Weights from a Safety Perspective for Interchange Lighting Prioritization

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The focus of this paper is to research and update weights (values indicating the effect) to multiply ratings of selected factors used in the Total Design Process (TDP) for interchange lighting prioritization from a safety perspective. Results based on analysis using data collected at 80 interchanges along nine segments in North Carolina showed differences in weights for currently used factors such as freeway median width, freeway number of lanes and night-time traffic volume per lane. Results also showed that considering the number of night-time crashes by severity instead of night-to-day crash rate ratio, for prioritization of interchange lighting system installation or maintenance, would reduce the bias towards interchanges with fewer numbers of crashes and lead to better utilization of limited available transportation funds.

INTRODUCTION

Transportation statistics indicate that approximately 25% of travel occurs at night (dark light conditions, typically between 7:00 PM and 6:00 AM). However, more than 50% of fatalities occur during this time period (NHTSA 2012). Inadequate roadway lighting in addition to factors such as fatigue, driving under the influence of alcohol or drugs, distracted driving, speeding, and failure to reduce speed are the most common contributing factors of crashes at night.

Improved visibility through illumination increases the probability of a driver to correctly react to the hazard and take appropriate action while driving at night (AASHTO 2005). It is often the first strategy considered and well perceived by the traveling public for locations with high night-time crashes. Several researchers in the past have shown that roadway lighting or illumination helps reduce nighttime crashes on roads and improve safety (Walker and Roberts 1976; Lipinski and Wortman 1978; Schwab et al. 1982; Elvik 1995; Preston and Schoenecker 1999; Elvik and Vaa 2004; Isebrands et al. 2004; Isebrands et al. 2006; Bruneau and Morin 2005; Harwood et al. 2007; Wanvik 2009; Rea et al. 2009; Donnell et al. 2010; Bullough and Rea 2011; Bullough et al. 2013). However, it is very expensive to install the hardware for required or additional lighting. The maintenance and utility charges associated with roadway lighting can often be costly for smaller jurisdictions (Hallmark et al. 2008).

AASHTO (2005) and NCHRP Report 152 (Walton and Rowan 1974) provide several warranting and screening methods to assess and identify potential locations that require roadway lighting to improve safety. The NCHRP Report 152 emphasizes various geometric, operational, and environmental conditions, while AASHTO emphasizes exposure or average daily traffic (ADT).

Several state agencies in the United States use the Total Design Process (TDP) discussed in the NCHRP Report 152 (Walton and Rowan 1974) to assess and prioritize interchange lighting needs. The TDP is a method of assessing the cost-effectiveness of installing roadway lighting and establishing a priority index to determine if investing funds is justified. The priority index is a number (with no units; not comparable with other measures) computed by multiplying need (warrant) and benefit factors (traffic volume) and then dividing by the cost.

The warrant factor is computed using various geometric, operational, and environmental factors, and night-to-day crash rate ratio. The geometric factors include ramp type, cross-road channelization to facilitate, separate or regulated traffic into definite paths of travel using pavement markings and/or traffic islands, frontage roads, freeway lane width, freeway median width, number of freeway lanes, horizontal curve, grade, and sight distance. The operational factors include level-of-service and freeway volume, while environmental factors include percent development, offset to development from traffic lanes, freeway lighting, and cross-road approach lighting. The night-to-day crash rate ratio is defined as the percent of nighttime crashes to the percent of daytime crashes divided by the percent of nighttime traffic volume to the percent of daytime traffic volume.

Each factor considered in the computation of warrants is divided into a maximum of five different ratings (categories 1 to 5) based on the complexity that the driver might encounter due to the factor. The rating of the factor is multiplied by the difference of unlighted and lighted weight for the factor (values indicating the effect of factor under unlighted and lighted conditions) to obtain the warranting points related to the factor. The warranting points of all factors are summed to compute the total interchange warranting points. Based on the tool currently used by the North Carolina Department of Transportation (NCDOT), the maximum number of points an interchange could have for geometric, operational, environmental, and crash factors are 40.5, 30, 23.5, and 40, respectively.

The minimum warranting condition is the total effectiveness achieved by lighting a traffic facility with an average rating of 3 on the subjective scale of 1 to 5 for each factor. It is equal to 90 points and 60 points for complete interchange lighting and partial interchange lighting, respectively. It is generally agreed by practitioners that this 40-year-old document lacks several needed updates. The TDP does not account for various factors that range from nighttime crash severity to traffic composition (percent of heavy vehicles and ramp volume ratio defined as the ratio of ramp volume to the freeway through volume) and other design criteria (e.g., acceleration and deceleration lane lengths). Considering these factors is essential for better utilization of limited available transportation funds. Moreover, no documents pertaining to computation of the lighted and unlighted weights used in TDP could be found in the literature. These weights play a vital role in computing the warranting points and the priority index. There is a need to research current practices, update the state of knowledge, and develop an updated mechanism to prioritize interchanges that require better and enhanced lighting needs. The objectives of the paper, therefore, are to research weights from a safety perspective and develop an updated mechanism to prioritize interchange locations that require lighting.

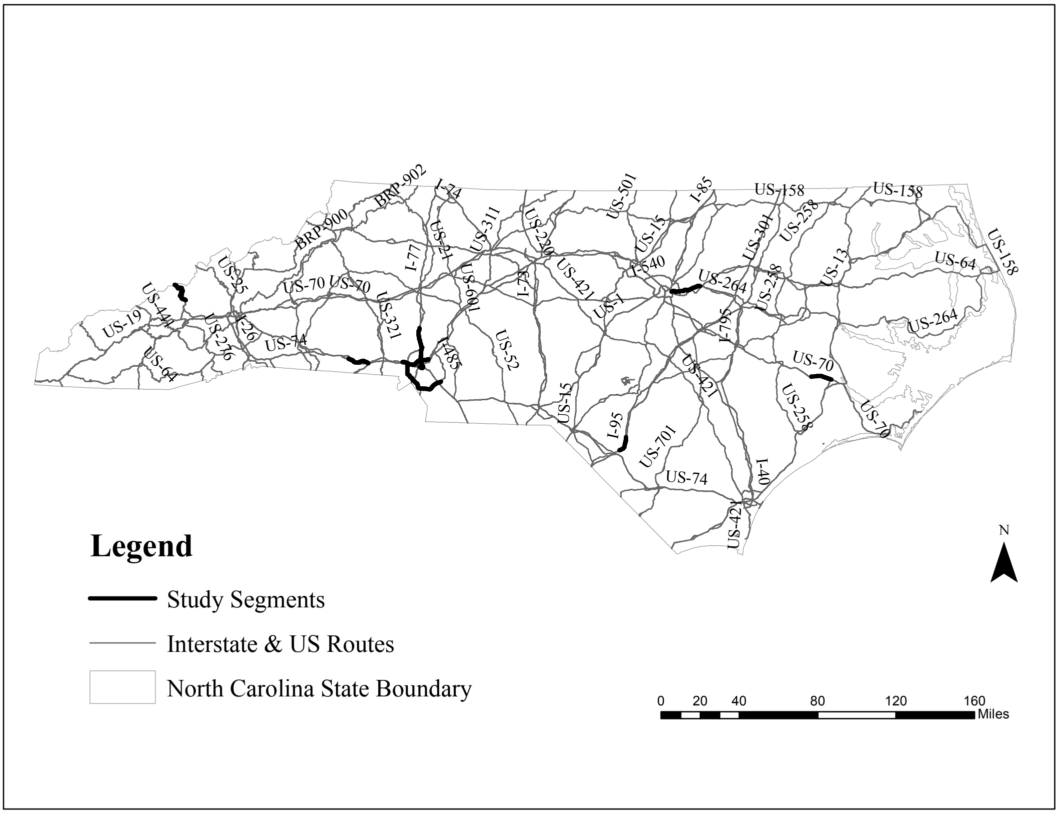
DATA AND RESEARCH METHOD

Nine study segments with full access control in North Carolina were selected to collect data, identify new factors, and compare results obtained from current and updated interchange lighting priority index tools (also referred to as current and updated tools, respectively). These nine study segments include six interstates and three U.S. routes. They are spatially distributed throughout the state of North Carolina (Figure 1). Further, the study segments were selected such that they are located in both rural and urban areas. Eighty interchanges were selected along these study segments for data collection and evaluation.

Interchanges were distinguished based on the exit number. Partial or full cloverleaf interchanges were considered as two separate interchanges. Ramps that have different exit numbers or connect different roads were also considered as separate interchanges.

Crash data from 2006 to 2011 were obtained for the selected interchanges from NCDOT. Traffic data were collected at 25 interchanges between 10:00 PM and 2:00 PM for at least half an hour through field visits. This was primarily done to observe if 25% of ADT (from NCDOT travel survey maps) occurs at night. Observed traffic data indicate that the nighttime traffic volume estimate is less than 15% of ADT at most of the selected interchanges. The percent of heavy vehicle volume at night was observed to be significantly higher (nearly 50% of traffic volume observed) at seven interchanges, with an overall average close to 25% of nighttime traffic volume. Ramp volumes were high at interchanges with a large number of developments. It was observed that ramp volume at

Figure 1: Selected Study Segments



interchanges with no developments within their proximity was less compared with ramp volume at interchanges with developments within their proximity.

Land use characteristics except business operation hours were identified using Google Earth. Most of the land uses within the vicinity of interchanges are residential and commercial developments. Freeway volume and ramp volume were comparatively high at interchanges in urban areas than at interchanges in rural areas, primarily due to commercial activity open at night in urban area. The urban areas also have residential developments near the freeway, resulting in a relatively higher ramp volume at night. All commercial establishments, except gas stations, near selected interchanges were found to be closed after 10:00 PM.

All geometric characteristics for each selected interchange were captured from Google Earth. The interchanges along the selected study segments have relatively flat terrain (less than 3% grade). None of the interchanges along the selected study segments have characteristics of a critical horizontal curve; all are reasonably straight sections.

All lighting characteristics except pole spacing were collected through field visits. Illuminance was measured using a luminance meter. Digital Illuminance / Light Meter LX1330B with a range of 0 to 20,000 foot-candle was used to measure the illuminance. Freeway lighting and cross-road lighting was differentiated as complete (illumination throughout or of all roadways in the interchange) and partial (illumination near or at some points critical to the driver). Type of roadway lights (High Pressure Sodium or any other type), presence of high mast lighting, and lighting from adjacent developments was also noted.

Identify New Factors, Their Categories and Ratings

The crashes at interchanges are typically associated with merging, diverging, and weaving maneuvers. Providing adequate acceleration and deceleration lane lengths will provide ample time for drivers to complete these maneuvers, reduce the number of crashes, and enhance safety at interchanges. The lack of roadway lighting further aggravates the likelihood of nighttime crashes. Therefore, these two factors were considered for further analysis and possible inclusion in the updated tool. Acceleration or deceleration lane length of 750 ft. is generally considered adequate for design purposes. The acceleration and deceleration lane lengths were therefore divided into three categories: 0 to 250 ft., 250 ft. to 750 ft., and greater than 750 ft. The 0 to 250 ft. is the most critical situation. Hence, it was given a rating of 5 in the updated tool. The 250 ft. to 750 ft. is relatively safer than 0 to 250 ft. and was given a rating of 3. As greater than 750 ft. is safest for acceleration or deceleration, it was given a rating of 1.

The placement of signboard also has an effect on diverging maneuvers at interchanges. A distance of one mile for signboard placement from the interchange is generally considered adequate for design purposes. If the signboard is placed at a distance less than one mile from the interchange, the time available for the driver to identify the path and make a decision to diverge from the freeway traffic is relatively less. The lack of roadway lighting at interchanges where signboards are placed close to the interchange would worsen the situation. Therefore, the distance of signboard placement from the interchange was considered as vital for improving safety at interchanges and was examined for further analysis and possible inclusion in the updated tool. The distance of signboard placement from the interchange was divided into three categories: 0 to 1,320 ft., 1,320 ft. to 5,280 ft., and greater than 5,280 ft. The signboard placement distance greater than 5,280 ft. is considered safest and was given a rating of 1. The signboard placement distance category 2,640 ft. to 5,280 ft. is relatively unsafe and was given a rating of 3, while signboard placement distance category 0 to 1,320 ft. was given a rating of 5 as it is more unsafe.

Nighttime crash severity is one major factor that was not considered widely while prioritizing interchanges for roadway lighting. Fatal crashes result in higher monetary costs than all other types of crashes. Severe or fatal injury crashes also result in substantial social costs that far exceed the less severe injury and property damage only (PDO) crash costs. The lack of roadway lighting limits visibility at interchanges and increases the probability of getting involved in severe crashes. Improving roadway lighting at interchanges with higher number of severe crashes also yields substantial benefits. Further, night-to-day crash rate ratio may be more biased toward interchanges with fewer numbers of crashes or low traffic volume. Considering nighttime crash severity would help better prioritize and allocate funds for interchange lighting installations. Nighttime crash data were, therefore, categorized into three categories: fatal and injury type “A,” injury types “B” and “C,” and PDO. The maximum number of nighttime fatal and injury type “A” crashes at the selected 80 interchanges from 2006 to 2011 is equal to 3. The fatal crashes were hence divided into three categories. Three or more nighttime fatal and injury type A crashes were given a rating of 5. One to two nighttime fatal and injury type A crashes were given a rating of 3, while zero nighttime fatal and injury type A crash was given a rating of 1. Likewise, the average number of nighttime injury type B and C crashes at the selected 80 interchanges from 2006 to 2011 is equal to 10. Therefore, nighttime injury type B and C crashes were categorized as 0 to 10, 10 to 20, 20 to 30, 30 to 40, and greater than 40 with ratings of 1, 2, 3, 4, and 5, respectively. Similarly, the average number of nighttime PDO crashes at the selected 80 interchanges from 2006 to 2011 is equal to 20. Thus, nighttime PDO crashes were categorized as 0 to 20, 20 to 40, 40 to 60, 60 to 80, and greater than 80 with ratings of 1, 2, 3, 4, and 5, respectively.

Illumination at interchanges generally would improve security and safety. An illuminance index equal to 0.7 foot-candle is considered adequate while inadequate levels result in a lack of visibility at night and could be probable cause of crashes under nighttime conditions. The illuminance index was therefore divided into three categories: less than 0.4 foot-candle, 0.4 foot-candle to 0.7 foot-candle, and greater than 0.7 foot-candle. An illuminance index less than 0.4 foot-candle was given a rating of 5 while illuminance index 0.4 foot-candle to 0.7 foot-candle was given a rating of 3. The rating was given as 1 if the illuminance index was greater than 0.7 foot-candle.

Traffic composition is another important factor that could have a bearing on the number of crashes at interchanges. Safety problems could be further aggravated due to the presence of heavy vehicles or truck traffic. As traffic data observed indicate, on average, 25% of nighttime traffic volume is heavy vehicles at the selected interchanges, the percent of heavy vehicles was categorized as 0 to 10%, 10% to 20%, 20% to 30%, 30% to 40%, and greater than 40% with ratings of 1, 2, 3, 4, and 5, respectively.

The ramp volume is divided by the freeway through volume to compute the ramp volume ratio. A higher ramp volume ratio indicates a higher number of vehicles carrying out weaving maneuvers (conflicting situations), which could contribute to increasing number of crashes at the interchange. The lack of roadway lighting worsens the condition and results in higher crash costs in such situations. The ramp volume ratio was categorized as 0 to 0.1, 0.1 to 0.2, 0.2 to 0.3, 0.3 to 0.4, and greater than 0.4 with ratings of 1, 2, 3, 4, and 5, respectively.

The new factors, categories, and ratings were presented to the Project Panel, comprising engineers from NCDOT. Feedback and input received was used to finalize the information and considered for further analysis.

Analyze Crash Data to Determine Unlighted and Lighted Weights

The lighted and unlighted weights used in the current tool were computed based on various field studies, literature, and collective judgments as stated by the authors of NCHRP Report 152 (Walton and Rowan 1974). Adequate details could not be found on the computation of unlighted and lighted weights used in the current tool. Since the previous study was performed more than four decades ago, there is a need to re-visit, research and document a method for computation of unlighted and lighted weights.

Crash data obtained from NCDOT were used to determine the effect of each factor on the number of crashes by light condition. The area within 0.3 miles (an influence area of 1,500 ft. including the acceleration or deceleration lane) from an onramp or off-ramp was considered as interchange influence area. Crashes occurring within 0.3 miles of both onramp and off-ramp of an interchange were therefore attributed to the interchange. These crashes within the interchange influence area could be due to merging, diverging, or weaving maneuvers.

The crashes occurring within the interchange influence area were identified for all the 80 selected interchanges along the study segments. Descriptive analysis was then conducted to tabulate these crashes by each factor provided in the interchange lighting priority index tool. Lighted and unlighted weights were then computed for freeway median width, number of freeway lanes, nighttime traffic volume per lane, ramp type, sight distance at cross-road intersections, percentage development, and cross-road approach lighting and freeway lighting. Lighted and unlighted weights for factors such as cross-road channelization to facilitate, separate, or regulate traffic into definite paths of travel using pavement markings and/or traffic islands, freeway lane width, freeway horizontal curve, freeway grade, level of service and offset to development from roadway were not computed as these were same for all the selected interchanges.

For freeway median width factor, the number of crashes at each interchange was processed and summarized for 4 ft. to 12 ft., 12 ft. to 24 ft., 24 ft. to 40 ft., and greater than 40 ft. median width categories. Table 1 shows the number of crashes by light condition and freeway median width categories. The number of nighttime crashes under unlighted conditions is greater than the number of crashes under lighted conditions when no freeway lighting is provided. As the number of crashes in the 4 ft. to 12 ft. freeway median width category is comparatively less (only two selected interchanges in this category), the number of crashes in the 12 ft. to 24 ft. freeway median width category was considered critical and used to compute the lighted and unlighted weights. The lighted weight was considered as 1. The unlighted weight was computed as the number of nighttime crashes per interchange with no freeway lighting for 12 ft. to 24 ft. freeway median width category (equal to 37.09) divided by the number of nighttime crashes per interchange with complete freeway lighting for the same freeway median width category (equal to 28.45) plus 1. The unlighted weight is, therefore, [(37.09 / 28.45) + 1] = 2.30, whereas the lighted weight is 1.00 for freeway median width category.

Table 1: Crashes by Lighting Condition and Freeway Median Width

Median Width (ft.)	Freeway Lighting	# Crashes Under Lighted Condition	# Crashes Under Unlighted Condition	# Interchanges	# Lighted Crashes per Interchange	# Unlighted Crashes per Interchange
4 to 12	Complete	0	0	0	0.00	0.00
	Partial	0	0	0	0.00	0.00
	No	2	43	2	1.00	21.50
	Total	2	43	2	1.00	21.50
12 to 24	Complete	313	192	11	28.45	17.45
	Partial	290	226	9	32.22	25.11
	No	88	408	11	8.00	37.09
	Total	691	826	31	22.29	26.65
24 to 40	Complete	126	91	6	21.00	15.17
	Partial	248	230	4	62.00	57.50
	No	134	206	4	33.50	51.50
	Total	508	527	14	36.29	37.64
>40	Complete	61	166	5	12.20	33.20
	Partial	48	122	3	16.00	40.67
	No	53	653	30	1.77	21.77
	Total	162	941	38	4.26	24.76

For the number of freeway lanes factor, the number of crashes at each interchange was processed and summarized for less than or equal to 4 freeway lanes, 4 to 6 freeway lanes, and greater than 6 freeway lanes categories. Table 2 shows the number of crashes by light condition and number of freeway lanes categories. From Table 2, the number of crashes (sum of complete, partial, and no freeway lighting) generally increased as the number of freeway lanes increased. Moreover, the number of nighttime crashes under unlighted conditions is greater than the number of crashes under lighted conditions when no freeway lighting is provided. This could be attributed to the fact that higher number of lanes would result in greater exposure and probably sharper weaving maneuvers. Unlighted roadway aggravates the problem by making it difficult for the driver to identify the exit ramp and make a decision promptly. As the number of crashes is highest for the greater than 6 freeway lanes category, the lighted and unlighted weights for number of freeway lanes were determined based on the number of crashes by light condition for this category. The lighted weight was considered as 1. The unlighted weight was computed as the number of nighttime crashes per interchange with no freeway lighting for the greater than 6 freeway lanes category (equal to 37.86) divided by the number of nighttime crashes per interchange with complete freeway lighting for the same freeway lanes category (equal to 31.27) plus 1. The unlighted weight is, therefore, [(37.86 / 31.27) + 1] = 2.21, whereas the lighted weight is 1.00 for the same number of freeway lanes category.

Table 2: Crashes by Lighting Condition and Number of Freeway Lanes

# Freeway Lanes	Freeway Lighting	# Crashes Under Lighted Condition	# Crashes Under Unlighted Condition	# Interchanges	# Lighted Crashes per Interchange	# Unlighted Crashes per Interchange
4 or Less	Complete	116	101	8	14.50	12.63
	Partial	17	32	1	17.00	32.00
	No	49	616	24	2.04	25.67
	Total	182	749	33	5.52	22.70
6 or less and >4	Complete	40	10	3	13.33	3.33
	Partial	49	59	4	12.25	14.75
	No	94	429	16	5.88	26.81
	Total	183	498	23	7.96	21.65
>6	Complete	344	338	11	31.27	30.73
	Partial	520	487	11	47.27	44.27
	No	134	265	7	19.14	37.86
	Total	998	1090	29	34.41	37.59

Likewise, for the total nighttime traffic volume per lane factor, the number of crashes at each interchange was processed and summarized for less than 1,000, 1,000 to 2,000, 2,000 to 3,000, 3,000 to 4,000, and greater than 4,000 nighttime traffic volume per lane (estimated from ADT) categories. Table 3 shows the number of crashes by light condition and total nighttime traffic volume per lane. In the current tool, total nighttime traffic volume per lane greater than 4,000 is the most critical situation. The total number of unlighted crashes per interchange with no freeway lighting is highest for this category. Hence, the number of crashes corresponding to this critical situation was used to compute the unlighted weight. The lighted weight was considered as 1. The unlighted weight was computed as the number of nighttime crashes per interchange with no freeway lighting for greater than 4,000 nighttime traffic volume per lane category (equal to 58.71) divided by the number of nighttime crashes per interchange with complete freeway lighting for the same nighttime traffic volume per lane category (equal to 8.00) plus 1. The unlighted weight is, therefore, [(58.71 / 8.00) + 1] = 8.34, whereas the lighted weight is 1.00 for total nighttime traffic volume per lane category.

The same procedure was used to estimate the unlighted and lighted weights for other aforementioned factors as well as acceleration lane length, deceleration lane length, and signboard placement distance.

To estimate unlighted and lighted weights for crash severity, the crash data were processed and categorized into three categories: fatal and injury type A, injury types B and C, and PDO. Table 4 shows the number of crashes by light condition and severity categories. The number of nighttime crashes under unlighted conditions is greater than the number of crashes under lighted conditions for each severity type. This implies that roadway lighting reduces the number of crashes at interchanges.

Table 3: Crashes by Lighting Condition and Total Nighttime Traffic Volume per Lane

Nighttime traffic Volume per Lane	Freeway Lighting	# Crashes Under Lighted Condition	# Crashes Under Unlighted Condition	# Interchanges	# Lighted Crashes per Interchange	# Unlighted Crashes per Interchange
<1000	Complete	0	0	0	0.00	0.00
	Partial	0	0	0	0.00	0.00
	No	0	0	0	0.00	0.00
	Total	0	0	0	0.00	0.00
1000 - 2000	Complete	0	0	0	0.00	0.00
	Partial	0	0	0	0.00	0.00
	No	3	185	13	0.23	14.23
	Total	3	185	13	0.23	14.23
2000 - 3000	Complete	172	159	9	19.11	17.67
	Partial	58	78	4	14.50	19.50
	No	89	453	17	5.24	26.65
	Total	319	690	30	10.63	23.00
3000 - 4000	Complete	304	273	10	30.40	27.30
	Partial	277	260	6	46.17	43.33
	No	73	261	10	7.30	26.10
	Total	654	794	26	25.15	30.54
>4000	Complete	24	17	3	8.00	5.67
	Partial	251	240	6	41.83	40.00
	No	112	411	7	16.00	58.71
	Total	387	668	16	24.19	41.75

Table 4: Crashes by Lighting Condition and Severity

Crash Type	# Crashes under Lighted Condition	# Crashes under Unlighted (Dark) Condition	Total # Crashes
Fatal & injury type “A”	28	32	60
Injury types “B” & “C”	422	622	1,044
Property Damage Only (PDO)	889	1,634	2,523

Different scaling levels (100, 10, and 1) were used to derive meaningful weights for the three crash categories. The unlighted weight for fatal and injury type A crash category was computed as 100 times the number of unlighted fatal and injury type A crashes (equal to 32) divided by the total number of fatal and injury type “A” crashes at the selected interchanges (equal to 60). The lighted weight was computed by subtracting the unlighted weight from 100. The unlighted weight is, therefore, $[100 \times (32 / 60)] = 53$, whereas the lighted weight is $(100 - 53) = 47$ for fatal and injury type A crash category. Subtracting 47 from 53 and then multiplying with a rating of 5 gives 30 warranting points (maximum) for this crash severity category.

The unlighted weight for injury type B and C crash category was computed as 10 times the number of unlighted injury type B and C crashes (equal to 622) divided by the total number of injury type B and C crashes at the selected interchanges (equal to 1,044). The lighted weight was computed by subtracting the unlighted weight from 10. The unlighted weight is, therefore, $[10 \times (622 / 1,044)]$

= 6, whereas the lighted weight is (10 - 6) = 4 for injury type B and C crash category. Subtracting 4 from 6 and then multiplying with a rating of 5 gives 10 warranting points (maximum) for this crash severity category.

The unlighted weight for PDO crashes was computed as the number of unlighted (dark) PDO crashes (equal to 1,634) divided by the total number of PDO crashes at the selected interchanges (equal to 2,523). The lighted weight was computed by subtracting the unlighted weight from 1. The unlighted weight is, therefore, (1,634 / 2,523) = 0.65 and lighted weight is (1 - 0.65) = 0.35 for PDO crash category. Subtracting 0.35 from 0.65 and then multiplying with a rating of 5 gives 1.5 warranting points (maximum) for this crash severity category.

Overall, a maximum of 30 points, 10 points, and 1.5 points are allocated for fatal and injury type A, injury type B and C, and PDO crash categories, respectively. The sum (30 + 10 + 1.5 = 41.5) is relatively close to the maximum of 40 points allotted for safety factor in the current tool. It should be noted that maximum warranting points are allocated if the rating is equal to 5.

The ratio of crashes under unlighted condition to lighted condition was used in the computation of unlighted and lighted weights for illuminance index, percent of heavy vehicles, and ramp volume ratio.

Table 5 compares the unlighted and lighted weights for factors used in the current tool and those estimated from this research.

Table 5: Summary of Lighted and Unlighted Weights

Factor	Current Tool			Updated Tool		
	Unlighted Weight (A)	Lighted Weight (B)	Diff. (A-B)	Unlighted Weight (A)	Lighted Weight (B)	Diff. (A-B)
Factors in the Current Tool						
Ramp Type	2	1	1	2.09	1	1.09
% Development	2	0.5	1.5	2.76	1	1.76
Cross-road Approach Lighting	3	2	1	2.06	1	1.06
Freeway Lighting	5	3	2	2.23	1	1.23
Freeway Median Width	1	0.5	0.5	2.30	1	1.30
# Freeway Lanes	10	8	2	2.21	1	1.21
Total Night-time traffic Volume per Lane	6	1	5	8.34	1	7.34
New Proposed Factors						
Deceleration Lane Length	Not applicable			2.07	1	1.07
Acceleration Lane Length				2.15	1	1.15
Signboard Placement				2.34	1	1.34
Fatal and Injury Type “A”				53	47	6
Injury Type “B” and “C”				6	4	2
PDO				0.65	0.35	0.30
Illumination				0.72	0.28	0.44
% Heavy Vehicles				0.72	0.28	0.44
Ramp Volume Ratio				0.72	0.28	0.44

DISCUSSION

The current tool used by NCDOT was updated by including the new factors, their categories and ratings, and unlighted and lighted weights. Table 6 summarizes interchange ID, interchange name, and selected data elements for 41 selected interchanges without lighting systems. The geometric conditions, traffic characteristics, and crashes varied for the selected interchanges.

As nighttime traffic volume data are not available, NCDOT assumes it as 25% of the freeway ADT at the interchange in the current tool. The percent of nighttime traffic volume divided by daytime traffic volume is, therefore, 25% / 75% = 1/3. This typically results in a night-to-day crash rate ratio equal to three times the ratio of the number of nighttime crashes to the number of daytime crashes.

Figure 2 shows warranting points from the current and updated tool for selected interchanges without lighting systems. The interchange ID is represented on the x-axis while warranting points are represented on the y-axis. TDP priority index could not be computed or compared for these interchanges due to lack of details pertaining to cost estimates.

The effect of new factors and weights on warranting points identified from this research other than crash severity seem to be marginal. This is because the difference in unlighted and lighted weights is not high enough to see noticeable effects at a macroscopic level.

However, the computed warranting points using the updated tool for 17 interchanges out of 41 selected interchanges without lighting systems was observed to be greater than warranting points computed from the current tool (Figure 2). At least one severe crash or over 100 nighttime total crashes occurred during the study period at more than 50% of these interchanges. The remaining 24 interchanges without lighting systems had computed warranting points from the updated tool that were less than computed values from the current tool.

From Table 6, overall, 36 out of the 41 interchanges without lighting systems have a night-to-day crash rate ratio less than 3 (or night-to-day crash ratio less than 1). It was observed equal to 3 at one interchange, equal to 4.5 at two interchanges, equal to 6 at one interchange, and a very high value at one interchange (all crashes occurred at night). While one interchange (US-64 / S New Hope Rd) with a night-to-day crash rate ratio equal to 4.5 had 0 fatal, 0 injury type A, 0 injury type B, 1 injury type C, 2 PDO nighttime crashes and 2 daytime crashes – 5 total crashes, the second interchange (US-70 / Tuscarora Rhems Rd) had 0 fatal, 0 injury type A, 0 injury type B, 2 injury type C, 13 PDO nighttime crashes and 10 daytime crashes – 25 total crashes. The interchange (US-70 / NC-41) with a night-to-day crash rate ratio equal to 6 had 0 fatal, 0 injury type A, 1 injury type B, 0 injury type C and 3 PDO nighttime crashes while the total number of crashes observed at this interchange was equal to 6. On the other hand, I-277 / Kenilworth Ave had 0 fatal, 1 injury type A, 5 injury type B, 7 injury type C and 17 PDO nighttime crashes and 130 daytime crashes – 160 total crashes with a night-to-day crash rate ratio equal to 0.69. This clearly indicates that using a night-to-day crash rate ratio could result in biased results (toward interchanges with fewer numbers of crashes).

Table 6: Summary of Crash Data for Selected Interchanges without Lighting System

IID	Interchange	ALL	DLL	SBPD	NTC						DTC	TC	CRR	LI	%HV	RVR
					K	A	B	C	PDO	Total						
1	I-40 / Cold Springs Creek Rd	1	1	1	0	0	2	4	27	33	56	89	1.77	0.1	66.4	0.0
2	I-85 / I-485	3	3	1	0	0	7	17	63	87	118	205	2.21	0.1	25.2	0.1
3	I-85 / I-77	3	3	1	2	0	10	14	32	58	121	179	1.44	3.6	30.8	0.3
4	I-485 / Providence Rd	3	3	3	0	2	2	5	28	37	97	134	1.14	0.1	28.9	0.2
5	I-485 / Johnston Rd	3	3	3	0	0	2	6	48	56	147	203	1.14	0.1	11.0	0.1
6	US-64 / I-540	3	3	3	0	0	0	0	1	1	1	2	3.00	0.1	6.2	0.3
7	US-64 / Knightdale Rd	2	3	1	0	0	1	4	16	21	35	56	1.80	0.6	9.6	0.2
8	US-64 / N Arendell Ave	2	2	1	0	0	2	1	31	34	74	108	1.38	0.1	15.4	0.2
9	US-70 / NC-41	2	2	1	0	0	1	0	3	4	2	6	6.00	0.1	21.0	0.2
10	US-70 / Clarks Rd	2	1	1	0	0	2	5	18	25	36	61	2.08	0.1	12.4	0.5
11	US-70 / Country Club Rd	2	1	3	0	0	0	0	0	0	0	0		1.7	0.0	0.1
12	US-74 / NC161	3	1	3	0	0	0	0	12	12	19	31	1.89	0.1	16.9	0.1
13	US-74 / Oak Grove Rd	3	1	3	1	0	0	5	14	20	27	47	2.22	0.1	18.4	0.1
14	US-74 / Shelby Rd	2	1	3	2	1	1	3	10	17	31	48	1.65	0.1	33.0	0.1
15	I-77 / W 5th St	2	2	2	2	7	20	79	185	293	610	903	1.44	1.7	12.7	0.3
16	I-85 / US-321	1	1	1	0	0	3	15	36	54	138	192	1.17	0.1	35.3	0.1
17	I-85 / NC-279	3	2	2	0	1	5	13	15	34	87	121	1.17	0.2	35.3	0.1
18	I-85 / S Main St	3	3	3	0	0	6	13	48	67	197	264	1.02	0.2	35.3	0.1
19	I-85 / NC-7	3	3	3	0	1	4	15	38	58	126	184	1.38	0.1	35.3	0.1
20	I-85 / McAdenville / N Main St	3	3	3	2	0	4	6	35	47	94	141	1.50	0.1	35.3	0.1
21	I-85 / NC-273	2	3	1	0	0	3	11	91	105	233	338	1.35	0.1	35.3	0.1
22	I-277 / Kenliworth Ave	3	3	1	0	1	5	7	17	30	130	160	0.69	7.3	11.8	0.1
23	I-277 / US-74	2	2	1	0	1	5	7	12	25	57	82	1.32	2.3	11.8	0.1
24	I-485 / Lawyers Rd	1	1	1	0	0	0	0	22	22	31	53	2.13	0.1	23.5	0.2
25	I-485 / Idlewild Rd	3	2	2	0	0	0	4	33	37	65	102	1.71	0.1	23.5	0.2

Table 6 (continued)

IID	Interchange	ALL	DLL	SBPD	NTC						DTC	TC	CRR	LI	%HV	RVR
					K	A	B	C	PDO	Total						
26	I-485 / Old Monroe Rd	3	3	3	0	0	1	4	20	25	66	91	1.14	0.1	23.5	0.2
27	I-485 / Rea Rd	3	3	3	0	0	0	10	22	32	0	32	>10	0.1	23.5	0.2
28	I-485 / NC-51	3	3	3	0	0	2	11	36	49	102	151	1.44	0.4	23.5	0.2
29	I-485 / Pineville Rd	2	3	1	0	0	4	21	103	128	284	412	1.35	0.1	23.5	0.2
30	US-64 / S New Hope Rd	2	2	1	0	0	0	1	2	3	2	5	4.50	0.3	10.4	0.2
31	US-64 / Hudge Rd	2	2	1	0	0	0	0	2	2	4	6	1.50	0.2	10.4	0.2
32	US-64 / Smithfield Rd	2	1	1	0	0	0	0	3	3	9	12	1.00	0.2	10.4	0.2
33	US-64 / Eagle Rock Rd	2	1	3	0	0	0	0	4	4	11	15	1.09	0.2	10.4	0.2
34	US-64 / Rolesville Rd	3	1	3	0	0	5	6	26	37	71	108	1.56	0.1	10.4	0.2
35	US-64 / Lizard Lick Rd	3	1	3	0	0	2	6	26	34	71	105	1.44	0.1	10.4	0.2
36	US-70 / Tuscarora Rhems Rd	2	1	3	0	0	0	2	13	15	10	25	4.50	0.1	11.1	0.3
37	US-70 / US-17 Bypass	3	3	1	0	0	0	0	0	0	2	2	0.00	0.1	11.1	0.3
38	US-70 / NC-43	3	3	1	0	0	0	0	0	0	0	0		0.1	11.1	0.3
39	US-70 / Glenburnie Rd	2	2	2	0	0	0	0	0	0	0	0		0.2	11.1	0.3
40	US-70 / US-70 Business Rd	1	1	1	0	0	0	0	0	0	0	0		0.9	11.1	0.3
41	US-74 / NC216	1	1	1	1	1	0	1	8	11	18	29	1.83	0.2	22.8	0.1

Note 1. IID is Interchange ID.

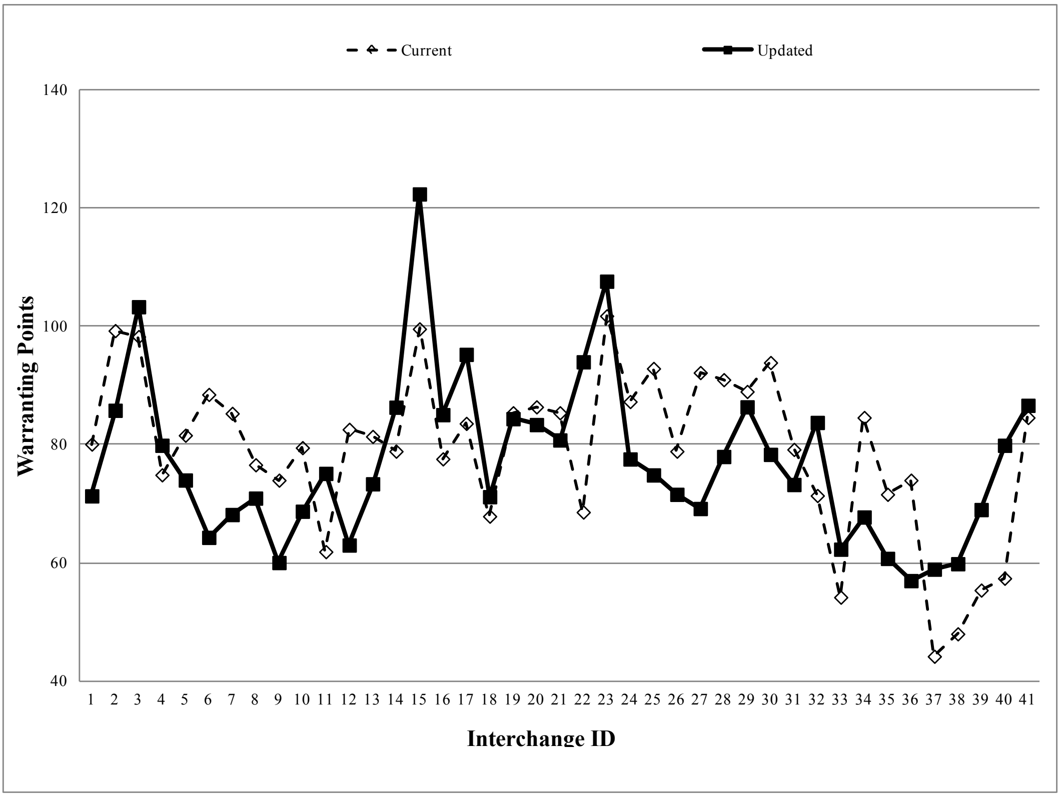
Note 2. ALL, DLL and SBPD are acceleration lane length, deceleration lane length, and signboard placement distance, respectively. 1, 2, 3 for acceleration lane length and deceleration lane length indicate < 250 ft, 250 to 750 ft and > 750 ft, respectively. Likewise, 1, 2, 3 for signboard placement distance indicate < 1,320 ft, 1,320 to 2,640 ft and 2,640 to 5,280 ft, respectively.

Note 3. NTC, DTC and TC are nighttime, daytime, and total number of crashes, respectively. K, A, B, C, and O are fatal, injury type A, B and C, and PDO crashes, respectively.

Note 4. CRR is night-to-day crash rate ratio. It is defined as the percent of nighttime crashes to the percent of day-time crashes divided by the percent of nighttime traffic volume to the percent of daytime traffic volume.

Note 5. LI, %HV and RVR are luminous index, % heavy vehicles, and ramp volume ratio, respectively.

Figure 2: Warranting Points for Selected Interchanges



Interchanges such as I-85 / I-77 and I-77 / W 5th St with fatal and more severe injury crashes have seen an increase and have more than 100 warranting points using the updated tool in comparison to the current tool. On the other hand, interchanges such as US-64 / S New Hope Rd and US-64 / I-540 have 94 and 89 warranting points, respectively, using the current tool (primarily due to a high night-to-day crash rate ratio) but have seen a decrease in warranting points using the updated tool.

CONCLUSIONS

Most of the interchanges with night-to-day crash rate ratio greater than 3 (used in the current tool) have seen fewer, less severe injury, or PDO crashes. Using crash severity would reduce the bias toward interchanges with fewer numbers of crashes and assign higher priority to interchanges with fatal and severe crashes. As fatal and severe injury crashes result in substantial social costs that far exceed the property damage only crash costs, incorporating crash severity into the TDP further increases the economic justification for improved visibility.

A comparison of warranting points using the current and updated tool indicates a decrease in warranting points at interchanges with fewer numbers of crashes or less severe crashes using the updated tool. In general, warranting points increased and are higher based on the updated tool for interchanges with more severe crashes. Therefore, it is recommended to consider the number of crashes by severity instead of the night-to-day crash rate ratio for prioritization using the TDP.

While other considered new factors and weights developed from this research seem to have an effect on warranting points, the difference when compared with the warranting points from the current tool seem to be marginal. This is due to the small difference in unlighted and lighted weights, and, the standard design characteristics of the study interchanges.

Overall, the enhancements and updates to the interchange lighting priority index tool could be efficiently used to prioritize interchanges based on safety in addition to other critical factors pertaining to geometric, traffic, and environmental conditions at the location.

Providing lighting at obsolete sections because of no traffic at night, due to closure of business or change in land use, is cost prohibitive. Field observations indicate that most businesses except gas stations in urban areas at the selected interchanges are closed by 10:00 PM. The nighttime traffic volume is less than 15% of ADT. This suggests that using 25% of ADT or values obtained from traffic forecasters in the Statewide Planning Branch as nighttime traffic volume may result in overestimating warranting points.

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Disclaimer

The contents of this report reflect the views of the authors and not necessarily the views of the university. The authors are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either a NCDOT or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

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