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NJ-2010-002

Tower Lighting

FINAL REPORT
February 2011

Submitted by

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In cooperation with

New Jersey
Department of Transportation
Bureau of Research

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TECHNICAL REPORT
STANDARD TITLE PAGE

<table>
<tr><td colspan="2">1. Report No.
NJ-2010-002</td><td colspan="2">2.Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="4" rowspan="2">4. Title and Subtitle
Tower Lighting</td><td colspan="2">5. Report Date
February 2011</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="4">7. Author(s)

Josh DeFlorio</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="4" rowspan="2">9. Performing Organization Name and Address
Cambridge Systematics, Inc.
38 East 32nd Street, 7th Floor
New York, NY 10016</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.</td></tr>
<tr><td colspan="4" rowspan="2">12. Sponsoring Agency Name and Address

New Jersey Department of Transportation
PO 600
Trenton, NJ 08625</td><td colspan="2">13. Type of Report and Period Covered</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="6">15. Supplementary Notes</td></tr>
<tr><td colspan="6">16. Abstract
This study explores the potential benefits of replacing conventional highway lighting systems with high mast systems. It provides a comparative lifecycle cost analysis, contrasts the ease and cost of maintenance as well as the potential safety implications for maintenance personnel and the motoring public, and reviews likely impacts on the environment and aesthetics.</td></tr>
<tr><td colspan="3">17. Key Words
Highway lighting, high mast lighting, tower lighting, electrical operations, electrical maintenance, safety, lifecycle cost analysis</td><td colspan="3">18. Distribution Statement</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td colspan="2">20. Security Classif. (of this page)
Unclassified</td><td colspan="2">21. No of Pages
45</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-69)

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EXECUTIVE SUMMARY

This study explores the potential benefits of replacing conventional highway lighting systems with high mast systems. It provides a comparative lifecycle cost analysis, contrasts the ease and cost of maintenance as well as the potential safety implications for maintenance personnel and the motoring public, and reviews likely impacts on the environment and aesthetics.

The process was rooted in a literature review, which examined regional and national warrants, standards, current and best practices, and challenges applicable to the use of high mast highway lighting. The review drew from the lighting design guidelines and specifications from 10 State DOTs (including New Jersey) and AASHTO. In order to enrich the literature review, five interviews were conducted with lighting maintenance personnel at four DOTs (Virginia, Maine, Florida, and Delaware) and NJDOT North Region—all agencies responsible for the maintenance of tower lighting.

The research team continued by comparing a hypothetical high mast system with the hybrid system currently in place at the interchange of I-78 and I-287. The evaluation incorporated the factors explored in the previous literature review, namely the comparative lifecycle costs of the two systems, the ease and costs of maintenance, the safety of maintenance personnel, impacts on the safety of drivers, and impacts on the environment and aesthetics.

The research team found that high mast lighting may offer significant benefits over conventional lighting for major urban and semi-urban interchange projects, particularly in non-residential areas, but present a few challenges as well.

- **Lifecycle Costs:** Overall, high mast lighting could save approximately $582,000 at the interchange of I-78 and I-287 over the 25-year life of the system, primarily due to reduced maintenance costs.
- **Safety of Maintenance Personnel:** By installing a high mast system instead of a conventional system, a significant reduction in incidents could reasonably be expected.
- **Safety of Motoring Public:** Motorist safety is likely to improve, with fewer opportunities for worker-driver incidents or pole strikes. Drivers may also experience better visibility.
- **Environment:** There is no significant difference in energy consumption between the high mast and existing systems, and thus no difference in emissions.
- **Aesthetics:** Light trespass and pollution are potential drawbacks of tower lighting. However, in appropriate contexts high mast lighting may be designed to minimize light spillage.

This study recommends that NJDOT:

- Enhance highway lighting selection factors to explicitly include the safety of maintenance personnel and motorists.
- Expand strategies for the control of light trespass, including curfews, to ensure that tower lighting is fairly considered as a design alternative.

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- Investigate the application of energy efficiency and alternative energy technologies, including LEDs and solar panels.
- Collect and analyze data on highway lighting and safety to better clarify the safety proposition of high mast lighting versus conventional highway lighting.
- Consider a full tower lighting system for the I-78/I-287 interchange, given that the current system is nearing the end of its useful life.

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INTRODUCTION

Proper highway lighting is critical to driver safety, particularly on interchange ramps and in urbanized areas. However, bulbs burn out, wiring issues cause strings of lights to go dark, and vehicle strikes destroy lighting standards and endanger drivers. As a result, the New Jersey Department of Transportation (NJDOT) devotes thousands of hours each year to the maintenance of its extensive highway lighting systems. Based on the observations of the Central Region Electrical Operations group, maintenance of conventional "cobra head" lighting can be resource intensive, time consuming, costly, and potentially endanger both maintenance workers and motorists. Electrical Operations identified high mast lighting[1]—with multiple, descending luminaires per pole and typically located outside the clear zone or behind guide rails—as a potential solution to these problems.

Accordingly, this study explores a range of potential benefits and drawbacks of replacing conventional highway lighting systems with high mast systems. Factors compared include 1) the ease and cost of maintenance, including expected staff hours 2) a lifecycle cost analysis, including capital costs, maintenance costs, energy costs, and anticipated system life, 3) the safety of maintenance personnel, 4) impacts on the safety of the motoring public, and 5) impacts on the environment and aesthetics. The objective is to provide NJDOT with a framework for understanding the potential benefits and constraints associated with utilizing high mast lighting in place of conventional lighting systems in appropriate contexts.

LITERATURE REVIEW

This research effort is rooted in an extensive literature review. The research team performed a regional and national scan of warrants, standards, current and best practices, and challenges applicable to the use of high mast (tower) highway lighting. The review drew from the published highway lighting design guidelines and specifications from 10 States (including New Jersey) and AASHTO, which sets standards incorporated, in whole or in part, by many State DOTs nationwide. Five interviews were conducted with lighting maintenance personnel at four DOTs (Virginia, Maine, Florida, and Delaware) and NJDOT North Region—all agencies with tower lighting— to enrich the literature review by providing field-level perspectives. Additionally, a literature review of industry publications was conducted in order to provide an objective accounting of tower lighting performance in several functional areas (see *Performance Categories*), although in many areas literature was sparse and/or dated and cannot be considered definitive.

[1] "High mast lighting" and "tower lighting" are used interchangeably in this report, as is the case in the NJDOT *Highway Design Manual*.

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Current Practice

The research team reviewed the published design guidelines and specifications for high mast lighting for 10 states,[2] including New Jersey, and AASHTO. Interviews with five of these states,[3] including the NJDOT North Region, revealed that additional high mast configurations, not encompassed by the official specifications, were currently in use in some states.

While DOT guidance tended to focus on warrants and specifications, a few States offered brief comments on the real or perceived benefits of replacing conventional highway lighting systems with high mast lighting. AASHTO, for example, states that tower lighting provides "excellent uniformity [of illuminance], lower glare [for drivers], fewer pole locations" and "performs well under adverse weather conditions such as fog and snow." Florida repeats some of these premises (high mast lighting "tends to produce a more uniform illumination [and] reduces glare") and additionally notes that tower lighting "allows placement of the poles farther from the roadway" and therefore out of the clear zone where they may be struck by motorists. New York cites safety, including increased roadside safety and visibility, as a principal advantage of tower lighting, but also shows concern for light trespass in residential areas. Several other agencies, including Florida, Maine, and Virginia expressed concern about light pollution and spillover in their interviews.

Warrants

Warrants (indications for use) for high mast lighting vary considerably from State-to-State, often depending on their adherence to AASHTO warrants. The AASHTO *Roadway Lighting Design Guide* (2005), is the definitive source for high mast lighting warrants and specifications, and includes guidance on standard/pole heights, illuminance, and uniformity of illuminance. For the States surveyed, the warranted applications include:

Complete Interchange Lighting (CIL)

AASHTO's warrants deal with this application, which was the most universal across DOTs. New Jersey's *Roadway Design Manual* (Section 11), for example, incorporates AASHTO's warrants for Complete Interchange Lighting, indicating that "tower lighting shall be considered first for full interchange lighting." The specific rationales for CIL fall into three primary categories:

- **Volume-based:** Tower lighting may be warranted when Average Daily Traffic (ADT) on ramps entering and exiting freeways or on crossroads exceed 10,000 vehicles for urban conditions, 8,000 vehicles for suburban conditions, and 5,000 for rural conditions. New Jersey, Illinois, and Pennsylvania, for example, have

[2] New Jersey, California, Delaware, Florida, Georgia, Illinois, Maine, New York, Pennsylvania, and Virginia.

[3] New Jersey, Delaware, Florida, Maine, and Virginia.

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adopted these volumes, whereas California references significantly lower volumes (5000, 3000, 1000 respectively). Other states, such as Georgia and New York, do not reference traffic volumes in their highway lighting guidelines.

- **Context-based:** Tower lighting may be warranted where "substantial commercial or industrial development lit during the hours of darkness" is located in the "immediate vicinity of the interchange."
- **Safety:** Tower lighting may be warranted where the ratio of night-to-day crashes within the interchange is at least 1.5 times "the statewide average for all unlit similar sections" and would significantly reduce the nighttime crash rate. Florida indicates that an analysis of crash history is an important factor in choosing high mast lighting, and New Jersey and Pennsylvania both include this warrant.

California is the sole State surveyed that warrants tower lighting for interchanges "where conventional lighting standards are difficult to maintain." Conversely, Pennsylvania requires a maintenance letter of intent from the relevant County, which appears to imply that PennDOT views tower lighting as more resource intensive to maintain than conventional highway lighting. Similarly, New York notes that a disadvantage of high mast lighting is the reluctance of agencies to accept maintenance responsibility. Maine DOT is not constructing new tower lighting due to difficulties with lowering the luminaire rings, a problem not reported as a significant issue by other States.

Partial Interchange Lighting

High mast lighting is not typically indicated as the first preference for partial interchange illumination; due to the smaller area of roadway requiring illumination, traditional highway lighting is generally considered first. However, several States offer lighting designers the opportunity to explore this option, while others, such as New York, set performance based targets for illuminance and light trespass that may be accomplished with tower lighting under certain circumstances.

Intersection Lighting

Delaware warrants high mast lighting for Federal and State route intersections, and Virginia warrants towers for some State highways. Florida warrants high mast lighting for urban collectors and high density places.

Freeways, Interstates, and Controlled Access Highways

Delaware and Florida both warrant high mast lighting for continuous highway lighting on all or some of these roadway types in certain contexts.

Rest Areas and Plazas

Delaware and New York both specifically warrant high mast lighting for rest areas, and Delaware and Florida additionally include warrants for plazas (Delaware specifies toll plazas).

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Special Considerations

Several DOTs, including New Jersey, reference some manner of discretionary process for circumstances in which high mast lighting is not normally warranted.

Specifications

Standards/Poles

- **Heights:** AASHTO defines the range of high mast pole heights as between 60 and 180 feet. Only one DOT surveyed, Illinois, deviates from this guideline by allowing standards of up to 200 feet (at which Federal Aviation Administration review would be required), although 100-150 foot standards are preferred. IDOT's adoption of the highest allowable mounting height of any State surveyed might not be coincidental, since it indicates that "in general, higher mounting heights tend to produce a more cost-effective design." New Jersey's official mounting height of 100 feet falls in the more typical height range of 80-120 feet. In recognition that such heights might pose challenges to siting, Georgia DOT conditions its warrant of tower lighting for interchanges by stating "unless the location has constraints on the pole height."
- **Materials:** While few precise material specifications were found in published manuals, only steel was referenced for high mast applications. Illinois DOT states that the preferred material is weathering steel, while Virginia has moved to galvanized steel. Because towers are not mounted on breakaway supports, they must be located out of the clear zone or, if clear zone incursions are unavoidable, protected by guardrails or crash cushions. Given the extra weight of towers and the additional stresses caused by wind resistance, particular attention must be paid to the foundation. Illinois, for example, requires a four foot in diameter concrete foundation, sunk to the depth indicated by a soils analysis and topped with a concrete work pad. Additional, detailed specifications may be found in AASHTO's *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*.

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Luminaires

- **Illuminance:** AASHTO recommends performance criteria for tower lighting, rather than specific luminaire wattage, quantities, or configurations. Average maintained illuminance should be between .6 and 1.1 footcandles, with minimum illuminance of .2 footcandles.[4] Illuminance uniformity (the ratio of average illuminance to minimum illuminance, a measure of how evenly light is distributed) should be 3:1 to 4:1. While many States reference AASHTO's illuminance criteria or list criteria of their own (e.g., California), only Florida declines to recommend specific luminaires.
- **Wattage**: Four wattages are in use among the surveyed States, including 250W (Virginia only), 750W (Illinois and VDOT only) and, most commonly, 400W and 1000W. New Jersey's sole official luminaire wattage is 400, although a limited number of 750W and 1000W luminaires are in service. Some States, such as Delaware and Georgia, only allow 1000W luminaires unless, in GDOT's case "satisfactory justification" for the use of lower wattages is "provided to GDOT."
- **Bulb Type:** Of the State specifications that include bulb type, High Pressure Sodium (HPS) was the only type cited. However, NJDOT North Region currently has 1000W metal halide bulbs in service in a few locations.
- **Quantity:** The range of luminaires per standard is 2 to 8, with most States either setting a specific range, a maximum (usually either 6 or 8), or simply requiring illuminance standards to be met. NJDOT's maximum is 8, which is generally used, although tower lighting in the Meadowlands area employs only 6.

Table 1, on the following three pages, summarizes published information relating to warrants and specifications, as well as a limited selection of related interview results, as applicable. A ☑ symbol indicates that an interview took place (Appendix C contains all interview records).

[4] For rough comparison, .2 footcandles is brighter than a full moon on a clear night but slightly darker than the waning minutes of twilight. 1.1 footcandles is the approximate brightness of sunset on a clear day.

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Table 1 - AASHTO and State DOT tower lighting warrants and specifications

State	Citation	Warrants	Standard(s)	Luminaire(s)	Notes
AASHTO	• *Roadway Lighting Design Guide* • *Complete Interchange Lighting (CIL)*	• CIL-1: ADT on ramp entering and exit freeway >10,000 for urban conditions, 8,000 for suburban conditions, 5,000 for rural conditions • CIL -2: ADT on crossroads >10,000 for urban conditions, 8,000 for suburban conditions, 5,000 for rural conditions • CIL-3: Substantial commercial or industrial development lit during hours of darkness located in immediate vicinity of interchange or crossroad approach legs lit for 0.5 mile + • CIL-4: Ratio of night-to-day crash rate within interchange is at least 1.5x statewide avg. for all unlit similar sections and results in significant reduction in night crash rate	• Heights range from 60 feet to 180 feet	• Avg. Maintained Illuminance: 0.6 to 1.1 • Minimum Illuminance: 0.2 • Illuminance Uniformity: 3:1 to 4:1	Benefits: Excellent uniformity, lower glare, fewer pole locations, performs well under adverse conditions such as rain fog and snow.
New Jersey (NJDOT) ☑	• *Roadway Design Manual, Section 11*	• AASHTO CIL-1,2,3,4 • Special considerations	• 100'	• HPS 400W, no more than 8 • 750W, 1000W (unofficial)	"Tower lighting shall be considered first for full interchange lighting."
California (Caltrans)	• *Traffic Manual, Chapter 9* • *2006 Standard Plan ES-6J* • *Signal, Lighting, and Electrical Systems Design Guide*	• Freeway interchanges "where conventional lighting standards are difficult to maintain" o Urban ADT >5000 o Suburban ADT>3000 o Rural ADT>1000	• 80' • 100' • 120' • 160'	• HPS 400W, 50,000 lumens min, 75 foot lamberts maximum brightness	Sizing of luminaires appears to be based on isofootcandle curve minimums and maximum foot lamberts

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State	Citation	Warrants	Standard(s)	Luminaire(s)	Notes
Delaware (DelDOT) ☑	• *Interview (Les Spicer)*	• Freeways, Interstates, and Controlled Access Highways • Intersections of U.S. Routes with U.S. Routes and U.S. Routes with Delaware Routes • Toll Plazas, Rest Areas, Weigh Stations	• 80'	• 1000W, 2-8 luminaires per mast	Pre-design meeting with DelDOT Traffic Section prior to performing any lighting design that includes high mast lighting
Florida (FDOT) ☑	• *Florida Greenbook* • *2010 FDOT Design Standards, Index 17502*	General: • Crash history • Analysis and investigation • Freeways, urban collectors, high density places, etc.	• 80' • 100' • 120'	• Sufficient for adequate illumination (AASHTO), 8 luminaires maximum	"The use of high mast lighting should be considered, particularly for lighting interchanges and other large plaza areas. This use tends to produce a more uniform illumination level, reduces glare, and allows placement of the poles farther from the roadway."
Georgia (GDOT)	• *Design Policy Manual v 2.0, 14.5.5* • *Design Policy Manual v 2.0, 5.5.1*	• "High mast lighting shall be used for interchange lighting unless the location has constraints on the pole height …"	• 100' nominal mounting height	• 1000W • "Lower wattage luminaires may be utilized if satisfactory justification is first provided to GDOT."	"High mast lighting should be positioned outside the clear zone. If this is impractical, cost-effective shielding shall be provided…"
Illinois (IDOT)	• *Design and Environmental Manual, Chapter 56-6*	• (General) Freeway interchanges: o Urban ADT>10000 o Suburban ADT>8000 o Rural ADT>5000	• 80'-200' • 100-150' preferred	• HPS 400W, 750W, 1000W • 4-6 luminaires per standard	"In general, higher mounting heights tend to produce a more cost-effective design."

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State	Citation	Warrants	Standard(s)	Luminaire(s)	Notes
Maine ☑	• *Interview (Bruce Ibarguen)*	• Interstates only	• unknown	• unknown	Not constructing new light towers due to light pollution and maintenance issues
New York (NYSDOT)	• *Highway Design Manual Chapter 12-Highway Lighting* • *Policy on Highway Lighting*	• If proper light control can be achieved and there is no objectionable light spillage or effect on adjacent residents, should be considered for interchanges and rest area locations.	• AASHTO standards dictate mast height, spacing, and location	• 400W, 1000W	• Advantages: o Increase roadside safety o Increase visibility Disadvantages: o Unwanted light "spilling over" to adjacent residences o Reluctance of agencies to accept maintenance responsibility
Pennsylvania (PennDOT)	• *Design Manual, Part 2, Chapter 5*	• Energy and maintenance letter of intent from county • AASHTO warrants	• 100' mounting height, pole not to exceed 120'	• HPS 400W, type V. quantity of luminaires required to meet footcandle and uniformity standards	"Locate poles on tangent sections and on the inside of curves a minimum of 15 m (50 ft) from the edge of pavement wherever practical."
Virginia (VDOT) ☑	• *Traffic Engineering Design Manual 2006*	• Interchanges and some state highways	• 60' to 150', more typically 100-120' and 70'	• HPS 250W, 400W, 750W, 1000W	The cost of a single high mast lighting tower and luminaire assembly is higher than that of a conventional or offset lighting standard. As a rule of thumb, the light that is provided by one high mast tower should replace 6 to 8 conventional lighting standards.

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Performance Categories

Economic

While several State DOT sources indicate that high mast lighting may be economically favorable in certain contexts (especially interchanges) when compared to conventional lighting, hard data are scarce. This is likely due to the unique nature of each lighting project, which may necessitate the performance of a separate benefit-cost analysis for each proposed application.

In its *Manual on Uniform Traffic Studies*, Florida DOT has established a mandatory benefit-cost procedure for highway lighting, which must be performed after the initial warrant categories have been satisfied (based on AASHTO and NCHRP Report 152 warrants). The methodology, which accounts for volumes, accidents, capital costs, and maintenance costs, returns a benefit-cost ratio, which must exceed 1.0 for priority safety projects and 2.0 for all others. Although the FDOT model is not explicitly oriented toward the selection of a lighting system (as opposed to the justification of highway lighting), an analysis for both high mast and conventional lighting could be performed for a single location (assuming that both are indicated in the Step 1 warrants). The ratios could then be compared to determine the superior system. The FDOT benefit-cost model and instructions are included in their entirety in Appendix D.

Texas DOT's *Highway Illumination Manual (HIM)* includes a framework for evaluating conventional lighting versus high mast lighting. TXDOT explicitly calls for a comparison of installation and maintenance costs, but does not offer a calculation methodology. The HIM explains that "high mast lighting for interchanges is frequently less expensive to install than conventional lighting, due to reduced complexity of conduit and conductor and the smaller number of fixtures and poles required. Outside the interchange, conventional lighting usually requires a smaller initial cost."

TXDOT additionally identifies a host of potential maintenance-related costs, which, as they are fundamentally related to the ease of maintenance and safety of maintenance personnel, are reported in the following section. The research team did not find any published information on potential energy cost savings.

Ease of Maintenance and Safety of Maintenance Personnel

In the context of high mast lighting, ease of maintenance and the safety of maintenance personnel are closely related and complementary. Simply, when towers are located outside of the clear zone, maintenance personnel are able to work farther away from traffic in greater safety. Although a few complications may arise, such as weather-related difficulties (snow or soggy ground), stuck/frozen luminaire rings, and pole failure (which endangers motorists), the overall message from both published sources and

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State DOT officials is that tower lighting is almost always safer and often easier[5] to maintain.

TXDOT's HIM states that "maintenance costs for the two types of systems [conventional and high mast] differ greatly." While referring specifically to cost, the reasons underlying these costs are inherent to the level of effort required to change luminaires: "Conventional lighting requires the use of a bucket truck and frequently requires extensive traffic control, such as signs, cones, and lane closures. When poles are mounted on concrete traffic barriers (CTBs) or single slope concrete barriers (SSCBs), the inside lane usually has to be closed, resulting in significant traffic disruptions." In contrast, the replacement of high mast luminaires is described as a comparatively easy and safe operation: "One or two persons with a pickup truck can usually perform maintenance on a high mast lighting system [due to cable-lowered luminaire rings]. High mast lighting may also eliminate the risks involved with having personnel working near high-speed traffic."

TXDOT offers designers "some deciding considerations" to guide the selection of a lighting system. First, will lane closures be required for maintenance, and, if so, what will be the impact on traffic? Second, what is the anticipated maintenance cost difference? This figure, TXDOT suggests, should include any costs to be borne by other agencies or local governments. Based on the typical results of these inquiries, TXDOT recommends consideration of high mast lighting "for most urban interchanges that qualify for complete interchange lighting and for [high volume] tangent sections of freeways … where lane closure would be necessary for the maintenance of a conventional lighting system and where a study shows that substantial traffic flow disruptions would occur during such lane closures."

TXDOT also prompts the designer to consider a wide variety of issues fundamental to costs when specifying a lighting system, including "would future upgrading of the roadway require relocating a conventional lighting system? Can a high mast system be installed that will not require relocation and that can provide construction lighting for future roadway projects?" New York DOT, in conjunction with Rensselaer Polytechnic Institute (RPI), tested the use of temporary tower lights as a replacement for traditional, portable work zone lighting for nighttime road work. No significant differences in visual performance or light pollution were found between the two systems. However, high mast lighting resulted in significant decreases in glare (as experienced by motorists) and were credited with reducing the test project's duration by 40 to 50 days (from 275 to 235). Although the total cost of the tower lighting alternative exceeded the estimated cost of a portable system by 16% ($1.425 vs. $1.225 million), over $930,000 of this was attributed to tower and luminaire rental and installation. If, as TXDOT suggests, future

[5] Maine has halted new installations of tower lighting due to stuck luminaire rings, whereas other States have not reported this to be a significant problem. In some instances, Maine was required to take down the tower, clearly a costly operation (Some DOTs recommend leaving adequate space for a crane should luminaire rings stick). While there is no clear reason for this difference, Maine's colder climate might partially account for these difficulties.

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nighttime construction needs are factored into the decision to deploy tower lighting, these additional costs will not be incurred.[6]

Safety of the Motoring Public

Several sources cited attributes of high mast lighting that might increase the safety of the motoring public, such as greater and more uniform illuminance, reduced glare, and fewer lane closures (and therefore less weaving or opportunity to collide with maintenance vehicles). However, only a limited selection of recent, rigorous studies on the effect of highway lighting on motoring safety was discovered. The Federal Highway Administration's (FHWA) *Older Driver Highway Design Handbook,* however, synthesizes much of the work available. Although the *Handbook* is clearly oriented toward the needs of older drivers and is not specific to tower lighting, it nonetheless provides a solid overview of how highway lighting affects nighttime crash rates.

The *Handbook* establishes that "freeway interchanges experience a higher accident rate than the mainline" and that "nighttime driving is associated with a higher accident risk for drivers of all ages." Interchange use at night would therefore presumably further amplify the risk of accident. The *Handbook* cites a study by Gramza et al. (1980)[7], which analyzed 400 nighttime crashes at interchanges in five States between 1971 and 1976. The study accounted for illumination levels, finding a range "from 0.0 lux to 10.76 lux (0.0 hfc to 1.0 hfc), with an average of 5.49 lux (0.51 hfc) for the lighted sections[8]." Gramza et al. determined that "increases in the illumination level … at interchanges were associated with significant reductions in two types of accidents: vehicle-to-fixed-object accidents involving property damage and vehicle-to-vehicle accidents involving fatalities and injuries." Although the standards for tower lighting in the 1970s are not known, the study determined that "the presence of high-mast lighting was found to significantly reduce total accident rates." Current standards for average maintained illuminance of .6 to 1.1 hfc (6.4 to 11.8 lux) would seem to validate this conclusion for modern high mast lighting systems as well.

Illumination coverage is also seen as an important issue in nighttime accidents, particularly for drivers navigating complex intersections. The *Handbook* touts high mast lighting as a potential solution for increasing coverage, citing a study by Hans (1993), which finds that high mast lighting can increase the nighttime field of vision from 30 to about 105 degrees (although the study claims that some target contrast is sacrificed).

In addition to designing for illuminance, which measures light incident on a surface (I.e., without regard to the surface characteristics), a limited number of transportation agencies recommend designing for luminance, which accounts for the light reflected

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[6] However, a higher quantity and wattage of luminaires might be preferable for construction (which, according to NCHRP Report 498, should be a minimum of 10 footcandles for resurfacing). NYSDOT used 1500W metal halide lamps on 70' standards to achieve acceptable illuminance.

[7] Attempts to locate the original article and full citation were unsuccessful.

[8] Lux is the international equivalent of horizontal footcandles (hfc). 1 hfc is equivalent to 10.76 lux.

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from the roadway and other surfaces. The Illuminating Engineering Society of North America (IESNA) issued a "National Standard Practice" guide (RP-8-00) in 2000, which provides guidelines for acceptable luminance of various roadway types. However, this luminance method does not seem to be conducive to lighting intersections or, presumably, interchanges. Burlington, Ontario, for example, has incorporated the IESNA luminance standards into its *Street Lighting Design Manual*, but requires the illuminance method for intersections ("The luminance method is difficult to use with the design of lighting for intersections due to the basic assumptions inherent in luminance design and the methods used in its calculation").

Finally, although AASHTO's *Roadway Lighting Design Guide* mentions reduced glare as a principal benefit of high mast lighting—a common sense proposition given the position of luminaires out of the driver's field of vision—the research team found no formal, quantifiable research on this topic.

Environment and Aesthetics

Light pollution and light trespass, or spillage, are the primary environmental concerns attending high mast lighting—all five of the DOTs interviewed mentioned dark sky issues with existing tower lighting. The International Dark-Sky Association (IDA) defines light pollution, or "sky glow," as the "brightening of the night sky over inhabited areas," and light trespass as "light falling where it is not intended, wanted, or needed" (e.g., residential areas). Many DOTs respond to this issue implicitly by conditioning warrants on the use of high mast lighting to exclude residential places. TXDOT's HIM is very explicit in its treatment of high mast systems and light trespass, stating that "high mast lighting should not be installed in areas where light trespass is an issue," including "areas where residential development is located directly along the highway right-of-way."

TXDOT, along with several other DOTs (including NJDOT North Region, DelDOT, FDOT, and Maine DOT), install full cutoff luminaires in systems adjacent to residential areas (which may additionally reduce glare for motorists). The AASHTO Center for Environmental Excellence, which identifies light pollution as a general highway lighting issue, offers additional suggestions for controlling light, including lowering luminaire wattage, reducing the number of luminaires, repositioning fixtures, and lowering the height of luminaires. The latter suggestion, while seemingly antithetical to high mast lighting, might involve lowering the luminaire height from 100 feet to 80 feet, for example (as NJDOT North Region did in the Meadowlands area). In all cases, lighting designers must consider the potential effect of these measures on motorist safety. Many of these measures may additionally reduce the energy consumption, and therefore cost, of all highway lighting types.

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WORK PERFORMED

Approach

The research team investigated the potential implications of replacing an existing highway lighting system with a hypothetical high mast system at a specific interchange in New Jersey. The evaluation incorporated the performance categories explored in the previous literature review, namely the comparative lifecycle costs of the two systems, the ease and costs of maintenance, the safety of maintenance personnel, impacts on the safety of drivers, and impacts on the environment and aesthetics.

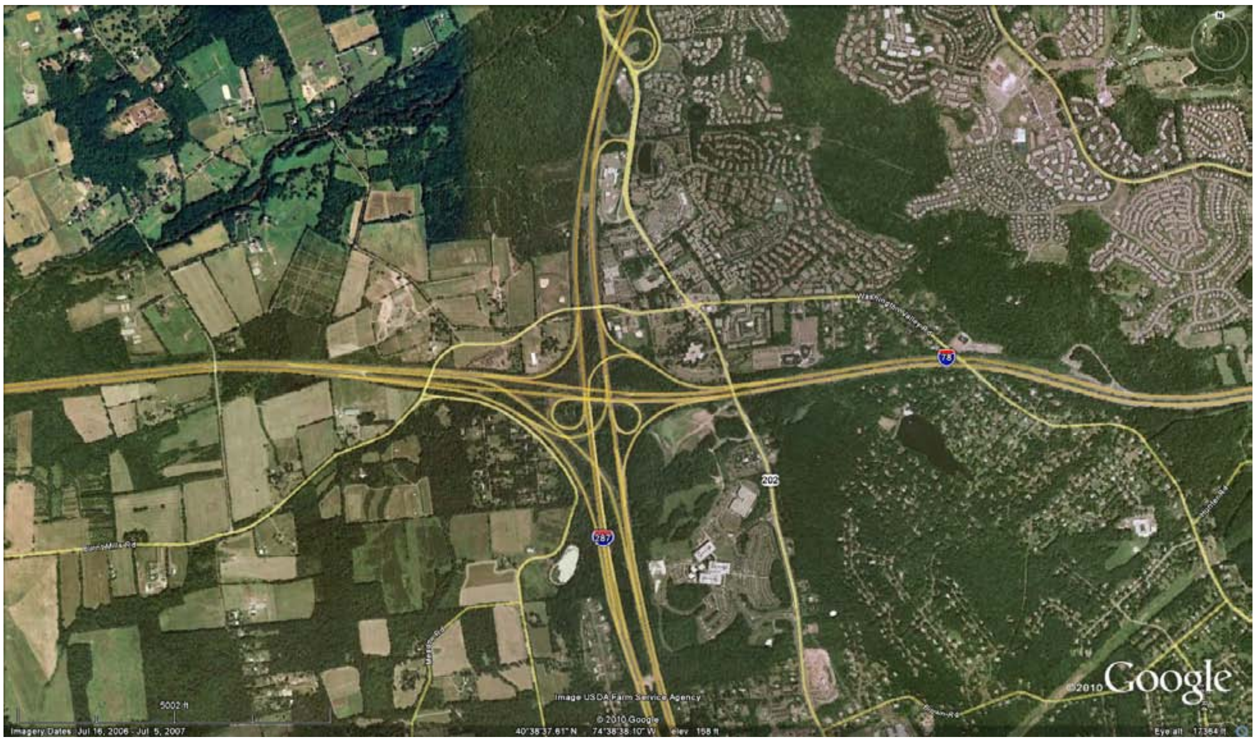

Figure 1 - Study Area, interchange of I-78 and I-287 (Image: Google Earth)

The first step required the selection of an interchange currently illuminated by a conventional or hybrid system and eligible under current NJDOT warrants for a full high mast system. The interchange of I-78 and I-287 was jointly selected by NJDOT and the research team as the representative test location due to the availability of drawings, the eligibility of the site for high mast lighting, and the existing lighting system, a mixture of cobra head and high mast. The research team created a design[9] employing exclusively high mast lighting, following the guidance of the NJDOT *Roadway Design Manual: Section 11, Highway Lighting Systems* for high mast lighting, including:

- Uniform mounting heights of 100 feet;
- 400 watt high pressure sodium luminaires, a maximum of eight per standard;

[9] Visual™ lighting design software was used.

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- Setbacks of at least 30 feet from the edge of the pavement to the standard centerline.

The final conceptual design, which was reviewed and approved by NJDOT, employs 232 luminaires in both symmetric and long and narrow asymmetric distributions on 35 lighting standards, none of which is in the clear zone[10]. This design, which is included in Appendix A, served as the basis for all subsequent quantitative analysis.

Results: Economic Analysis

A comparative analysis was performed to determine the potential lifecycle cost and energy benefits, or disbenefits, of conventional versus high mast systems. A capital cost estimate for the existing system and the design case were generated using recent public bid documents for analogous NJDOT projects (summarized in Table 2 and included in full in Appendix B).

Table 2 - High mast vs. existing installed cost

	High Mast	Existing
Number of fixtures	232	315
Total Installed Cost	$2,810,106	$2,953,077

Maintenance costs, including a blended material, equipment and staff hour cost per lighting standard, were derived using NJDOT data from two comparable, 60-acre interchanges on NJ 34, one with conventional lighting and the other with a high mast system (summarized in Table 3). See the subsequent section, “Results: Ease of Maintenance” for a detailed breakdown.

Table 3 - High mast vs. existing O&M costs

	High Mast	Conventional
Number of fixtures	232	315
Total yearly cost	$21,321	$38,989

Annual energy costs for each were calculated by determining the energy requirements (peak demand and consumption) for each system based on output wattages for each luminaire and PSE&G projected monthly service hours, and then using a spreadsheet programmed with the Large Power and Light Service (LPL) rate set forth in the *Tariff for Electric Service* (August 1st, 2003, First Revised Sheet No. 123). Over the course of a year, the difference in utility rates was estimated to be just $98, in favor of the existing system ($63,086 for high mast vs. $62,988 for the existing system, see Table 4 for

[10] The medians are typically over 70 feet wide and elevated from the traveled way by as much as 10 feet, whereas the clear zone typically extends 30 feet from the roadway.

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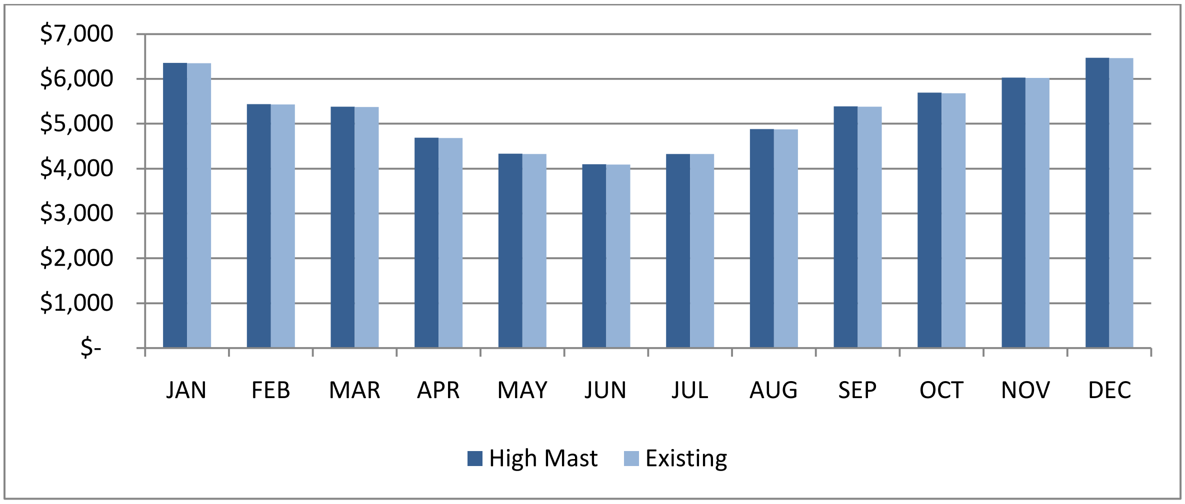
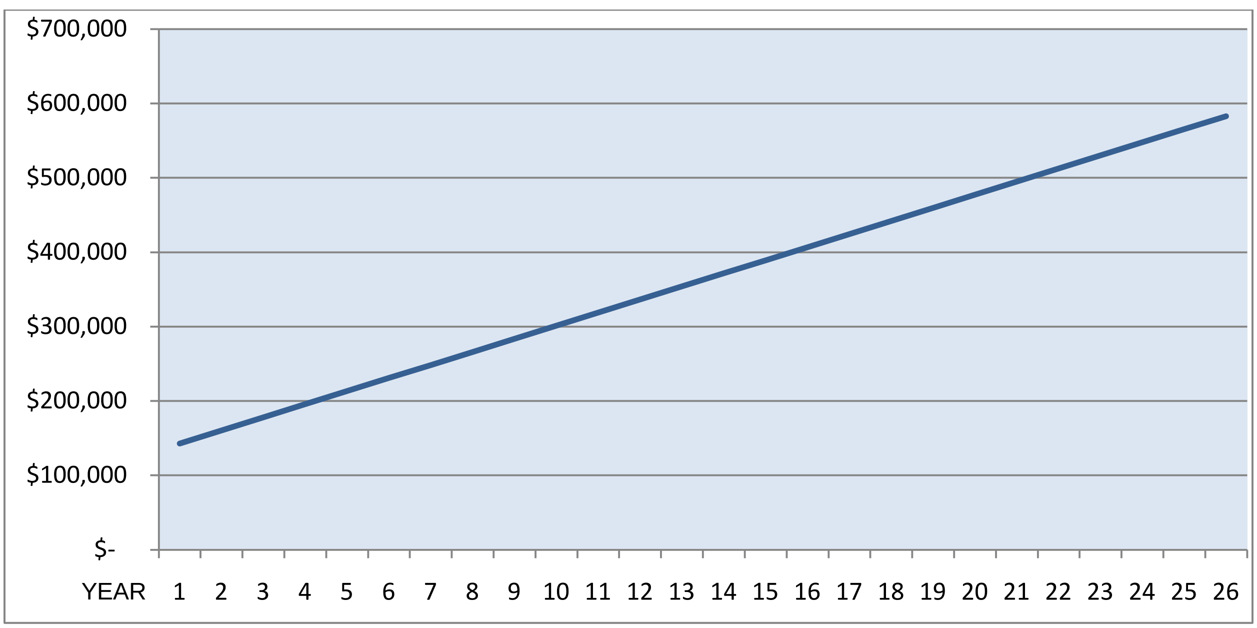
monthly costs). Although this difference is included in the lifecycle cost analysis (LCCA), effectively no measurable difference exists between the two scenarios.

Table 4 - High mast vs. existing monthly electricity costs



Using these cost inputs, a discounted lifecycle cost analysis was performed for each system, using 25 years (the anticipated system lifespan) as the analysis period. The result is a lifecycle cost differential between systems of approximately $583,000 (net present value at 5% discount)[11], favoring the high mast system (see Table 5).

Table 5 - Estimated lifecycle cost differential of high mast lighting vs. existing system



[11] Utility rates are assumed to escalate at 2% per year and O&M costs (including labor), are assumed to increase by 5% per year.

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Results: Ease of Maintenance

The ease and cost of maintenance on highway lighting systems are integrally related. More staff hours (whether indicating more required personnel, more time per fixture, or both) and more equipment needs equate to greater costs. In order to estimate the potential labor and equipment inputs from each system (existing versus design case), comparable 60-acre cloverleaf interchanges were identified along NJ 34 and I-195 and NJ 18, illuminated by high mast and conventional systems, respectively (see Figure 2).

Figure 2 - NJ 34 and I-195 (left) and NJ 34 and NJ 18 (right) (Image: Google Earth)

Using records from the NJDOT Maintenance Management System (MMS) for the last three available years (2007, 2008, and 2009), costs for labor, equipment, and material were compiled for all lighting maintenance activities, shown in Table 6. Of course, raw MMS data for the two sites cannot alone show true cost comparisons, as a variety of factors are omitted, but the research team and NJDOT agreed that it provided the best data available within the scope and budget of this study.

Table 6 - Labor, equipment, and materials costs for highway lighting at comparable interchanges

Interchange	Labor	Equipment	Material	Luminaires	$/unit/year
NJ 34 and I-195 (high mast)	$8,089	$2,485	$2,660	48	$91.90
NJ 34 and NJ 18 (cobra)	$13,834	$5,749	$4,883	50	$163.11

Although labor hours cannot be precisely derived, because labor rates should be approximately constant for each interchange, it may be assumed that cobra lighting is roughly 70% more labor intensive per luminaire than high mast lighting, which generally requires smaller crews due to self lowering luminaire rings and maintenance activities outside the clear zone. If, for example, labor rates averaged $22.88 per hour, each high mast luminaire would require 1.87 hours of yearly maintenance, whereas each conventional luminaire would need over 3 hours. Using the same methodology, equipment costs were 131% greater for the conventional system than for the high mast system, possibly due to the absence of a bucket truck. This equates to yearly

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equipment costs of $38.33 and $16.57, respectively, per conventional and high mast luminaire. Material costs would most commonly include replacement bulbs, but could include standards, wiring, junction boxes, et cetera. Material costs ran 84% higher for the conventional system than the high mast system, yielding yearly costs of $33.91 and $17.73, respectively, per conventional and high mast luminaire. Combined yearly costs per luminaire are about 75% higher for the conventional system. Over the 25-year lifecycle of the systems, the differential in maintenance costs plays the most significant role in achieving savings for high mast systems.

Results: Safety of Maintenance Personnel and of the Motoring Public

As stated in the Literature Review, conventional lighting maintenance activities typically take place in the clear zone, and sometimes on the roadway itself, whereas high mast lighting systems are generally located outside of the clear zone or behind guide rail. High mast lighting is, as TXDOT claims, inherently safer for both maintenance personnel and motorists because, without direct exposure to one another, the probability of collision is minimal. Accident risk is further decreased by the reduced amount of time workers spend on site (potentially 40% less). Although deriving a quantitative degree of potential safety benefits would require a focused State- or National-level review beyond the scope of this study, determining the directionality of the impact is a simple proposition: a significantly lower probability of collision, coupled with fewer opportunities, equals potentially much safer outcomes.

The comparative affect of different highway lighting systems on motorist safety can be considered in two additional dimensions: the potential for pole strikes (and fatalities or serious injuries resulting) and driver visibility, especially on curving ramp segments. Pole strikes, as with vehicle-worker collisions, are highly unlikely with high mast systems given that standards are located outside of the clear zone. Cobra head standards are located a minimum of 5'6" from the pavement edge as opposed to 30 feet, and are spaced much closer together than towers—particularly on ramps[12]. However, conventional lighting employs break-away standards, whereas high mast standards are solid, meaning that impacts with towers may be more likely to result in a fatality.

Tower lighting may increase motorist safety by providing greater, more uniform illuminance with reduced roadway glare, although a focused study on crash data, such as the study performed by Gramza et al. in the 1970s, would be required to confirm and quantify this supposition[13]. The previous Literature Review summarizes the results of Gramza et al. and other relevant sources.

[12] Minimum separation is 100 feet, except on ramps.

[13] NJDOT crash data as currently reported does not permit this fine-grained level of analysis.

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Results: Environment and Aesthetics

This study examines a limited selection of potential environmental and aesthetic impacts of high mast lighting, as compared to conventional lighting systems.

By calculating electricity requirements for each scenario, this study generates key input for greenhouse gas (GHG) emissions analysis. However, given that energy consumption is nearly identical in both scenarios, there is no measurable difference in GHG emissions. In each case, about 461,000 kWh is consumed (mostly in off-peak hours), resulting in GHG emissions of approximately 238 metric tons per year based on the U.S. EPA-reported average CO^2 emissions rate for New Jersey. This is the rough equivalent of 46 cars (each traveling 12,000 miles/year at 20.3 mpg) on New Jersey's roads. However, should NJDOT decide to switch to more energy efficient light emitting diode (LED) fixtures in the future, tower lighting is better suited than conventional lighting for adaptation.

As mentioned in the literature review, light trespass is a primary concern of State DOTs implementing tower lighting, especially in residential or rural areas. Although eye illuminance, measured in lux or footcandles, is objective in that it can be measured by a light meter, the effect of illuminance on individuals is subjective and may depend on context. The Illuminating Engineering Society of North America (IESNA) uses an "Environmental Area Classification" system to determine contextually-appropriate levels of illuminance, shown in Table 7..

Table 7 - Environmental area classifications, with pre- and post-curfew suggested horizontal footcandles (hfc)

	Description	Pre (hfc)	Post (hfc)
E1	Areas with intrinsically dark landscapes. [Includes] residential areas where inhabitants have expressed a strong desire for strict limitation of light trespass.	0.10	0
E2	Areas of low ambient brightness. These may be outer urban and rural residential areas. Roadways may be lighted to typical residential standards.	0.30	0.10
E3	Areas of medium ambient brightness. This will generally be urban residential areas. Roadway lighting will normally be to traffic route standards.	0.80	0.30
E4	Area of high ambient brightness. Normally this category will include urban areas with mixed residential and commercial use with a high level of nighttime activity.	1.50	0.60

Although, as an interchange, the study area warrants the use of high mast lighting, inspection of aerial photographs indicates that the surrounding area is semi-rural in character and has pockets of residential development, particularly along Country Club Road (following the contour of the southbound ramp of I-287). Conservatively, this area

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might be classified as E2, meaning that up to 0.3 horizontal footcandles might be acceptable to residents up to a certain time (perhaps 11pm), but only 0.1 horizontal footcandles thereafter ("post-curfew"). 0.1 footcandles is also the permissible level of light spillage allowed on any residential property by the New Jersey Turnpike Authority[14].

Figure 3, shows illuminance contour lines from the high mast lighting design in the Country Club Road area (a full key map and illuminance statistics are included in Appendix A). The outermost contour line represents an illuminance of 0.1 footcandles, the presumed maximum permissible level for this area. No dwelling is subject to measurable direct illuminance from the high mast system, although 0.1 footcandles falls on the unoccupied outer edges of some properties near County Club Road (which is itself illuminated by conventional lighting). There is, of course, no guarantee that all residents will find light levels acceptable, but most residents are unlikely to be disturbed by eye illuminance from a tower lighting system at this location. In the few instances where illuminance of greater than 0.1 footcandles is cast on a structure, all such properties are non-residential (commercial and recreational).

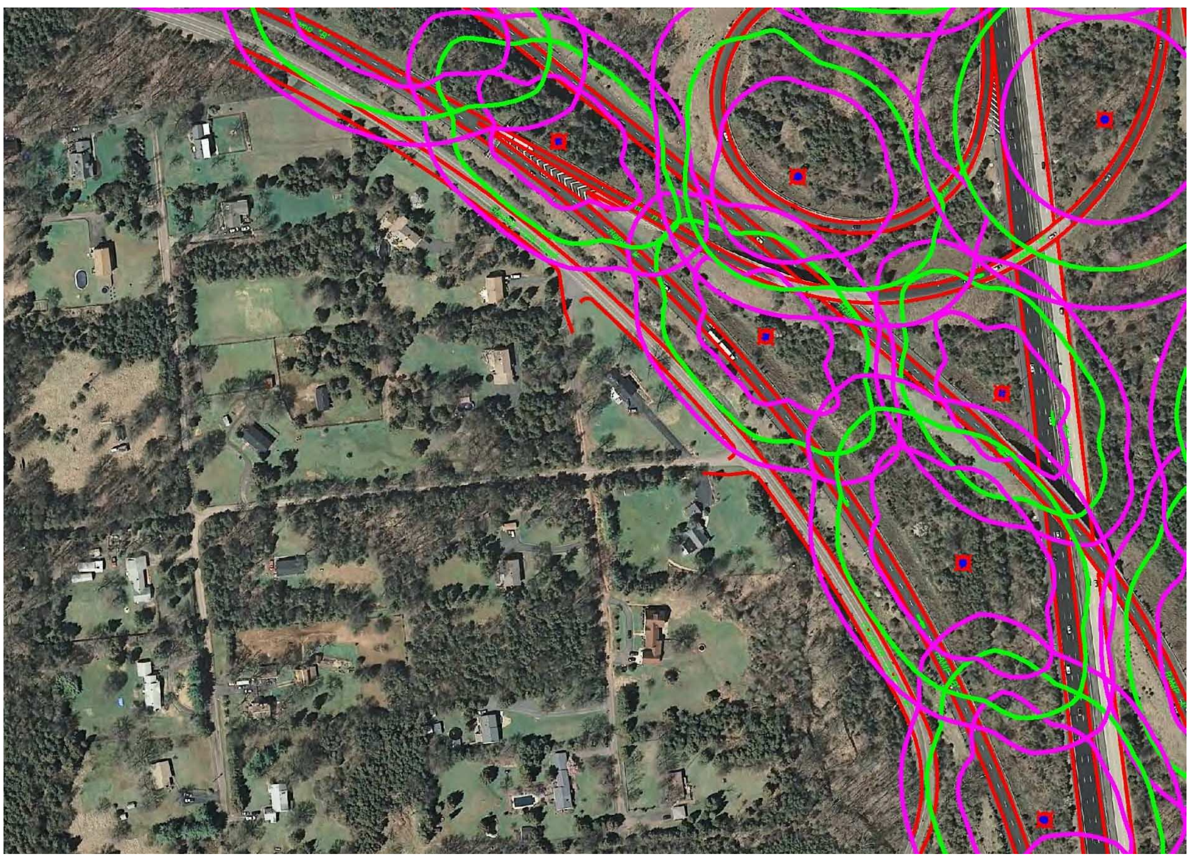

Figure 3 - Illuminance diagram, detail of County Club Road (Image: KS Engineers)

[14] *NJTA Design Manual, Section 7*

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CONCLUSIONS AND RECOMMENDATIONS

High mast lighting may offer significant benefits over conventional lighting for major urban and suburban interchange projects, particularly in non-residential areas, but present a few challenges as well.

Lifecycle Costs: Overall, high mast lighting could save approximately $582,000 at the interchange of I-78 and I-287 over the 25-year life of the system.

- **Capital cost:** While costs will differ based on interchange characteristics, high mast lighting is projected to offer a moderate cost advantage over the existing lighting system for the studied site and should be competitive at similar sites. Over the 25-year life of the system, lower first costs for a high mast system could be expected to save approximately $141,000 (discounted).
- **Maintenance and material costs:** Labor, equipment, and material costs were projected to be significantly lower for high mast lighting than the existing system at the study interchange. Over the 25-year design life of the system, tower lighting could be expected to save approximately $440,000 in maintenance costs (discounted).
- **Electricity cost:** Electricity costs were virtually identical between tower lighting and the study site's existing lighting system.

Safety of Maintenance Personnel: A quantitative accounting of potentially avoided incidents related to switching from conventional to high mast lighting cannot be performed at this level of analysis. However, high mast lighting maintenance activities are typically performed outside of the clear zone and require fewer onsite staff hours. By installing a high mast system instead of a conventional system, a significant reduction in incidents could reasonably be expected—a presumption supported by state- and national-level literature.

Safety of Motoring Public: Just as the risk of vehicle strikes may be lower for maintenance personnel working on high mast lighting, motorists are probably less likely to strike personnel or the poles they work next to. Several reputable sources, including AASHTO, cite better driver visibility as a benefit of tower lighting, although no rigorous research was found to support this notion.

Environment: Without a significant difference in energy consumption between the high mast and existing systems, no difference in emissions was observed. However, tower lighting is easier to adapt to more efficient LED luminaires, which may yield significant future energy savings.

Aesthetics: Light trespass and pollution are among the most often-cited potential drawbacks of tower lighting. However, in appropriate contexts—and even in some residential areas—high mast lighting may be designed to minimize light spillage. Lighting design software provides illuminance levels, making it a relatively straightforward task to evaluate the light trespass implications of design alternatives.

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Ultimately, the highway lighting designer must make the case for a particular lighting strategy, but it is up to NJDOT to provide a review framework that encourages better solutions without adding significant burden to the review process. Accordingly, this report recommends that NJDOT:

Enhance highway lighting selection factors: NJDOT's *Highway Design Manual* already requires the consideration of tower lighting for full interchange lighting. If a tower lighting system is proposed by the designer, it must undergo a series of reviews. First, the designer must demonstrate that light trespass is kept to acceptable levels and obtain approval from the Office of Traffic Signal and Safety Engineering. Then, "the designer shall address, analyze, and compare determining factors such as initial installation cost, maintenance costs, and energy consumption costs. Other factors should be made explicit in this review process, most notably potential traffic disruptions due to maintenance activities and the potential impact on the safety of maintenance personnel and motorists—a practice currently employed by Texas DOT. Perhaps, just as NJDOT electrical engineers review factors related to illuminance and cost, Electrical Operations personnel should review designs for maintenance and personnel safety implications.

Expand strategies for the control of light trespass: As perhaps the most formidable obstacle to the adoption of tower lighting, NJDOT should consider additional strategies for addressing light pollution from higher wattage luminaires at greater heights. The *Highway Design Manual* suggests the use of cutoffs, the standard first line strategy for controlling light spillage. However, the use of long and narrow asymmetrical lighting distributions and/or the removal of luminaires are also important to establishing appropriately contained lighting patterns—neither is mentioned in 11.03.2 *Selection of Types of Highway Lighting*. In addition to design strategies, timing can play an important role in controlling contextually inappropriate illuminance. Depending on the characteristics of the roadway, a curfew (or partial curfew, in which only certain luminaires are extinguished) could be considered as long as roadway safety is not significantly impacted.

Investigate the application of energy efficiency and alternative energy technologies: 200 watt LED fixtures are currently on the market as potential substitutes for 400 watt HPS fixtures. With half the energy consumption and up to 100,000 hours of useful life—meaning fewer bulb changes and correspondingly less maintenance labor— NJDOT may wish to investigate adding this option to the *Highway Design Manual*. Although New Jersey has already deployed pole-mounted solar photovoltaic panels on streetlights across the State, interchanges provide opportunities for larger scale installations. Projects like Oregon DOT's Solar Highway, a 104 kW installation sited within a tower-lit interchange, contribute meaningfully to lighting energy needs and are likely more economical than smaller, more dispersed panel-by-panel installations.

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Figure 4 - Oregon Solar Highways project (Image: Oregon DOT)

Collect and analyze data on highway lighting and safety: Currently, inadequate State and National data exist on the safety implications of high mast lighting versus conventional lighting systems. Standard crash data currently collected by NJDOT does not provide sufficient detail for a comparative analysis of interchanges (lit vs. unlit, tower lit vs. conventionally lit). NJDOT could launch an effort to collect crash data at selected intersections over time, which would also require a multi-dimensional method of characterizing intersections. Alternatively, NJDOT could involve AASHTO, the I-95 Corridor Coalition, or other multi-state body to bring more resources and a larger sample size to the study effort.

Consider a full tower lighting system for the I-78/I-287 interchange: It is difficult to make a case for the full replacement of a conventional lighting system in the midst of its useful life (and probably impossible from a purely economic perspective). However, the study interchange is drawing toward the end of its useful life, and may require replacement in the near future. Given the results of this study, which clearly favor the application of tower lighting over the current hybrid system at this site, high mast lighting should be strongly encouraged during alternatives analysis.

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APPENDIX A

HIGH MAST LIGHTING DESIGN

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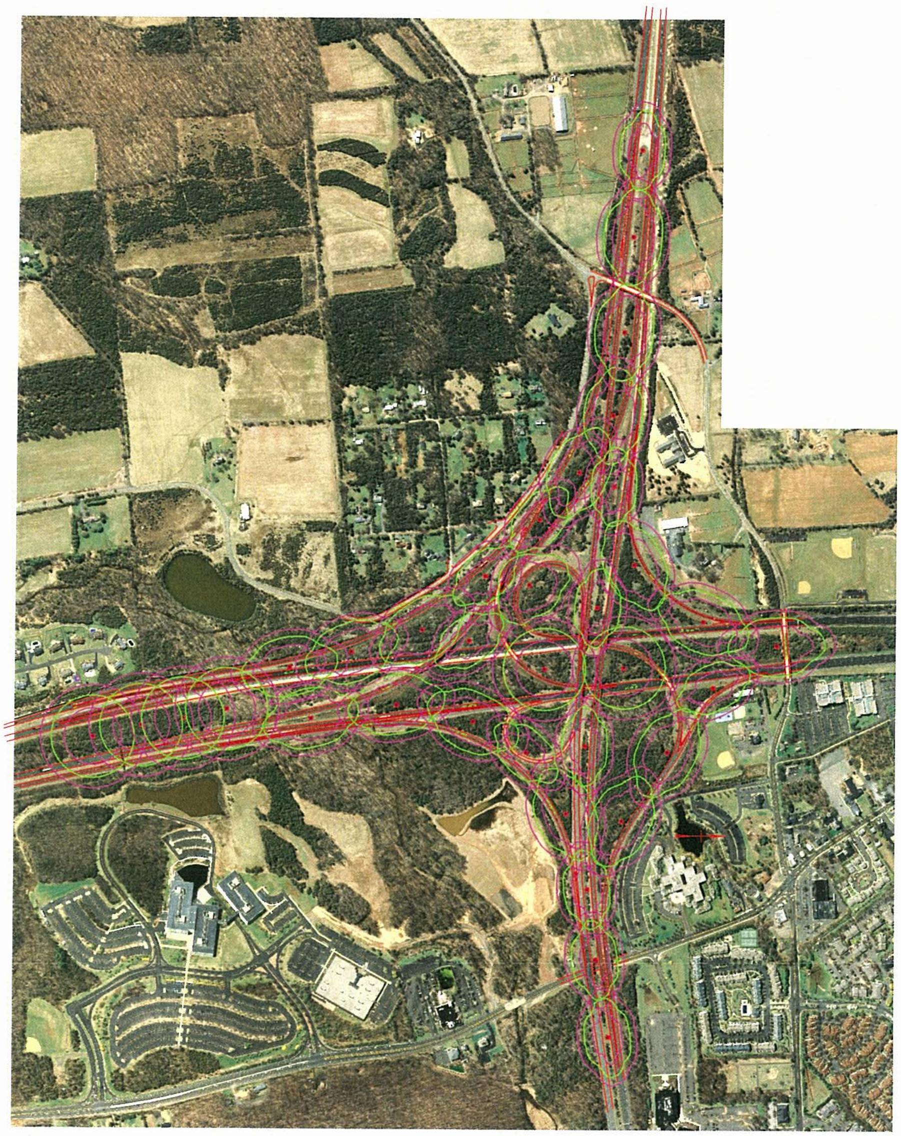

Designer
M. Choudhury

Sep 22 2010

Scale

Drawing No.

1 of 1

LIGHTING ANALYSIS

HIGH MAST LIGHTING

INTERCHANGE RT. 78 AND RT. 287

KSE
KS Engineers, P.C.

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STATISTICS

Description	Symbol	Avg	Max	Min	Max/Min	Avg/Min
DECEL LANE RT 78 WB	+	0.68 fc	1.82 fc	0.20 fc	9.1:1	3.4:1
RAMP A	+	0.77 fc	2.01 fc	0.28 fc	7.2:1	2.8:1
RAMP B	+	0.61 fc	2.05 fc	0.23 fc	8.9:1	2.7:1
RAMP 'C'	+	0.62 fc	1.84 fc	0.20 fc	9.2:1	3.1:1
RAMP 'D'	+	0.60 fc	2.38 fc	0.27 fc	8.8:1	2.2:1
RAMP 'E'	+	0.61 fc	1.54 fc	0.23 fc	6.7:1	2.7:1
RAMP 'F'	+	0.64 fc	1.43 fc	0.26 fc	5.5:1	2.5:1
RAMP 'G'	+	0.65 fc	1.65 fc	0.26 fc	6.3:1	2.5:1
RAMP 'H'	+	0.68 fc	2.14 fc	0.30 fc	7.1:1	2.3:1
RAMP 'J'	+	0.61 fc	1.13 fc	0.29 fc	3.9:1	2.1:1
RT 78 EB	+	0.71 fc	1.78 fc	0.25 fc	7.1:1	2.8:1
RT 78 WB	+	0.60 fc	1.97 fc	0.21 fc	9.4:1	2.9:1
RT 287 'NB'	+	0.62 fc	2.77 fc	0.20 fc	13.9:1	3.1:1
RT 287 'SB'	+	0.71 fc	2.76 fc	0.20 fc	13.8:1	3.6:1

KSE
KS Engineers, P.C.

LIGHTING ANALYSIS
HIGHMAST LIGHTING
INTERCHANGE RT.78 AND RT.287

Designer
M Choudhury

Date
Sep 22 2010

Scale

Drawing No.

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APPENDIX B

CANDIDATE INTERCHANGES FOR TOWER LIGHTING

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Interchange	Load Center	Existing Conventional Luminaires	Year installed
Route 287 & (NB) Ramps D - H Country Club Road Bridgewater Township Somerset County	BC	54	1975
Route 287 & (SB) Ramp B - Country Club Road Bridgewater Township Somerset County	BF	38	1975
Route 287 & (NB) Ramp F-Burnt Mills Road Bedminister Township Somerset County	BD	49	1975
Route 287 & Route 202-206 - Schley Mt. Bedminister Township Somerset County	T	6	1975
Route 202-206 & (NB) Route 287 Ramp Exit 22 Bedminster Township Somerset County	A	6	1975
Route 287 & (NB) Mount Airy Road Bernard's Township Somerset County	BT	31	1975
Route 287 & (SB) Mount Airy Road Bernard's Township Somerset County	MA	14	1975
Route 287 & Madisonville Road Bernard's Township Somerset County	BU	20	1975
Route 287 & (NB) North Maple Avenue Bernard's Township Somerset County	BV	17	1975
Route 287 & (SB) North Maple Avenue Bernard's Township Somerset County	MP	19	1975
Route 202-206 & (SB) Exit 22 A Route 287 (Pluckemin) Bedminster Township Somerset County	LM	8	1975
Route 78 & Exit 11 (WB) Pattenburg Rd Union Township Hunterdon County	CD	35	1975
Route 78 & Exit 12 (WB) Jutland Rt 173 Union Township Hunterdon County	CB	36	1975
Route 78 & Exit 12 (EB) Jutland Union Township Hunterdon County	CC	45	1975
Route 78 & Exit 13 Ramp F Union Township Hunterdon County	BZ	41	1975
Route 78 & Exit 15 Pittstown Road Clinton Township Hunterdon County	BY	34	1975
Route 78 & Exit 16 Route 31 Clinton Township Hunterdon County	BV	49	1975
Route 78 & Route 31 SB Clinton Township Hunterdon County	BS	39	1975
Route 78 & Route 31 SB Clinton Township Hunterdon County	BU	43	1975
Route 78 & Old Allerton Rd. Clinton Township Hunterdon County	BR	41	1975
Route 78 & Route 22 WB Clinton Township Hunterdon County	BP	31	1975
Route 78 & Route 22 EB Clinton Township Hunterdon County	BQ	57	1975
Route 78 & Exit 20 Cokesbury Road Lebanon Boro Hunterdon County	BN	65	1975
Route 78 & (Oldwick) Co. Rd. 523 Tewksbury Township Hunterdon County	BJ	44	1975
Route 78 & (Exit 24) Co. Rd. 523 Tewksbury Township Hunterdon County	BK	42	1975
Route 78 & Exit 26 Rattlesnake Road Bedminster Township Somerset County	BG	62	1975
Route 202-206 & (NB) No. Of Rt. 78 Westbound overpass Sta. 32+55 Bedminister Township Somerset County	BA	25	1975
Route 78 & Exit 33 - Martinsville Rd Bernard's Township Somerset County	I	29	1975
Route 78 & Exit 36 - King George Road Warren Township Somerset County	J	36	1975

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Interchange	Load Center	Existing Conventional Luminaires	Year installed
Route 287 & (RT 78 EB) Ramp B - Burnt Mills Rd Bedminister Township Somerset County	BB	44	1975
Route 78 & Exit 40 - Hillcrest Road Warren Township Somerset County	L	25	1975
Route 78 & Exit 41 - Stony Road Watchung Boro Somerset County	ANO	24	1975

List provided by Russell Bellmont, Assistant Regional Supervisor, Central Region Electrical Operations, New Jersey Department of Transportation.

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APPENDIX C

COMPARATIVE CAPITAL COST ESTIMATES

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CAPITAL COST ESTIMATES (2010)

TO BE CONSTRUCTED	UNITS	LOAD CENTER						TOTAL	Total Price
		A	**B**	**C**	**D**	**E**	**F**		
TOWER LIGHTING									
3" RIGID NON METALLIC CONDUIT	LF	4300	2550	1900	3500	2750	-	15,000	262,950.00
18"X36" JUNCTION BOX	EA	9	7	7	10	7	-	40	60,222.00
TOWER LIGHTING	EA	8	6	6	9	6	-	35	2,057,475.00
METER CABINET, TYPE 2M-MC	EA	1	1	1	1	1	-	5	42,875.00
GROUND WIRE, NO. 2 AWG	LF	4515	2679	1995	2520	2887	-	14,597	33,865.27
MULTIPLE LIGHTING WIRE NO. 2 AWG	LF	13545	8038	5985	7560	8662	-	43,791	158,524.51
LUMINAIRE	EA	64	48	24	48	48	-	232	188,314.40
SERVICE WIRE	LF	300	300	300	300	300	-	1,500	5,880.00
TOTAL									$2,810,106.18
EXISTING LIGHTING									
3" RIGID NON METALLIC CONDUIT	LF	6300	6300	6300	6300	6300	6300	37,800	$662,634.00
18"X36" JUNCTION BOX	EA	52	52	53	53	52	55	317	$477,259.35
LIGHTING STANDARD ALUMINUM	EA	52	52	53	53	52	53	315	$992,880.00
METER CABINET, TYPE 2M-MC	EA	1	1	1	1	1	1	6	$51,450.00
GROUND WIRE, NO. 2 AWG	LF	6400	6400	6400	6400	6400	6400	38,400	$89,088.00
MULTIPLE LIGHTING WIRE NO. 2 AWG	LF	19200	19200	19200	19200	19200	19200	115,200	$417,024.00
LUMINAIRE	EA	52	52	53	53	52	53	315	$255,685.50
SERVICE WIRE	LF	300	300	300	300	300	300	1,800	$7,056.00
TOTAL									$2,953,076.85

Estimate performed by KS Engineers, PC., September 2010.

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APPENDIX D

STATE DOT INTERVIEWS

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NJDOT Tower Lighting Assessment: Interview Form		
Source (Agency, Department)	**NJDOT – North Region**	
Name and Address	Howard Donovan (973-770-5062)	
Website *(link to lighting guidelines)*	http://www.state.nj.us/transportation/eng/documents/RDME/sect1E2001.shtm	
Approved tower lighting configurations *(standards, luminaries, etc.)*		
100' towers are standard, but some are 80' towers in the area of the Meadowlands. Most towers use 400 watt HPS fixtures but some locations have 1000 watt metal halide and other fixtures have been upgraded from 400 HPS to 750 HPS. Rings typically have 8 lights but some have 6 (such as in the Meadowlands area)		
Allowable tower lighting applications *(Interstate, interchange, state route, etc.)*		
Interchanges in rural or commercial areas		
Recently implemented tower lighting projects *(Route, interchange, town, etc.)*		
There is a new installation planned at Route 3/Routes 1/9		

Attribute	Reported Result (pos/neg/neutral/n.a.)	Notes
Capital cost	Did not know	
Electricity cost	Did not know	
Other operating cost	Did not know	
Ease of maintenance / labor hours	Positive	Easy to access and fix problems. For existing 22' lights, lane closures, staffing, and overtime hours present problems when a pole is knocked down.
Safety of personnel	Positive	Work performed off the roadway or behind a barrier
Driver safety	Positive	Conventional poles are frequently knocked down close to the road (such as on entrance/exit ramps). Often, they install a 40-foot pole across the roadway and use a 400 watt expressway luminaire because they cannot close the left lane or shoulder
Light trespass	Neutral	In areas where there are residences, which are few, they will use a shield or cut-off
Environment	Not reported	
Other	Not reported	

Notes

Mr. Donovan mentioned that in the southern part of the State interchanges are less complex, and this could be a reason why there are not many (if any) high mast installations. He also said that the lighting designers were aggressive in the North Region and as a result there is more high mast lighting.

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NJDOT Tower Lighting Assessment: Interview Form	
Source (Agency, Department)	**Delaware DOT**
Name and Address	Les Spicer (302-894-6315)
Website *(link to lighting guidelines)*	http://deldot.gov/information/pubs_forms/manuals/road_design/index.shtml
Approved tower lighting configurations *(standards, luminaries, etc.)*	
80 foot poles with luminaire configurations from 2-8 lights, 1000 watt fixtures	
Allowable tower lighting applications *(Interstate, interchange, state route, etc.)*	
Interchanges	
Recently implemented tower lighting projects *(Route, interchange, town, etc.)*	
Putting up new lights by the Christianna Mall at Route 7/I-95	

Attribute	Reported Result (pos/neg/neutral/n.a.)	Notes
Capital cost	Positive	Fewer pole strikes leads to fewer replacements
Electricity cost	Did not know	
Other operating cost	Positive	Fewer pole strikes = fewer maintenance hours
Ease of maintenance / labor hours	Positive	Two tower types: conventional cable-lowered ring and "bending" poles, which are lowered onto a truck bed for fixture changes (require an extra concrete pad to support trucks)
Safety of personnel	Positive	Poles are located way off road or are protected by jersey barriers
Driver safety	Positive	Very bright. Also, less of a chance to knock down poles
Light trespass	Negative	DelDOT has added shields to some of the lights because they are located near residential areas
Environment	Pos	They try to site tower lighting near commercial developments because there is less risk of light spillover to residential areas
Other	Not reported	

Notes

The conventional 30-foot poles along the edge of the roadway tend to be knocked down and have to be replaced often. There is thought to be a cost savings (both capital cost and maintenance) with the use of tower lighting.

DelDOT recently installed new tower lighting at the Delaware Memorial Bridge toll booths.

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NJDOT Tower Lighting Assessment: Interview Form	
Source (Agency, Department)	**Florida DOT**
Name and Address	Richard Kerr (850-410-5808)
Website *(link to lighting guidelines)*	http://www.dot.state.fl.us/rddesign/FloridaGreenbook/FGB.shtm
Approved tower lighting configurations *(standards, luminaries, etc.)*	
Fixtures have four lights	
Allowable tower lighting applications *(Interstate, interchange, state route, etc.)*	
Interstate routes	
Recently implemented tower lighting projects *(Route, interchange, town, etc.)*	
New Installation at I-75/I-10,, Pensacola along I-10. 8 New projects last year	

Attribute	Reported Result (pos/neg/neutral/n.a.)	Notes
Capital cost	Unknown	
Electricity cost	Negative/Neutral	It is thought to be expensive to power the lights, although bills are lump sum. FDOT has cut back on the number of fixtures at the interchange
Other operating cost	Negative	Issues with base plate fatigue, lights must be lowered during hurricane warnings, a lengthy process
Ease of maintenance / labor hours	Positive	Light poles are located off the edge of the roadway, making them safer to work on
Safety of personnel	Positive	See above
Driver safety	Positive	FDOT prepares a lighting justification report before installing lighting fixtures. This helps ensure that they will use the correct light intensity for driver vision
Light trespass	Negative	In urban areas such as Miami, Orlando, and Tampa, they are removing tower lights because of the intrusion caused by the lighting. However, tower lighting is still being installed in rural areas where there would be no impact to local residents.
Environment	Positive	To address dark sky issues, they use <1 ft-candle in their design and have full cut off-fixtures
Other	Positive	Towers become nesting sites for ospreys

Notes
Placement of the foundation is critical: Poles in low lying areas are hard to reach in wet weather. Soil issues can complicate tower light pole placement. The light poles have four lights each. However, FDOT is now removing one light fixture per pole to save money.

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NJDOT Tower Lighting Assessment: Interview Form	
Source (Agency, Department)	**Maine DOT**
Name and Address	Bruce Ibarguen (207-624-3600)
Website *(link to lighting guidelines)*	http://www.maine.gov/mdot/technical-publications/hwydesignguide.php
Approved tower lighting configurations *(standards, luminaries, etc.)*	
Four light fixtures per tower	
Allowable tower lighting applications *(Interstate, interchange, state route, etc.)*	
Interstate Only	
Recently implemented tower lighting projects *(Route, interchange, town, etc.)*	
Not constructing new light towers	

Attribute	Reported Result (pos/neg/neutral/n.a.)	Notes
Capital cost	Unknown	
Electricity cost	Positive	Turn off lights at night at low volume interchanges
Other operating cost	Negative	Actual costs to operate were equal to or more expensive than conventional lighting because of light fixtures used
Ease of maintenance / labor hours	Negative	Difficulties lowering light ring
Safety of personnel	Positive	Since poles are off roadway, safer for maintenance crews. However, location of poles sometimes made them difficult to reach in winter weather
Driver safety	Positive and Negative	Better lighting directly at interchange, but conventional lighting provides more even distribution of lighting
Light trespass	Negative	Shields were required on lights adjacent to residential areas
Environment	Negative	Dark Sky issues due to the height of poles
Other	Not reported	

Notes

Maine DOT has had problems with high mast lighting and is going back to conventional lighting with new LED luminaires. They have had trouble lowering the lights, and sometimes they cannot unlock the lighting device and actually have to take down the pole. Placement of the pole is also important; if the pole is placed in a low lying area it might be hard to get to in the snow.

They also use a smart eye for turning lights on. At locations where the overnight traffic is low, they turn off the lights all together. They have saved an estimated $100,000 with this practice.

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NJDOT Tower Lighting Assessment: Interview Form	
Source (Agency, Department)	**Virginia DOT**
Name and Address	Mark Hodges (804-786-2868) and Bruce McAuliffe (804-786-6757)
Website *(link to lighting guidelines)*	http://www.extranet.vdot.state.va.us/locdes/electronic%20pubs/TEDM/TEDM(PDF)/Section%20V%20-%20Lighting/Sect%20V%20-%20Chap%203/Section%20V%20Chap%203.pdf
Approved tower lighting configurations *(standards, luminaries, etc.)*	
100-120 feet, some 70 feet, with 6 to 8 light luminaires	
Allowable tower lighting applications *(Interstate, interchange, state route, etc.)*	
Interchanges and on some state highways where they used the tower lighting to replace conventional lighting	
Recently implemented tower lighting projects *(Route, interchange, town, etc.)*	

Attribute	Reported Result (pos/neg/neutral/n.a.)	Notes
Capital cost	Not reported*	
Electricity cost	Not reported	
Other operating cost	Not reported	
Ease of maintenance / labor hours	Not reported	
Safety of personnel	Not reported	
Driver safety	Not reported	
Light trespass	Negative	VDOT has received complaints that lights are too bright on the fringe of residential areas.
Environment	Not reported	
Other	Not reported	

Notes

VODT placed 70 ' high mast light towers, using 400W HPS fixtures, on state roadways leading into urban downtowns. The towers were typically placed in commercial or industrial areas. Once outside the downtown area, they revert to 100 to 120-foot towers.

They are not using weathering steel poles any more, only galvanized poles.

*This interview was with non-maintenance personnel, who could not comment on most areas of interest. Attempts to reach maintenance/asset management personnel were unsuccessful.

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APPENDIX E

FDOT BENEFIT-COST MODEL

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15.3 STEP 2: BENEFIT-COST ANALYSIS

(1) The purpose of this step in the roadway lighting justification procedure is to determine if the project is justified based on its benefit-cost ratio. If the benefit-cost ratio is equal to 1.0 or more, then lighting is justified for high crash locations as identified by the State Safety office. At other locations the benefit-cost ratio should be 2.0 or greater. However, projects should be ranked according to their value in benefit to the public. Those with a higher ratio offer more value than those with a lower ratio. The procedure can be used to analyze either an existing or proposed lighting system. There are two primary differences between the two analyses.

(2) First, for an existing lighting system, the night unlighted crash rate is assumed to be 1.5 times the night lighted rate. This insures an adequate safety factor in the analytical process and assumptions. But for a proposed system, the night unlighted crash rate is based on actual crash data collected at the site. In cases when reliable crash data are not available, a minimum unlighted crash rate of 3.0 crashes per million vehicle miles has been determined to be a reasonable "default" value for conditions in Florida.

(3) The second difference between the analyses is that if an existing lighting system is being evaluated to determine if it should continue to operate, the cost of the installation is not considered because it is a sunk cost. This recognizes that the initial investment in lighting hardware has already been made.

(4) It must be stressed that while defaults are suggested in this report, they do not appear to be the best value to describe local cost scale nor can they be used without yearly cost adjustment. It is the user's responsibility to justify the value to adopt in analysis.

(5) The following equations are used to calculate the benefit-cost ratio.

15.3.1 Analysis of New Roadway Lighting Systems

Benefit-Cost Ratio for Lighting Installation =

$$\frac{\text{ADT x \%ADTn x 365 x NRU x CRF x ACC}}{\text{(AIC + TMC + AEC) x 1,000,000}}$$

Where:

ADT = Average Daily Traffic (Existing or Projected)
%ADTn = Percent of ADT at night
NRU = Night crash rate unlighted
CRF = Crash reduction factor
ACC = Average crash cost (U.S. dollars per crash)
AIC = Annualized installation cost
TMC = Total annual maintenance cost
AEC = Annual energy cost