How Light Roadways?
Among the chief reasons for installing roadway lighting, according to guidance from the Illuminating Engineering Society (IES, 2000), is the potential for lighting to contribute to improved nighttime safety. And the logic that roadway lighting provides drivers with improved visibility and in turn greater distance and longer time to respond to potential hazards along the roadway is largely sound. Multiple studies of roadway lighting (IES, 1989; CIE, 1992) have found links between the presence of roadway lighting and fewer nighttime crashes, leading to estimates that lighting contributes to a 30% reduction in the night-to-day crash ratio. Figures similar to this 30% value are often used by transportation agencies to justify installation of roadway lighting.

Studies of roadway lighting and safety are difficult to conduct for several reasons (IES, 1989; CIE, 1992). First, crashes are rare events, making it difficult to gather sufficient data to perform reliable statistical analyses of safety benefits. Second, roadway lighting is not randomly assigned to locations; rather, highway engineers install it where they believe it has the best chance to influence nighttime safety. Comparing both daytime and nighttime crashes through the night-to-day ratio helps, but does not completely control for this factor (CIE, 1992). Third, roadway lighting is often installed alongside other safety engineering treatments such as signs and signals, improved road markings, and geometric features that might also interact with nighttime traffic safety. These factors could impact estimates of nighttime safety from observational studies.

A Two-Pronged Approach
Although the logic relating improved visibility from lighting to improved safety makes sense, and one of the allowed criteria for specifying roadway lighting in North America has been small target visibility (IES, 2000), there are few direct links from roadway lighting to improvements in visual performance by drivers, and in turn to reductions in nighttime crashes. Recently, a research team from the Pennsylvania State University (PSU) and from the Lighting Research Center at Rensselaer Polytechnic Institute (LRC) performed a two-pronged study of roadway lighting (Bullough et al., 2013). One prong focused on the statistical relationships between lighting and traffic safety at different intersection types, and the second focused on the visual performance improvements related to lighting at the same types of intersections.

Crunching the Numbers
A database of roadway intersections in the state of Minnesota from the Highway Safety Information System (HSIS) was the basis for the first prong of this study, the statistical approach. The HSIS database contained lighting presence data as well as nighttime and daytime crash data for each of the more than 6400 individual intersections throughout Minnesota, for the years 1999 to 2002. Importantly, it included many operational and geometric factors not included in previous studies of roadway lighting, such as traffic volume, posted speed limits, presence of medians and shoulders, presence of traffic signals, percent-ages of large truck traffic, the type of location (urban, suburban or rural) and others.

Donnell et al. (2010) found that on average across all intersections in Minnesota, roadway lighting at intersections was associated with a safety improvement corresponding to a 12% reduction in the night-to-day crash ratio. Controlling for all of the non-lighting, but potentially safety-related factors in the HSIS Minnesota intersection database, resulted in a substantially lower nighttime safety impact than the 30% figure reported in many previous studies (IES, 1989; CIE, 1992), but this result was still consistent with the notion that roadway lighting can provide a net nighttime safety benefit. Looking specifically at specific intersection types, such as intersections in rural or urban/suburban locations (urban and suburban intersections in the database behaved very similar with respect to lighting and were combined for the purpose of statistical analysis), and intersections with and without traffic signals installed, it was possible to use the same approach as Donnell et al. (2010) to devise estimates for the nighttime safety impact associated with roadway lighting. Table 1, found on page 34, summarizes the statistical modeling results. Again, as might be expected, roadway lighting was usually associated with reductions in the night-to-day crash ratio, although these could be small or negligible for certain intersection types, particularly in rural locations.

See Table 1. Statistical modeling results for Minnesota intersections (Donnell et al., 2010; Bullough et al., 2013) on page 34.

Determining What Drivers See
To carry out the second prong of the study the LRC and PSU researchers developed simulations of lighting

Continued on page 34
at prototypical roadway intersections using photometrically accurate lighting calculation software. The simulations included extended and localized lighting configurations, depending upon whether the roadway lighting at the intersection was likely to be part of a continuous lighting system of multiple lights along the intersecting roads, as in many urban and suburban locations, or an isolated light at the intersection as in most rural locations. The simulations also included headlights for vehicles approaching the intersection, since these light sources could contribute to both visibility and glare for drivers. Ambient light typical of urban/suburban and rural locations (Li et al., 2006) was also included.

To estimate drivers’ visual performance as they would navigate through the intersection, the relative visual performance (RVP; Rea and Ouellette, 1991) model was used. The RVP model provides a measure of the speed and accuracy of visual processing as a function of the luminance of a target, the target’s contrast against its background, the target’s size and the age of the observer. A range of ages from 30 to 60 years was assumed, and the small target specified by the IES (2000) was used for the visibility calculations. Visibility was estimated for drivers approaching the intersection and for drivers waiting at the intersection to cross or to turn onto the intersecting road. Importantly, the locations of vehicles along the approaching road were further from the intersection for rural roads than for urban and suburban roads, since the posted speed limits in rural locations are higher than in urban and suburban areas, and the relevant target locations are further from the intersection for high-speed rural roads.

Table 2 lists the representative lighting characteristics, alongside the calculated visual performance increment associated with roadway lighting having the characteristics shown in the table.

### Table 1. Statistical modeling results for Minnesota intersections (Donnell et al., 2010; Bullough et al., 2013).

<table>
<thead>
<tr>
<th>Roadway Intersection Type</th>
<th>Modeled Change in Daytime Crashes Associated with Lighting</th>
<th>Modeled Change in Nighttime Crashes Associated with Lighting</th>
<th>Change in Night-to-Day Crash Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>All intersections (n=22,058, 46% lighted)</td>
<td>+5%</td>
<td>-8%</td>
<td>-12%</td>
</tr>
<tr>
<td>Urban/suburban signalized (n=2,875, 97% lighted)</td>
<td>+3%</td>
<td>-3%</td>
<td>-7%</td>
</tr>
<tr>
<td>Urban/suburban unsignalized (n=7,730, 76% lighted)</td>
<td>+5%</td>
<td>-9%</td>
<td>-13%</td>
</tr>
<tr>
<td>Rural signalized (n=394, 94% lighted)</td>
<td>-2%</td>
<td>-2%</td>
<td>0%</td>
</tr>
<tr>
<td>Rural unsignalized (n=1,101, 10% lighted)</td>
<td>+9%</td>
<td>+7%</td>
<td>-2%</td>
</tr>
</tbody>
</table>

### Table 2. Lighting characteristics and visibility improvements (RVP scores) for different Minnesota intersection types (Bullough et al., 2013).

<table>
<thead>
<tr>
<th>Roadway Intersection Type</th>
<th>Roadway Illuminance (lux)</th>
<th>Intersection Illuminance (lux)</th>
<th>Ambient Illuminance (lux)</th>
<th>Speed Limit (mph)</th>
<th>Extended/Localized</th>
<th>Visibility Improvement (RVP Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban/suburban signalized</td>
<td>18</td>
<td>30</td>
<td>2</td>
<td>30</td>
<td>Extended</td>
<td>+0.73</td>
</tr>
<tr>
<td>Urban/suburban unsignalized</td>
<td>9</td>
<td>15</td>
<td>0.2</td>
<td>30</td>
<td>Extended</td>
<td>+1.86</td>
</tr>
<tr>
<td>Rural signalized</td>
<td>6</td>
<td>10</td>
<td>0.2</td>
<td>55</td>
<td>Localized</td>
<td>+0.27</td>
</tr>
<tr>
<td>Rural unsignalized</td>
<td>6</td>
<td>10</td>
<td>0.02</td>
<td>55</td>
<td>Localized</td>
<td>+0.21</td>
</tr>
</tbody>
</table>

### Lighting in the simulations

Lighting in the simulations was based on the Minnesota Department of Transportation’s *Roadway Lighting Design Manual* (2006), itself derived from IES (2000) recommendations and verified through limited spot checks of roadway photologs. Table 2 lists the representative lighting characteristics, alongside the calculated visual performance increment associated with roadway lighting having the characteristics shown in the table.

### Linking Safety to Visibility

Although Tables 1 and 2 were based on very different types of analyses, they share some similarities. In general, the types of intersections where roadway lighting had the largest...
visual performance improvements were the same types where statistical modeling predicted lighting would yield the largest nighttime safety benefit. Figure 1 shows the relationship between visual performance and nighttime crash safety (Bullough et al., 2013).

![Figure 1. Relationship between the visual performance improvement and night-to-day crash ratio reductions associated with roadway lighting (Bullough et al., 2013).](image)

The relationship illustrated in Figure 1 (Bullough et al., 2013) provides a provisional transfer function relating visual performance, which can be predicted quite precisely (Rea and Ouellette, 1991), to nighttime crash safety. The correspondence between these two very different analyses supports the idea that roadway lighting at intersection indeed enhances nighttime safety by providing drivers with improved visibility.

**Shaping Decision-Making**

Importantly, the provisional transfer function in Figure 1 provides an objective basis for decision-making by transportation agencies considering whether and where to install roadway lighting. The installation and operation of roadway lighting systems have specific costs that can be identified with some precision based on initial costs of luminaires, poles and on electrical energy prices. And if, as Figure 1 suggests, roadway lighting at intersections can reduce the frequency of nighttime crashes by varying amounts, the economic value of avoided crashes at night can also be determined using figures published by the U.S. Department of Transportation for crashes involving fatalities, injuries or property damage.

![Figure 2. Benefit/cost ratio for roadway lighting installed along rural unsignalized intersections, as a function of traffic volume (Bullough and Rea, 2011).](image)

Since the benefits of lighting in terms of avoided crashes depend on traffic volumes, but the costs of lighting in terms of equipment and energy are fixed, the ratio between the benefits and costs changes as a function of traffic volume (Bullough and Rea, 2011). Figure 2 shows the benefit/cost ratio of roadway lighting at rural unsignalized intersections as a function of the annual average daily traffic (AADT) of the major intersecting roadway, and Figure 3 shows the same for urban/suburban signalized intersections. The figures also show the AADT value for a benefit/cost ratio of one for each intersection type. The AADT for rural intersections is lower than for urban/suburban intersections because the lighting system in rural locations is usually isolated at the intersection, while roadway lighting at urban/suburban intersections is more likely to be part of an extended, continuous system of more light poles, resulting in higher initial costs. Charts like those in Figures 2 and 3 could inform decision makers in identifying locations where investments in roadway lighting are most likely to pay off.

![Figure 3. Benefit/cost ratio for roadway lighting installed along urban/suburban signalized intersections, as a function of traffic volume (Bullough and Rea, 2011).](image)

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Future Plans

We believe the future is Wi-Fi through internal wireless systems vs. an external cellular data solution as a continued ability to provide emergency services with access to municipal data for day-to-day operations and considering disasters and incidents including environmental or pandemic. Our concern with cellular data is the potential collapse due to overload. The key role of municipal government is to take care of the citizens, which mean that when an event happens where citizens may be hurt or impacted in a negative way, it is crucial that the government has the infrastructure to maintain services.

We believe this is the reason more and more municipalities look at Wi-Fi as a cost saving measure. While the initial investment may appear to be larger than using cellular a responsible government mitigates the risks including financial and impact to its citizens. This direction appears to be further solidified with more and more technology being geared towards utilizing Wi-Fi over 3G, 4G or even LTE.

The City of Airdrie also envisions incorporating Encom Wireless into their wireless plan in order to provide high bandwidth access to municipal information.

How Encom has benefited the City of Airdrie

- Deployed eNergy 24/58 Broadband radios, which are part of the Synergy Architecture for client access within areas of the city that would not merit a MESHing technology without significant increase in cost.
- Deployed 330° pinwheel style sector antenna design allowing for directional access to the Primary communications tower from anywhere within the City of Airdrie boundaries.
- Provided the City of Airdrie with a reliable and flexible solution that was budget friendly and capable of long-term growth to handle the changing needs of the municipality.
- Extended their existing Mobile Workforce into more dense areas of the city with MESHing was too expensive
- Providing the City of Airdrie with the ability to centrally manage and monitor their equipment
- Protected the City of Airdrie’s existing solution and investment and also provided them with the ability to fold in Encom Wireless equipment overtime to replace and upgrade the current investment.
- Provided a trusted, lasting partnership and the security of knowing that Airdrie’s Investment will pay for itself many times over.

References

Bullough JD, Donnell ET, Rea MS. To illuminate or not to illuminate: Roadway lighting as it affects traffic safety at intersections. Accident Analysis and Prevention 53: 65-77.

Bullough JD, Rea MS. 2011. Intelligent control of roadway lighting to optimize safety benefits per overall costs. 14th International IEEE Conference on Intelligent Transportation Systems, Washington, DC.


