As can be seen in Figure 12, the measured level of illumination is relatively high when the posted speed limit is equal to 30mph compared to other roadways, but it is doubtful that the level of illumination is exclusively achieved by street lighting. It is fair to assume that the higher levels of illumination on those roadways may be from the presence of landuse that induces nighttime activities, which can result in increasing the potential for nighttime crashes.

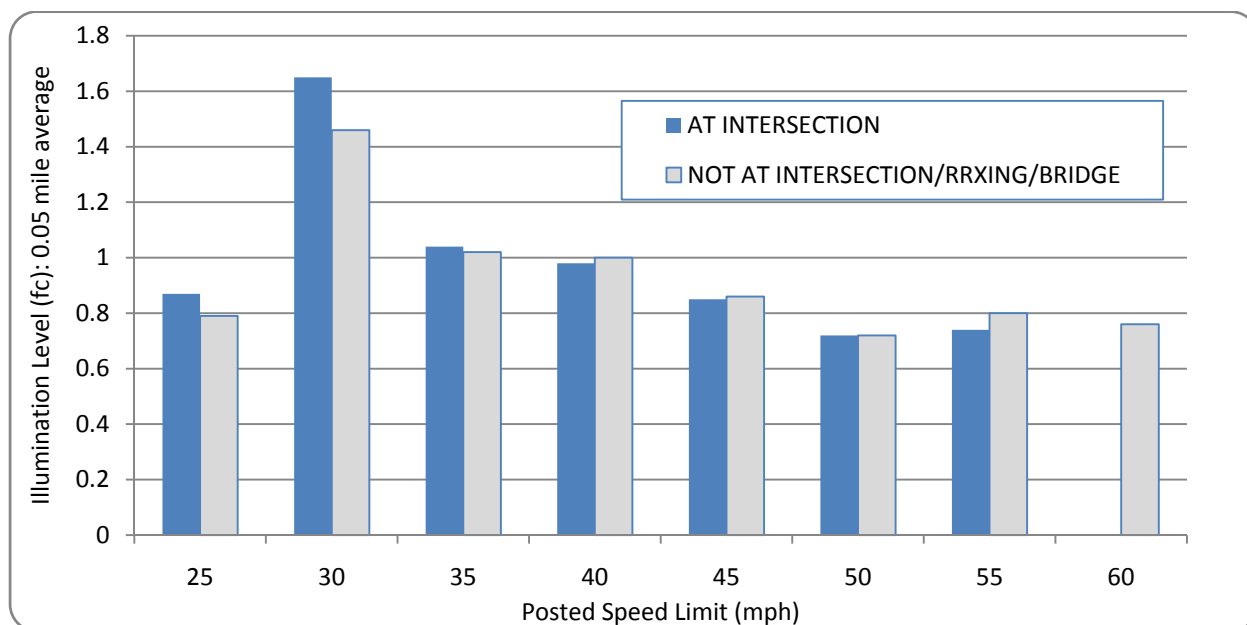


Figure 12 Average Illumination Level based on Posted Speed Limit

As can be seen in Figures 12 and 13, the study does not find a significant statistical association between illumination level and pedestrian crash or bike crash during nighttime. It shows somewhat fragmentary relationship and the number of nighttime crash seems to increase slightly as the level of illumination increases until illumination level is equal or less than 1.0 fc.

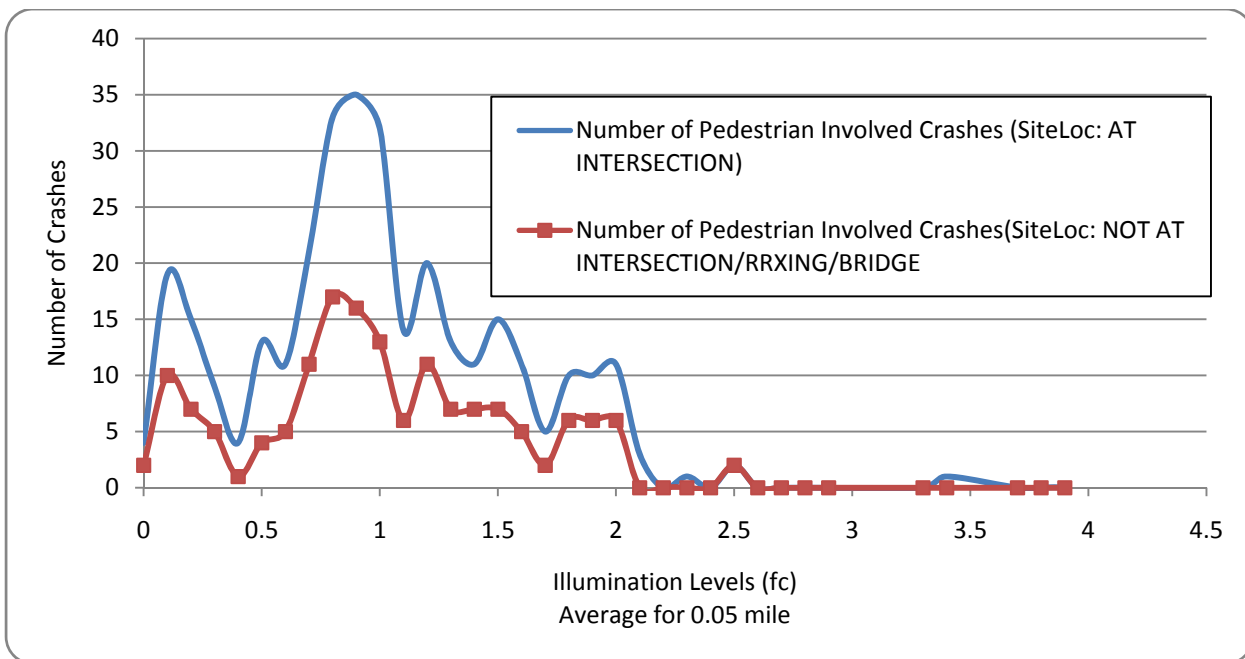


Figure 13 Number of Pedestrian Involved Crashes by Site Location

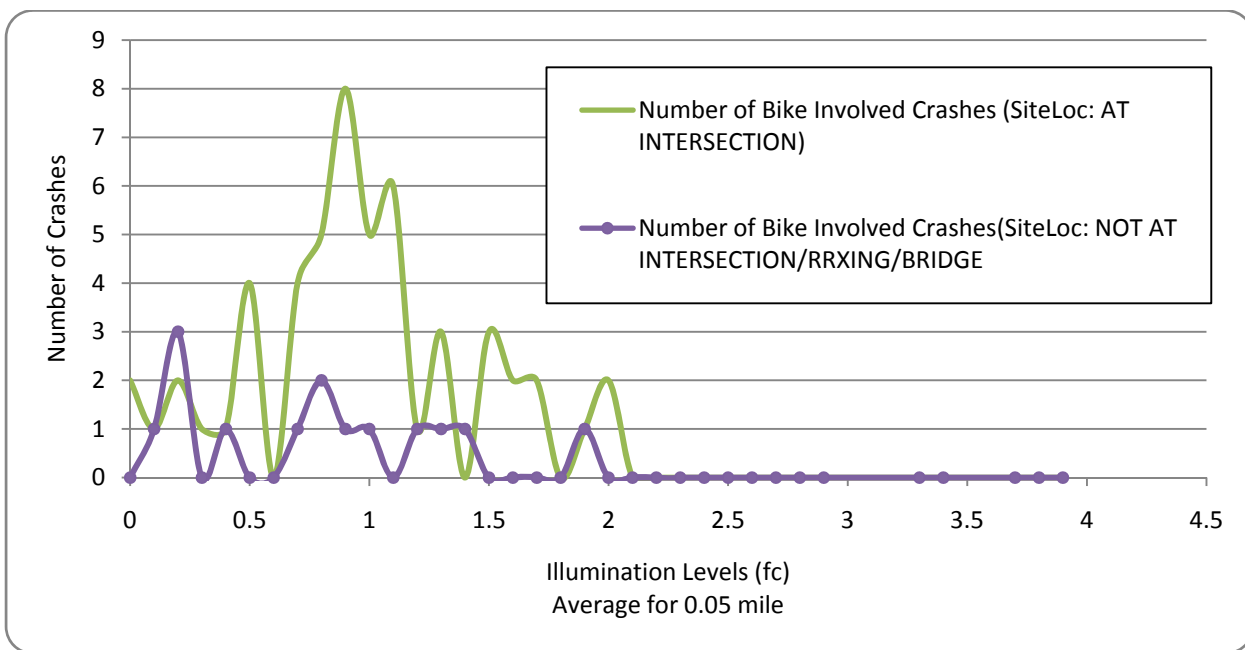


Figure 14 Number of Bicycles Involved Crashes by Site Location

As can be seen in Figures 14 and 15, DUI and speed-related crashes occurring during nighttime also showed a similar relationship as pedestrian or bicycle crashes.

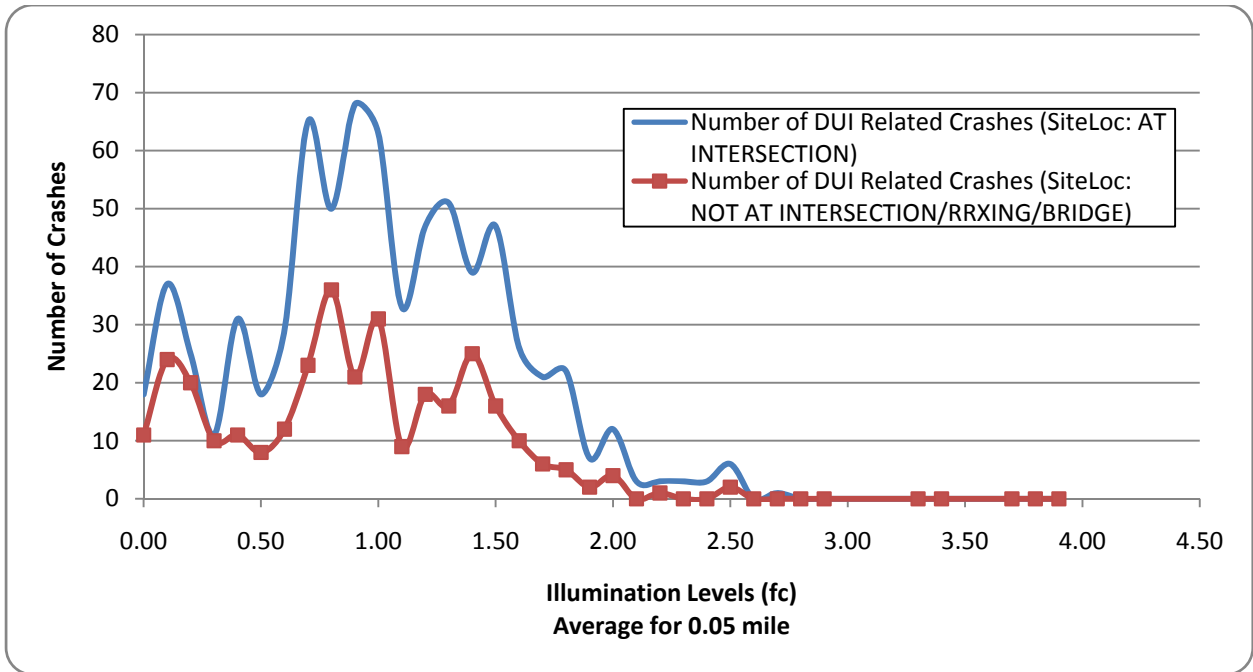


Figure 15 Number of DUI-Related Crashes by Site Location

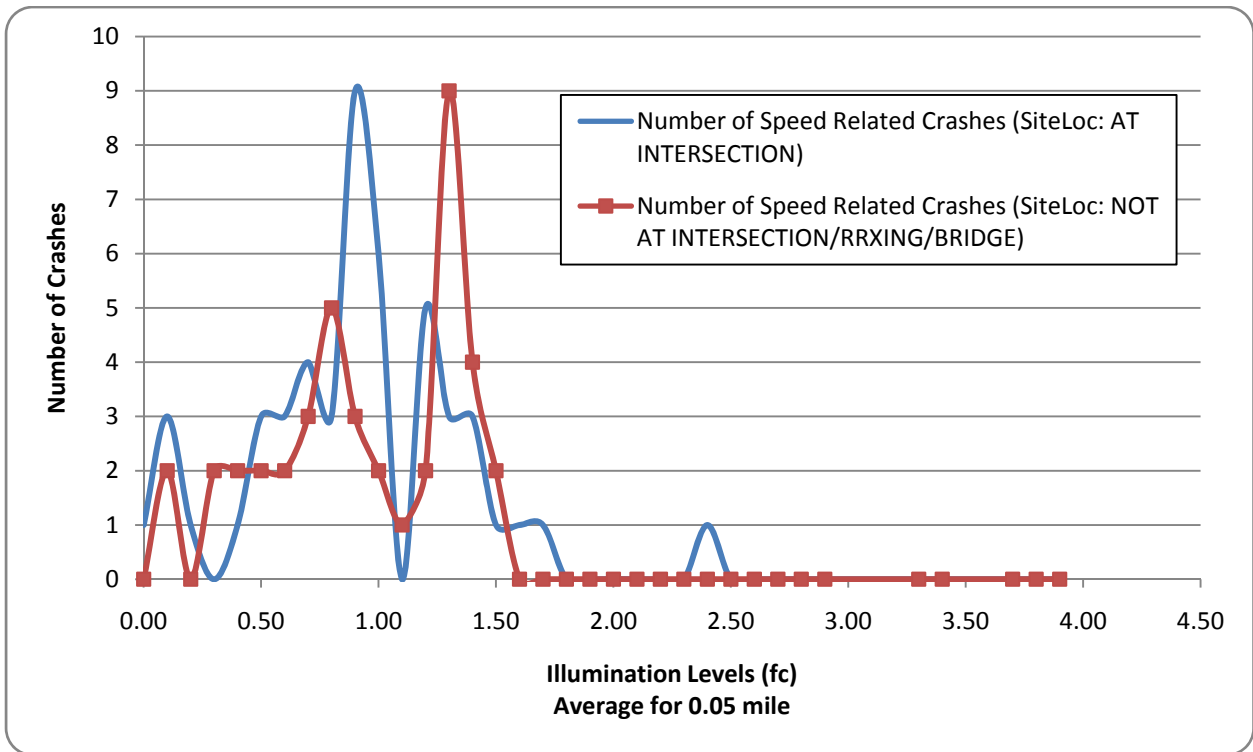


Figure 16 Number of Speed-Related Crashes by Site Location

Conclusion

In this study, illuminance lighting level data were collected from approximately 245 centerline miles of roadways in FDOT District 7. The illuminance measurements were collected every 40 ft on the right (outside) side and left (inside) side lane for each direction of the roadway. The collected lighting data were aggregated to 0.05-mile segments, and three years (2005-2007) of crash data for the area were obtained and aggregated to the same interval.

After initial analysis efforts, it was found that there is a difference in illumination levels between intersection and non-intersection areas in general. To address the issue in an effective and efficient manner, “At Intersection” crashes and “Not at Intersection/RRxing/Bridges” were divided and studied separately. Major findings are follows:

- When the illumination level is the same, intersections have many more crashes than mid-block locations during nighttime.
- In general, nighttime crashes at various illumination levels are proportionally distributed among the inventory of illumination levels for roadways.
- The study was intended to understand the relationship between illumination levels and crash history. Since illumination levels were measured only once (in 2007), the study was designed as a cross-sectional study. The fundamental difference between cross-sectional and longitudinal studies is that cross-sectional studies take place at a single point in time and longitudinal studies involve a series of measurements taken over a period of time.
- To minimize potential bias from illumination environment changes across the years, crash data collection was limited to three years.
- According to the measurement in 2007, the illumination levels of most roadways in the study area do not meet the standards recommended by FDOT’s Plan Preparation Manual.
- To understand the spatial distribution of nighttime crashes on roadways, two Nighttime Crash Index (NCI) methods were developed and applied to entire roadways based on AADT information from the FTI (Florida Transportation Information) DVD. When the number of crashes is normalized using traffic volumes, the nighttime crash rate is two times higher than daytime in the study area. Five corridors were identified as high nighttime crash roadways based on the indexes. However, no clear statistical association was observed between the indexes and illumination levels.
- A simple linear regression model was proposed to explain the relationship between “Not at Intersection/RRxing/Bridge” crashes and illumination level. It appears that illumination level is not a dominant variable that affects the occurrence of nighttime crashes at intersections. No clear relationship was observed between illumination level and crashes at intersections.

- The study did not find a significant relationship between illumination level and pedestrian or bicycle crashes during nighttime. It shows a somewhat fragmentary relationship, and the number of nighttime crashes increases slightly as the level of illumination increases.
- Interestingly, many roadway segments where illumination levels are high enough often have a significant number of nighttime crashes. Since most roadway segments in this study are urban arterials, it is possible that a significant presence of nighttime activities along roadways, even though they have better illumination levels, may increase the potential for nighttime crashes.

According to this study, levels of illumination are affected by various sources, and it is important to be able to collect extensive lighting data across short distances along the roadways. As the illumination level data are aggregated and averaged for longer distances, the ability to understand the relationship between illumination levels and nighttime crashes is significantly reduced.

It seems that mid-block locations of roadways with good illumination levels have lower nighttime crash potential, but no clear relationship is found between illumination levels and nighttime crashes at intersections. It is recommended that illumination level data be collected from intersection and non-intersection areas separately. Also, it is recommended that locations where the illumination level is abnormally high or low be revisited to confirm the source of illumination.

Additionally, several items were identified in the study that may help to understand the relationship between illumination levels and nighttime crashes such as land use along roadways including access and nighttime demand and activities.