# INDIANA DEPARTMENT OF TRANSPORTATION

***Driving Indiana's Economic Growth***

## Design Memorandum No. 16-03
## Technical Advisory

January 12, 2016

**TO:** **All Design, Operations, and District Personnel, and Consultants**

**FROM:** ***/s/ David Boruff***
**David Boruff**
**Manager, Office of Traffic Administration**
**Traffic Engineering Division**

**SUBJECT:** **Lighting Design Procedure**

**REVISE:** ***Indiana Design Manual* Section 502-4.02(03) through 502-4.07, Figures 502-4D, -4P, -4S, and Editable Documents 502-04-02, and 502-04-03**

**EFFECTIVE:** **Immediately**



The Department's lighting design procedure has been revised. The default service life used in performing the service cost per year has been increased to 20 years. The revisions also address the following:

- metered electrical services for solid state luminaires
- the average cost of electricity (used in the service cost per year calculation)
- how the uniformity ratio is to be used/interpreted
- lighting at roundabouts, underpasses, and pedestrian facilities
- adaptive lighting
- the BUG (backlight, uplight, and glare) rating system
- veiling luminance
- light trespass
- the equipment factor (used in the computation for lumen depreciation)

The revisions to the referenced IDM sections, figures, and Editable Documents are an attachment to this memo and have been incorporated into the on-line version of the IDM. Please contact the Office of Traffic Administration if you have any questions or need additional background information.

Local officials may determine the feasibility of providing lighting on a state highway within city or town limits.

### 502-4.02(01) Warrant Criteria for Freeways

Freeway lighting should be considered where the night-to-day ratio of crashes is greater than 0.5 and the lighting is expected to be cost effective.

In addition, warrant CFL-2 and CFL-3 of the AASHTO *Roadway Lighting Design Guide* may be considered.

### 502-4.02(02) Warrant Criteria for Interchanges

Interchange lighting should be considered where the night-to-day ratio of crashes is greater than 0.5 and the lighting is expected to be cost effective

In addition, AASHTO *Roadway Lighting Design Guide* warrants CIL-1 and CIL-2 for complete interchange lighting and warrant PIL-1 for partial interchange lighting may be considered.

### 502-4.02(03) Warrant Criteria for Non-Freeways [Rev. Jan. 2016]

Non-freeway lighting should be considered where the night-to-day ratio of crashes is greater than 0.5 and the lighting is expected to be cost effective.

In addition, lighting should be considered for locations with a relatively high potential for crashes, such as a section with numerous driveways, channelized islands, significant commercial or residential development, a high percentage of trucks, nighttime pedestrian volumes, or geometric deficiencies such as substandard safe stopping sight distance.

Where a state-maintained highway intersects with or closely parallels local streets with existing lighting or which may have future lighting, provisions should be made for possible future illumination on the state-maintained highway.

### 502-4.02(04) Criteria for Highway-Sign Lighting

Sign lighting will be provided only where it is determined by the District Traffic Office that the reflective sign sheeting by itself is not sufficient for nighttime visibility.

### 502-4.02(05) Criteria for Rest Area

Lighting will be provided for all areas within a rest area that have pedestrian activities. Rest area ramps are also lighted, especially if continuous lighting is provided on the freeway. Highway-type light standards and luminaires should be used to light the parking areas and the ramps.

### 502-4.02(06) Criteria for Truck Weigh Station

Each permanent truck weigh station should be lighted where weighing will occur after daylight hours. Highway-type light standards and luminaires should be used to light the weighing area, parking areas, speed change lanes, and ramps. Lighting may be provided for the sign preceding a truck weigh station which indicates that the station is open or closed.



### 502-4.02(07) Criteria for Bridge Structure

The following should be considered when determining the need for lighting on a bridge structure.

1. Lighted Approaches. Lighting should be placed across or under a bridge where one or both approaches have or are planned to have lighting. Ownership of the lighting will be determined in the same manner as for a roadway.

2. Geometrics. Lighting can be considered for a long, narrow bridge, though the approaches are not lighted. Lighting should be considered where there is unusual or critical roadway geometry under or adjacent to the underpass area.

### 502-4.02(08) Criteria for Tunnel or Underpass [Rev. Jan. 2016]

The lighting of a tunnel or underpass should be in accordance with the AASHTO *Roadway* Lighting Design Guide. Lighting of underpasses that are less than 75 ft in length is not normally needed. Daytime lighting should be considered for tunnels or underpasses with a length to height ratio that exceeds 10:1. *ANSI/IESNA RP-22-11* publication on American National Standard Practice for Tunnel Lighting contains additional information.

### 502-4.02(09) Criteria for Roundabout [Rev. Jan. 2016]

The lighting of a roundabout should be in accordance with the AASHTO *Roadway Lighting Design Guide* and NCHRP *Report 672*.

Lighting at the roundabout should include the central circulatory roadway and extend at least 400 ft from the circulatory roadway along all approaches. Lighting on the approaches should also extend through any pedestrian crosswalks and/or splitter islands. The remaining limits of the intersection can be delineated with RPM's or by other methods.

### 502-4.02(10) Criteria for Other Facilities

Lighting should be considered at the following locations:

1. commuter park-and-ride lot;
2. bikeway;
3. walkway; or
4. other pedestrian facility.

The need for lighting at one of these locations will be determined as required for each situation. See the *AASHTO Roadway Lighting Design Guide* for information on the lighting of walkways/bikeways separated from the roadway.



### 502-4.02(11) Reduction or Removal of Lighting [Rev. Jan. 2016]

Where an existing highway lighting system is no longer warranted, feasible, or cost effective, it should be considered for reduction in the lighting level or for removal. Where light levels are reduced, they should not be reduced below the criteria described in Figure 502-4G. Prior to reducing lighting or removing the system, an engineering investigation will be required. Concurrence by the Highway Design and Technical Support Division and approval by the Commissioner will be required. If federal-aid funds were used for the original installation and the project is on the National Highway System and is not exempt from FHWA oversight, a copy of the report should be submitted to the FHWA.

If determining whether an existing lighting system should be removed or the lighting reduced, the following should be considered.

1. Freeway Lighting. Continuous freeway lighting should be removed or reduced where a cost analysis shows that such action will be cost effective. The cost analysis will be similar to the one prepared for the installation of a new lighting system. However, this study must consider the increase in accidents and cost to remove the system. A 50% increase in nighttime accidents should be assumed over a period of three years for analysis purposes.

2. Interchange Lighting. Complete interchange lighting should be reduced to partial interchange lighting where the average traffic volume falls below the levels given in the *AASHTO Lighting Design Guide,* table 3-3, both cases CIL-1 and CIL-2, but satisfies that shown in table 3-4, case PIL-1. An engineering analysis will be required to determine the extent of lighting reduction. Removal of complete or partial lighting will require a cost analysis to determine the cost effectiveness of removing the lighting system. A 50% increase in nighttime accidents should be assumed for analysis purposes.

3. Non-Freeway Lighting. Where lighting is no longer warranted on a non-freeway section, a benefit/cost analysis should be conducted to confirm that the lighting is no longer warranted. Section 502-4.01(03) item 7 describes the procedure for removal of lighting if the local agency no longer can or is willing to pay the maintenance and operation costs for the lighting system.

4. Obsolete or Substandard System. Where it has been determined that a lighting system is obsolete, substandard, or is beyond its useful service life, it should be removed, replaced, or modified. An engineering investigation should be conducted to determine the appropriate action. If removal is considered, local input should be included in the investigation. A new replacement system should be installed only if it satisfies the warrants for a new system. Current accident data may be used for the analysis. However, the data should be adjusted to reflect the expected increase in accidents if the system is removed.

To study the effects of removing or reducing lighting, the Department may turn off part or all of the system. This may only be performed after an engineering analysis has been conducted to determine the expected effect of turning the lights off. This study period should not be less than one year or more than four years. After the study has been completed, the system may be either re-energized or removed.

After the decision has been made to remove or reduce the level of highway lighting, the lights should be turned off but left in place for a period of at least one year and not longer than four years. An accident analysis study will be required during this time period to determine the effects of the reduced lighting. A final cost analysis will be required with the updated accident and capital-improvement data. A system removal will be accomplished either by state forces or by a contractor as part of other project work.

**502-4.03(12) Alternative criteria for urban streets [Added Jan. 2016]**

Local agencies may refer to NCHRP Report 152, Highway Lighting Warrants for a thorough methodology to determine need for lighting on existing facilities,

**502-4.02(13) Transition Lighting [Added Jan. 2016]**

Where light levels are significant consideration should be given to providing a gradual transition to segments that are not lighted. See ANSI/IESNA RP-8.

**502-4.02(14) Adaptive Lighting [Added Jan. 2016]**

The fundamental concept of adaptive lighting is to provide lighting only when and where it is needed, essentially managing the roadway light level as an asset. Refer to "Publication No. FHWA-HRT-14-050 dated June 2014 for more information. Adaptive lighting may involve lighting curfews, or reduction of lighting during periods of low demand, e.g. from 1 a.m. to 4 a.m.

Adaptive lighting can be considered when lighting is installed/warranted based on the pedestrian counts but is not applicable for INDOT lighting systems which are installed based on other considerations. Lighting curfews can be implemented only with the use of solid state luminaire technology.



## 502-4.03 Lighting Equipment

A number of options are available in selecting luminaire equipment that will satisfy the desired design criteria. Figure 502-4C, Typical Light-Pole Installation, provides an illustration of the parts of the lighting standard and luminaire. In addition to the INDOT *Standard Drawings* and the INDOT *Standard Specifications,* the following provides guidance regarding INDOT's approved lighting equipment.

The selected equipment should be determined to be in accordance with standard hardware designs. Specialized equipment and designs can increase the installation and maintenance costs, thereby reducing the cost effectiveness of the lighting system.

### 502-4.03(01) Foundation

Upon determining the foundation design, the following should be considered.

1. Material. Each foundation for a permanent installation should be concrete class A. It may be either cast-in-place or precast.

2. Design. The INDOT *Standard Drawings* provide the details for depth, width, reinforcing, etc., for both conventional and high-mast light standards. For a high-mast foundation, a soil survey is required to determine if additional support is required.

3. Placement and Grading. The INDOT *Standard Drawings* and Section 502-4.06(05) provide the criteria for the placement of a light standard relative to the roadway and ditch lines. They also provide criteria for grading around the light standard foundation.



### 502-4.03(02) Light Standard or Pole

A factor in highway lighting design is the selection of the luminaire and the mounting height. A higher mounting height will reduce the number of light standards required. The INDOT *Standard Specifications* and the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* provide the Department's criteria for light standards. The following describes the light standards used by the Department.

1. Conventional. This type of pole is used most often. It has a mounting height ranging from 30 ft to 50 ft. INDOT practice is to use a light pole with a mounting height between 40 ft and 50 ft. The recommended minimum mounting height is 40 ft. Details for conventional light poles appear in the INDOT *Standard Drawings*.

2. High-Mast. A high-mast pole can range from 80 ft to 200 ft in height. This type should be used where there is a large area that requires lighting, e.g., interchange. The use of high-mast lighting and higher-wattage lamps reduces the number of poles, yet retains the quality of the lighting. High-mast lighting should be considered where practical. Details for high-mast towers appear in the INDOT *Standard Drawings*.

3. Materials. Light standards for a permanent installation are made of galvanized steel, stainless steel, or aluminum. Wood poles are used as service poles or for temporary lighting, e.g., in a construction zone.

4. Base. Unless otherwise protected, a breakaway base should be provided for each light pole within the clear zone along a rural or high-speed urban highway. However, where pedestrians are present, a breakaway base should not be used. Section 502-4.06(05) provides additional criteria on the appropriate application of where to use a breakaway or non-breakaway base. Each breakaway base should be in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The base types include the following.

   a. Breakaway Transformer Base. A transformer base consists of an aluminum apron between the concrete foundation and the base of the pole. The breakaway transformer base is designed to be struck by a car's bumper. Once hit, the base deforms and breaks away. All wiring inside the base must also be connected to the breakaway device. The cast-aluminum transformer base should be used.

   b. Non-Breakaway Steel Transformer Base. A steel transformer base is similar in design to an aluminum base. However, it is not in accordance with the AASHTO breakaway criteria. Section 502-4.06(05) discusses the appropriate locations where a breakaway base is not required.

   c. Breakaway Support Coupling. A breakaway support coupling is an aluminum connector or sleeve which is designed to shear once the pole is hit. The bottom of the coupling is threaded onto the foundation anchor bolts, and the light standard is attached to the top of the coupling. Four couplings are used with each light standard. The support coupling length is 5 in.

   d. Anchor Base. An anchor base is a metal plate which is welded to the bottom of the luminaire support. The plate allows the post to be bolted to the foundation without an intermediate breakaway device or to a breakaway coupling, slip plate, or transformer base.

5. Structural Design. Each light standard should be designed in accordance with the structural design criteria described in the INDOT *Standard Specifications*, including the criteria for wind loading, maximum horizontal deflection, maximum stresses, luminaire loads, material strengths, welds, bolts, etc.

6. <u>Effective Mounting Height</u>. A light standard must be constructed so that it provides a luminaire mounting height above the roadway pavement as shown in Figure 502-4C, Typical Light-Pole Installation. After determining the mounting height, the appropriate pole length can then be determined.

7. <u>Lighting Location Identification Numbering System</u>.

Lighting identification numbers should be incorporated into the plans and should be determined as follows:

a. Overall Numbering Format.

1) The first set in the identification is the county number in which the lighting system is located.

2) The county number is followed by a 1-, 2-, or 3-digit route number of the mainline route or major road on which the system is located.

3) The mainline route number is followed by the cross road number.

If the cross road is a numbered route on the state highway system the 1-, 2-, or 3-digit route number of the cross road should be used.

If the cross road is not a numbered state highway system route then a special identifier is needed for the county road, city street, exit number, rest area or weigh station. See item 7.b for details.

4) The last set is the 1-, 2-, or 3-digit number specifying the individual pole, sign, or underpass location.

b. Specialized Numbering for Cross Roads that Are Not Numbered State Routes.

1) Intersection of an Interstate Route and a County Road or City Street.

The cross road should be labeled with “EX” (for exit) as a special identifier followed by the mile marker exit number of the interchange.

2) Intersection of S.R. or U.S. Route and a County Road.

The cross road special identifier should be “CR” (for County Road) followed by the county road number.

3) Intersection of S.R. or U.S. Route With a City Street.

The first two letters of the city's name should be used as the special identifier followed by a three- or four-letter abbreviation of the crossroad's name.

4) Rest Area Located on the Interstate.

"NR", "SR", "ER" or "WR" (for northbound rest area, southbound rest area, eastbound rest area or westbound rest area respectively) should be used as the special identifier followed by the 1-, 2-, or 3-digit mile marker number closest to the rest area.

5) Rest Area Located on a S.R. or U.S. Route.

"RA" should be used as the special identifier followed by a three- or four-letter abbreviation of the rest area's name.

6) Weigh Station Located on the Interstate.

"NW", "SW", "EW" or "WW" (for northbound weigh station, southbound weigh station, east bound weigh station, or westbound weigh station respectively) should be used as the special identifier followed by the 1-, 2-, or 3-digit mile marker number closest to the weigh station.

7) Weigh Station Located on a S. R. or U.S. Route.

The special identifiers are to be used in the same manner as for weigh station on interstates routs with the exception that instead of using a 1-, 2-, or 3-digit mile marker numbers, there will be a four-letter unique identifier created for that particular weigh station.

When more than two routes intersect at a location, only the two most primary or major route numbers shall be used to identify the location.

When two routes intersect more than once in a county, then the letters "NJ", "SJ", "EJ" or "WJ" shall be used after the 1-, 2-, or 3-digits of the crossroad route number and before the hyphen to indicate that a given intersection is the north junction, south junction, east junction, or west junction respectively.

### 502-4.03(03) Mast Arm

A mast arm allows placement of the light source near the edge of the travel lane. The use of a longer mast arm is recommended, although the initial costs may be higher. A longer mast arm allows the pole to be placed farther from the traveled way, thus providing a safer roadside environment. Otherwise, the use of a longer mast arm can have a negative effect on the loading capabilities of the base. In addition to the INDOT *Standard Specifications*, the following provides information and design guidance regarding the use of a mast arm.

1. Material. Mast arms are made of the same material as the light standard.

2. Mast Arm. The following should be used to determine the appropriate mast-arm type.

   a. Less than 8 ft. This may be either of the single-member or the truss-type design. The design should be consistent with other nearby mast arm types.

   b. 8 ft or Longer. This should be of only the truss-type design.

3. Mast-Arm Length. The length of the mast arm should be such that the luminaire is placed over the center of the width of the shoulder.

4. Bridge. Each mast arm for a bridge-deck light standard should be of the truss-type design.

5. Rise. Figure 502-4D, Mast-Arm Rise, provides the maximum rise that should be used, based on the mast-arm length. See Figure 502-4C for Typical Light-Pole Installation and illustration of Mast-Arm Rise.



### 502-4.03(04) Luminaire [Rev. Jan. 2016]

A luminaire is defined as a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute light. The INDOT *Standard Specifications*, along with the following, provide the Department's criteria for luminaire hardware. Section 502-4.06(03) item 1 discusses the light distributions for a luminaire. For additional information, the designer should contact the Traffic Administration Manager, Traffic Engineering Division for the latest products and specifications.

1. Light Source. The following provides information on the light sources that may be used.

a. High-Pressure Sodium (HPS). The HPS lamp produces a soft, pinkish-yellow light by passing an electric current through a sodium-and-mercury vapor.

b. Low-Pressure Sodium (LPS). Its disadvantage is that it requires long tubes and has poor color quality. INDOT does not allow the use of LPS on a state facility. However, a local agency can consider the use of an LPS lighting source. The LPS lamp produces a yellow light by passing an electrical current through a sodium vapor.

c. Metal Halide (MH). A metal-halide lamp produces color at higher efficiency than a mercury vapor (MV) lamp. However, life expectancy for a traditional MH lamp is shorter than that for an HPS or MV. An MH lamp is also more sensitive to lamp orientation than other light sources. The traditional MH luminaire is used for lighting a sports arena or major sports stadium, for high-mast lighting, or for lighting a downtown area or park. Metal Halide luminaires utilizing solid state ballasts are viable options for general roadway applications. Metal halide produces good color rendition. Light is produced by passing a current through a combination of metallic vapors.

d. Light Emitting Diode (LED). LEDs are arranged in clusters which are attached to a panel. Various designs utilize different LED types Heat sinks are built into the housing to facilitate heat dissipation and maximize luminaire service life. Light is directly emitted from the lens, so reflectors are not required, resulting in the light being delivered more efficiently than the HPS type and also resulting in less light pollution. LEDs are energy efficient, have a long life, and generate a full color spectrum resulting in good color rendition. Due to the manner in which light is emitted the arrays must be carefully arranged to provide sufficient light distribution and yet be energy efficient. Properly arranged LEDs can provide energy efficient, effective light distribution.

LED retrofits are available for existing high mast luminaires. LED modules are attached to a threaded rod which is fit into the existing housing. Luminaire dimensions should be verified as housing diameters less than 16 inches may require an attachment plate as well as the threaded rod, pending the retrofit manufacturer's specific design.

e. Light Emitting Plasma. Plasma lamps generate light by exciting gas with radio frequency power. They produce visible light without phosphor conversion which results in a higher luminaire efficiency and which eliminates color shift. The point-source light they generate results in an even distribution of light through highly efficient optics. Plasma luminaires have no electrodes which reduces maintenance requirements. They are highly efficient, have a long life, and generate a full color spectrum resulting in good color rendition. Heat sinks are built into the housing to facilitate heat dissipation and maximize luminaire service life.

f. Induction Lighting. Magnetic induction lamps also contain no electrodes resulting in an extended service life. The power used to generate light is transferred from outside the lamp to inside via electromagnetic fields. Induction lamps are also efficient light generators compared to HPS lamps.

2. Optical System. The optical system consists of a light source, a reflector (except for LED), and also a refractor (or lens for LED).

a. Light Source. Item 1 above discusses light sources that should be considered.

b. Reflector. The reflector is used in optical control to change the direction of the light rays. Its purpose is to take that portion of light emitted by the lamp that otherwise will be lost or poorly utilized, and to redirect it to a more desirable distribution pattern. A reflector is designed to work either alone or with a refractor. Reflectors are specular or diffuse. A specular reflector is made from a glossy material that provides a mirror-like surface. A diffuse reflector is used where the intent is to spread the light over a wider area.

c. Refractor. The refractor is another means in optical control to change the direction of the light. A refractor is made of transparent high-strength glass or plastic. Plastic is used in a high-vandalism area. However, plastic can yellow over time due to heat and ultraviolet exposure. The refractor, through its prismatic construction, controls and redirects both the light emitted by the lamp and the light reflected off the reflector. It can also be used to control the brightness of the lamp source.

3. Ballast/Power Driver. Each luminaire must operate with an input voltage variation of ±10% of the rated operating voltage specified, with non-solid state technologies this is accomplished through a built-in ballast. A ballast is used to regulate the voltage to the lamp to ensure that the lamp is operating within its design parameters. It also provides the proper open-circuit voltage to start the lamp. The ballast should be an auto-regulator type. Figure 502-4E, Lamp Data, provides the approximate expected operating wattage for a ballast based on the lamp wattage.

For solid state technology luminaires the input voltage is controlled by a power driver. Power drivers are completely electronic and are considered to be the controlling component in the performance and service life of the luminaire. Electronic power drivers allow for the light source to be dimmed so they provide an opportunity to reduce energy consumption through adaptive lighting (reduced light levels after a certain time at night).

4. Housing Unit. Luminaire housing requirements are dependent upon the application type. In selecting a luminaire housing, the following should be considered.

   a. Roadway-Lighting Luminaire. The housing unit should allow access from the street side and allow for adjustments to the light. The luminaire should also have a high-impact, heat-resistant, glass, or plastic prismatic refractor.

      Since LEDs generate a substantial amount of heat and since they are sensitive to heat buildup, their housings are provided with apparatus known as heat sinks to dissipate heat in an effective manner. The typical heat sink is a shape or plate placed in contact with the LED panel. The shape or plate is usually made of a conductive metal such as aluminum.

   b. Sign Luminaire. A sign luminaire requires the same housing as a roadway-lighting luminaire, except that it should also provide a durable, plastic, vandal-resistant shield that blocks the view of the refractor from an approaching motorist. The unit is attached to the sign walkway as shown on the INDOT *Standard Drawings.* The mounting attachment is adjustable to allow for directing the light onto the sign.

   c. Underpass Luminaire. An underpass luminaire requires the same housing as a roadway-lighting luminaire, except that it should also provide a durable, plastic, vandal-resistant shield. The ballast should be placed as shown on the INDOT *Standard Drawings*. An underpass luminaire may be attached to the vertical-side surface of a bridge bent structure, or may be suspended by the use of a pendant.

   d. High-Mast Luminaire. A high-mast luminaire is an enclosed unit with a reflector and a borosilicate glass refractor. The luminaire is attached to the mast ring. The mounting attachment is adjustable to allow for directing the light.

5. Backlight, Uplight, and Glare (BUG) Rating. I.E.S.N.A. has recently adopted a system of classifying the amount of light that is generated in three distinct directions from the luminaire. The BUG rating system is an alternative to the conventional "cut-off" system as a means of classifying light distribution.

Backlight is defined as the light distributed away from the street (towards sidewalk, shoulder, etc.) and below the luminaire. Uplight is the amount of light that is directed above the luminaire either to the front or back. Glare, or offensive light, results from light distributed to the street side below the luminaire and towards the driver at an acute angle from the luminaire (less than 30 degrees from horizontal).

BUG ratings can be specified to limit or control the amount of glare, sky glow and light trespass effecting the environment of the lighting system. For example for locations adjacent to observatories and planetariums it may be desirable to keep the amount of uplight to a minimum thereby reducing sky glow and interference with astronomical observations. In urban settings a certain amount of backlight on sidewalk and parking lot areas may be desirable for added security. For luminaires mounted at lower heights (less than 30 ft) the designer should consider models with a glare rating no greater than 3.

Each of the three ratings is on a scale of 0 to 6, higher the number the greater the affect.

For additional information on the BUG rating system refer to the following I.E.S.N.A. publication: *https://www.ies.org/pdf/education/ies-fol-addenda-1-%20bug-ratings.pdf*.

**502-4.03(05) Other Equipment [Rev. Jan. 2016]**

In developing a highway-lighting system, the equipment component can affect the design of the system. The elements include the following and are addressed in the INDOT *Standard Drawings*, the INDOT *Standard Specifications* and the manufacturer's criteria.

1. Electric Components. See Section 502-4.03(04) for a discussion of electrical components for various light sources, including ballasts, fuses, photoelectric controls, wiring, conduit, handholes, connections, breaker boxes, circuit breakers, relay switches, etc.

2. High-Mast Light Standard. The components include the luminaire ring assembly for attaching a luminaire, head frame assembly, winch assembly, external drive system used to lower the luminaire for maintenance, cable terminator, and lightning rod.

3. Utility Service. Since many electric providers have not yet adopted a flat billing rate for solid state light sources when solid state is to be used the designer should consider specifying a metered service so that the owner may better realize the benefit of reduced energy consumption. This will involve coordination with the electric provider and either the district office or the agency of jurisdiction.

## 502-4.04 Lighting Methodologies

The lighting-design methodologies are those for illuminance, luminance, and small-target visibility. The Illuminating Engineering Society (IES) of North America has been the leader in the development of these procedures. Only the illuminance methodology should be used in the design of highway lighting. For additional information on these procedures, see the references listed in Section 502-4.01(01).



**502-4.04(01) Illuminance**

Illuminance is defined as the density of the luminous flux incident on a surface measured in footcandles. The methodology is concerned with the measurement of the light's intensity striking a particular point on the pavement. The brightest spot will occur directly under the luminaire and diminish the farther a motorist is away from the source. The disadvantage of this methodology is that one does not see incident light, but instead sees the light reflected from an object or surface. This sensation is known as brightness, with objects distinguished by the difference in brightness or contrast. Brightness can be expressed mathematically as luminance, or the luminous intensity per unit area directed towards the eye.

The factors in illuminance methodology are the measurement of average maintained horizontal illumination, $E_h$, and the uniformity ratio of the average-maintained illuminance to the minimum-maintained illuminance.

### 502-4.04(02) Luminance

Luminance is defined as the luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction. It is measured in candelas per square foot. The luminance methodology is concerned with the measurement of light from the luminaire reflecting off the pavement surface to the motorist's eyes. This measurement is affected by the pavement's reflectivity characteristics. To obtain the lighting measurements for the roadway, readings are taken from a set of observation points spread across the roadway in a grid pattern. Compared to the illuminance methodology, the luminance methodology is considered a more-accurate representation of the motorist's visibility requirements. However, the methodology is more complicated to understand and use. Also, the pavement reflectivity must be estimated for the current time and for the future.

The design factors in luminance design include average maintained luminance ($L_{avg}$), minimum luminance ($L_{min}$), maximum luminance ($L_{max}$), maximum veiling luminance ($L_v$), and ratios of $L_{avg}$ to $L_{min}$, $L_{max}$ to $L_{min}$, and $L_v$ to $L_{avg}$. This methodology should not be used in lighting-determination design.

### 502-4.04(03) Small-Target Visibility (STV)

IES has proposed the STV methodology in an effort to better-define actual visibility requirements of the motorist. This methodology is similar to the luminance methodology in measurement of the light's reflectivity but, instead of measuring the pavement's reflectivity, it measures the reflectivity of a flat, square target of 7 in. diameter with 20% diffuse reflectance against the pavement background. The target is perpendicular to the roadway surface and is located a fixed distance of 270 ft ahead of the observer. The observer's target sight line is parallel to the centerline of the roadway. The STV methodology is more complex than the other methodologies and is considered impossible to calculate manually. Therefore, a computer is required. The STV methodology should not be used.

## 502-4.05  Design Procedure [Rev. Jan. 2016]

For additional design information, see the references listed in Section 502-4.01(01).

Lighting-system design should consider various light sources and may require several iterations for each type of light source to produce an acceptable design. After the first run, if the design criteria are not satisfied, the initial parameters should be changed, e.g., pole spacing, mounting height, light source, luminaire wattage, and lamp lumen output. The design should be rechecked to determine if it then satisfies the criteria. This process is repeated until the design is optimized and all criteria are satisfied.

As part of the scope of work on a project the designer may be given specific parameters for the lighting system, e.g., tower or conventional, pole height, and luminaire type, to supplement or supersede the guidance provided in this section.

Lighting in the interchange area should be maintained at the same level or better as on the crossroad approaches. Partial interchange lighting should include the merge and diverge areas-see Figure 502-4M.

Conflict points, protected turn lanes, and approaches to divided areas and traffic islands should be illuminated when intersection lighting is provided.

### 502-4.05(01)  Computerized Design [Rev. Jan. 2016]

To determine an acceptable lighting system requires iterations using variables. The chance for error in manually solving its equations is high. Therefore, one of the commercial computer software packages that are available should be used.

Each software package requires the same input and performs the same calculations. However, the method of input can vary. The user should first determine which programs are currently acceptable to INDOT. The PC-based program VISUAL®, developed by Acuity Brands, or AGi32, by Lighting Analysts should be used for its lighting calculations. These programs are used to generate templates for design and to check lighting levels and uniformity.

The design model files for a lighting design prepared by a consultant, should be provided to the Traffic Design and Review Team, Traffic Engineering Division.

### 502-4.05(02) Design Process [Rev. Jan. 2016]

Lighting may be designed under four different scenarios. The procedural steps in designing a lighting system for each are as follows.

1. Spot Lighting. Spot lighting comprises no more than one or two lights at an intersection or other particular spot along the roadway where it is deemed necessary to identify that roadway feature at nighttime.

   In this circumstance AASHTO design criteria need not be applied so it is not necessary for the designer to perform light level computations.

   The design should be developed as follows:

   a. Coordinate with the utility company to determine the availability of electric service and to identify the location of the service point. Reimbursement costs to the utility company should be identified in a special provision and the cost incorporated into the bid estimate.

   b. Develop a plan sheet for the location. The plan sheet should include the roadway geometry, the location of the service point indicating the voltage being supplied, location of the pole(s), the orientation of the luminaire(s), the light source type and luminaire wattage, as well as any underground wiring, conduit, handholes, and cable duct markers needed.



2. Luminaire Replacement or Partial Modernizations. This type of project involves the replacement of luminaires on existing poles. Other equipment may also be replaced.

   The design should be developed as follows:

   a. Assembly of Information. Obtain a plan of the existing lighting system.

   b. Verification of Plan. Verify that the geometrics and lighting system are accurately detailed on the existing plan sheet.

   c. Confirmation of Scope. Confirm which elements in the system are to be modernized. This should be coordinated with the district Traffic Office.

   d. Selection of Design Criteria. Select the appropriate AASHTO design criteria based on the type of roadway. See 502-4.06(02) for more information.

e. Selection of Light Source Type. Select the optimal light source type and wattage to satisfy the design criteria in a cost effective manner. Because calculations by computer are relatively quick and easy, the designer should try a number of alternative light source types even if the first design satisfies the criteria since more than one alternative may be satisfactory. Systems with 40-ft height poles will typically utilize a luminaire that provides approximately 28,000 or 50,000 lumens of initial light output in a M-S-Type II, III or Type IV IES distribution classification. See Figure 502-4C for more information on lumen output and Figure 502-4 I for information on the IES classification system.

At a minimum the alternatives should include one HPS, one LED, one plasma, and one metal halide model. Other light source types may also be considered. For systems utilizing a shorter mounting height (e.g. with streetscape projects utilizing pedestal poles), induction lighting may be viable. Only luminaire types and models that have an accessible IES light distribution file can be used. For a list of manufacturers that have approached INDOT about use of their luminaires go to Y:\TrafficManagement\Luminaire Manufacturers. Consultants and local agencies may contact their Project Manager or the Office of Traffic Administration to obtain this information.

Design optimization should include an analysis for the purpose of minimizing service costs. The lowest service cost per year alternative should be selected. The service cost is defined to be:

Service Cost per Year =

Annual Energy Cost + Annual Routine Luminaire Maintenance Costs + Installation Cost/Service Life

Where:

Annual Energy Cost = (Total Luminaire Wattage of the System) x (Hours Operated per Year) x (Cost of Electricity)

Hours Operated per Year = 4380 h

Cost of Electricity (estimated) = $0.10 per kWh (as of Oct. 2014)
The average cost of electricity for the transportation sector in the state of Indiana is available from the U.S. Energy Information Administration's Electric Monthly Report, table 5.6.b, at http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_b.

The electric provider or district may have a more location specific unit cost.

Maintenance Cost for HPS should be based on re-lamping the entire system every 3 years as well as other miscellaneous work. Currently this cost is estimated at $60 per year for each 250-watt or 400-watt luminaire and $105 per year for each 1000-watt high-mast luminaire. The cost for non-HPS light sources may be estimated at $25 per year for roadway luminaires and $50 per year for high-mast luminaires plus any additional maintenance costs that are specific to the type and model. The designer should confer with the manufacturer for these specific maintenance costs; however, typically plasma emitters will need to be replaced after 50,000 (11 years). LED arrays and power drivers may also need to be replaced within the expected service life- these additional maintenance costs should be included. If manufacturer specific information is not available additional annual maintenance costs of $15 per LED or plasma roadway luminaire and $20 per LED or plasma high mast luminaire may be used; bringing the total estimated annual maintenance costs for the lighting system to $40 per roadway luminaire and $70 per year for high mast.

Recent bid history as obtained on the INDOT website should be used to estimate the cost of HPS luminaires. Cost of luminaires utilizing alternative light sources should be obtained from the manufacturer along with an estimate of the cost to install for about 1 hour of labor per luminaire. A $75 estimate can be used for labor cost.



Service life may be estimated at 20 years, including the luminaire regardless of light source type..

A Service Costs Analysis for Luminaire Modernization worksheet should be completed for each alternative considered and placed in the project file. An editable version of this worksheet is available from the Department's Editable Documents webpage at http://www.in.gov/dot/div/contracts/design/dmforms/, under Lighting. If the service cost analysis does not yield a clear choice, other factors such as the light color or district preferences should be weighed into the decision regarding the type of light source.

f. Electric Design. Once the luminaire model has been selected, the designer will need to determine the voltage drop for the system. Section 502-4.06(07) provides information on how to determine the voltage drop for the lighting system. If the most cost effective model results in too much voltage drop the designer may either check the voltage drop of the second most cost effective design for use or may try additional luminaire models.

g. Preparation of Plans. The plan sheet should indicate the average illumination level and uniformity ratio and should show the location of the existing equipment being reused with an indication of what items are being replaced or added. Equipment includes the service point indicating voltage being supplied, pole(s), the orientation of the luminaire(s), underground wiring, conduit, handholes, and cable duct markers. The light source type, luminaire wattage, total initial lumen output, estimated light loss factor, and the IES file type used will be given on the plans with a note that the distribution pattern of the actual luminaire to be supplied will be equivalent, e.g., "Luminaire shall provide a light distribution equivalent to IES distribution type GE 452918.IES." This distribution pattern is based on how a specific luminaire model distributes light, i.e., how it is designed, and also corresponds to the lumen output and power draw of the fixture. If a particular backlight/uplight/glare rating is needed this information should also be specified on the plans. The luminaire table, service point amp table, and the lighting ID numbers should also be included on the plans.

h. Utility Notification. If there is a change in service location or an increase in the power required the designer must coordinate with the electric provider. Reimbursement costs to the utility company should be identified in a special provision and the cost incorporated into the bid estimate.

i. Working (Shop) Drawing Check. As part of the working drawing approval the contractor will submit the IES photometric distribution file for each model when the IES file number is different from that indicated on the plans, i.e., when the contractor is submitting a different model than that on which the design is based. In these cases, the IES files will be provided to the design engineer of record for his/her review and concurrence that the design light level criteria will be satisfied.

3. New Lighting System or Full Modernizations. This procedure should be followed when designing a new system or when modernizing and the existing poles and foundations will not be reused.

a. Assembly of Information. Necessary information to be assembled includes the following.

a. Contact the Traffic Review Team for the current design policies and procedures applicable to the project, sample plans, schedules, pay quantities, and example calculations.
b. Gather roadway and bridge plans including plan and profile sheets and details sheets, e.g., those for overhead signs.
c. Determine existing and expected utility locations.
d. Discuss special considerations with the road or bridge designer.
e. Conduct field reviews. Note areas of high ambient lighting and facilities that are sensitive to light trespass or sky glow (e.g. farms, observatories).
f. If this project is a local-agency project, hold discussions with local officials.

b. Determination of Classifications. The roadway classification and environmental conditions should be determined. If not already included in the project report, this information can be obtained from the Environmental Policy Team. The roadway classifications, for lighting purposes, are defined in Section 502-4.06(01).

c. Selection of Design Criteria. The pertinent design methodology described in Section 502-4.04 should be selected, along with the appropriate criteria based on the classification selected in Step 2. See Section 502-4.06(02) for information. For an INDOT-route lighting project**,** only the illuminance design methodology should be used.

d. Selection of Optimum Design and Light Source Type. Because recalculations by computer are relatively quick and easy, the designer should try several alternatives even if one design satisfies the criteria. There is often more than one satisfactory alternative.

At a minimum, the alternatives should include one HPS, one LED, one plasma, and one metal halide model, although other light source types may also be considered. For systems utilizing shorter mounting height (e.g. with streetscape projects utilizing pedestal poles) induction lighting may be viable. Only luminaire types and models that have a published IES light distribution can be used. For a list of manufacturers that have approached INDOT about use of their luminaires go to Y:\TrafficManagement\Luminaire Manufacturers-list. Consultants and local agencies may contact their Project Manager or the Office of Traffic Administration to obtain this information.

Design Optimization should include an analysis for the purpose of minimizing service costs. The lowest service cost per year alternative should be selected. The service cost is defined to be:

Service Cost per Year =

Annual Energy Cost + Annual Routine Luminaire Maintenance Costs

+ Installation Costs/Service life

Where:

Annual Energy Cost = (Total Luminaire Wattage of the System) x (Hours Operated per Year) x (Cost of Electricity)

Hours Operated per Year = 4380 h

Cost of Electricity (estimated) = $0.10 per kWh (as of Oct. 2014)

The average cost of electricity for the transportation sector in the state of Indiana is available from the U.S. Energy Information Administration's Electric Monthly Report, table 5.6.b, at http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_b. *The electric provider or district may have a more location specific unit cost.* *The electric provider or district may have a more location specific* unit cost.

Maintenance Cost for HPS should be based on re-lamping the entire system every 3 years as well as other miscellaneous work. Currently this cost is estimated at $60 per year for each 250-watt or 400-watt luminaire and $105 per year for each 1000-watt high-mast luminaire. The cost for non-HPS light sources may be estimated at $25 per year for roadway luminaires and $50 per year for high-mast luminaires plus any additional maintenance costs that are specific to the type and model. The designer should confer with the manufacturer for these specific maintenance costs; however, typically plasma emitters will need to be replaced after 50,000 (11 years). LED arrays and power drivers may also need to be replaced within the expected service life- these additional maintenance costs should be included. If manufacturer specific information is not available additional annual maintenance costs of $15 per LED or plasma roadway luminaire and $20 per LED or plasma high mast luminaire may be used; bringing the total estimated annual maintenance costs for the lighting system to $40 per roadway luminaire and $70 per year for high mast.

Installation Cost should include poles and foundations as well as the luminaires. Recent bid history as obtained on INDOT website should be used. Cost of luminaires utilizing other light sources should be obtained from the manufacturer along with an estimate of the cost to install for about 1 hour of labor per luminaire. A $75 estimate can be used for labor cost.

Service life may be estimated at 20 years, including the luminaire regardless of light source type.

A Service Costs Analysis for New or Fully Modernized Lighting worksheet should be completed for each alternative considered and placed in the project file. An editable version of this worksheet is available for download from are available for download from the Department's Editable Documents webpage at http://www.in.gov/dot/div/contracts/design/dmforms/, under Lighting. If the service cost analysis does not yield a clear choice, other factors such as the light color or district preferences should be weighed into the decision regarding the type of light source.



i. Selection of Equipment and Light Output Characteristics. In the preliminary design, initial assumptions should be made regarding the equipment composition and light output. This includes mounting height, pole setback distance, light source, mast-arm length, light source type, lamp wattage, etc. A 40-ft height pole should be used with a luminaire that provides approximately 28,000 or 50,000 lumens of initial light output in an M-S-Type II, III or Type IV IES distribution classification. See Figure 502-4 I for information on the IES classification system. Figure 502-4E, Lamp Data, provides the information on lighting levels for lighting sources. See Sections 502-4.03 and 502-4.06(03) for additional information on equipment selection. After selecting the luminaire equipment, the photometric data sheet should be obtained from the manufacturer for the luminaire selected.

   Normally mounting heights and mast arm lengths will be uniform through the project limits. If the project ties into adjacent lighting systems consideration should be given to matching these considerations.

ii. Selection of Layout Arrangement. Section 502-4.06(04) provides information on the commonly used lighting arrangements. The selection of the appropriate layout design depends upon local site conditions and engineering judgment. Section 502-4.06(05) provides the roadside-safety considerations in selecting the lighting arrangements. Section 502-4.06 (06) provides other layout considerations.

iii. Luminaire Spacing. For an INDOT-route lighting project, the illuminance methodology should be used to determine the appropriate luminaire spacing. This step is conducted by the computer.

iv. Check for Uniformity. Once the spacing has been determined, the uniformity of light distribution should be checked and compared to the criteria selected in Item c. Use the following equation to determine the uniformity ratio:

$$\text{Uniformity Ratio} = \frac{\text{Average Maintained Illumination Value}}{\text{Minimum Maintained Illumination Value}} \qquad \text{(Equation 502-4.05)}$$

When comparing alternative designs that yield approximately equivalent annual service costs the designer should also consider the number of poles- from a safety consideration the fewer the better.

e. Electric Design. Once the type, number, size, and location of the luminaires are determined, the electric voltage drop should be determined for the system. Section 502-4.06(07) provides this information.

f. INDOT Pre-Design Approval. For a consultant-designed project, the consultant should submit the service cost analysis worksheets and discuss the optimum alternatives with the Traffic Review Team prior to preparing the plans to expedite project development. Upon approval from INDOT, FHWA if necessary, and the local utility company, the final development of the plans may proceed.

g. Preparation of Plans. Once the final design has been selected, the plan sheets, quantities, cost estimate, voltage drop calculations, circuit schematic layouts, and special provisions, should be submitted to the Traffic Review Team for review. The light source type, luminaire wattage, total initial lumen output, estimated light loss factor, luminaire table, service point amp table, and the lighting ID numbers should be included on the plans. Additionally the IES file type used in the design will be given on the plans with a note that the distribution pattern of the actual luminaire to be supplied will be equivalent, e.g., “Luminaire shall provide a light distribution equivalent to IES distribution type GE 452918.IES.” If a particular backlight/uplight/glare rating is needed this information should also be specified on the plans

h. Working (Shop) Drawing Check. As part of the working (shop) drawing approval the contractor will submit the IES photometric distribution file for each model when the IES file number is different from that which is indicated on the plans, i.e., when the contractor is submitting a different model than that on which the design is based. In these cases, the IES files will be provided to the design engineer of record for review and concurrence that the design light level criteria will be satisfied.

4. Design-Build Projects. The following provides the procedural steps in designing a lighting system as part of a roadway design-build project. The design-build team will complete the following:

   a. Assembly of Information. Necessary information to be assembled includes the following.

      i. Contact the Traffic Review Team for the current design policies and procedures applicable to the project, sample plans, schedules, pay quantities, and example calculations.

      ii. Gather roadway and bridge plans including plan and profile sheets and details sheets, e.g., those for overhead signs.

      iii. Determine existing and expected utility locations.

      iv. Discuss special considerations with the road or bridge designer.

      v. conduct field reviews. Note areas of high ambient lighting and facilities that are sensitive to light trespass or sky glow (e.g. farms, observatories).

      vi. If this project is a local-agency project, hold discussions with local officials.

   b. Determination of Classifications. Determine the roadway classification and environmental conditions. If not already included in the project report, this information can be obtained from the Environmental Policy Team. The roadway classifications, for lighting purposes, are defined in Section 502-4.06(01).

   c. Selection of Design Criteria. Based on the above information, the designer will select the pertinent design methodology and the appropriate criteria based on the classification selected in item b. See Section 502-4.04 for design methodologies. For an INDOT-route lighting project, only the illuminance design methodology should be used.

d. Selection of Equipment. In the preliminary design, the designer will need to make some initial assumptions regarding the equipment composition. This includes mounting height, pole setback distance, mast arm length, light source type, luminaire wattage, photometric distribution pattern (INDOT typically uses M-S-Type II, III, or IV), and initial lumen output (typically 28,000 or 50,000). See Sections 502-4.03 and 502-4.06(03) for additional details on equipment selection.

Normally mounting heights and mast arm lengths will be uniform through the project limits. If the project ties into adjacent lighting systems consideration should be given to matching these considerations.

At a minimum the alternatives should include one HPS, one LED, one plasma, and one metal halide model, although other light source types may also be considered. For systems utilizing shorter mounting height (e.g. with streetscape projects utilizing pedestal poles) induction lighting may be viable. Only luminaire types and models that have an accessible IES light distribution file can be used. For a list of manufacturers that have approached INDOT about the use of their luminaires go to Y:\TrafficManagement\Luminaire Manufacturers. Consultants and local agencies may contact their Project Manager or the Office of Traffic Administration to obtain this information.

e. Selection of Layout Arrangement. Section 502-4.06(04) provides information on commonly used lighting arrangements. The selection of an appropriate layout design depends upon local site conditions and the engineer's judgment. Section 502-4.06(05) provides the roadside safety considerations in selecting the lighting arrangements. Section 502-4.06(06) provides other layout considerations.

f. Luminaire Spacing. For an INDOT-route lighting project, use the illuminance methodology to determine the appropriate luminaire spacing. This step is conducted by the computer.

Normally for a tangent alignment where roadway width is constant, spacing will be uniform through the project limits. If the project ties into adjacent lighting systems consideration should be given to matching the spacing.

g. Check for Uniformity. Once the spacing has been determined, the designer should check the uniformity of light distribution and compare this to the criteria selected in Item c. Use the following equation to determine the uniformity ratio:

Uniformity Ratio = Average Maintained Illumination Value / Minimum Maintained Illumination Value (Equation 502-4.05)

h. Selection of Optimum Design. Because recalculations by computer are relatively quick and easy, the designer should try several alternatives even if the first design satisfies the criteria. There is often more than one satisfactory alternative. Design Optimization should include an analysis for the purpose of minimizing service costs. The service cost is defined to be:

Service Cost per Year =
Annual Energy Cost + Annual Routine Luminaire Maintenance Costs + Installation Cost/ Service Life

Where:

Annual Energy Cost = (Total Luminaire Wattage of the System) x (Hours Operated per Year) x (Cost of Electricity)

Hours Operated per Year = 4380 h

Cost of Electricity (estimated) = $0.10 per kWh (as of Oct. 2014)
The average cost of electricity for the transportation sector in the state of Indiana is available from the U.S. Energy Information Administration's Electric Monthly Report, table 5.6.b, at
http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_b.
The electric provider or district may have a more location specific unit cost.

The electric provider or district may have a more location specific unit cost.
Maintenance Cost for HPS should be based on re-lamping the entire system every 3 years as well as other miscellaneous work. Currently this cost is estimated at $60 per year for each 250-watt or 400-watt luminaire and $105 per year for each 1000-watt high-mast luminaire. The cost for non-HPS light sources may be estimated at $25 per year for roadway luminaires and $50 per year for high-mast luminaires plus any additional maintenance costs that are specific to the type and model. The designer should confer with the manufacturer for these specific maintenance costs;

however, typically plasma emitters will need to be replaced after 50,000 (11 years). LED arrays and power drivers may also need to be replaced within the expected service life- these additional maintenance costs should be included. If manufacturer specific information is not available additional annual maintenance costs of $15 per LED or plasma roadway luminaire and $20 per LED or plasma high mast luminaire may be used; bringing the total estimated annual maintenance costs for the lighting system to $40 per roadway luminaire and $70 per year for high mast.

Estimated cost of the system should include poles, foundations, wiring, conduit, handholes, service points as well as the luminaires. Recent bid history as obtained on INDOT website should be used. Cost of alternative technology luminaires should be obtained from the manufacturer along with an estimate of the cost to install for about 1 hour of labor per luminaire. A $75 estimate can be used for labor cost.

Service life may be estimated at 20 years, including the luminaire regardless of light source type.

A Service Costs Analysis for New or Fully Modernized Lighting worksheet should be completed for each alternative considered and placed in the project file. An editable version of this worksheet is available for download from the are available for download from the Department's Editable Documents webpage at http://www.in.gov/dot/div/contracts/design/dmforms/, under Lighting. If the service cost analysis does not yield a clear choice, other factors such as the light color or district preferences should be weighed into the decision regarding the type of light source.

When comparing alternative designs that yield approximately equivalent annual service costs the designer should also consider the number of poles- from a safety consideration the fewer the better.

i. Electric Design. Once the type, number, size, and location of the luminaires are determined, the designer will need to determine the appropriate electric voltage drop for the system. Section 502-4.06(07) provides information on how to determine the voltage drop for the lighting system. For light source types other than HPS, the design current (amperage) requirement should be obtained from the manufacturer.

j. Preparation of Plans. Once the final design has been selected, the lighting designer will prepare and submit to the Traffic Review Team the plan sheets, design criteria, initial lumen output, estimated light loss factor, photometric files, service cost analysis worksheets, luminaire shop drawing, quantities, cost estimate, voltage drop calculations, circuit schematic layouts for review. The plan sheet shall indicate the IES photometric distribution file number used in the design, the luminaire type and initial lumen output, and should include the luminaire table, service point amp table, and the lighting ID numbers. If a particular backlight/uplight/glare rating is needed this information should also be specified on the plans.

k. Plans Submission. Plans should be submitted in accordance with the project witness and hold point schedule.

## 502-4.06 Conventional Lighting Design



The elements or factors to be considered have been standardized by the IES. However, not all elements are appropriate. In addition to the following, Figure 502-4F, Lighting Design Parameters, provides guidance regarding the design values used for a lighting design.

### 502-4.06(01) Roadway Classification

In selecting the appropriate design criteria, the highway's functional classification must be determined as mentioned in Section 502-4.05(02), items 3.b. and 4.b. The following definitions are used to define roadway classification for highway-lighting purposes only.

1. Freeway. A divided major roadway with full control of access with no crossings at grade. This definition applies to a toll or non-toll road. An interstate highway is a freeway.

2. Expressway. A divided major roadway for through traffic with partial control of access and with interchanges at major crossroads. An expressway for noncommercial traffic within a park or park-like area is considered a parkway.

3. Arterial. That part of the roadway system which serves as the principal network for through-traffic flow. Such a route connects areas of principal traffic generation and rural highways entering a city. For an INDOT route, use the city-street design criteria.

4. Collector. This is a distributor roadway servicing traffic between an arterial and local roadway. This is used for traffic movements within a residential, commercial, or industrial area. For an INDOT route, use the city-street design criteria.

5. Local Road. This is used for direct access to residential, commercial, industrial, or other abutting property. It does not include a road which carries through traffic. A long local road will be divided into short sections by collectors. For an INDOT route, use the city-street design criteria.

6. Sidewalk. A paved or otherwise improved area for pedestrian use, located within the public-street right of way which also includes the roadway for vehicular traffic.

7. Pedestrian Walkway. A public walk for pedestrian traffic not necessarily within the right of way for a vehicular-traffic roadway. This includes a skywalk or pedestrian overpass, subwalk or pedestrian tunnel, walkway providing access to a park or block interior, or mid-block street crossing.

8. Isolated Interchange. A grade-separated roadway crossing which is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

9. Isolated Intersection. The area where two or more non-continuously lighted roadways join or cross at the same level. This area includes the roadway and roadside facilities for traffic movement in that area. One type of isolated intersection is the channelized intersection in which traffic is directed into definite paths by means of islands with raised curbs.

10. Bikeway. A road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facility is designed for the exclusive use of bicyclists or will be shared with other transportation modes.

    a. Type A, Designated Bicycle Lane. A portion of a roadway or shoulder which has been designated for use by bicyclists. It is distinguished from the portion of the roadway for motor-vehicle traffic with a paint stripe, curb, or other similar device.

    b. Type B, Bicycle Path. A separate trail or path from which motor vehicles are prohibited and which is for the exclusive use of bicyclists or the shared use of bicyclists and pedestrians. Where such a trail or path forms a part of a highway, it is separated from the roadway for motor-vehicle traffic with an open space or barrier.

### 502-4.06(02) Design Criteria [Rev. Jan. 2016]

The lighting criteria vary according to the design methodology, highway classification, area classification, and pavement type. The following provide AASHTO and INDOT lighting design criteria.

1. Figure 502-4G provides the roadway illuminance design criteria.

2. NCHRP *Report 672, Roundabouts: An Informational Guide*, provides the recommended illuminance design criteria for roundabout lighting.

The Uniformity Ratios given in Figure 502-4G should be regarded as target values. A driver's visual ability may be adversely affected by lighting that varies significantly from the recommended uniformity value, i.e. it is possible for lighting to be too uniform or too non-uniform.

### 502-4.06(03) Equipment Considerations [Rev. Jan. 2016]

Figure 502-4H, Luminaire Geometry, illustrates the terms used in defining and designing luminaires, e.g., mounting height, overhang, rotation. Other equipment considerations for design are as follows.

1. Light Distribution. In determining the lighting-design layout, the expected light distribution must be known for the luminaire. Photometric data can be obtained from luminaire manufacturers. The proper distribution of light from the luminaire is a factor in the design of efficient lighting. Figure 502-4 I, Luminaire Classification System, provides the IES classifications for luminaire light distributions: width, spacing, and glare control. Figure 502-4J, Luminaire Placement and Light Type, provides additional guidance for the selection of luminaires based on these classifications. Figure 502-4K, Plan View for Luminaire Coverages, illustrates a plan view of a roadway which has been modified to show a series of Longitudinal Roadway Lines (LRL) and Transverse Roadway Lines (TRL) and how these distribution factors are interrelated. The following describes these classifications.

    a. Vertical Light Distribution. This can be short, medium, or long. The selection of a vertical light distribution is dependent upon the mounting height and light source. Pavement brightness is increased if the vertical light angle is increased. The vertical-light distribution types are defined as follows.

i. Short Distribution. The maximum luminous intensity strikes the roadway surface between 1 and 2.25 mounting heights from the luminaire. The theoretical maximum spacing is 4.5 mounting heights.

ii. Medium Distribution. The maximum luminous intensity is between 2.25 and 3.75 mounting heights from the luminaire. The theoretical maximum spacing is 7.5 mounting heights. This is the most commonly-used distribution type.

iii. Long Distribution. The maximum luminous intensity is between 3.75 and 6 mounting heights from the luminaire. The theoretical maximum spacing is 12 mounting heights.

b. Lateral Light Distribution. The IES has developed the lateral light distributions which are provided in Figure 502-4K. The following provides information on the placement for lateral light distribution.

i. Type I. The luminaire is placed in the center of the street or area where lighting is required. It produces a long, narrow, oval-shaped lighted area. Some types of high-mast lighting are also considered a modified form of Type I.

ii. Type I, 4-Way. The luminaire is placed in the center of the intersection and distributes the light along the four legs of the intersection. This type applies to high-mast lighting.

iii. Type II. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces a long, narrow, oval-shaped lighted area which is applicable to a narrow-width street.

iv. Type II, 4-Way. The luminaire is placed at one corner of the intersection and distributes the light along the four legs of the intersection.

v. Type III. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces an oval-shaped lighted area and is applicable to a medium-width street.

vi. Type IV. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces a wider, oval-shaped lighted area and is applicable to a wide street.

vii. Type V. The luminaire is placed in the center of the street, intersection, or area where lighting is required. It produces a circular, lighted area. Type V can be applied to high-mast lighting.

c. Control of Distribution. As the vertical light angle increases, discomforting glare also increases. To distinguish the glare effects on the motorist from the light source, IES has defined the glare effects as follows.

i. Cutoff. This occurs where the luminaires' light distribution is less than 25,000 lm at an angle of 90 deg above nadir, or vertical axis, and less than 100,000 lm at a vertical angle of 80 deg above nadir.

ii. Semi-cutoff. This occurs where the luminaires' light distribution is less than 50,000 lm at an angle of 90 deg above nadir, and less than 200,000 lm at a vertical angle of 80 deg above nadir. This is the distribution used for lighting design.

iii. Non-cutoff. This occurs where there is no limitation on the zone above the maximum luminous intensity.

d. Veiling Luminance. The designer should select lighting system equipment that minimizes veiling luminance, or glare. Glare hinders visibility.

Optical devices such as shields, reflectors, refractors may be utilized to reduce the possibility of disabling glare and the mounting height selected should take into account the probability that glare will be created. The higher the luminaire is mounted, the further it is above normal line of vision and the less glare it creates. Mounting heights less than 20 feet cannot be considered a good practice for typical roadway lighting.

e. Light trespass. Light trespass is commonly understood to mean light that falls beyond its intended target, and across a property line so as to create a perceived nuisance. Spill light of this kind, if it emanates at a high angle from the luminaire, can be a public nuisance and contribute to light pollution. Light trespass is somewhat subjective because it is difficult to define when, where, and how much light is unwanted.

A common cause of light trespass is the inappropriate selection, tilting, or aiming of luminaires. To minimize the likelihood of light trespass the designer should:

- consider the surrounding area during the design, and select luminaires, locations, and orientation that minimize spill light into adjacent properties.

- specify luminaires with an appropriate light distribution type- luminaires are available with either asymmetric or symmetric distributions and can be equipped with shields to control light at the desired lines.

- indicate aiming of luminaires so that the entire light output falls within the area intended to be lit.

- Consider light trespass when selecting pole heights.

Refer to I.E.S.N.A. RP 33-99 for additional information on Light Trespass.

2. Mounting Height. There are two criteria for determining a preferred luminaire mounting height: the desirability of minimizing direct glare from the luminaire and the need for a reasonably uniform distribution of illumination on the street surface. A higher-wattage bulb allows the use of a higher mounting height, fewer luminaires, and fewer support poles, and still provides the lighting quality. A higher mounting height tends to produce the most efficient design. For practical and aesthetic reasons, the mounting height should remain constant throughout the system. The manufacturer's photometric testing results are required to determine the appropriate adjustments for mounting height. The mounting height for INDOT projects should be at least 30 ft but no more than 50 ft, using an even 5-ft increment.

3. Coefficient of Utilization. The coefficient-of-utilization curve defines the percentage of bare-lamp lumens that are required to light the desired surface. Figure 502-4L illustrates a sample coefficient-of-utilization curve. The curve and the isolux diagram are used to determine the amount of illumination to a given point on the pavement. The curve provides a value for the street side of the luminaire and the private-property side. If the luminaire is located over the roadway, the private-property-side value should also be used to determine the level of illumination. The manufacturer is required to provide these charts with its photometric testing results.

4. Light-Loss Factor, or Maintenance Factor. The efficiency of a luminaire is reduced over time. This reduction must be determined to properly estimate the light available at the end of the lamp or LED service life. The maintenance factor for HPS lighting can range from 0.50 to 0.90 and from 0.5 to 0.70 for LED lighting. Figure 502-4F, Lighting Design

Parameters, provides the factors used for designing a lighting system. The maintenance factor is the product of the following.

a. Lamp/LED Lumen Depreciation Factor (LLD). As the light source progresses through its service life, the lumen output of the lamp or LEDs decreases. The initial lumen value is adjusted by means of a lumen depreciation factor to compensate for the anticipated lumen reduction by the end of the light source's service life. This ensures that a minimum level of illumination will be available at the end of the assumed service life of 20 years, even though lumen depreciation has occurred. This information should be provided by the manufacturer. For HPS, a typical LLD factor of 0.90 may be used. Since LED depreciation may vary greatly from one manufacturer to another a test verified lumen depreciation factor specific to the model should be used. The factor should estimate the lumen depreciation at 85,000 hrs., In lieu of manufacturer specific information a default value of 0.70 may be used. Lumen depreciation for plasma emitters and other light source types should be confirmed with the manufacturer.

b. Luminaire Dirt Depreciation Factor (LDD). Dirt on the exterior and interior of the luminaire, and to an extent on the lamp, reduces the amount of light reaching the roadway. Various degrees of dirt accumulation can be anticipated depending upon the area in which the luminaire is located. Industry, exhaust of vehicles, especially large diesel trucks, dust, etc., all combine to produce dirt accumulation on the luminaire. A higher mounting height, however, tends to reduce vehicle-related dirt accumulation. Information on the relationship between the area and the expected dirt accumulation is shown in Figure 502-4K. An LDD factor of 0.87 should be used. This is based on a moderately-dirty environment and three years exposure time. If deemed necessary, another value may only be used with approval from the Office of Traffic Administration.

c. Equipment Factor (EF). Accounts for inefficiencies inherent in the manufacture and operation of the equipment. A factor of 0.95 may be used.

d. LED Survival Factor (LSF) The LSF applies only to LED luminaires and takes into account any failures early in the expected service life (at least 50,000 hrs). This factor may be conservatively estimated at 0.98 but can be adjusted per the manufacturer.

**502-4.06(04) System Configuration**

Figure 502-4N, Lighting-System Configurations, illustrates the layout arrangements used. Figure 502-4N also illustrates the recommended illuminance calculation points for the arrangements.

See Section 502-4.05(02), step 7. A light standard should not be placed in the median unless a barrier wall is present. A light standard should be placed in such a location to avoid being struck by an errant vehicle, i.e., not on an outside-edge barrier wall at a ramp on a horizontal curve.

Figure 502-4 O illustrates a layout for partial lighting of an interchange.

**502-4.06(05) Roadside-Safety Considerations**

The placement of a light standard should be such that it will not reduce roadside safety. However, the physical roadside conditions can dictate the light-standard location. Such limitations should be considered in the design process. An overpass, sign structure, guardrail, roadway curvature, right-of-way limitation, gore clearance, proximity of another existing roadside obstacle, or the limitations of the lighting equipment are all factors that must be considered in design. The roadway and area classification, design speed or posted speed limit, safety, aesthetics, economics, environmental impacts should be considered.

There should be adequate right of way, driveway control, or utility clearance to allow the placement of the proposed light standards according to the safety requirements. Otherwise, additional right of way, driveway control, or utility relocations will be required. The following should be considered when determining the location of light poles relative to roadside safety.

1. Breakaway. A conventional light pole placed within the clear zone or the obstruction-free zone will be provided with a breakaway device except at a location with a sidewalk. The following should be considered.

    a. Pedestrians. A pole should not be mounted on a breakaway device in an area, including a rest area, where pedestrian traffic exists or is expected.

    b. Support. The maximum projection of the portion of a breakaway lighting support that remains after the unit has been struck is 4 in. See Figure 502-4P, Breakaway Support Stub Clearance Diagram.

    c. Breakaway Device. Each breakaway device should be in accordance with the applicable AASHTO requirements for structural supports. It may be one that has been approved for use as a breakaway device. See Section 502-4.03(02).

    d. Wiring. Each pole that requires a breakaway device should be served by underground wiring and should be designed with breakaway connections. No. 4 copper wire should be used between poles. No. 10 copper wire should be used up the poles to the luminaire. See the INDOT *Standard Drawings* for wiring details.

2. Grading. Grading at a breakaway light standard should be as described in Chapter 49.

3. Gore Area. A pole should be located to provide adequate safety clearance in the gore area of an exit or entrance ramp, with a minimum of 50 ft, as illustrated in Figure 502-4Q, Pole Clearance for Ramp Gore.

4. Horizontal Curve. A pole should be placed on the inside of a sharp curve or loop.

5. Maintenance. In determining a pole location, a hazard which can be encountered while future maintenance is being performed on the lighting equipment should be considered.

6. Barrier. The placement of a light standard in conjunction with a roadside barrier should be as described in Section 49-5.0. The following should also be considered.

    a. Placement. A light standard should be placed behind the barrier.

    b. Deflection. A pole behind a guardrail should be offset by at least the deflection distance of the guardrail. See Section 49-5.0 for information. This will allow the railing to deflect without hitting the pole. If this clearance distance is not available, such as in a 2:1 side-slope condition, or if the pole is located within the approach end of the railing, a breakaway device should be added. A breakaway device should be used behind guardrail.

    c. Concrete Median Barrier. A pole that is shielded by a rigid or non-yielding barrier will not require a breakaway device.

    d. Impact Attenuator. A pole, either with or without a breakaway device, should be located such that it will not interfere with the functional operation of an impact attenuator or other safety breakaway device.

7. Protection Feature. A feature such as a curb, barrier, or other obstacle should not be constructed primarily to protect a light pole, should not be used.

8. High-Mast Tower. An unprotected high-mast tower should be at least 80 ft from the nearest edge of the mainline or ramp travel lane. The minimum clear distance will be the roadway clear-zone width through the area where the high-mast lighting is located. Access for service vehicles should be provided for each high-mast tower or service pole.

9. Existing Installation. An existing breakaway light standard should be evaluated to determine if it is necessary to relocate it, re-grade around its base, or upgrade the breakaway mechanism to current criteria. The determination of the work necessary on an existing breakaway light standard involves a review of variables. Therefore, this decision must be made by the Highway Design and Technical Support Division. If federal-aid funds will be used for construction, the project is on the National Highway System, or it is not exempt from FHWA oversight, the FHWA should also be consulted.

### 502-4.06(06) Other Considerations [Rev. Jan. 2016]

1. Sign. A pole should be placed to minimize interference with the motorist's view of a highway sign. The luminaire brightness should not detract from the legibility of the sign at night. Conversely to avoid adversely impacting the light distribution light poles should be located at a minimum separation of 60 ft (for 40 ft E.M.H poles) and 40 ft (for 30 ft E.M.H. poles).
2. Overhead Sign. Sign lighting will be provided only where it is determined by the district Traffic Office that the reflective sign sheeting by itself is not sufficient for nighttime visibility. If needed, an existing overhead sign's lights should be tied into the new lighting system's circuits.
3. Structure. A pole should be placed far enough away from an overhead bridge or overhead sign structure so that the light from the luminaire will not cast distracting shadows on the roadway surface or produce unnecessary glare for the motorist.

4. Tree. A tree should be pruned so that it does not cause shadows on the roadway surface or reduce the luminaires' efficiency. The luminaire should be designed with the proper height and mast-arm length to account for the effect of a tree on lighting distribution.

5. Retaining Wall. A pole may be located either on top of or behind a retaining wall. A pole mounted atop a retaining wall will require consideration in the retaining-wall design.

6. Median. Although not desirable, a pole may be placed in a median where the width of the median is adequate or if a barrier will be used. The median width should be equal to or greater than the pole's mounting height. Where twin poles are used, the mast arms on both sides should have the same length.

### 502-4.06(07) Voltage-Drop Determination

A highway-lighting distribution circuit consists of two 240-V circuits provided by a multiple-conductor armored cable. Power supply to the lighting system is 240/480 V, single phase, 60-

cycle alternating current. The designer shall be responsible for determining the service requirements of each individual location. The lights are alternately connected to each side of the four-wire circuit. Ground rods are provided at each light standard. Voltage drop should not be over 10% to the last light in the circuit, or 5% to the last light in the circuit for bridge underpass lighting. Figure 502-4R provides the design amperages for various luminaires. Figure 502-4S provides resistances for various wire types. Equation 502-4.1 should be used to determine the voltage drop between two adjacent luminaires.

$$E = IR \qquad \text{[Equation 502-4.1]}$$

Where:

$E$ = voltage, or electric potential (V)
$I$ = current (A/mi)
$R$ = resistance (Ω)

Figure 502-4T illustrates the voltage drop between two adjacent luminaires

**502-4.07 High-Mast Lighting Design [Rev. Jan. 2016]**

The design of a high-mast lighting system consists of the same procedures as discussed in Section 502-4.05(02). The following should also be considered.

1. Lighting Source. For HPS designs a 130,000 lumen (1000 watt) light source should be used. For LED and plasma design the lumen and wattage requirements may vary. The number of required luminaires should be determined based on the area to be lighted and target design criteria as shown in Figure 502-4U. At a minimum the designer should consider one HPS, one LED, and one plasma model when determining the optimal design.

2. Effective Mounting Height (EMH). The INDOT *Standard Specifications* allow an EMH range from 100 to 200 ft. Once determined, it should be specified to the higher 5-ft increment. An EMH of 100 to 160 ft is the most practical. An EMH of 165 ft or greater requires more luminaires to maintain the illumination level. However, such an EMH allows for fewer towers and provides more uniformity. Use of such an EMH should be confirmed with the district traffic engineer.

3. Location. When determining the location for a tower, the plan view of the area should be reviewed to determine the more critical areas requiring lighting. In selecting the appropriate location for a tower, the following should be considered.

   a. Critical Area. A tower should be located such that the highest localized level of illumination occurs within a critical-traffic area, e.g., freeway/ramp junction, ramp terminal, merge point.

b. Roadside Safety. A tower should be located at a distance from the roadway so that the probability of a collision is virtually eliminated. It should not be placed at the end of a long tangent.

c. Sign. A tower should be located so that it is not within a motorist's direct line of sight to a highway sign.

4. Design. The methodologies for checking the adequacy of uniformity are the point-by-point method and the template method. The point-by-point method checks illumination by using the manufacturer's isolux diagram. The total illumination at a point is the sum of the contributions of illumination from all luminaire assemblies within the effective range of the point. The template methodology uses isolux templates to determine the appropriate location for each tower. The templates may be moved to ensure that the minimum-maintained illumination is provided, and that the uniformity ratio has been satisfied.

A retaining wall should be included with the concrete pad at the base of the tower if the surrounding ground's slope is steeper than 5:1. The height of the retaining wall should be determined from Figure 502-4V.

5. Foundation and Soil Test. After the final location of each tower is determined, a geotechnical investigation should be requested from the Office of Geotechnical Engineering. The standard foundation of 20-ft depth and 4-ft diameter should be specified for each tower where the soil properties are as follows.

a. Soft Clay. Undrained shear strength of 750 $lb/ft^2$, density of 120 $lb/ft^3$, and strain of 0.01 at half the maximum stress for an undrained triaxial test. The soil should not include excess rock.

b. Sand. Angle of internal friction of 30 deg, density of 115 $lb/ft^3$, and modulus of subgrade reaction of 20 $lb/in.^3$. The soil should include a minimum of gravel or clay.

If a tower of 180 ft or higher is required where soil is sandy, a foundation of 22-ft depth and 4.5-ft diameter should be specified, and its details should be shown on the plans.

The standard foundation has been designed with the assumption that no groundwater is present. The Office of Geotechnical Engineering should be contacted if groundwater is present or if excess rock is present in clay soil.

For other soil conditions or properties, the Office of Geotechnical Engineering can recommend an alternate foundation. Such an alternate foundation should be shown on the plans.

6. Information To Be Shown on Plans. This includes the tower location, foundation details if not standard, estimated mounting height, retaining-wall height if applicable, and number of luminaires. The IES file type used in the design will be given on the plans with a note that the distribution pattern of the actual luminaire to be supplied will be equivalent, e.g., "Luminaire shall provide a light distribution equivalent to IES distribution type GE 452918.IES." The plans should indicate the light source type and also include luminaire wattage, total initial lumen output, luminaire table, service point amp table, and the lighting ID numbers.

   When a high mast luminaire retrofit is selected as the best option, the designer should include a unique special provision that incorporates any needed changes to the standard specifications on High Mast Luminaires, as well as information on the existing high mast luminaire since the housing will be re-used. At a minimum this information should include manufacturer, model name/number, and dimensions of the housing. Additionally the designer should include a pay item for Luminaire, High Mast, Retrofit, ___ (watts),….each. The unique special provision should include a basis of payment section indicating that in addition to the cost of the LEDs and mounting hardware, the cost of all work necessary to remove, disassemble, re-assemble with the new LED modules, and then reinstall the existing luminaire is included in the Retrofit pay item.



## 502-5.0 INTELLIGENT TRANSPORTATION SYSTEM (ITS)

### 502-5.01 General

The goals of the National ITS Program are as follows:

1. increase transportation system efficiency and capacity;
2. enhance mobility;
3. improve safety;
4. reduce energy consumption and environmental costs;
5. increase economic productivity; and

| | |
|---|---|
| Lamp Lumen Depreciation Factor, LLD | 0.90* |
| Luminaire Dirt Depreciation Factor, LDD | 0.87 |
| Percent of Voltage Drop Permitted | 10% |
| Pole Height | 40 ft |
| Lamp Size | 150 W, HPS (Underpass)<br>250 W or 400 W, HPS (Conventional)<br>1000 W, HPS (High-Mast) |

* For High Pressure Sodium Lamps only. For Solid State Light Sources the LLD should be as given by the manufacturer.



LIGHTING DESIGN PARAMETERS

Figure 502-4D

| Lamp Wattage, Type | Line Voltage | | |
|---|---|---|---|
| | 120 | 240 | 480 |
| 250 W, MV | 2.7 | 1.4 | 0.7 |
| 400 W, MV | 4.2 | 2.1 | 1.1 |
| 150 W, HPS | 1.7 | 0.9 | 0.5 |
| 250 W, HPS | 2.9 | 1.4 | 0.7 |
| 400 W, HPS | 3.9 | 2.0 | 1.0 |
| 1000 W, HPS | 9.0 | 5.0 | 2.5 |

MV luminaire information is for information only.



DESIGN AMPERAGES FOR VARIOUS HPS LUMINAIRES

Figure 502-4P

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| Estimated Mounting Height, EMH (ft) | Lumens (HPS Light Source) | Number of Luminaires |
|---|---|---|
| 100 | 400,000 | 4 |
| 105 ≤ EMH ≤ 120 | 600,000 | 4 or 6 |
| 125 ≤ EMH ≤ 150 | 800,000 | 6 or 8 |
| 155 ≤ EMH ≤ 200 | 1,600,000 | 6, 8, 10, or 12 |



NUMBER OF LUMINAIRES FOR
HIGH-MAST TOWER

Figure 502-4S

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