Facility Design

A. General

The basic goal of street lighting is to provide patterns and levels of pavement luminance to provide a safer night driving environment and reduce conflict between motorists and pedestrians. A driver's eye discerns an object on or near the street due to contrast between the brightness of the object and the brightness of the background or pavement, or by means of surface detail, glint, shadows, or detection of motion.

Lighting design is concerned with the selection and location of lighting equipment so as to provide improved visibility and increased safety while making the most efficient use of energy with minimum expenditure for the lighting equipment. There are two basic concepts of lighting design - the illumination concept and the luminance concept.

The illumination concept, which is almost universally used in the United States, is based on the premise that by providing a given level of illumination and uniformity of distribution, satisfactory visibility can be achieved. The luminance concept is based on the premise that visibility is related to the luminance of the pavement compared to the luminance of the objects on the pavement. Calculations to determine the luminance of pavement or objects require the estimation of the reflectivity of varying pavement surfaces and objects within the driver's field of vision. These reflectivity values can be difficult to estimate and can vary widely.

The luminance concept is fairly popular in parts of Europe and is being promoted by lighting professionals in the United States. At this time, ANSI/IESNA RP-8-00, R2005 (RP-8) supports both lighting design concepts. However, it is believed the next revision of RP-8 will favor the luminance concept. Although other design concepts are discussed in RP-8, such as Small Target Visibility, the illuminance concept design method remains predominant in the United States. Therefore, the illuminance method will be the only design concept discussed in this chapter.

B. Design Process

By definition, lighting design according to the illumination method relies on the "illumination" or amount of light flux reaching the pavement from the lighting source (quantity) and the uniformity of that illumination on the pavement surface (quality). The steps in the design process are as follows:

- Determination of the design illumination and uniformity criteria by assessing the facility to be lighted.
- Selecting the type of light source.
- Selecting light source size and mounting height.
- Selecting luminaire light distribution type.
- Determining luminaire spacing and location.
- Checking for design adequacy.

These steps are arranged in the order in which they are usually encountered in the design process.

1. **Design Criteria:** The first task of the lighting designer is to research and determine if any requirements (such as ordinances, resolutions, or policies) pertaining to street lighting are in effect in the jurisdiction. Many municipalities have no requirements at all. Some may have adopted a published standard in its entirety or have adopted it with some variations. Others may have developed prescriptive guidelines that, for a given street type, specifically describe the luminaire size and type, specific mounting height, and pole spacing. Still others may have developed a combination of these depending on the street type. Finally, a municipality may have requirements that do not deal directly with the amount of light on the street. Rather, they may simply be lighting limitations such as maximum footcandle levels at property or right-of-way lines to control light trespass, or allow only cutoff type luminaires to control sky glow or excessive glare.

   The designer's first obligation is to conform to state codes and jurisdictional requirements, but in the absence of such requirements, it is recommended that the designer follow a nationally recognized written street lighting design standard such as RP-8.

   To perform street lighting design, two parameters need to be considered - illumination level and uniformity. The amount of illumination at any given point on a street surface is expressed in footcandles (fc). Since the luminous flux from street lighting is typically not distributed evenly over the pavement surface, the illumination is expressed in average footcandles when describing the level of illumination over a defined area. This parameter describes the "quantity" of light provided.

   While the average amount of illumination on the street surface may be satisfactory, the lighting distribution may consist of very high (bright) and very low (dim) localized illumination areas. A driver traveling down a street illuminated in this manner will experience difficulty seeing the street and other objects due to the inability of the eye to rapidly adjust to the varying light conditions. Therefore, another parameter is needed to describe the evenness or uniformity of the applied lighting. This parameter is known as the uniformity ratio of the illumination distribution and is defined as either the ratio of maximum-to-minimum footcandle values or the ratio of the average-to-minimum footcandle values over the project area. The most popular choice is the average-to-minimum ratio. This parameter describes the "quality" of the illumination distribution. A ratio of 1:1 represents perfectly uniform illumination distribution. A real-life example of this is moonlight at night from a full moon overhead. The illumination level of moonlight is approximately 0.5 fc but it is almost perfectly uniform.

   The Illuminating Engineering Society of North America has established acceptable illumination levels and uniformity ratios for various public street types. See Table 11C-1.01. To obtain the recommended average illumination and uniformity ratio for a given street, there are three classifications that need to be determined - the street use, the pavement type, and the level of pedestrian conflict associated with the street.

Table 11C-1.01: Illuminance Method - Recommended Values

Street and Pedestrian Conflict Area		Pavement Classification (Minimum Maintained Average Values)			Uniformity Ratio E_{ave}/E_{min}	Veiling Luminance Ratio L_{max}/L_{avg}
Street	***Pedestrian Conflict Area***	***R1 fc***	***R2 and R3 fc***	***R4 fc***		
Freeway Class A	N/A	0.6	0.9	0.8	3.0	0.3
Freeway Class B	N/A	0.4	0.6	0.5	3.0	0.3
Expressway	High	1.0	1.4	1.3	3.0	0.3
	Medium	0.8	1.2	1.0	3.0	0.3
	Low	0.6	0.9	0.8	3.0	0.3
Major (Arterial)	High	1.2	1.7	1.5	3.0	0.3
	Medium	0.9	1.3	1.1	3.0	0.3
	Low	0.6	0.9	0.8	3.0	0.3
Collector	High	0.8	1.2	1.0	4.0	0.4
	Medium	0.6	0.9	0.8	4.0	0.4
	Low	0.4	0.6	0.5	4.0	0.4
Local	High	0.6	0.9	0.8	6.0	0.4
	Medium	0.5	0.7	0.6	6.0	0.4
	Low	0.3	0.4	0.4	6.0	0.4

Pedestrian Conflict Area Classifications:

- High - Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during darkness. Examples are down-town retail areas, near theaters, concert halls, stadiums, and transit terminals.
- Medium - Areas where lesser numbers of pedestrians utilize the streets at night. Typical are down-town office areas, blocks with libraries, apartments, neighborhood shopping, industrial, older city areas, and streets with transit lines.
- Low - Areas with very low volumes of night pedestrian usage. These can occur in any of the cited street classifications but may be typified by sub-urban single family streets, very low density residential developments, and rural or semi-rural areas.

Source: Adapted from *ANSI / IES RP-8-00* (R2005)

Table 11C-1.02: Street Surface Classifications

Class	Q_o*	Description	Mode of Reflectance
R1	0.10	PCC street surface. Asphalt street surface with a minimum of 12% of the aggregates composed of artificial brightener (e.g., Synopal) aggregates (e.g., labradorite, quartzite).	Mostly diffuse
R2	0.07	Asphalt street surface with an aggregate composed of minimum 60 percent gravel [size greater than 1 cm (0.4 in.)]. Asphalt street surface with 10% to 15% artificial brightener in aggregate mix. (Not normally used in North America).	Mixed (diffuse and specular)
R3	0.07	Asphalt street surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular
R4	0.08	Asphalt street surface with very smooth texture.	Mostly specular

* Q_o = representative mean luminance coefficient

Source: *ANSI / IES RP-8-00* (R2005)

a. **Street Use:** While the street types in Table 11C-1.01 vary from high speed freeways down to low speed local streets, this chapter is only concerned with the major (also known as arterial), collector, and local street classifications. Some jurisdictions have already classified their streets and it is recommended to follow these classifications first. If the jurisdiction has not established classifications, refer to the descriptions in Chapter 5 - Roadway Design to determine the classification of the subject street.

b. **Pavement Type:** Pavement types are classified into four categories, R1 through R4. For the purposes of determining lighting criteria, two of the pavement classifications, R2 and R3, are combined, forming three illumination classifications. Refer to Table 11C-1.02 to determine the pavement type classification of the subject street.

c. **Pedestrian Conflict:** Pedestrian conflict is categorized into three classifications - high, medium, and low. The level of pedestrian conflict is almost entirely driven by the land use adjoining the street and the potential of the land use to cause pedestrian traffic during nighttime hours. For example, pedestrian conflict would be low for a local residential street as compared to a high pedestrian conflict level for a local street next to a movie theater. Refer to the pedestrian conflict classification descriptions following Table 11C-1.01 to determine the potential pedestrian conflict for the subject street.

   Using the defined classifications, determine the recommended illumination and uniformity ratio for the subject street. The illumination values listed represent average maintained footcandles over the street surface. The uniformity ratio is average footcandles divided by the minimum footcandle value. These values represent the minimum illumination and the maximum uniformity ratio recommended. The designer may consider more illumination and/or better uniformity for the street if it would better serve expected activity along the route.

2. **Selecting the Type of Light Source:** The vast majority of street lighting in municipalities is owned, operated, and maintained by the local electric utility. The cost for the installation, energy, and maintenance is paid for by the municipality in monthly installments based on established utility tariff rates for the type of lighting units installed. These rates are regulated and set by the utility with approval from the Iowa Utilities Board. If the street lighting to be installed on a particular project will be utility owned, the lighting equipment will need to be selected from that available from the utility. While the utility maintains a stock of various lighting source types, the only allowable type for public street lighting is HPS unless certain other conditions or exceptions can be met per Iowa Code.

   Currently, electric utilities do not maintain a stock of LED lighting luminaires for two reasons: the LED lighting package sizes have not been standardized, and LED technology is in a rapid state of flux. The energy consumption of any given LED package size may or may not fit in the utility's current tariff rate structure. Because they are regulated, utilities are not at liberty to create custom tariff rates to fit random load sizes. Also because of the rapid change in the industry, LED luminaire costs are varying widely and are considerably more expensive than HPS luminaires. This will likely change in the future when LED technology plateaus, cost compared to performance stabilizes, and the industry introduces more standardization. For now, LED lighting must be owned by the customer and must be on metered electric services.

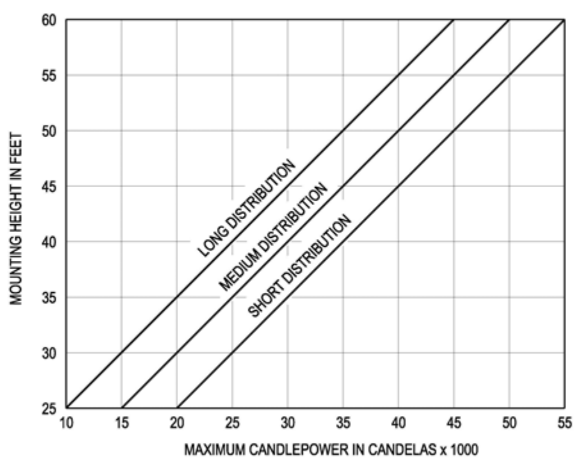
   If the street lighting will be owned and operated by the municipality, the choice of light source type is a little more open, but again, the installation still needs to meet Iowa Code. HPS lighting is a stable technology that can be installed economically with little risk from unknowns. LED lighting on the other hand, has more unknowns, such as will LEDs last as long as predicted and what will be the true cost of maintenance in the future. In spite of this, LEDs are seeing more use in applications, and with proper layout design, are proving to provide better quality lighting for less energy consumption compared to HPS.

If initial cost is an important parameter, currently HPS will have lower installation cost. If life-cycle cost is the deciding factor, then LED will likely win out, but the designer will have to develop layouts for each type to make the comparison. If the color of the light and color rendering of objects are important, LED will be the choice. In the future with the increase in performance of LEDs, the confirmation of LED rated life and the initial cost of LED luminaires nearing the cost of traditional HPS luminaires, LED will become the primary lighting source.

3. **Selecting Light Source Size and Mounting Height:** The distance the lamp/luminaire is mounted above the street will affect the illumination intensity, uniformity of brightness, area covered, and relative glare of the unit. Higher mounted units will provide greater coverage, more uniformity, and reduction of glare, but a lower illumination level. The illumination of an object from a light source varies inversely to the square of the distance from the light source, so doubling the distance will reduce the illumination on the object to one fourth of the original value. Therefore, greater mounting heights will require larger wattage luminaires. It is necessary to weigh the effects of larger wattage luminaires against a greater number of smaller units at lower mounting heights with an increase in glare potential.

   Mounting heights of street luminaires vary from 15 feet to more than 100 feet above the street surface. Conventional municipal street lighting utilizes mounting heights of 25 to 50 feet. Generally, the greater the target uniformity ratio, the shorter the mounting height and vice versa. Local street lighting uses 25 to 30 feet mounting heights while collector and major streets will use 30 to 40 feet mounting heights. The lower mounting heights may require the use of luminaires with a semi-cutoff distribution or better to minimize glare. Figure 11C-1.01 shows minimum mounting heights for various maximum candela levels and vertical light distributions.

Figure 11C-1.01: Minimum Mounting Height vs. Maximum Candela



Source: Adapted from *Roadway Lighting Handbook*

4. **Selecting Luminaire Light Distribution Type:** Selection of the luminaire light distribution type (lateral, vertical, and cutoff) for a given street lighting application depends on several elements, the mounting height, the pole placement pattern, the cross sectional geometry of the street, and any jurisdictional ordinances that control or limit light trespass, glare, or sky glow.

   Table 11B-1.02 is a guide to selecting which lateral light distribution(s) are best suited for the street width and pole placement pattern. This is only a guide. While lighting distribution types are defined, luminaires that fit into a type still vary between manufacturers. A Type II from one manufacturer may provide better illumination than a Type III from another for a wider street. For the given street width, pole pattern, and mounting height, the distribution pattern from the Type II may “fit” together better and provide more uniform light.

   The designer may select the first luminaire that meets the illumination criteria. However this may not be optimum selection based on defined goals of the project. Street lighting design is an iterative process if optimization is to be achieved.

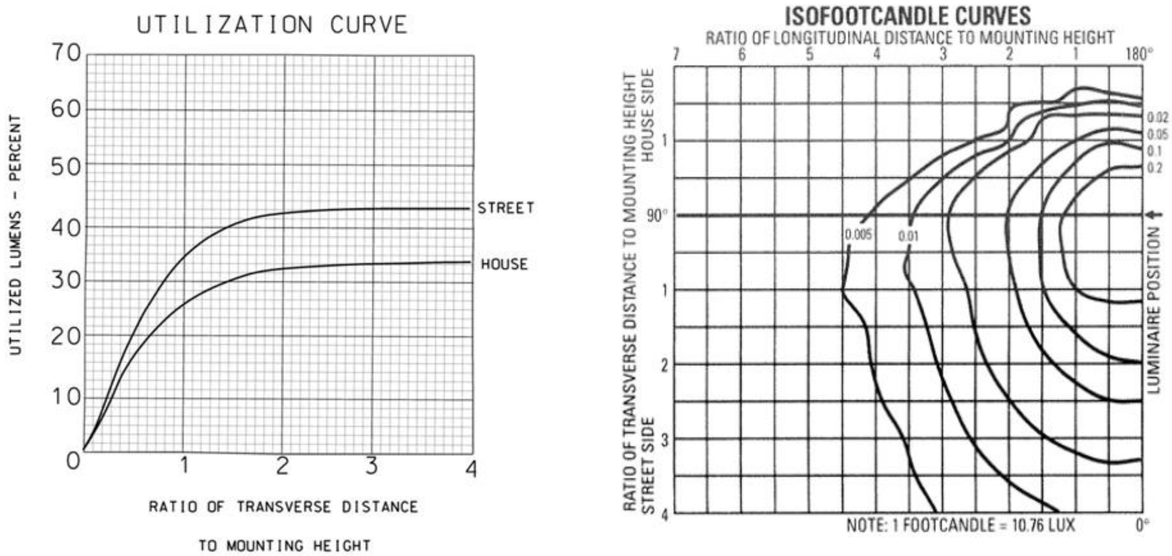
5. **Determining Luminaire Spacing and Location:** The most common lateral location of street lighting luminaires is positioned over the curb line or edge of pavement (zero overhang). This is also the base line for luminaire design. Since it would be impractical to place light poles directly at the edge of the street, lighting support structures typically consist of a poles fitted with mast arms to set the poles back away from and provide clearance for traffic and pedestrians. Streets typically have defined clear zones behind the curb or pavement edge, the width of which depends on the street characteristics. The designer needs to consider setback to determine if a mastarm of sufficient length is available to place the luminaire at the street edge. Luminaires positioned with excessive negative overhang will likely require shorter longitudinal luminaire spacing to compensate.

   Section 11B-1 discusses theoretical maximum longitudinal luminaire/pole spacing for a given vertical light distribution. However, this spacing may not be practical to fit the site. The designer needs to consider how the street interfaces with the adjoining property features. These factors include location of sidewalks, bike trails, driveways, alleys, and cross streets. Many times, particularly in residential areas, it is desirable to place the light poles in line with the side property lines.

6. **Checking for Design Adequacy:** All of the above selected elements are formed into a design concept or model. The next step is to perform calculations to verify the chosen equipment and layout to meet the design criteria. For many years, manual calculations were the only methods used to determine the resulting design illumination and uniformity. Since the advent of the computer, numerous software programs have been developed and are available to automate the calculation process.

   a. **Manual Calculation Method:** The most popular manual calculation method is the coefficient of utilization and isofootcandle plot method. As the name implies, two pieces of graphical information are required, a coefficient of utilization curve and an isofootcandle plot. These are developed by luminaire manufacturers and are required for the calculation process. Examples of such are shown in Figure 11C-1.02. The coefficient curve is a quantitative description of the percentage of total lumens emitted from the fixture that will land on or be utilized to illuminate the street below based on the street width and relative position of the luminaire to the street.

Figure 11C-1.02: Typical Luminaire Utilization and Isofootcandle Plots



Rather than repeat the process here, the designer is recommended to visit and access Minnesota DOT Street Lighting Design Manual, Sections 4 and 5. The discussion in this document provides a good step-by-step description of the manual calculation process.

b. Computer Modeling Method: All that is required is to obtain a lighting application software program to run on the computer to have the tools to model lighting installations and perform photometric calculations. There are numerous programs available, both purchased and free. Some software packages can be very sophisticated with the ability to create such things as shade plots and shade and shadow renderings to closely represent what the human eye would see. For the design purposes described herein, all that is required of the software is to take luminaire photometric data and perform point-by-point calculations on a defined plane and be able to export the numerical results.

The first requirement is to create a computer model of the street to be lit. For most situations, this involves defining the width and length of the street. Most of the lighting programs have drawing tools to create the model directly in the program. If an electronic representation of the street is available from a computer-aided design file such as that created by AutoCAD or Microstation, this can be imported into the lighting program to form the model. Once this is done, the designer will “place” luminaires spatially above the model surface locating them with the desired mounting height and overhang from the street edge.

For each luminaire type to be considered, the designer needs to acquire a photometric file that describes the photometry or lighting distribution characteristics of the luminaire. These files are generated by the manufacturer through laboratory testing. They are text files containing a defined array of light intensity values (candela) in standardly defined spatial directions emanating from the luminaire. The files are commonly referred to as IES photometric files (or IES files) since the standard was developed by the Illuminating Engineering Society of North America (IESNA). The files are readily available from the manufacturer’s website at no cost.

The files are imported into the program to model the performance of the selected luminaires. The candela values in the file are typically based on a default lamp lumen value of 1,000 lumens. The designer will be required to input the proper initial lamp lumen value, which will scale the intensity values accordingly. For LED luminaires however, the file usually contains the actual initial lumen value of the luminaire assembly since the LEDs are not necessarily a removable modular element of the luminaire. In any case, the designer is cautioned to verify the proper lumen value is used. Also, the designer will need to enter the lumen maintenance factor for each luminaire model.

The final task is to define a calculation area by drawing a region on the street model surface. The width of the area could be back of curb to back of curb for example, or it could be right-of-way to right-of-way to calculate the illumination from building face to building face in a downtown business district. Within this area, the designer will create a calculation grid that is a defined set of points on the surface, at which the footcandle illumination level will be calculated. Typical calculation point grids are a 10 feet by 10 feet or a 5 feet by 5 feet rectangular array. More points in the calculating area will usually yield more accurate results but require more computer processing time. For a small area, this is not a problem, but if the designer has created a large area, the time may be significant.

The program utilizes the superposition principal to perform the calculation. The program will step through each point and calculate the illumination contribution at that point on the model surface from each luminaire defined in the model. Each of these contribution values are simply added together to get the overall illumination at that point. Once all of the points are calculated, the program determines the average illumination value of all of the points in the grid, giving the average illumination of the entire surface. The program then uses the point with the lowest footcandle value to calculate the average-to-minimum uniformity ratio.

A clear advantage of using computer modeling is the ease in which the designer can make changes to the luminaire layout model and obtain the illumination results for different scenarios. For example, the designer could change luminaire, type, wattage, mounting height, or position; or any combination of these to optimize the lighting design and minimize the energy consumption.

Most available lighting design software packages contain pre-defined street models or “wizards” for quick luminaire spacing optimization. This allows a designer to simply input a luminaire at a mounting height, a street width, a mounting pattern (one-side, each side staggered, etc.), and target illumination criteria, and have the program calculate the optimum longitudinal luminaire spacing.

C. References

Federal Highway Administration. *Roadway Lighting Handbook*. 1978.

Illuminating Engineering Society of North America. *American National Standard Practice for Roadway Lighting*. ANSI / IENSA RP-8-00, (R2005).

Minnesota Department of Transportation. *Roadway Lighting Design Manual.* 2003.