Traffic Safety Benefits of Using Highway Lighting Technology: (Case Study: 4-Lanes Expressways in the Rural Areas)

Muamer Abuzwidah1, *, Mohsin Balwan2, Mohamed Abdel-Aty3, Ghazi Al-Kateeb4

1Department of Civil and Environmental Eng., University of Sharjah, Sharjah, U.A.E
2Traffic Engineering Department., Sharjah Roads & Transport Authority, Sharjah, U.A.E
3Department of Civil, Environmental, and Construction Eng., University of Central Florida, U.S.A
4Department of Civil and Environmental Eng., University of Sharjah, Sharjah, U.A.E

mabuzwidah@sharjah.ac.ae, m.balwan@srta.gov.ae, m.aty@ucf.edu, galkhateeb@sharjah.ac.ae

Abstract. Highway Lighting (HL) is designed and implemented on the transportation system for expected societal, safety and security reasons. The use of Technologies such as LED lighting and the solar power can encourage many transportation agencies to implement the Highway Lighting on their roads, especially on the rural roads where there are difficulties to connect the power, also it known that the typical Highway Lighting is need a lot of energy. The main goal of this paper is to evaluate the safety effectiveness of the implementation of highway lighting on the Night-Time Crashes on 4-Lanes expressways in the rural areas. An advanced Cross-Sectional method was used to evaluate the effect of adding highway lighting on the safety performance of expressways as a major part of the transportation system. The data was carefully selected and only expressways with 4-lanes were chosen because there were enough treated and reference segments for them. In the Cross-sectional models, a total number of 22 treated segments and 155 untreated segment located on the 4-lanes expressways in Florida State were used. The results showed that adding HL has a positive effect on Crash reduction for the night-time Crashes (all crash types and all severity levels) by an approximately 30 percent. The night-time fatal and serious injury crashes were reduced by 27 percent while the Non-Injury crashes were reduced by 21 percent. Overall, implementing HL technologies is highly encouraged especially on the rural roads to improve safety and security. The Crash Modification Factors developed would help transportation officials to benefit from the extensive research in adding highway lighting to the road network, especially on expressways by providing quantitative information on crash analysis and evaluation for decision making in planning, design, operation, and maintenance.

1. Introduction

In recent decades, urbanization has increased rapidly, resulting in an unprecedented growth in transportation crashes that cause losses of life and property. Preventing traffic crashes in order to improve public safety, transportation system performance, and safe routing has become crucial. It is highly useful to predict potential future crash situations (how, when, or where), not only for individual travelers and transportation administrators but also for public safety stakeholders etc. [1, 2].
Highway Lighting (HL) is designed, fabricated and installed for expected societal and security reasons at night. Determination of the value of adding lighting to transportation system is hard to quantify, because its value rests not simply upon its tangible implementation and operation costs but on its expected benefits, which are inherently difficult to estimate [3].

The literature showed that highway lighting can improve safety on the transportation system by an average 20 percent [4, 5]. However, this statement must be carefully qualified in light of the potential biases that are inherent to study the effect of the treatment. First, and foremost, these estimates may be biased because of other safety measures closely associated with the implementation of lighting [6]. Moreover, these statistics give no indication of where and when lighting might or might not affect transportation safety. But, it appears for example that lighting has little benefit in areas where there is limited chance of vehicle-vehicle or vehicle-pedestrian conflict [7]. Previous research has been done by National Cooperative Highway Research Program (NCHRP) to assess the possible role of lighting in transportation safety. Some samples of highway lighting presence and crash data were assembled and analyzed to evaluate the impacts of highway lighting on traffic safety in general [3, 9].

Overall, an extensive data collection that includes all 4-lanes expressways in Florida was collected in this study including, traffic data, geometric and crash data. It’s worth to mention that in Florida, there are more than 750 miles of expressways (toll roads). These roads vary in classification (urban, sub-urban, or rural) and the highway lighting condition [10]. To the best of our knowledge, there are no specific study that evaluated the safety impacts of adding highway lighting on the 4-Lanes expressways. So, the main goal of this paper is to evaluate the traffic safety effectiveness of the implementation of the highway lighting on the transportation system performance.

2. Data Preparation
The detailed objectives were achieved for this study by the following main procedures; 1) Data Collection including all 4-Lanes expressways that have HL treatment on the transportation system in Florida. 2) Estimating advanced statistical crash risk evaluation models. 3)Analyzing crash injury severity for these Highways, and 4) Developing crash risk evaluation models.

An advanced Cross-Sectional method was used to evaluate the effect of adding highway lighting on the transportation safety performance of the 4-Lanes expressways. The Cross-sectional method requires the development of crash prediction models known as Safety Performance Functions (SPFs) for the calculation of Crash Modification Factors (CMFs). The data was carefully selected and only expressways with 4-lanes were chosen as a major part of the transportation system.

The models were developed using crash data for both treated and untreated sites for the same time period. The literature recommended that, Cross-Sectional method should include more samples than the Before-After study, (more than a hundred sites) [11]. Sufficient sample size is particularly important when many variables are included in the SPF. This ensures large variations in crash frequency and variables, and helps better understand their inter-relationships. The treated and untreated sites must have comparable geometric characteristics and traffic volume [12].

In this study, a total number of 177 segments (22 treated segments and 155 untreated segment) located on 4-Lanes expressways in the State of Florida were used. A set of SPFs using Negative Binomial (NB) models were developed to estimate CMFs for the HL treatment at expressways. Negative binomial distribution, also known as Pascal distribution, is a constituent of probability distribution that is used alongside random discrete variables [10]. Compared to the NB model, the Poisson-lognormal model provides more flexibility; however, it does have certain limitations, such as its multifaceted approximation of parameters because of the fact that there is no closed form in the Poisson-lognormal distribution.

3. Analysis and Results
Cross-sectional method was used in this study; it should be noted that the CMF for certain treatments can only be estimated using the Cross-sectional method, but not Before-After method. This is because it is difficult to isolate the effect of the treatment from the effects of the other treatments applied at the same time using the Before-After method.
The method is used in the following conditions [12]: 1) the date of the treatment installation is unknown, 2) the data for the period before treatment installation are not available, and 3) the effects of other factors on crash frequency must be controlled for creating a Crash Modification Function (CMF).

The Cross-sectional method requires the development of crash prediction models (i.e. SPFs) for calculation of CMFs. The models are developed using the crash data for both treated and untreated sites for the same time period (3-5 years). According to the Highway Safety Manual [12], 10~20 treated and 10~20 untreated sites are recommended. However, the Cross-sectional method requires much more samples than the Before-After study, say 100~1000 sites.

The SPFs describe night-time crash frequency as a function of explanatory variables including the presence of adding lighting, AADT and length of highway segments as follows:

\[ F_i = \exp(\alpha + \beta_1 \text{Adding Lighting} + \beta_2 \text{Length} \ast \text{AADT}^\beta) \quad (1) \]

where,
- \( F_i \) = Night-Time crash frequency on a road segment i;
- \( \text{Adding Lighting}_i \) = presence of adding lighting on a road segment i (= 1 if the Lighting of a segment i is implemented, = 0 if the Lighting of a segment i is not implemented);
- \( \text{Length}_i \) = length of a road segment i (mile);
- \( \text{AADT}_i \) = average annual daily traffic on a road segment i (veh/day);
- \( \alpha \) = constant;
- \( \beta \) = coefficients for variables.

The results of SPFs for four-lane expressways by severity (injury/non-injury) are shown in table 1. All the factors are statistically significant at a 95 percent confidence level.

| Sev* levels | Night-Time Crashes |
|-------------|---------------------|
| All         | Intercep | Log(AADT) | Adding Lighting | Length | ODP*(K) |
| All         | Est*  | P-Value   | Est*  | P-Value   | Est*  | P-Value   | Est*  | P-Value   |
| All         | -15.216 | <.0072    | 1.669  | <.0058    | -0.310 | 0.0441    | 0.664  | <.0001    | 0.982 |
| Non-Injury  | -12.181 | <.0002    | 1.495  | <.0001    | -0.230 | 0.0361    | 0.724  | <.0001    | 0.954 |
| F+I         | -14.312 | <.0372    | 1.469  | <.0108    | -0.350 | 0.0081    | 0.554  | <.0001    | 0.857 |
| Serious injury | -13.764 | <.0079    | 1.376  | <.0037    | -0.320 | <.0325    | 0.986  | 0.0035    | 1.320 |

Sev* = Severity, Est* = Estimate, ODP* = Over Dispersion Parameter and F+I = fatal and Injury crashes.

After developing the SPFs, the Crash Modification Factors were calculated using the following equation:

\[ CMF = \exp(\beta_1 \ast (1 - 0)) = \exp(\beta_1) \quad (2) \]

The above model can be applied to for prediction of the total crash frequency or frequency of a specific crash type or severity. The standard error (SE) of the CMF is calculated as follows [13]:

\[ SE = \frac{\exp(\beta_k \ast (x_{kt} - x_{kh}) + SE_{\beta_k}) - \exp(\beta_k \ast (x_{kt} - x_{kh}) - SE_{\beta_k})}{2} \quad (3) \]

where,
- \( SE \) = standard error of the CMF;
\( SE_{\beta_k} \) = standard error of the coefficient of the variable (Adding_Lighting).

Table 2. Recommended CMFs for Adding Lighting to 4-lanes Expressways.

| Crash Type               | Severity Levels | CMF | Standard Error | Safety Effectiveness of the treatment (1 - CMF) x 100 = % |
|--------------------------|-----------------|-----|----------------|----------------------------------------------------------|
| All types                | fatal and Injury crashes | 0.73 | 0.09 | (1 - 0.73)*100 = 27%                                      |
|                          | Non-Injury       | 0.79 | 0.10 | (1 - 0.79)*100 = 21%                                      |
|                          | Serious injury   | 0.73 | 0.09 | (1 - 0.73)*100 = 27%                                      |
|                          | All Severity     | 0.70 | 0.10 | (1 - 0.70)*100 = 30%                                      |

It is clear that the treatment has positively affect the night time crashes on the transportation network (4-lane expressways) by reducing all crash types and severity levels as shown in table 2. The fatal and Injury crashes (F+I) were reduced by 27% while the Non-Injury crashes were reduced by 21%. Similar, the Serious injury crashes were reduced by 27% while the all crashes all severity were reduced by 30%.

4. Conclusion

Highway Lighting (HL) is designed and implemented on the transportation system for expected societal, safety and security reasons. The use of Technologies such as LED lighting and the solar power can encourage many transportation agencies to implement the Highway Lighting on their roads, especially on the rural roads where there are difficulties to connect the power, also it known that the typical Highway Lighting is need a lot of energy.

The main goal of this paper is to evaluate the safety effectiveness of the implementation of highway lighting on the Night-Time Crashes on 4-Lanes expressways in the rural areas. An extensive data collection that includes all 4-lanes expressways in Florida was collected in this study including, traffic data, geometric and crash data. It’s worth to mention that in Florida, there are more than 750 miles of expressways (toll roads). These roads vary in classification (urban, sub-urban, or rural) and the highway lighting condition. To the best of our knowledge, there are no specific study that evaluated the safety impacts of adding highway lighting on the 4-Lanes expressways.

The results of this study showed that adding HL has a positive effect on crash reduction for the night-time crashes (all crash types and all severity levels) by an approximately 30 percent. Also, the night-time fatal and Serious injury crashes were reduced by 27 percent while the Non-Injury crashes were reduced by 21 percent.

Overall, implementing HL technologies is highly encouraged especially on the rural roads to improve safety and security. The Crash Modification Factors developed would help transportation officials to benefit from the extensive research in adding highway lighting to the road network, especially on expressways by providing quantitative information on crash analysis and evaluation for decision making in planning, design, operation, and maintenance.

References

[1] Abuzwidah M 2011 Evaluation and Modeling of the Safety of Open Road Tolling System, Master Thesis. Orlando, University of Central Florida.

[2] Ahmed M, Abdel-Aty M, Qi S, Abuzwidah M 2014 Synthesis of state-of the-art in visibility detection systems’ applications and research, J. transport. safety security, 6(3) 183-206.

[3] Bullough J, Rea M, Zhou Y 2009 Analysis of Visual Performance Benefits from Roadway Lighting (NCHRP Project 5-1 report), submitted to National Cooperative Highway Research Program.

[4] Donnell E, Shankar V, Porter R 2009 Analysis of Safety Effects for the Presence of Roadway Lighting (NCHRP Project 5-19 report), submitted to National Cooperative Highway Research Program.
[5] Fisher A 1977 Road Lighting as an Accident Countermeasure, *Australian Road Res.* **7**(4) 3-15.

[6] Bullough J D, Hickcox K, Klein T R, Narendran N 2011 Effects of flicker characteristics from solid-state lighting on detection, acceptability and comfort, *Light. Res. Technol.* **43** 337-48.

[7] Beyer F, Ker K 2009 Street Lighting for Preventing Road Traffic Injuries, *Cochrane Database Syst. Rev.* CD004728.

[8] Donnell E, Shankar V, Porter R 2009 Analysis of Safety Effects for the Presence of Roadway Lighting (NCHRP Project 5-19 report), submitted to National Cooperative Highway Research Program.

[9] Bullough J, Rea M, Zhou Y 2009 Analysis of Visual Performance Benefits from Roadway Lighting (NCHRP Project 5-1 report), submitted to National Cooperative Highway Research Program.

[10] Abuzwidah M, Abdel-Aty M 2018 Crash Risk Analysis of Different Designs of Toll Plazas, *J. Safe. Sci.* **107** 77-84.

[11] Carter, J. A., Agol, E., Chaplin, W. J., et al. 2012 A Pair of Planets with Neighboring Orbits and Dissimilar Densities, *Sci.* **337** (6094) 556.

[12] AASHTO, 2010. The Highway Safety Manual, American Association of State Highway Transportation Professionals, Washington, D.C., [http://www.highwaysafetymanual.org](http://www.highwaysafetymanual.org).