FINAL REPORT

DOCUMENTATION OF SEMI-PERMANENT HIGH-MAST LIGHTING FOR CONSTRUCTION

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16. Abstract

This report documents the first-time use by New York State of semi-permanent, high-mast pole-mounted fixtures used to illuminate nighttime road work construction and maintenance. This illumination approach was used along a three-mile stretch of Interstate 90 in Albany, NY, as an alternative to the more common portable light towers. The Lighting Research Center documented the high-mast lighting system and its performance in terms of construction work quality, safety, visibility (for workers and drivers), and economics; conducted photometric measurements on site; and developed recommendations for further refinement and optimization of the approach.

The high-mast lighting system was found to have performed well and as intended. The installation provided a level of illumination sufficient for performing the maintenance and construction activities at the site, with few shadows and relatively low glare. The high-mast lighting system probably provided a higher level of safety than the portable light towers for several reasons, including better illumination and uniformity on the task for both workers and motorists; reduced risk of injury due to the elimination of daily lighting equipment setup and removal; and reduced exposure to fumes and noise from generators. Despite the higher total cost of the high-mast lighting system, the economic and societal benefits may be considerable. This lighting approach probably allowed the I-90 construction project to be shortened, leading to a significant reduction of traffic delays for motorists.

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EXECUTIVE SUMMARY

This report documents the first-time use by New York State of semi-permanent, high-mast pole-mounted fixtures used to illuminate nighttime road work construction and maintenance. This illumination approach was used along a three-mile stretch of Interstate 90 in Albany, NY, as an alternative to the more common portable light towers. Through on-site measurements (Section 3) and computer simulation (Section 4), the Lighting Research Center at Rensselaer Polytechnic Institute documented aspects of the high-mast lighting system and evaluated its expected performance in terms of construction work quality, safety, and visibility (for workers and drivers). An economic analysis was also performed (Section 5.4) based upon the data available. Potential benefits and liabilities associated with high-mast lighting were discussed. Based upon the analyses, recognizing the limited scope of this project, recommendations for high-mast light system refinements and optimizations were suggested, along with an approach to developing warrants for using this type of lighting (Section 7).

The high-mast lighting system was found to have met NYSDOT lighting performance specifications. There were no recorded accidents at the site during the construction period. The project was completed ahead of schedule, in part due to the lighting system, reducing congestion and risk exposure to construction workers and to drivers. The cost of the high-mast lighting system was approximately 16% higher than the estimated cost of the portable light towers.

The installation provided a level of illumination sufficient for performing the maintenance and construction activities at the site. An analytical comparison of the high-mast lighting to the portable light towers (Section 5.2) suggested that the high-mast lighting system would significantly reduce shadows and glare, thereby increasing visibility of hazards and improving performance of visual tasks. Based upon these analyses, the high-mast lighting system should provide a higher level of safety than the portable light towers for the construction workers and for the drivers traveling through the construction zone (Section 6). The high-mast lighting system should also reduce the risk of injury to the construction workers during high-exposure times when they would be setting up and removing portable lighting equipment. The reduced risk to workers from exposure to fumes and noise from generators used to power the portable light towers should not be ignored. Analyses showed that the high-mast lighting system is comparable to the conventional lighting approach in terms of sky glow around the construction site, which reduces the opportunity for near-by residents to make astronomical observations. No evidence could be found that light trespass or glare were greater for the high-mast system, nor that there would be greater damage to surrounding flora or fauna from the temporary increase in environmental light surrounding the construction site (Section 5.1.4). It should be stressed that these conclusions are specific to this site and not necessarily germane to locations where maintaining the natural environment is paramount (e.g., the Adirondack Park) or to other construction sites containing narrow or highly curvilinear roadways.

Despite the higher estimated cost of the high-mast lighting system, the economic and societal benefits appear considerable in this particular location, namely an urban, heavily traveled throughway. In particular, this lighting approach probably allowed the duration of the construction period to be shortened, leading to a reduction in worker and driver risk exposures and to a reduction in traffic delays for motorists.

1 INTRODUCTION

Nighttime highway construction and maintenance is a growing concern, primarily for the purpose of reducing daytime traffic congestion (Ellis et al., 2003) and also to reduce the safety impact of work zones on drivers (since there are generally fewer drivers during the night than during the day) (Antonucci et al., 2005). Such nighttime work zone operations necessarily require illumination systems, both for the work being performed and for drivers navigating through the work zone (Bryden and Mace, 2002a, 2002b). The use of temporary, portable "light towers" in nighttime work zones is common, yet this approach is recognized as less than ideal because the relatively low fixture mounting heights on the temporary towers creates potential for shadows and glare to construction workers, and for producing glare to drivers. This approach also can require significant deployment time at the start and end of each nighttime work session that increases the cost and duration of nighttime highway operations.

An approach for illumination of nighttime work zones that before now had not been utilized in New York State involves the use of semi-permanent, high-mast pole-mounted fixtures containing floodlights for illumination of the work zone and of traffic areas adjacent to the work zone (Figure 1). The present report documents the details of the first use of this approach for nighttime road maintenance and construction work in New York State. For a highway maintenance project along a three-mile stretch of Interstate 90 (I-90) in Albany, NY, the contractor working for the New York State Department of Transportation (NYSDOT) on this project worked with a lighting manufacturer to design and install the high-mast lighting. NYSDOT contracted with the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute to document the system and its performance in terms of construction work quality, safety, visibility (for workers and drivers) and economics, to conduct photometric measurements on site, and in combination with these measurements and with simulation calculations, to develop recommendations for further refinement and optimization of the approach.

In general, the high-mast lighting system performed well and as intended. As documented in the present report, the installation provided a level of illumination sufficient for performing the maintenance and construction activities at the site, with few shadows and relatively low glare. No safety-related incidents were connected to the lighting installation. Despite its higher initial cost (about 16%), the lighting system probably contributed to the maintenance project's earlier-than-scheduled completion.

The present report, following a brief discussion of nighttime work zone lighting and safety issues, describes the documentation activities undertaken by the LRC during the course of the present project, as well as the analyses of system performance and safety issues and recommendations for identifying the most promising applications for this novel approach to nighttime construction lighting.

Figure 1. Different views of the semi-permanent high-mast lighting installation on I-90 between Exit 5 and the New York Thruway. [Photo credits: Top and middle rows, Dennis Guyon-LRC; bottom row, MUSCO Lighting.]

2 BACKGROUND

As described above, nighttime highway maintenance and construction operations are becoming increasingly common, in part to reduce daytime highway congestion and to minimize the safety impacts of construction on the driving public (Ellis et al., 2003; Antonucci et al., 2005). Yet nighttime operations themselves have safety implications. It is estimated that almost half of all fatal crashes in work zones occur at night (Antonucci et al., 2005) while only about a quarter of driven mileage occurs at night (Box, 1971). About 90 percent of the fatalities in work-zone related crashes involve drivers or other occupants of vehicles, but work zones are viewed as critical for roadway construction workers as well because the fatality rate for these individuals is eight times higher than for workers in general industry (Antonucci et al., 2005).

The use of temporary, portable light towers powered by diesel or gasoline generators is a common practice for providing illumination in nighttime work zones (Bryden and Mace, 2002b). These installations utilize fixtures mounted on relatively low poles. A field review of several nighttime work zone locations (Ellis et al., 2003) found several problems with this strategy:

- low-mounted and occasionally misaimed fixtures produced shadows in work areas, making the construction and maintenance tasks more difficult; sometimes visual tasks were performed in positive contrast while the same tasks in other parts of the work zone would be seen in negative contrast

- the lower mounting heights for the fixtures and proximity to traffic and work areas often resulted in direct glare to both construction workers and to drivers

After a review of visual tasks performed in nighttime highway construction and maintenance operations, Ellis et al. (2003) recommended that several illuminance categories be used in the design and implementation of lighting systems for nighttime work zones:

- 54 lx (5 fc) for safe movement of construction workers, for slow moving equipment, or for large visual objects of interest

- 108 lx (10 fc) on and around construction equipment and for tasks such as resurfacing roadways

- 216 lx (20 fc) for visually difficult tasks such as filling cracks, electrical work or for fast moving equipment

While Ellis et al. (2003) did not recommend specific levels of uniformity (recognizing that temporary lighting installations from low mounting heights are not conducive to uniform light distributions), they did recommend careful attention to the glare-producing properties of lighting configurations and the use of screens (when practical) to shield adjacent traffic from glare.

Another issue with the portable light tower approach is the setup and takedown time needed to position, aim and stow light fixtures and other associated equipment and the reduction of effective work time every shift (crews cannot start working until lighting is in place and operational). The contractor with NYSDOT for the present project (personal communication) estimated that a crew of ten workers would require at least three hours to setup and remove the portable lighting units every night, resulting in the reduction of the effective working time of each shift by two hours, resulting in a significant number of person-hours each night.

Nighttime work zone lighting using fixed pole-mounted fixtures are considered in a number of locations, particularly when existing roadway lighting (and therefore, an existing power source) is available (Ellis et al., 2003). Increasing wattages of lamps in existing fixtures and temporarily attaching additional fixtures to poles already containing light fixtures are two approaches that have been utilized. In addition, several state and local departments of transportation (DOTs) have evaluated semi-permanent, high-mounted lighting for highway maintenance and construction projects:

- The city of Houston let a separate contract, as part of a nighttime operation, specifically for high-mast lighting in preparation for work on an elevated section I-45 in the downtown area. It was reported that this practice, along with other contractual practices such as advertising campaigns to educate the driving public, contributed to significant reductions in the amount of time needed to complete the work for this project (FHWA, 2000).

- Washington State has adopted the use of semi-permanent high-mast lighting for locations requiring long-term road construction and maintenance work. The practice adopted in Washington included the use of 100-ft timber poles located in non-conflict areas. Washington DOT reported that the uniform, high light levels produced by this system have contributed to increased safety and work quality, and that the greatest benefits would be expected in high-speed/high-volume projects, especially where detours and temporary channelization are needed (FHWA, 2000).

- In Virginia, the state DOT installed permanent high-mast lighting two miles south and three miles north of the I-95 James River Bridge, as part of a larger restoration plan for the bridge. Although the lighting was originally designed as a permanent solution for this location, which contained an interchange with another interstate highway (I-64), it was reported that the new lighting briefly assisted the nighttime restoration work, which involved the need for lane closures (Kozel, 2003).

Although there are relatively few reports describing the use of high-mast lighting, those that are available seem to converge in their conclusions that the use of semi-permanent high-mast lighting for nighttime road construction has the potential to improve visibility for nighttime road work and in some cases, to allow it to be completed more efficiently in some locations. Further, the reports from the DOTs described above, while largely qualitative and perhaps even anecdotal in nature, are consistent with expectations when using high-mast lighting solely for roadway illumination (i.e., not in construction work zones). It is generally reported that the increased light uniformity obtained with high-mast lighting improves visibility (IESNA, 2000). On this basis, recommendations for light levels when high-mast lighting is used, have in the past been lower than when conventional equipment was used (IESNA, 1983). This reduction, however, has been somewhat controversial and has not been propagated in current recommendations until it can be substantiated by research findings.

The contractor with NYSDOT for a maintenance project along I-90 in Albany, NY, proposed the use of semi-permanent, high-mast lighting for illuminating the nighttime construction work zone along a three-mile stretch of I-90. Upon reviewing, and approving, the initial proposals for the proposed lighting approach, NYSDOT contracted with the LRC to document and evaluate the performance of the system in terms of photometric performance, visibility and glare for both workers and drivers, and economics. While the relatively short duration of this single project did not permit detailed analysis of safety for workers and drivers, it is expected that visibility provided by illumination systems will contribute to safety by making potential hazards, for both workers and drivers, more readily seen and therefore more readily avoided. In the analyses of lighting system performance, the issues of shadows in work areas, and glare - primarily to adjacent traffic, since drivers traveling at high speeds have very few options to avoid glare, but also to workers - are considered. The impact of the high-mast approach is assessed in comparison to conventional methods using portable equipment. These visibility issues are assumed to impact safety for both drivers and workers.

In addition to documenting the lighting system's performance, the LRC was asked to provide some initial recommendations for potential further optimization of the lighting approach as well as for deciding when this approach would be most justified based on economic considerations, including initial and operating costs and impacts on project duration.

3 PHOTOMETRIC MEASUREMENT OF LIGHTING SYSTEM

The details of the lighting system as installed by the NYSDOT contractor and the manufacturer working with the contractor, including aerial photographs of the installation layout, manufacturer specifications of the lighting fixtures, and manufacturer specifications of the diesel generators used to power the fixtures, are included in Appendix 1. Appendix 2 provides a photographic record of the installation, showing the lighting system as installed and in use at the work zone location.

In order to characterize the performance of the semi-permanent high-mast lighting installation, a group of researchers from the LRC traveled to the site to measure illuminances and luminances along a representative section of the road. John Van Derlofske, Michele McColgan, and Nicholas Skinner formed the team making the lighting survey. Gary Hall also attended as a representative from NYSDOT in his capacity of subcontracted inspector.

The section of the road was selected in advance of the measurements and met two main criteria:

- the poles were at the same level as the pavement
- the spacing was the same for neighboring poles

Measurements were taken west of Exit 4 on the eastbound side of I-90, starting at pole #28 (Appendix 1). The highway was closed to traffic between Exits 2 and Exits 5.

All measurements were taken on the night of August 25, 2005. Measurements were taken with no ambient light contribution and followed standard photometric measurement practices per IESNA (Rea, 2000) recommendations, such as using calibrated photometers (X91 illuminance meter by Gigahertz-Optik, and LS-110 luminance meter by Minolta), avoiding shadows on the sensor heads, and allowing the lighting equipment to stabilize before taking measurements. A measurement grid was laid out in advance per IESNA (Rea, 2000) recommendations for roadway measurements (Figures 2 and 3). The pavement line on the right side was used as the reference for the measurement grid.

Figures 4 through 6 show the horizontal and vertical illuminances, and luminance measurements. Luminance measurements were made from a distance of 83 m ahead of pole #28 as indicated in Figure 6.

Figure 4 summarizes the measurements of horizontal illuminance on the roadway surface. As these measurements show, the light levels in the installation, averaging more than 100 lx, were sufficient to facilitate movement of construction personnel and performing visual tasks such as resurfacing the roadway surface (Ellis et al., 2003).

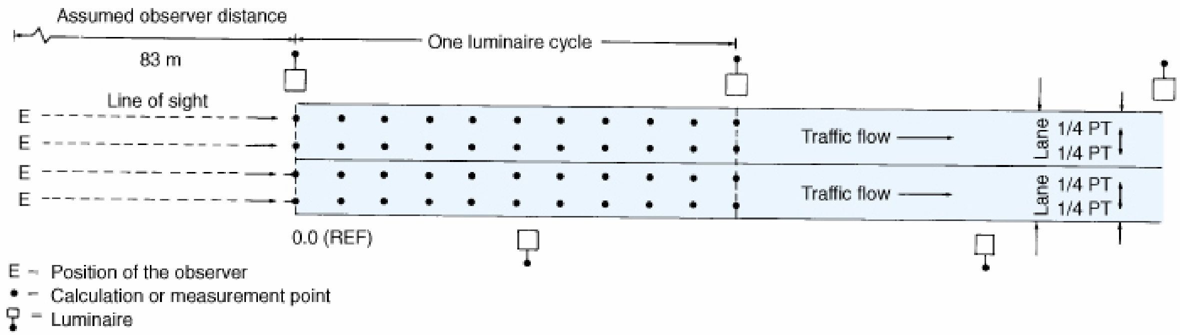


Figure 2. Recommended practice for luminance and illuminance measurement locations for roadways (from Rea, 2000).

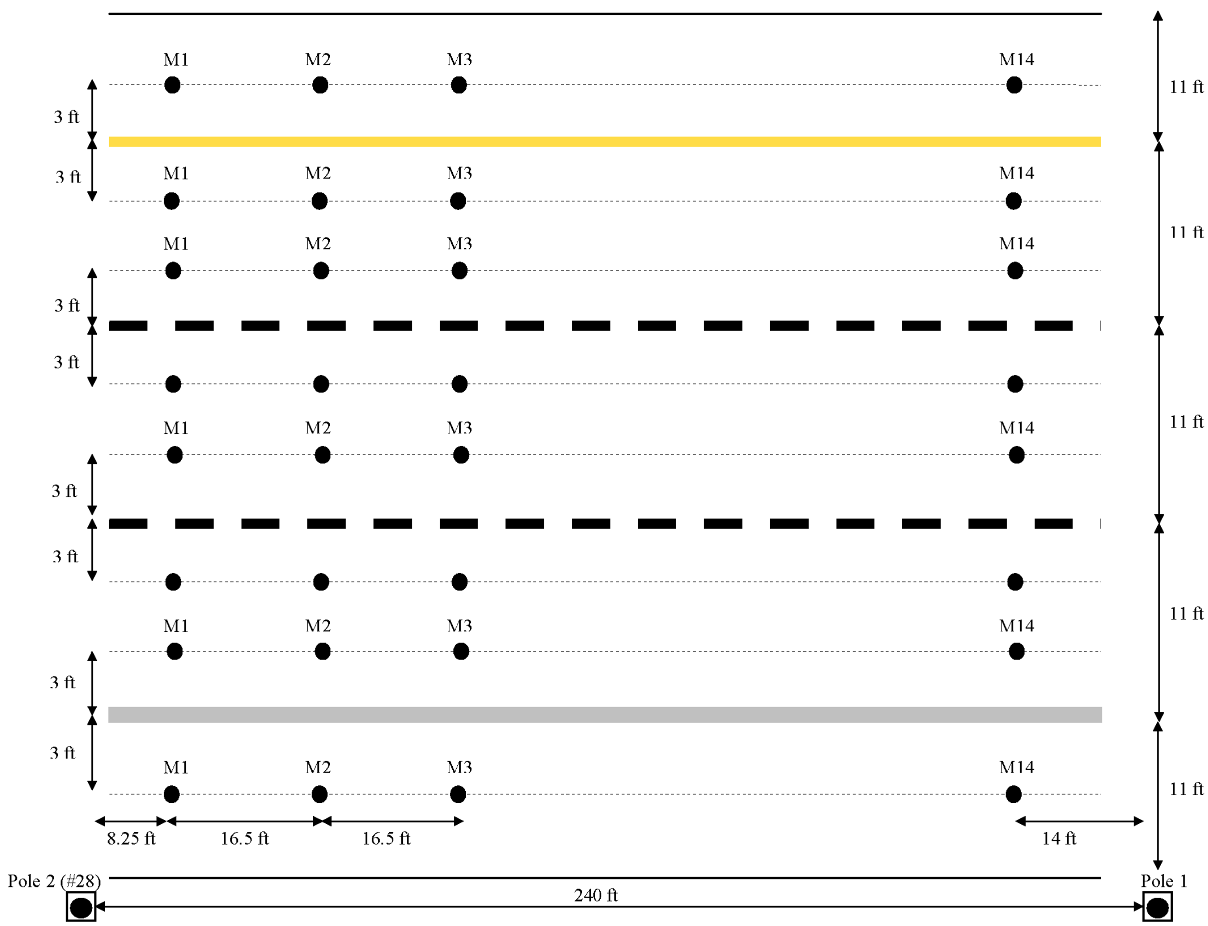


Figure 3. Schematic diagram of the grid used for horizontal illuminance measurements. The dotted black lines correspond to lane lines; the gray line to the edge line of the road and the yellow line to the median line. Rows M1, M2, etc., through M14 are 16.5 ft apart.

		Illuminance measurements on site at pavement level (lx)													
		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14
S1	Median shoulder (3' from yellow line)	180	166	148	131	117	108	111	118	132	155	179	199	209	202
S2	Fast lane (3' to yellow line)	185	175	152	131	117	111	111	120	135	159	183	201	207	198
S3	Fast lane (3' to dashed line)	187	171	147	120	116	111	116	127	145	169	191	200	187	199
S4	Middle lane (3' from fast lane)	189	175	152	132	122	114	116	126	144	165	189	197	186	190
S5	Middle lane (3' from slow lane)	193	180	101	120	116	115	123	140	162	182	189	113	115	115
S6	Slow lane (3' from middle lane)	186	168	162	146	130	112	105	108	132	148	171	174	150	153
S7	Slow lane (3' from white lane)	172	155	161	147	127	119	113	114	124	138	155	160	147	130
S8	Outer shoulder (3' from white line)	158	158	163	150	138	122	111	107	108	117	127	138	128	106
	Average	148 lx													
	Average/minimum	1.5													
	Maximum	209 lx													
	Minimum	101 lx													
	Maximum/minimum	2.1													

Figure 4. Horizontal illuminance measurement values (in lx) corresponding to the grid shown in Figure 3.

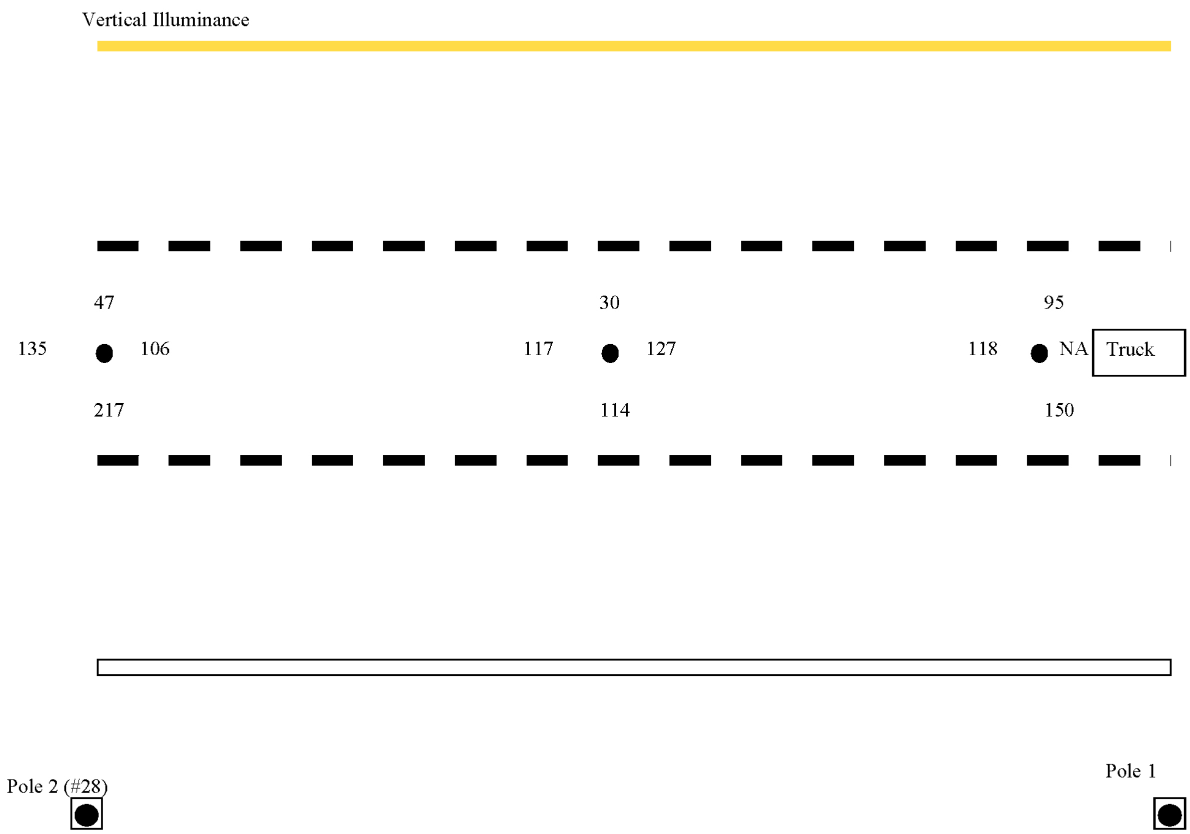


Figure 5. Vertical illuminance measurements (in lx) corresponding to the grid shown in Figure 2.

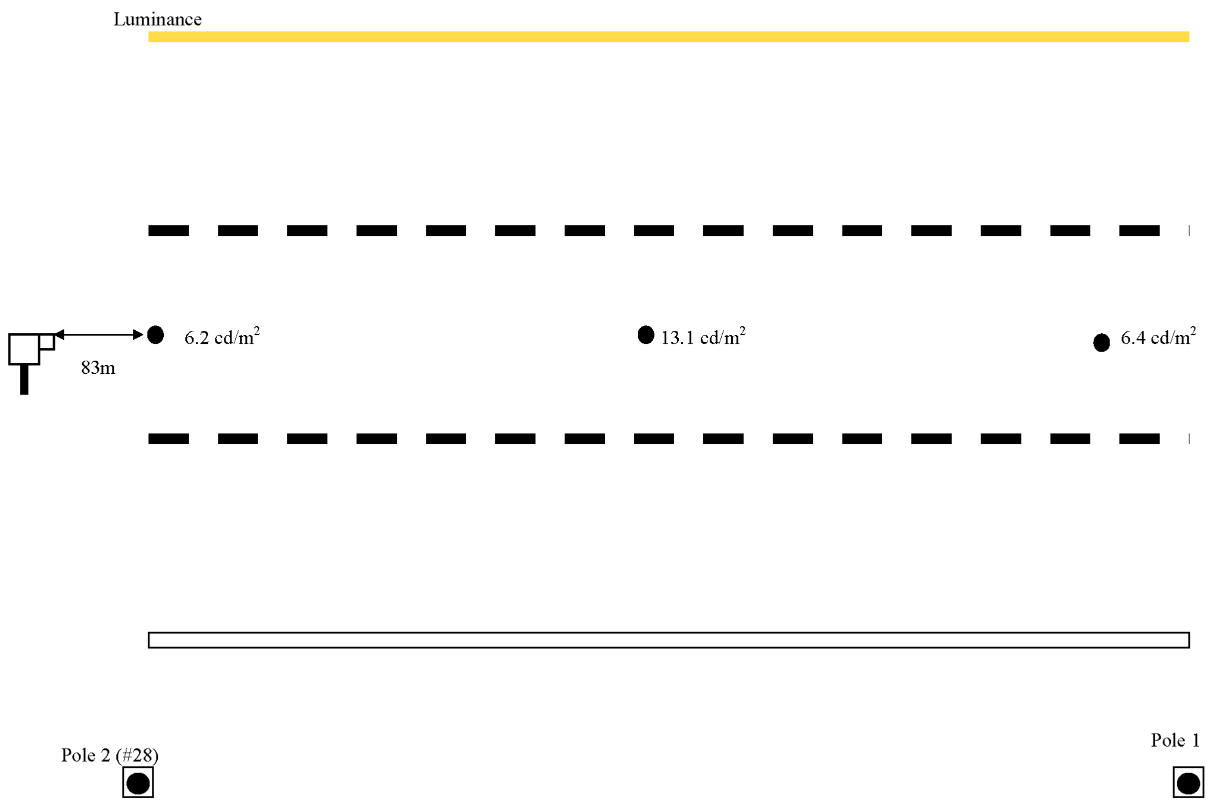


Figure 6. Pavement luminance measurements (in cd/m²) corresponding to the grid shown in Figure 3.

4 DEVELOPMENT OF COMPUTER SIMULATION MODEL

In order to evaluate the performance of the semi-permanent high-mast lighting system, it was necessary to develop a computer simulation of the system. Using the AGI32 lighting calculation program (Lighting Analysts, Inc.), a program that can be used to calculate light levels (illuminances and luminances) in a scene using photometric data for specific light fixtures present in the scene, the LRC developed a model of a sample of the I-90 installation.

Because the light fixtures used in the present installation were custom developed for this location by a manufacturer working in conjunction with the NYSDOT maintenance work contractor, photometric performance data for the fixtures were not readily available.

From the information by the light fixture manufacturer included in Appendix 1, from the photometric measurements outlined in the previous chapter of this report, and from telephone discussions with personnel from the NYSDOT contractor and with the manufacturer, the LRC concluded that the fixtures were similar to conventional floodlights and that their distributions could probably be estimated using photometric data for existing floodlight fixtures of differing distributions. Through a sampling process of different beam distributions, the LRC identified that a floodlight having a NEMA type 5H6V distribution could reasonably be used in the lighting calculation and simulation software to approximate the distribution of light levels in the I-90 work zone location.

Appendix 3 shows the illuminances calculated across a 1000-ft by 165-ft section of roadway using a commercially available 5H6V floodlight fixture equipped with one 1500-W metal halide lamp. The predicted illuminances on the pavement surface are in close agreement with those found in the field.

With a photometrically validated model, it was then possible to systematically analyze the potential effects on visibility of workers and drivers from the portable light towers and high-mast lighting system.

5 EVALUATION OF LIGHTING SYSTEM PERFORMANCE

5.1 Compliance with Existing Standards and Practices

The following items provide general design guidelines and criteria of the design variables considered during the analysis of the high-mast lighting solution.

5.1.1 Light levels (Illuminance)

Illuminance is one of the many quality factors of any lighting installation. It is the most common criterion for many applications because it is easily quantifiable and serves as a relatively good predictor of visual performance (e.g., accuracy and speed of visual tasks). It is worth noting that visibility (the ability to obtain information from the environment visually) also depends on factors such as contrast, size, and time.

In working environments such as heavy construction sites, there are several critical visual tasks and the characteristics of the environment (i.e., color and finish of surfaces) cannot be controlled. Illuminance on the task plane can then be critical for certain tasks, especially those involving low contrast or peripheral detection of unsafe situations. In most applications, including nighttime road work, illuminance recommendations need to be taken as part of a broader context where quality metrics of lighting design such as glare, peripheral detection, vertical illuminance, and uniformity are also considered (Rea, 2000; Boyce and Rea, 2001; and Boyce, 2003).

Based on the photometric measurements made on-site and on the calculations resulting from the development of the simulation model, the high-mast solution was designed and installed so that it would meet or exceed the lighting requirements of NYSDOT (NYSDOT, 1995) as well as the light level recommendations of Ellis et al. (2003).

5.1.2 Uniformity

In general, completely uniform illumination is neither desired nor practical. However, too much non-uniformity is typically disliked, as it can result in visual confusion and clutter.

The most common metrics used to characterize uniformity are descriptive statistics such as ratios among maximum, minimum, and average illuminance. Different studies show that a minimum to maximum ratio of at least 0.7 will be acceptable to most people if a high uniformity is expected (Boyce, 2003). However, the literature shows that the requirements for uniformity of illuminance are most likely context based (Boyce, 2003). This conclusion seems to imply that if non-uniformity is expected, the recommendations can be relaxed.

It is also worth emphasizing the difference between the distribution over an entire area and that over a task plane or work area. In the case of a large space, carefully planned non-uniformities can add visual interest to a scene. In the case of work areas, research studies have shown that most people prefer uniform illumination in the immediate area of the task and a lower illuminance in the area outside (Boyce, 2003). The IESNA recommends illuminance ratios of 1.5 to 3 between the task plane and the immediate surroundings. In most cases, this range helps to focus on the task plane without causing eye fatigue (Rea, 2000). In the specific case of roadway lighting, the recommended uniformity ratios are 3.5 to1 (average to minimum) and 6 to 1 (maximum to minimum) (Rea, 2000; NYSDOT, 1995).

Uniformity is not necessarily the main objective of a lighting installation; rather, it is a tool that can lead to visual comfort and performance when used properly. For nighttime road work, uniformity ratios are a tool to evaluate and perhaps predict if a particular lighting solution will produce shadows or dark areas that would impair the performance of a task or the safety of the people involved. Further, a general uniform illumination may help workers psychologically by reducing dark spots and by enhancing the detection of the work area boundaries.

The very high uniformity (1.5 to 1, average to minimum) achieved with the high-mast lighting can be observed in the pictures of Figure 1 and Appendix 2. The asymmetric and semi-custom reflector design of the luminaires, along with the selected mounting height and pole spacing, are the reasons for the high uniformity.

5.1.3 Glare

Glare is frequently a negative descriptor of any lighting installation. Glare can occur in two forms, reflected or direct. Reflected glare is the result of the light source being imaged on the visual field, an effect that may only occasionally be an issue during road work given the low and semi-diffuse reflectance of pavement. However, the light source-eye geometry can contribute to reflected glare, hence the preference for higher luminaire mounting locations and smaller aiming angles. Direct glare is the result of a light source being in the field of view and can often be eliminated by shielding the light source or by limiting its maximum luminance. In either of its forms, glare can cause a loss of visual performance or a feeling of discomfort (Boyce and Rea, 2001).

Light sources used for nighttime roadwork should be shielded to avoid direct glare as much as possible. If direct view of a light source cannot be eliminated, the following criteria should be considered to reduce the negative effects of glare (NYSDOT, 1995):

- The maximum permissible luminous intensity at an angle of 70º from the vertical shall be 20,000 cd.

- All luminaires shall be aimed such that the center beam axis is no greater than 60º from the vertical.

A report filed by DOT inspectors on April 19, 2005 makes explicit mention to the high quality of the illumination, including minimal glare throughout the work zone. Interviews with people involved in the project (contractor, workers, DOT subcontracted inspector) confirmed this assessment unanimously. Additionally, the estimated aiming angle of the luminaires is 50º to 55º from the vertical, therefore complying with standard specifications (NYSDOT, 1995). Further, the use of special shielding reduced spill light that would otherwise contribute to light pollution.

There is no direct form to evaluate the potential for glare of an installation without the actual photometric distribution of the light fixtures (not available in this case due to proprietary reasons). However, by using the simulation model described above, the LRC performed the glare analysis described in the following section.

5.1.4 Light Pollution

Light pollution can be defined and discussed in three different ways, depending upon the context: sky glow, light trespass and glare. Each is related to the amount of light leaving a site (in this case the roadway right of way), but each is measured in different ways.

Sky glow is simply the amount of light leaving a site. Sky glow will limit observations of astronomical objects due to obscuration by the light scattered into the atmosphere. The computer simulation model we developed to characterize the high-mast and portable lighting systems was used to calculate the amount of sky glow (in lumens) generated into the atmosphere by these two lighting systems. For the same, illuminated, linear segment of the construction site (about 1 mile), the calculated amount of light leaving the site was 200% greater for the portable lighting system than for the high-mast system, primarily owing to the fact that the portable lights require much higher aiming to achieve the required light levels. This results in increased direct illumination leaving the sides and top of the roadway site. Since the entire length of the segment of I-90 under construction was illuminated by the high-mast lighting system, whereas the portable system would only illuminate a portion of the work zone on a given night, the total amount of light leaving the entire site during the construction phase from the high-mast system was about the same as from the portable system. Overall, the semi-permanent high-mast lighting system will generate a similar amount of sky glow during construction as the portable lighting system. In an urban or sub-urban environment which already has a great deal of light pollution, sky glow may not be important, but in rural areas (e.g., Adirondacks), sky glow might be a significant consideration, even if the poles are temporary. In such a case, a decision to turn on only a portion of the semi-permanent high-mast fixtures at any given time might be made to reduce light pollution.

Light trespass is obtrusive light emitted from one site to another occupied by people. An example of light trespass is light coming into an occupied bedroom window at night. There is no formal definition of light trespass or method to measure it. Consequently, no analysis of light trespass was performed for this project, although it is worth noting that published reports of the I-90 project stated that NYSDOT engineers believed that the system would be no more problematic than the conventional portable light tower approach (Woodruff, 2005). It should be noted, however, that the LRC is presently developing a measure of light trespass in collaboration with four leading lighting fixture manufacturers.

Glare is light that either reduces visibility or causes discomfort to a viewer. Glare has been previously discussed and, although no quantitative assessments have been made of glare for areas adjacent to the work zone other than lanes for drivers traveling through the zone, it is logical to assume that the high-mast lighting would usually produce less glare than the portable lighting systems, not only for drivers and workers, but for residents adjacent to the construction zone. (See calculations in section 5.2.2.) It should be emphasized, however, that glare is quite situational. Under the high-mast lighting system, people standing at two different viewing positions near or in the construction site will experience similar, but modest amounts of glare. For the portable lighting system, however, one of those two people might experience intolerable glare while the other experiences none at all, depending upon the spatial geometry of viewing angle relative to the light source. Generally speaking, then, one would expect the high-mast lighting system to produce less glare overall to areas adjacent to the work site than the portable lighting system.

The project team searched the local newspaper (Albany's *Times Union*) to assess the public's interest and reaction to the semi-permanent lighting at the construction site, and yielded several articles. Other than a comment from a NYSDOT engineer that the high-mast lighting would likely be less problematic to adjacent locations than the conventional approach using portable light towers, there was no mention of any negative comments on the project. A search of such publications as the Save the Pine Bush (an advocacy group for the nearby Albany Pine Bush) newsletter, concerned with the flora and fauna in the protected Pine Bush area adjacent to the construction site, made no mention of light pollution connected to the work on I-90. Whereas there may well be disruptions to the flora and fauna in protected areas due to light pollution, there is no documented evidence that temporary sources of light pollution in construction zones have lasting impact on the mortality or viability of species found in these areas. Absent a formal interview process with residents near the site or with advocacy groups, which was outside the scope of this project, the following conclusions were drawn about light pollution from the construction site.

- The high-mast lighting system (lighting the entire work zone) and the portable lighting system (lighting about a third of the work zone) produced similar amounts of sky glow.
- Overall glare for residents near the construction site was probably less than would have been experienced with the portable lighting system, but this would be highly situational.
- No complaints were registered in the public domain about light pollution from the semi-permanent high-mast lighting system.
- The impact of temporary lights, of any kind, used for construction in work zones on the local flora and fauna is unknown.

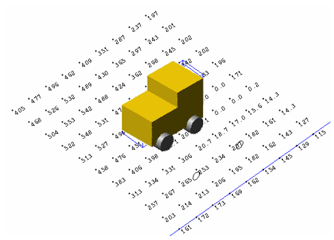
5.2 Visibility Analyses

Because Ellis et al. (2003) found that shadows and glare for construction workers and glare for drivers were the primary problems found when observing nighttime work zone lighting installations, the visibility analyses focus on these three areas.

5.2.1 Visual Performance for Construction Workers

To illustrate the potential benefits of the high-mast lighting approach on visibility for the construction workers through the reduction of shadows (Ellis et al., 2003), the same lighting simulation software was used to simulate the presence of a truck in the work zone. Under the conventional method of lighting using portable light towers, the directional lighting would result in one or more sides of the vehicle being lighted to a high light level and one or more sides being covered in shadow. Under the high-mast system, shadows are reduced because of increased uniformity and reductions in visibility caused by shadows are less likely.

Figure 7 shows (in plan view) the horizontal illuminances around the truck, located in the center of the work zone, for the conventional approach and for the high-mast approach.



a)

405	477	496	462	409	351	287	237	197
468	526	532	489	430	365	297	243	201
504	553	542	488	424	362	298	245	202
522	548	531	476	414	354	293	242	202
513	527	490	443	390	333	278	233	196
458	476	451	23.2	0.0	0.0	0.0	0.0	171
383	406	398	23.1	20.8	3.1	0.0	0.0	0.2
313	334	331	306	20.7	18.7	17.0	15.6	14.3
257	267	265	253	234	207	182	161	14.3
203	214	213	206	195	182	162	143	127
161	172	173	169	162	154	145	129	115

b)

77.0	80.0	83.6	87.8	92.7	97.9	103	109	116
76.4	79.6	83.6	88.4	93.9	99.4	105	112	121
76.3	79.0	84.0	89.3	95.0	100	107	115	124
75.6	80.5	28.4	27.6	96.2	102	109	118	127
73.7	27.2	26.5	26.5	25.9	23.3	110	119	128
71.8	25.6	23.4	1.1	0.7	0.8	103	122	131
67.9	73.4	80.3	73.8	81.7	90.5	101	124	133
65.8	71.1	77.1	69.7	80.4	89.2	98.2	109	134
63.5	68.4	73.8	82.7	77.1	85.8	95.8	107	130
60.8	65.9	72.9	79.2	74.2	82.6	92.3	103	116
59.8	64.5	69.8	74.2	82.3	89.8	98.6	98.4	111

Figure 7. Horizontal illuminances (in lx) on the pavement around a vehicle in the work zone under a) portable light towers and b) under high-mast illumination. The grid spacing is 5-ft.

Figure 8 shows the vertical illuminances on the four sides of the vehicle (front, back, median-facing and shoulder-facing) under the portable lighting system, while Figure 9 shows the vertical illuminances for the same locations under the high-mast lighting system.

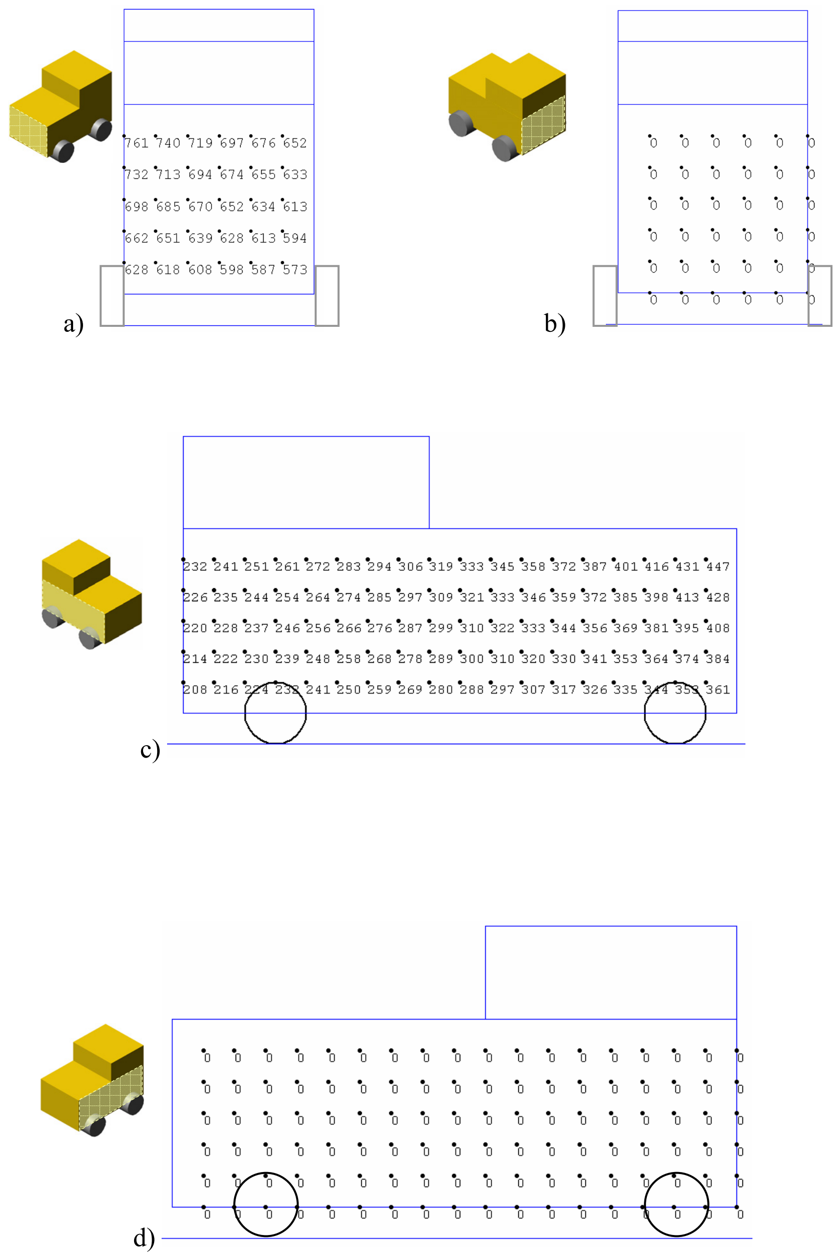


Figure 8. Vertical illuminances (in lx) on the vehicle for the a) front, b) back, c) median-facing side and d) shoulder-facing side of the vehicle under the portable tower installation. Values of 0.0 correspond to illuminances less than 0.1 lx. The grid spacing is 1 ft.

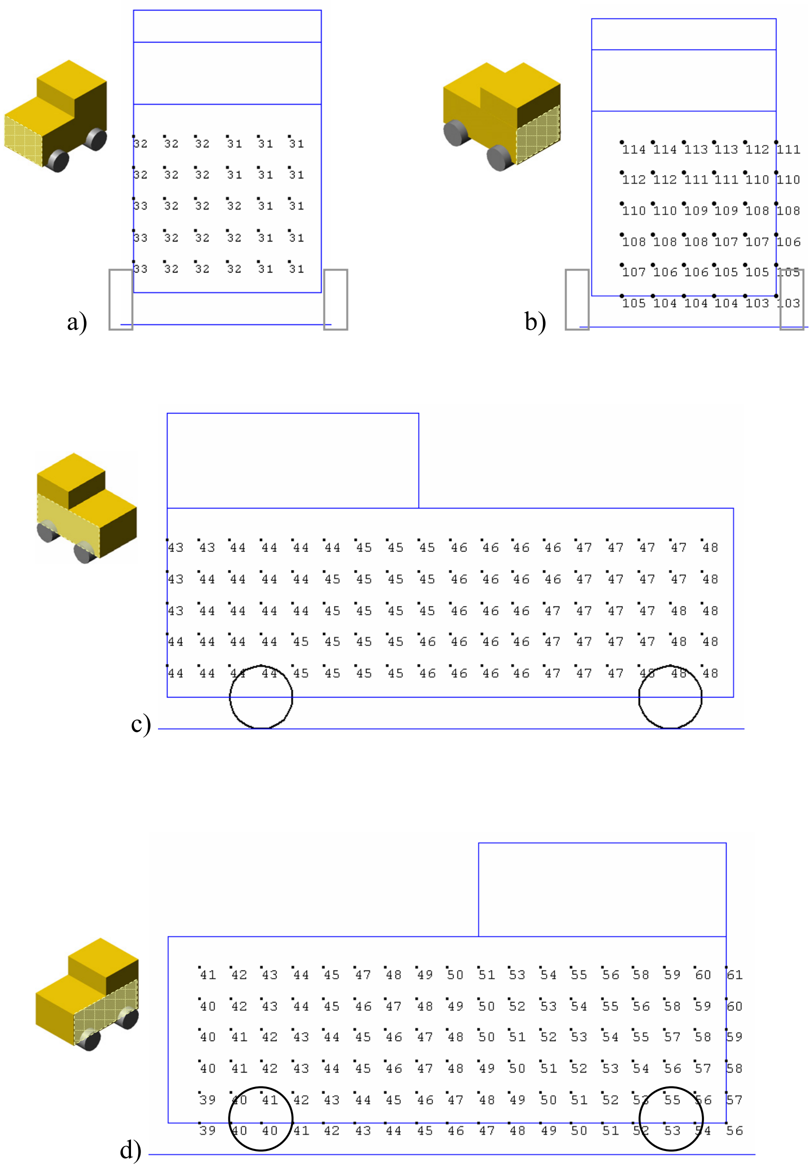


Figure 9. Vertical illuminances (in lx) on the vehicle for the a) front, b) back, c) median-facing side and d) shoulder-facing side of the vehicle under the high-mast lighting installation. The grid spacing is 1 ft.

Figure 10 shows a grayscale rendering of the test vehicle under portable light towers and under high-mast lighting.

a)

b)

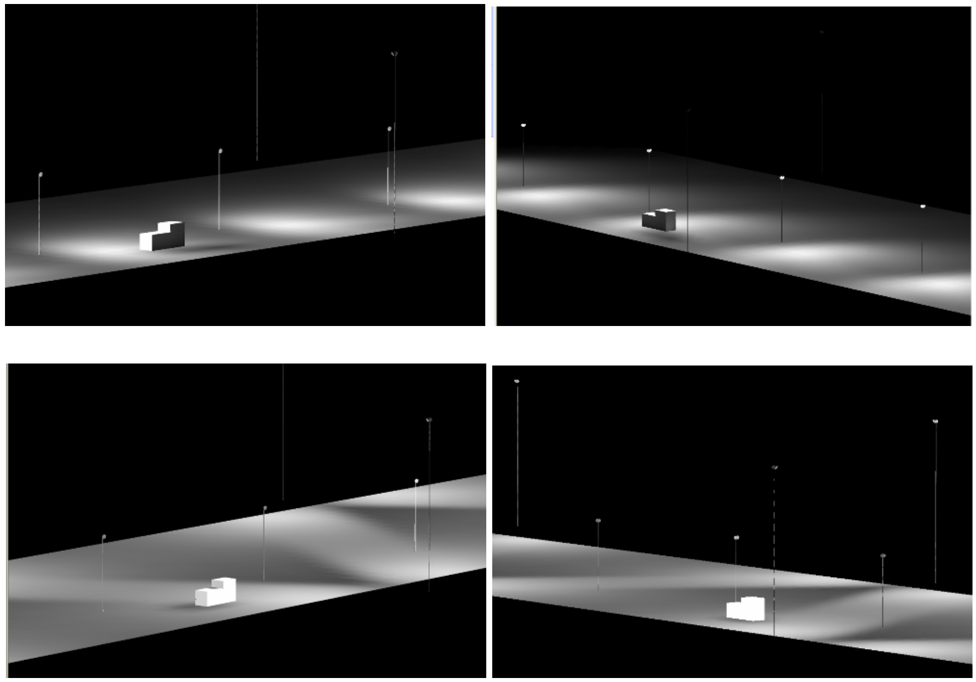


Figure 10. Grayscale renderings of the vehicle for a) the portable light tower light system and b) the semi-permanent high-mast lighting system.

Assuming a pavement reflectance of 0.07 (IESNA, 2000), a vehicle surface reflectance of 0.2 and assuming a reflectance of a small objects such as a tool, or a washer, having a reflectance of 0.2, it is possible to estimate the visibility level (VL) and relative visual performance (RVP) of objects on the ground around the vehicle and of a keyhole on each side of the vehicle (Rea, 2000). VL is a measure of an object's contrast against its background relative to the threshold contrast needed to see the object. When VL is below 1, an object is invisible. RVP is a relative measure of the speed and accuracy with which an object can be detected (Rea and Ouellette, 1991). All visual performance analyses in this section were conducted assuming an observer aged 50 years old.

Table 1 shows the VL and RVP value for several objects under the portable tower lighting (tool and washer on the ground, and a keyhole on the vehicle), calculated using the light level data in Figures 7 and 8, and using the following assumptions: tool size is 8 inches long by 1 inch wide, washer size is 0.25 inches in diameter, keyhole size is 0.25 by 0.125 inches rectangular. Objects on the ground are assumed to be viewed from a distance of 5 ft, while the keyhole is viewed from a distance of 2 ft. Table 2 shows the visibility data for the same objects under the high-mast lighting installation.

Table 1. Visibility level (VL) and relative visual performance (RVP) (Rea, 2000; Rea and Ouellette, 1991) for several objects located along each side of a vehicle under the portable tower work zone illumination. Shaded cells indicate when an object was invisible, caused by shadows on and around the vehicle.

Location	Tool on Ground	Washer on Ground	Keyhole on Vehicle
Front of vehicle	VL: 18.2 RVP: 0.98	VL: 18.2 RVP: 0.98	VL: 12.8 RVP: 0.97
Back of vehicle	VL: - RVP: -	VL: - RVP: -	VL: - RVP: -
Median-facing side of vehicle	VL: 17.9 RVP: 0.98	VL: 17.9 RVP: 0.98	VL: 11.5 RVP: 0.96
Shoulder-facing side of vehicle	VL: 10.1 RVP: 0.92	VL: 10.2 RVP: 0.92	VL: - RVP: -

Table 2. Visibility level (VL) and relative visual performance (RVP; Rea and Ouellette, 1991) for several objects located along each side of a vehicle under the semi-permanent high-mast illumination. In none of the cases was any of the objects invisible.

Location	Tool on Ground	Washer on Ground	Keyhole on Vehicle
Front of vehicle	VL: 16.4 RVP: 0.97	VL: 16.3 RVP: 0.97	VL: 8.1 RVP: 0.92
Back of vehicle	VL: 20.1 RVP: 0.99	VL: 20.1 RVP: 0.98	VL: 8.7 RVP: 0.93
Median-facing side of vehicle	VL: 16.7 RVP: 0.97	VL: 16.7 RVP: 0.97	VL: 8.6 RVP: 0.92
Shoulder-facing side of vehicle	VL: 19.6 RVP: 0.98	VL: 19.6 RVP: 0.98	VL: 8.6 RVP: 0.93

This simple analysis is not an exhaustive exploration of all of the potentially important visual objects that a construction worker would need to see during highway maintenance operations. Rather, it is designed to demonstrate the relative insensitivity of the high-mast lighting system to fluctuations in visibility that are caused by shadowing effects from directional lighting systems, such as portable light towers. Even though VL and RVP values are actually lower in some cases with the high-mast lighting system than with the portable tower system, the high-mast system results in more consistent visibility regardless of the direction of view.

5.2.2 Glare for Drivers and Construction Workers

The second issue with lighting systems in construction is the presence of direct and reflected glare (Ellis et al., 2003). To illustrate the differences between portable light towers and high-mast lighting as potential glare sources, the same lighting simulation software was used to predict the glare ratings from drivers and workers located at different positions throughout the work zone. Glare ratings are commonly used as a metric to differentiate between outdoor lighting systems that could cause glare problems (CIE, 1994).

Conventional portable lighting is a frequent cause for glare complaints from driver and workers, largely due to the lack of beam control, lack of use in practice of shielding accessories, and the high aiming angles that result from the short mast height and the desire to cover as large of an area as possible. High-mast lighting is usually considered to cause minimal glare, mostly due to the much higher mounting locations afforded (fixtures are out of view) that also result in the use of more concentrated beam distributions.

Table 3 shows the maximum glare ratings calculated in AGI32 for four different driving positions and four different worker locations within the work zone.

Table 3. Maximum glare ratings (CIE, 1994) calculated for the portable light tower and high-mast lighting systems.

	Glare rating by Portable light towers	Glare rating by High-mast lighting
Driver 1	10	36
Driver 2	67	37
Driver 3	69	36
Driver 4	66	37
Worker 1	51	23
Worker 2	62	33
Worker 3	62	34
Worker 4	62	34

	Glare Rating
Unbearable	90
	80
Disturbing	70
	60
Just Admissible	50
	40
Noticeable	30
	20
Unnoticeable	10

The data in Table 3 is plotted in Figure 11 for ease of comparison across lighting systems. As expected, the glare ratings for the high-mast installation are lower than those for portable light towers with one exception (Driver 1). It is worth emphasizing that glare is highly dependant on location and viewing angle. The location of driver 1 was purposely chosen just behind a light tower, as if the driver was just to enter the work zone. It can be seen that the glare rating for driver 1 is very low until entering the work zone –at that point glare ratings reach values over 60. A similar condition can be observed from the locations of a worker inside the work zone. However, once a person is inside the work zone, even the most favorable location could potentially result in glare given the high illuminance ratios across the work zone, high aiming angles, and lack of glare mitigation accessories. On the other hand, as expected, the glare ratings are much lower and consistent across the different viewing positions inside and outside the work zone.

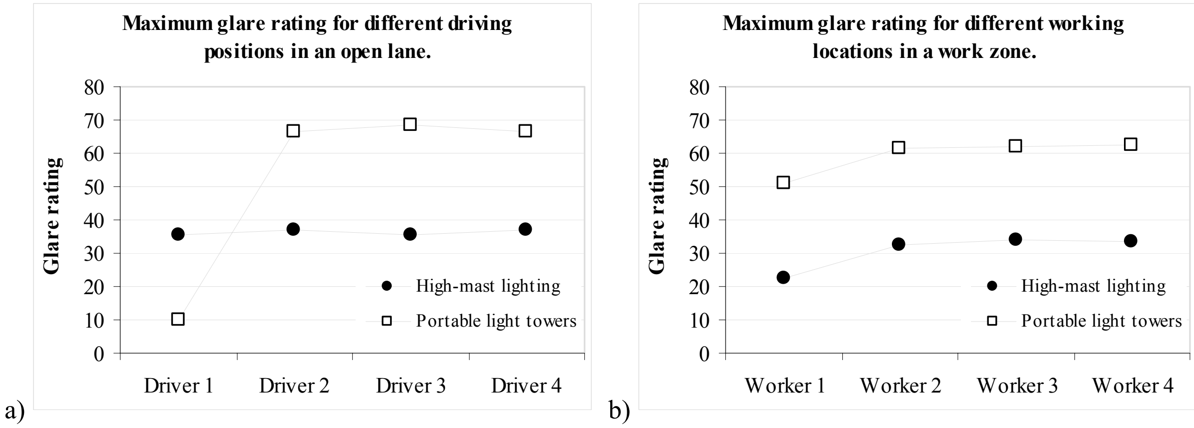


Figure 11. Glare ratings for a) different driving positions in an open lane and for b) different working locations in a work zone. An explanation of the glare ratings is provided in Table 3.

The ratings to the high-mast lighting range from 23 to 37, just above the noticeable level. The glare ratings to the portable light tower conditions range from 51 to 69 inside the work zone, corresponding to subjective evaluations of just admissible to intolerable. Both ranges seem to nominally correlate well with the documented issues of portable light towers and the feedback from users of high-mast lighting.

5.3 Safety Considerations

5.3.1 Crash Risk Factor

A report dated February 17, 2005, (on file with NYSDOT) summarized the contractor's proposal for the use of semi-permanent high-mast lighting. The proposal was originally met by NYSDOT with the overriding concern that 68 out of the 108 proposed high-masts would be in the clear zone. Acknowledging that portable lighting is always in the clear zone and in fact closer to drivers, NYSDOT produced a safety analysis concluding that high-mast lighting had a 60 percent lower risk factor than portable light towers, hence authorizing the contractor to proceed with the installation and roadwork. The following are the main reasons behind NYSDOT's conclusion:

- While in use, portable light plants are always inside the clear zone.
- Only 68 of the 108 high-mast poles needed to be located in the clear zone. This lower number of poles, compared to portable units, can potentially overcome the added risk of drivers' constant exposure to semi-permanent poles. However, additional safety features are recommended, such as traffic barriers, guards, or crash cushions.
- High mast poles avoid the high-risk exposure of workers every night during set up and removal of a large number of portable units. In the I-90 project, it was estimated that at least 8250 worker-hours of high-exposure would be eliminated.
- High-mast poles have more flexibility to be located outside the clear zone without compromising light levels.
- Time savings in mobilization of portable lights meant night construction could be completed in 222 days rather than 275, reducing the work to one construction season. NYSDOT's authorization was conditioned on the removal of the high-mast poles by winter shutdown, regardless of the contractor's work accomplishments.

5.3.2 Worker Safety Implications in the Work Zone

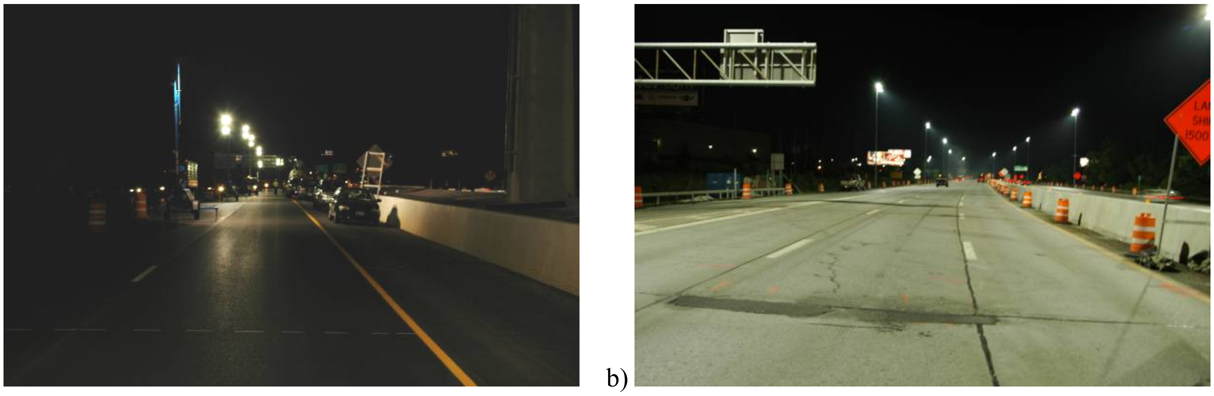
While light towers are extremely useful because of their portable nature, there are a number of known issues regarding the difficulty of their installation, operation, and maintenance. First, there are a large number of warnings associated with most products (during setup, operation, maintenance, stowing, and transportation). Second, the two main risks associated with the use of portable light towers are 1) the interaction of workers with traffic during setup and removal when both conditions represent a high risk of collision between workers and drivers, and 2) the setup of light towers near power lines. Although there are no published statistics, it is believed that crews are at risk to raise a mast near power lines, resulting in damages or fatalities.

It follows that by having a semi-permanent lighting installation, all of the risks mentioned would not be present. A great benefit that could not be quantified as part of this report, was the fact that warning, signal, and other material could be set up each night under lighted conditions, as opposed to regular practice where all the warning signals are set up by workers in advance of having the light towers operational.

Figure 12 shows an example of the typical lighting conditions under portable light towers. Figures 13 and 14 show examples of similar work zones illuminated by portable light towers and high-mast illumination. The pictures were presented here to demonstrate the bright and dark zones that result from the typical aiming of the light towers (generally 50º to 75º from the vertical). The two implications from this aiming are that 1) glare from the towers makes it almost impossible to detect people or vehicles approaching from behind the light tower, and 2) the short-range reach of each tower renders people and machines in a bright and dark zone pattern, reducing the visibility range of machine operators to detect on-foot workers. Ellis et al. (2003) reported that approximately 50 percent of injuries in work zone result from construction vehicles running over on-foot workers.

The Environmental Protection Agency recommends a maximum noise level of 75 dBA in work environments for hearing conservation. Though most of the commercial light towers have a noise level rating of 71 dBA, the large number of light towers and their proximity (typical spacing is 100-ft between units) can cause noise to add up to levels that could be more than the maximum recommended. During this project, five large generators powered the high-mast lighting installation. Each of these generators was at 71 dBA, dramatically reducing noise levels throughout the site. Workers of this project commented that the noise reduction enabled them to hear vehicles approaching, again greatly decreasing their risk of injury by a moving vehicle or machine.

Figure 12. Example of the light and dark zones that are created with typical light towers in a work zone.



a) b)

Figure 13. Similar work zones along I-90 illuminated by a) portable light towers and b) high-mast lighting.

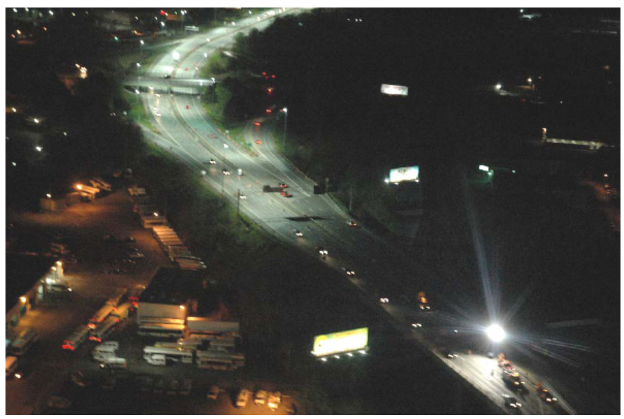


Figure 14. Photograph of the I-90 work zone showing the transition between areas illuminated by high-mast lighting (upper half of the road) and portable light towers (lower section of the road). Notice the portable light tower's glare, visible from the helicopter used to take this picture. [Photograph credit: MUSCO Lighting]

Finally, by using high-mast lighting, workers were not exposed to the fumes and harmful pollutants that result from each portable light tower and that can cause headaches, fatigue, and potential heart problems (OSHA, 2002).

5.4 Economic Analysis

Tables 4 and 5 summarize the economic costs of a lighting system using the portable towers and the high-mast system, respectively.

Despite the higher estimated cost (approximately 16% higher) of the high-mast system as outlined in these two tables, there were several positive economic implications that resulted from the use of high-mast lighting. One significant benefit was the time saved every day from not having to setup and remove the portable light towers. This time could be used performing the contracted maintenance work rather than setting up lighting equipment, probably contributing to the ahead of schedule completion of the project. In this project, the estimated cost of setup and removal of portable light tower added up to $ 330,000 (30 worker-hours per night at $40 per hour, for 275 days). For larger jobs this cost could increase considerably.

The contractor estimated a 40-day reduction in the planned duration of the project. While not possible to quantify in terms of economic benefits, the benefits for roadway users (in terms of avoided traffic delays) are also apparent. An accurate calculation to single out the contribution of the lighting system is not possible because NYSDOT allowed the contractor to close the entire length of one side of the road over weekends, effectively increasing the work time from 21 hours per weekend (Friday, Saturday and Sunday nights, at seven hours per shift) to 60 hours (Friday night to Monday morning with crews working three shifts).

The NYSDOT contractor and a few workers interviewed during the construction work agreed that the higher light levels and uniformity allowed them to work at a much faster pace, and possibly improved the quality of their work at the same time.

Relamping could also increase the cost of the light tower system relative to the high-mast system, as well. Although the lamps used in either portable units or high-mast luminaires have nominally the same life, the working conditions of the lamps in the portable units (e.g., constant vibration, raising and stowing the mast, transportation from yard to site) would likely promote a shorter life.

Another important factor was the fact that no injuries were reported for this project (Woodruff, 2006). The people involved in the project attributed this fact to the higher and uniform light levels. In fact, not having to check light levels every night at by a NYSDOT engineer can also be equated to a considerable economic benefit to NYSDOT. The visibility and glare analyses included in this report (above) also allude to benefits from the high-mast approach, although it was not possible to more quantitatively assess worker safety over the course of this single, relatively short project.

Table 4. Estimated total operational cost of 120 portable light towers over the duration of the project.

Estimated number of portable light towers required	**120**[1]
Daily setup and removal cost	
Number of crew members in charge of setup and removal	10
Estimated number of hours to setup and remove light towers, per night	3
Total worker hours per night	30
Estimated cost per hour (base rate + benefits + overhead & profit)	$ 40
Total setup and removal cost per night	$ 1,200
Daily operational cost	
Hourly operational cost per light tower (fuel, oil, regular maintenance, etc.)	$ 3.60
Estimated daily cost per light tower (@ 6 hours per night)	$ 21.60
Daily rental cost (@ $990 per month rent)	$ 33
Total operational cost per night (assuming contractor owns 100 towers and rents 20)	$ 3,252
Total cost per night (setup, removal, and operation)	$ 4,452
Estimated duration of project in days	275[2]
Total cost to provide lighting with 120 portable light towers	**$ 1,224,300**

Notes:

1. The semi-permanent high-mast installation was able to illuminate the whole length of the project, on both sides of the road, while the portable units are capable of illuminating a short section only at a given time. At an approximated spacing of 100 ft, 120 portable light towers can illuminate only a limited section of the road on one side only. In order to provide lighting to the whole length of the project with portable light towers, it would be necessary to use about 530 units, increasing the operational costs by approximately a factor of 4.

2. The combination of high-mast lighting and the total closure of traffic during weekends helped to reduce the total project time by about 40 days from the initial estimated time of 275 days. It is not possible to estimate the relative impact of the lighting and the road closure separately, but informal discussions with the NYSDOT contractor revealed the opinion that the lighting was a significant part of this reduction. The reduction in work time translated into savings caused by reducing the delays to drivers. It is assumed that improved visibility by reducing glare also yields safety benefits to drivers as well, but the strongest testimonials to safety were from the people involved in the project who described an increased perception of safety due to the higher light levels and uniformity. In general, these factors are thought by the NYSDOT contractor to more than outweigh the initially higher economic cost of the high-mast system, although it was not possible in the scope of the present project to quantify these benefits economically.

Table 5. Estimated total operational cost of 108 high-mast lighting poles with a total of 432 1500-W luminaires over the duration of the project.

Number of high-mast poles installed	**108**
Number of 250-kW generators installed	**5**
Installation costs	
Estimated installation cost per pole	$ 2,844
Estimated installation cost per kW of generator capacity	$ 24.50
Total estimated installation costs (poles and generators)	$ 337,777
Lighting equipment rental	
Estimated rental cost per pole with four luminaires	$ 5,500
Total lighting equipment rental (for the duration of the project)	$ 594,000
Generation costs	
Estimated purchase cost per kW of generator capacity	$ 200
Estimated total generators purchase cost	$ 250,000
Operational cost	
Hourly operational cost per generator @ 55% load (fuel, oil, regular maintenance)	$ 25.83
Total operational cost per night (@ 8 hours per night)	$ 1,033.20
Estimated duration of project in days	235[1]
Estimated total operational cost over the length of the project	$ 242,802
Total cost to provide lighting with 108 high-mast poles	**$ 1,424,579**
Incremental cost over portable lighting towers	**$ 200,279**
	16%

Notes:

1. See note 2, Table 4.

5.5 Optimizing Semi-Permanent High-Mast Lighting Installations

There are several aspects that need to be considered in order to optimize a semi-permanent high-mast lighting installation. The following are the main design criteria that should be considered:

- Light levels
- Pole height and spacing
- Acceptable uniformity ratios
- Equipment cost (initial, operation)
- Safety analysis
- User costs (avoided delays if the lighting is expected to reduce the length of the project)
- Increase in productivity and quality

Additionally, the type and size of road, initial lighting conditions, extent of the work required, lane closure scheduling, and the availability of clear zones can also significantly affect whether high-mast scenarios could provide more benefits than portable units. As an initial evaluation work, different lighting scenarios were modeled (Appendix 4) to investigate the effect of height and spacing on the potential economic savings.

In order to make meaningful comparisons, the first scenario analyzed was one with the same dimensions, pole height and spacing, and type of light distribution to the one used in this project. A 1500-W metal halide luminaire with a NEMA 5H6V distribution (Rea, 2000) was found to provide very similar results to the field measurements. This scenario was used as a base case for comparison.

A sensitivity analysis showed that if the power of the lamps in the fixtures was reduced to 1000-W, it was not possible to reach an average of 100 lx (Ellis et al., 2003) on the work zone by selecting different beam distributions or aiming angles. One solution would be decreasing the spacing between poles, but this would obviously result in a greater number of poles, counteracting the reduction in power. Also, because of the temporary nature of most construction projects, the estimated rental cost per pole (approximately $5500 for this project) could be much greater than the reduction in energy costs. For this example, the estimated energy cost savings per pole would be approximately $1000 over 235 days.

A second conclusion reached from the scenarios modeled in Appendix 4 is that increasing the spacing of the poles is possible but difficult to predict the benefits without considering the actual length and road geometry of each specific project. As the lighting layouts in Appendix 1 show, the actual distance between poles is in some cases very different from the average of 320 ft intended in the original design. The location of exit and entrance ramps, overpasses, utility poles and other features made it impossible to locate poles at any precise spacing, even if the spacing has been increased slightly. Some poles needed to be located closer together than planned in order to accommodate the features of the specific roadway site. In other words, the road conditions could make it almost impossible to reduce the number of poles by increasing the spacing just a little bit (a fraction of one mounting-height). During this analysis it was found that in order to decrease the number of poles significantly (e.g., from 7 poles in a 1000-ft stretch of road, to 4 poles) it would be necessary to increase the pole height to 120 ft. In this one side arrangement, 4 luminaires per pole would illuminate both sides of the road with the same uniformity as the base case but to an illuminance of only about half (~56 lx on average). The implications of this would be 1) a need for 75 percent more fixtures per pole (i.e., 7 luminaires per pole) to reach the design target illuminance, 2) no energy savings, and 3) a much higher installation cost per pole due to increased foundations, types of crew and cranes needed for the job, and pole costs. However, a reduced number of poles might still be considered an advantage from the safety point of view given that the amount of time a driver would be exposed to a pole would be reduced by 43 percent. Along the present roadway under study (I-90) where traffic patterns are fairly controlled and decision points are relatively few (relative to a major urban roadway), the reduction in exposure to poles in this case may not be a significant improvement. On a narrower road with more curves, for example, such a consideration might carry more weight.

Thus, the system as used by the NYSDOT contractor and its manufacturer partner appears to be reasonably well suited and optimized in terms of height and number of poles, lamp wattage and light level. It is not possible to generalize this specific lighting approach, however, to all other possible installations, because the specific layout of the lighting will depend very much on the specific features present at each location.

6 DISCUSSION

6.1 Overall Evaluation of System Performance

Based on the results of the analyses included in the present report, the semi-permanent high-mast installation along I-90 was successful in meeting recommended and statewide performance criteria (NYSDOT, 1995; Ellis et al., 2003), while addressing several potential shortcomings of conventional methods using portable light towers:

- The installation provided relatively high, uniform illumination that corresponded well with previously published (Ellis et al., 2003; NYSDOT, 1995) recommendations for nighttime work zone lighting. The average illuminance on the horizontal roadway surface exceeded 100 lx, more than sufficient for movement of construction workers and for performing visual tasks such as resurfacing roadways. While Ellis et al. (2003) did not make explicit recommendations for uniformity in nighttime work zone illumination, the uniformity provided by the high-mast system was within the limits specified by the IESNA (2000) for freeways and expressways and met NYSDOT specifications (NYSDOT, 1995).

- The uniformity of the illumination contributed to an overall reduction in glare along the installation. While the use of portable light towers aimed away from traffic in the adjacent lane would tend to produce less glare for drivers in that lane, the would create the potential for significantly higher glare to oncoming drivers in the opposing driving lanes. The higher oncoming glare itself can be found uncomfortable and can make it difficult to maneuver through lane changes by drivers, based on field observations (Ellis et al., 2003). Further, the changes in visual adaptation caused by alternating light and dark areas while driving along a roadway, created by pockets of light from the portable towers, could result in misadaptation, making objects close to the visual threshold difficult to see (IESNA, 2000). While nonuniformity is perhaps more critical for drivers (who do not have the option of turning away to rest their eyes while driving through a nighttime work zone), glare for construction workers would cause similar problems.

- The overall uniformity of lighting reduces the negative impacts of shadows (Ellis et al., 2003) in the work area. Shadows can reduce the visibility of important objects and potential hazards (tools, cables, holes in the ground) and make equipment controls in shadowed locations difficult to see. Again, the high-mast lighting tends to reduce the variability in visual performance throughout the site, whereas the portable lighting installation approach has the potential to create random areas of high visibility adjacent to areas with little or no visibility. In addition, a reasonable (but not tested in the present project) hypothesis is that large non-uniformities in the lighted scene in a nighttime work zone can detract from the conspicuity of signs, cones, markings and reflective clothing, which are important features in safe navigation through these zones (Bryden and Mace, 2002b).

These points are all consistent with the project team's observations of the I-90 installation, with discussions with NYSDOT engineers responsible for overseeing work at the site, and with previously published literature describing the use of high-mast lighting installations in nighttime construction operations. While the short duration and small scope of the lighting installation under study did not permit the direct evaluation of safety (in terms of crashes or other incidents), it is assumed that the increased visibility provided by the present system would indeed contribute to increased safety.

The simple economic analysis in the present report also demonstrates that the high-mast lighting approach, despite its increased cost in the present scenario, can contribute to more efficient highway maintenance and construction operations and the potential for reduced overall risk to construction personnel by reducing their exposure to nighttime traffic.

As discussed in the present report, a formal analysis of the impact of the lighting on crash safety or on exposure to risk to construction workers and to drivers was not possible because of the limited scope and duration of the roadway maintenance project, and because no crashes or worker injuries occurred during the project (Woodruff, 2006). Using worker visibility and glare to drivers and workers as surrogate measures related to safety, however, the high-mast lighting approach does appear to provide a positive benefit in terms of safety for both workers and drivers.

6.2 Toward Development of Standard Approaches to High-Mast Construction Lighting

The analyses in the present report also demonstrate that the use of so-called standard floodlighting equipment, in combination with photometric analysis software, can probably lead to standard design approaches for evaluating the potential beneficial aspects of high-mast lighting in nighttime work zones. The reasonably close correlation between the measured light levels during the project team's site visit and those calculated (making some assumptions about the distribution of the custom light fixtures developed for the project by the manufacturer working with the maintenance contractor) will allow the design of "patterns" for such installations that could be modified to account for site-specific characteristics.

6.3 Additional Potential Benefits of this Lighting Approach

While not studied in detail given the limited scope of the present project, the approach to lighting explored here has several potential benefits worth discussing: performance on wet pavement, and the influence of light source spectral distribution on peripheral visibility.

6.3.1 Wet Pavement

One shortcoming of almost all conventional roadway lighting, whether in a work zone or not, is the problem of reflected glare from wet pavement surfaces. Bright reflections compete with the visibility of objects in the visual scene, making important objects less conspicuous.

Because of the increased fixture mounting heights inherent in high-mast lighting, there are often generally fewer "problem" locations from these fixtures where they can produce reflections along the roadway surface, and these moreover tend to be located further away from the work zone. (Where intersections and conflict points are found along a roadway, extra care must be taken to ensure that high-mast systems do not result in wet-pavement reflections at these conflict points, but these are rarer in channelized traffic situations such as in work zones.) The potential reduction in the number of location of light source reflections on wet pavement is indeed one issue that is often cited to support the use of high-mast lighting (Sullivan, 1976).

6.3.2 Mesopic Vision

The light sources available for portable lighting equipment used in nighttime work zones include tungsten filament sources, and high intensity discharge sources such as high pressure sodium and metal halide lamps. Filament sources have lower luminous efficacy than discharge sources but are most commonly used as headlamps, and since they have instant strike and restrike characteristics, they do not require delay times when switching them on before they produce a useful amount of light. Discharge sources require several minutes to increase to a useful light output, and they also require a cool-down period of several minutes when switched off before they can be switched on again. Nonetheless, for large areas, discharge sources are commonly used for illumination because of their high lumen output and increased efficacy.

Ellis et al. (2003) recommends that high pressure sodium lamps, having a yellowish color, be used for illuminating very large areas, with metal halide more suitable for areas of medium size. Metal halide is also recommended when recognition of colors is an important consideration. At light levels corresponding to 100 lx or more, high pressure sodium lamps, despite their poorer color rendering characteristics relative to metal halide lamps, probably provide sufficient color rendering ability (Leslie and Rodgers, 1996).

The present high-mast lighting installation used metal halide lamps for illumination of the work zone along I-90. This light source selection might have had a benefit in addition to the potential for improved color rendering, in terms of the ability of drivers and workers to detect objects outside the immediate work zone area using their peripheral vision (Rea et al., 2004; Bullough and Rea, 2004). At low light levels corresponding to less than 100 lx on asphalt pavement surfaces, the spectral sensitivity of the visual system shifts toward shorter wavelengths. This shift corresponds to the shift from vision relying only on the eye's cone photoreceptors, to vision using both the cones and the rod photoreceptors (the rods are sometimes called the nighttime photoreceptor and are populated in the peripheral part of the eye's retina). Since rods are maximally sensitive to shorter wavelengths than cones, lamps that produce relatively more short-wavelength light will result in improved peripheral visibility. From a practical point of view, then, metal halide lamps can be more effective than high pressure sodium lamps of the same wattage.

This may result in improved ability to detect objects and potential hazards located adjacent to, but not necessarily in, the nighttime work zone, and could contribute to increased safety. Although this aspect was not formally studied in the present project, characterizing the impact of light source color on peripheral visibility while traversing nighttime work zones could perhaps result in future recommendations to use lamps with "whiter" appearance.

7 RECOMMENDATIONS

The high initial cost of high-mast lighting could prevent its application on short-term projects (about 4 months, estimated by the contractor) and even in longer term projects. Roadwork construction is a highly competitive business. During the bidding process, an incremental cost of 15 percent for lighting could be enough reason not to propose the use of high-mast lighting by the contractor despite the obvious benefits. One possible way to encourage the change in practice is by making it a specification item. Being part of NYSDOT's specification would not only promote use of high-mast lighting, but would open the opportunity for a more competitive market. The higher initial cost of high-mast lighting would resolve itself once more contractors have the opportunity to offer products for this application and adopt the practice. Over time, contractors could buy the equipment and depreciate the cost over the length of several projects, much like the way they do presently with the portable units that they own.

High-masts present a clear safety concern that needs to be fully addressed. Whenever possible, high-mast should be located outside the clear zone. When this first approach is not feasible, additional design features need to be proposed, for example adding traffic barriers, temporary guard rails, or crash cushions. Breakaway features are typically not practical for high-mast poles (AASTHO, 2005).

7.1 A Potential Approach to Warranting

The analysis in the present report demonstrates that the precise lighting layout will depend largely on the specific characteristics of the nighttime work zone location to be lighted. It would therefore be premature to develop specific warrants for the use of semi-permanent high-mast lighting for nighttime work zones. However, through the LRC's observations during the site visit and during the analyses in the present report, several issues could form the basis for a more detailed approach to developing warranting conditions for this type of lighting:

- **Duration of the project.** The NYSDOT contractor estimated that the high-mast approach to lighting such as that used on I-90 would not be feasible for projects shorter than four months in duration. Certainly, the use of high-mast lighting on the present I-90 project, which was seven months in duration, appeared to be successful with the benefits in terms of improved visibility and increased efficiency of work outweighing the increased expense.

- **Geometric factors.** I-90 is a controlled-access interstate highway with limited conflict points (entrance or exit ramps) and without narrow-radius curves. These factors could reduce the necessity for a large clear zone in which the presence of lighting poles would be undesirable. Certainly as large a clear zone as possible is wanted, but some locations might not have available space for such a zone.

- **Availability of channelization or traffic barriers.** Again, because lighting poles in the high-mast approach will often need to be located relatively close to the roadway, they might not permit a large clear zone. The presence of strongly channelized and barricaded traffic pattern has the potential to reduce the risk of road runoffs and therefore to potentially reduce the need to keep adjacent zones clear of poles.

- **Sensitivity of location to light pollution and light trespass.** The high-mast lighting system will result in a similar amount of upward light from the nighttime work zone location, contributing to sky glow, as the portable system. While the NYSDOT estimated that the high-mast approach would not provide increase light trespass potential in the I-90 location where this system was installed (Woodruff, 2006), residential areas adjacent to other proposed locations could possibly experience light trespass from the high-mast light fixtures. These issues might be especially important in very environmentally sensitive locations such as Adirondack Park.

These issues are summarized in Table 6, which could in the future serve as a prototype warranting procedure for determining the potential benefit of high-mast lighting for nighttime work zones. Obviously, the list of considerations in Table 6 is incomplete and would require further analysis of system performance at a number of additional locations, but the general approach could readily be modified to incorporate new criteria and considerations. As a very preliminary example (which of course is subject to change in the future), a negative score would not be considered for this lighting approach, whereas a score of +4 or higher would strongly be considered for this approach. Scores between 0 and +4 would require a more extensive analysis before the high-mast approach could be ruled in or out.

NYSDOT is encouraged to continue to study the potential benefits of the high-mast lighting approach, including collection of safety data, as well as economic costs and the performance of the lighting in terms of mitigating glare and shadows for workers and drivers.

Table 6. Potential approach to identify whether high-mast lighting for nighttime work zones is warranted. Engineers should circle one response in each row of the table, in order to obtain a score.

Consideration	**Score: -1**	**Score: 0**	**Score: +1**
Duration of project	**Short:** 1 to 2 months	**Medium:** 3 to 5 months	**Long:** 6+ months
Availability of space clear zone	**Limited:** Less than 30 feet	**Medium:** 30 to 50 feet	**High:** More than 50 feet
Number of traffic conflict points	**High:** Urban/suburban location	**Medium:** Rural location	**Few:** Controlled access highway
Type of curves	**Small:** Traversed at low speed (<30 mph)	**Medium:** Traversed at 30 to 40 mph	**Large:** Traversed at high speed (40+ mph)
Presence of traffic barriers	**Low:** Markings only	**Medium:** Traffic cones and barrels	**High:** Strong lane control and heavy barriers
Environmental considerations	**High:** Very sensitive environmental or residential location	**Medium:** Some residential areas nearby	**Low:** Little or no sensitive areas nearby

8 STATEMENT OF IMPLEMENTATION

This report documents the first time use by New York State Department of Transportation (NYSDOT) of semi-permanent high-mast lighting on a construction project. This research project has developed a potential approach for identifying whether or not high-mast lighting for nighttime work zones is warranted. NYSDOT intends to disseminate this final report internally to its eleven regions. Although further research and analysis is recommended, the information within the report offers the Regional Offices a starting point in assessing the potential benefits of using the high-mast lighting on future construction and maintenance projects.

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APPENDIX 1

SUMMARY OF THE SPECIFICATION OF THE LIGHTING AND POWER EQUIPMENT
HIGH-MAST SYSTEM LAYOUT
LIGHT FIXTURE MANUFACTURER SPECIFICATIONS
GENERATOR MANUFACTURER SPECIFICATIONS

Summary of the Specification of the Lighting and Power Equipment

A total of 108 seventy-foot steel high-mast poles each with four luminaires were installed for this project. The high-mast poles and luminaires were designed and manufactured by MUSCO Lighting (Oskaloosa, IA) as part of its standard Light Structure Green product series. Each pole is designed to work as a system and comprises a pole top luminaire assembly (mounting arm and tenon, luminaires), an internally wired steel pole, an electrical components enclosure, and a precast concrete base. Each pole is built and wired in the factory; similarly, the luminaires and reflectors ship assembled and connect structurally and electrically to the cross arm using one attachment. A geared-aiming device ensures that the factory aiming is preserved in the field or is easily adjustable if needed. The installation of the poles was completed in 10 working days, and removal took two days.

The manufacturer offers several hundred standard reflector distributions, making it possible to select the most appropriate according to the geometry of the job and the installation conditions. Due to the proprietary nature of the information, the beam distribution of the luminaires could not be obtained for inclusion in this report. However, based on a lighting modeling exercise, the distribution of the luminaires appears to be an asymmetric distribution approximately similar to a NEMA type 5H6V. Each luminaire housed a 1500 W metal halide lamp designed for horizontal operation. Additionally, each luminaire was fitted with a shield visor to further control the beam distribution from the reflector and control glare and spill light.

Five 250-kW diesel generators (SDMO model JS 275) were installed temporarily on site to power the lighting installation from four locations. A portable generator was on site as backup. The NYSDOT contractor installed temporarily buried electrical lines along the shoulder of the road. The four locations are shown in the aerial photographs in the following section of this Appendix. The generators where installed on crushed stone leveling pads about 15 to 30 yards from the road, so that some of them were likely located within the clear zone, although this could not be verified from the information on the plans. Each generator was surrounded by chain link fencing (Figure A-1.1, generator 1) with access for refueling purposes.

Although the installed capacity of the generators was almost twice as much as the estimated load of the lighting system, five generators were needed for practical reasons including system reliability, voltage drop, and fuel consumption. A full tank of fuel can last approximately 5 hours at full load, whereas at the estimated 55 percent load factor of each generator, the refueling cycle was approximately every 10 hours.

Figure A-1.1. Photographs of generator #1 (Gen #1) located on the contractors yard near Exit 2.

Table A-1.1 summarizes the main characteristics of the temporary high-mast lighting installation.

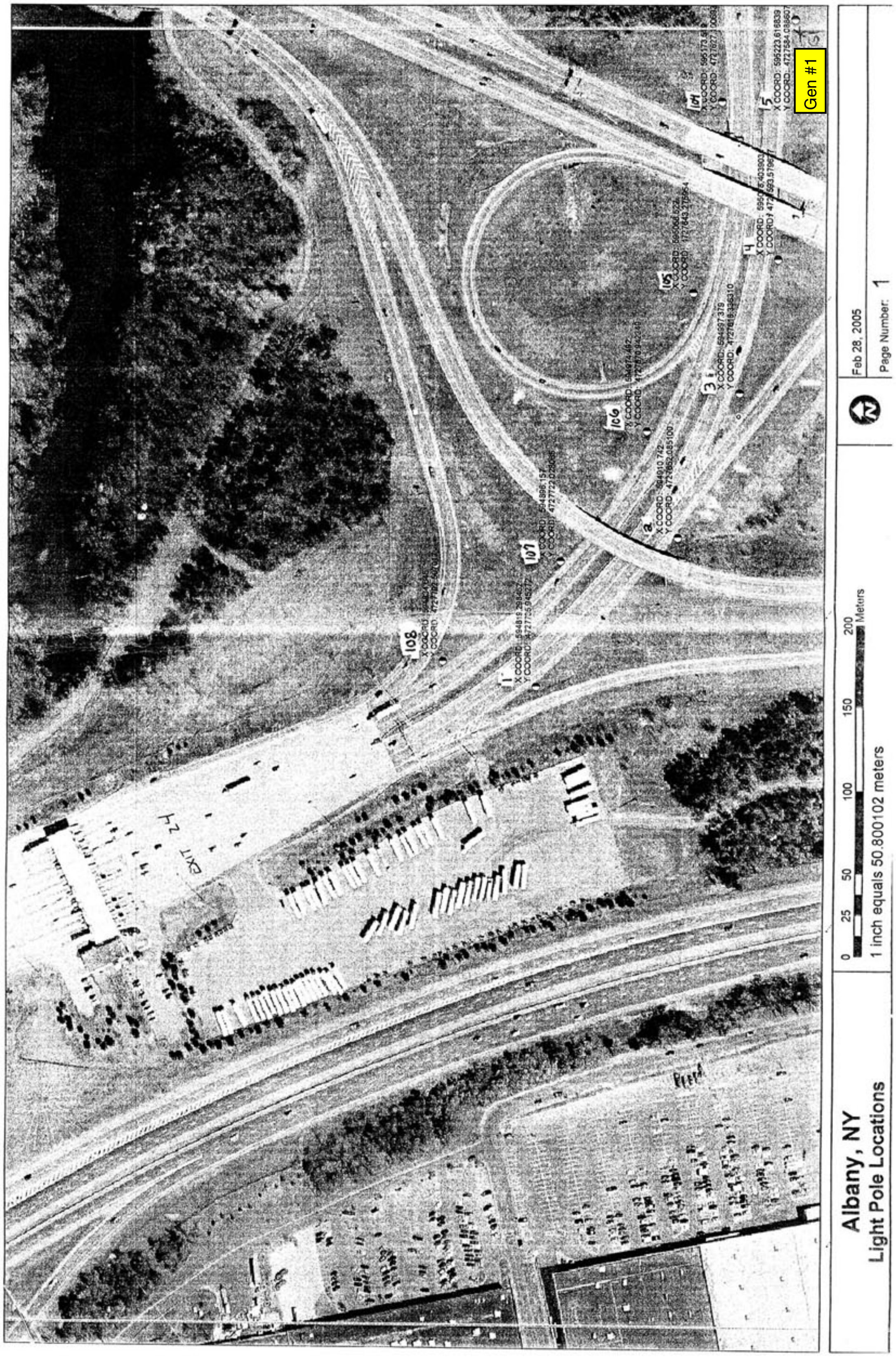
Table A-1.1. Summary of the temporary high-mast lighting installation along I-90.

Photometric characteristics:

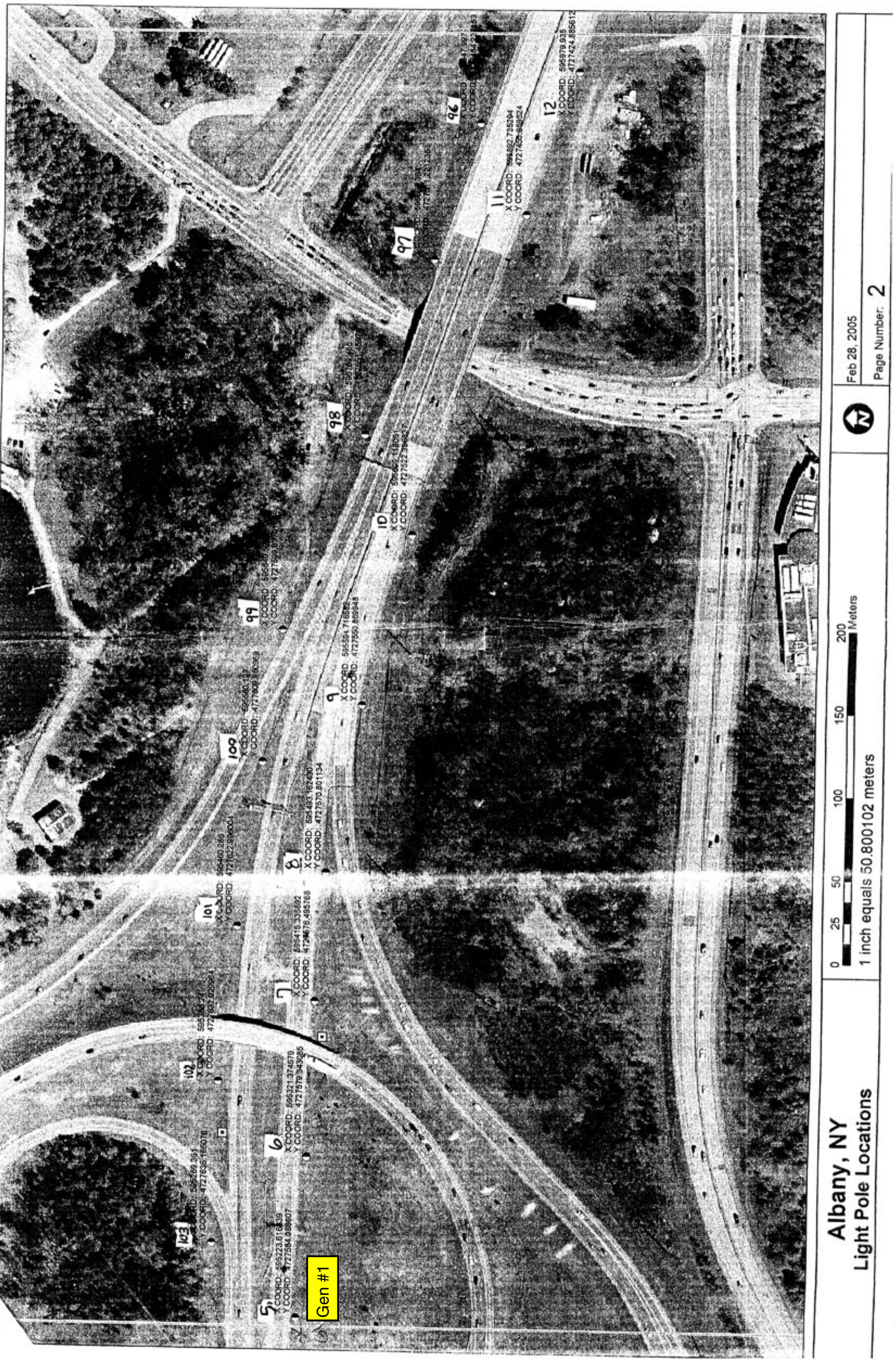
Total number of pole locations	108
Mounting height	70-ft
Typical pole spacing (staggered layout)	320-ft between poles on the same side of the road
Number of luminaires per pole	4
Total number of luminaires	432
Lamp type per luminaire	Metal halide, 1500-W
Lamp life	7000 to 8000 hours
Predicted illuminance on the pavement (software calculation)	
Average	133 lx
Maximum	233 lx
Minimum	80 lx
Average to minimum ratio	3.0:1
Maximum to minimum ratio	2.9:1
Actual illuminance on the pavement (measured on site)	
Average	148 lx
Maximum	209 lx
Minimum	101 lx
Average to minimum ratio	1.5:1
Maximum to minimum ratio	2.1:1

Electrical characteristics:

Input power per luminaire	1564 W
Total installed load for lighting	675.6 kW
Number of generators installed	5
Total power available per generator	250 kW
Total installed generation capacity	1250 kW


Albany, NY
Light Pole Locations
1 inch equals 50.800102 meters
0 25 50 100 150 200 Meters
Feb 28, 2005
Page Number: 1
Gen #1
EXIT 24

022I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Light Pole Locations
Feb 28, 2005
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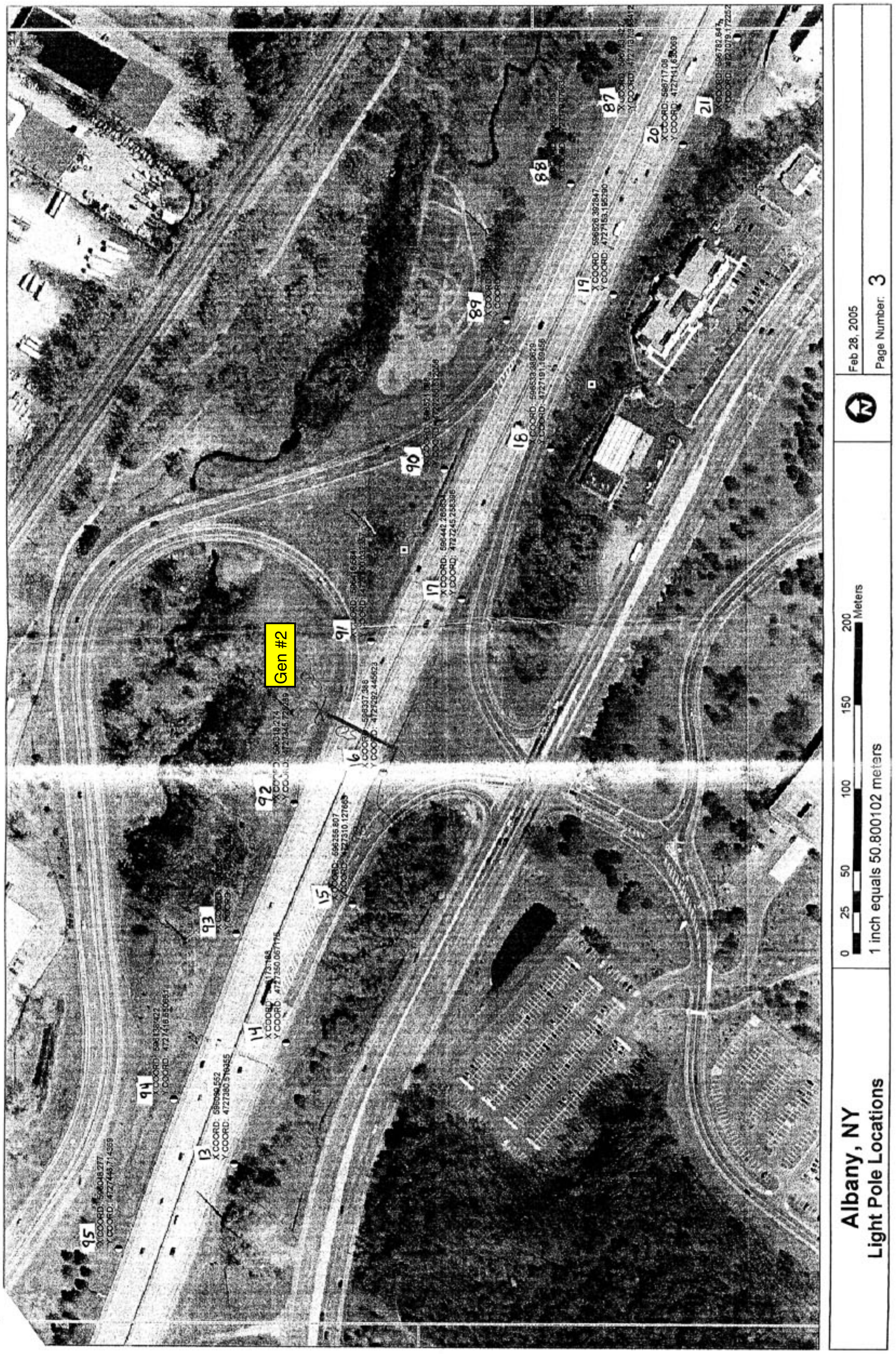
1 inch equals 50.800102 meters
Gen #1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Light Pole Locations
1 inch equals 50.800102 meters
Meters
Feb 28, 2005
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Gen #2

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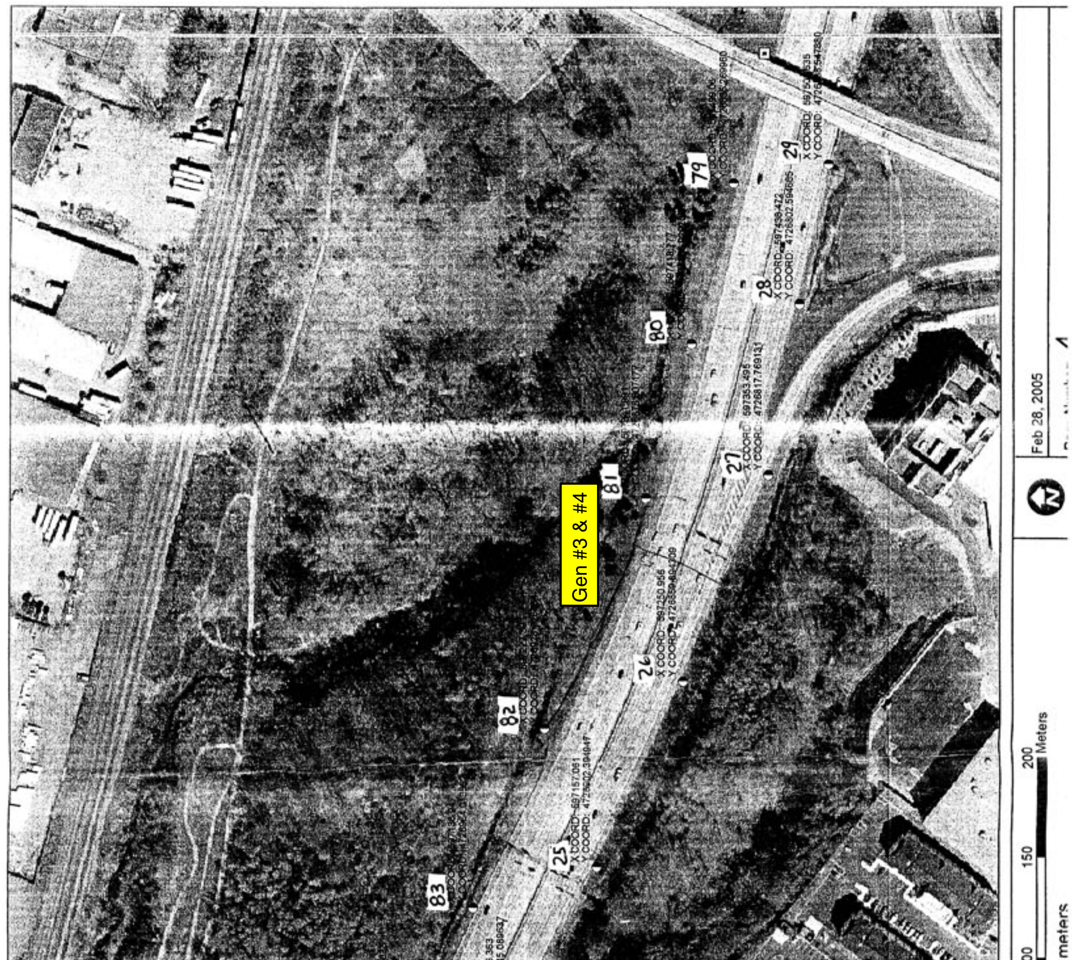

Albany, NY
Light Pole Locations
Feb 28, 2005
1 inch equals 50.800102 meters
0 25 50 100 150 200 Meters
Gen #3 & #4
21
22
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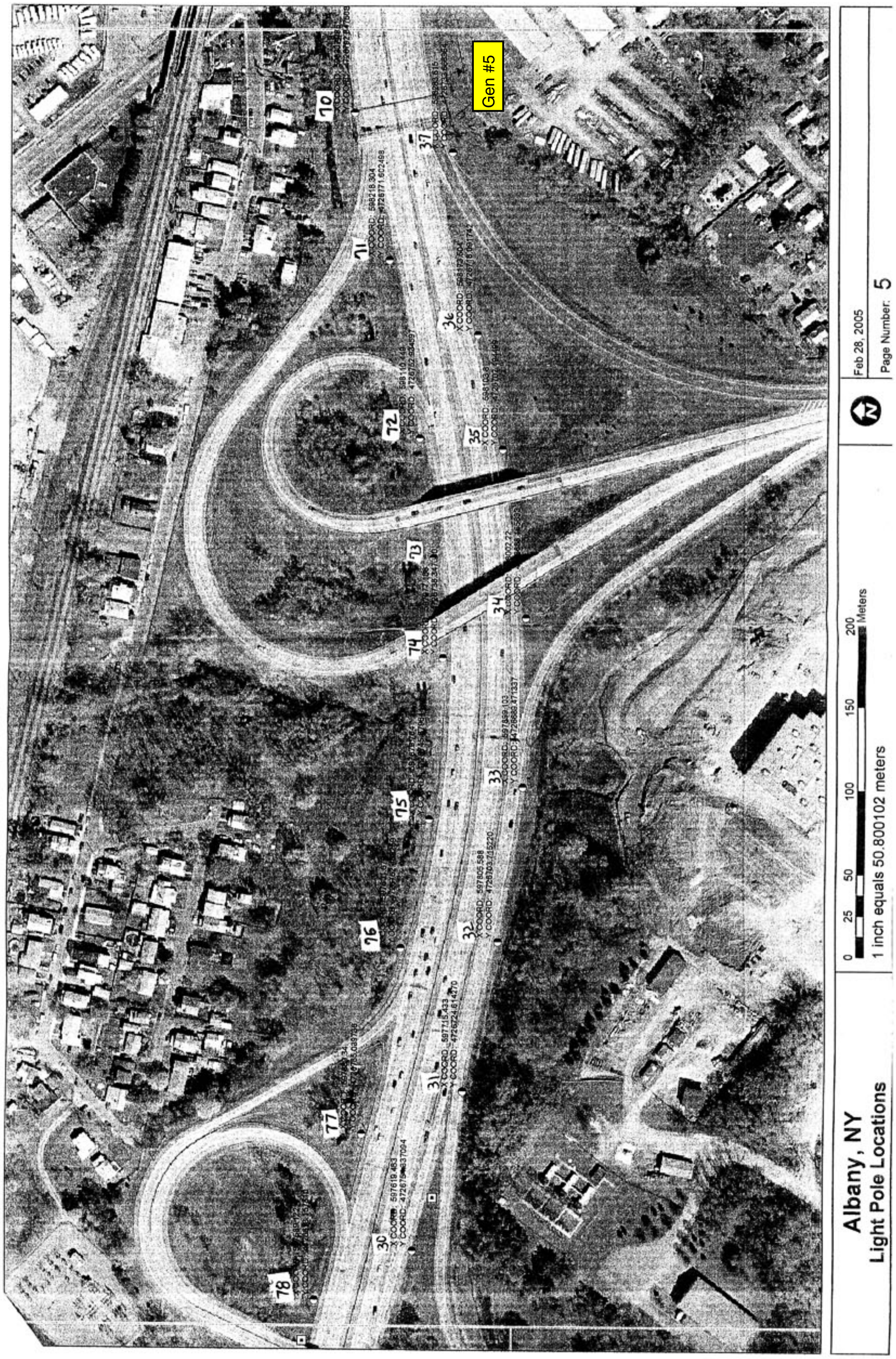
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Albany, NY
Light Pole Locations
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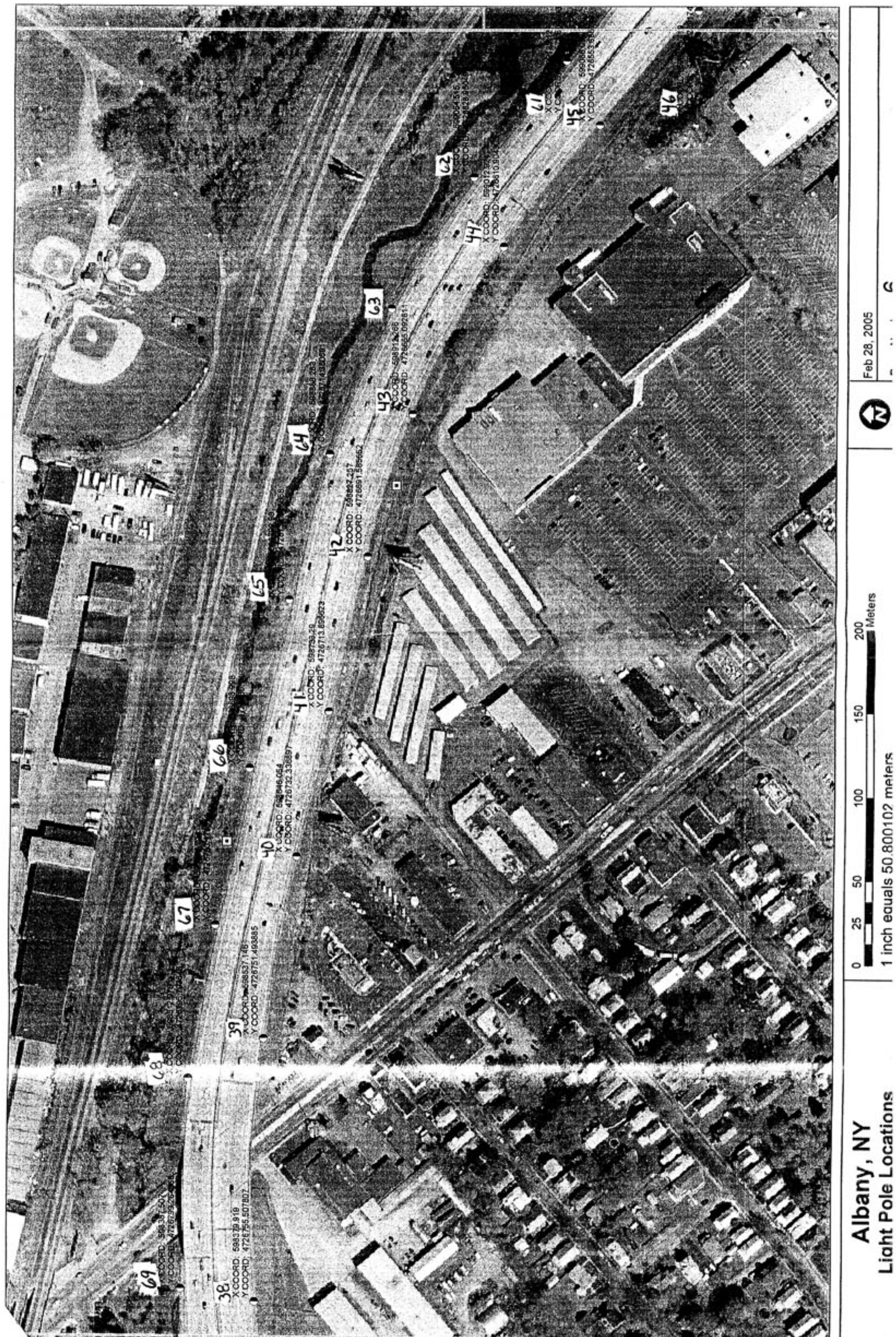
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Meters
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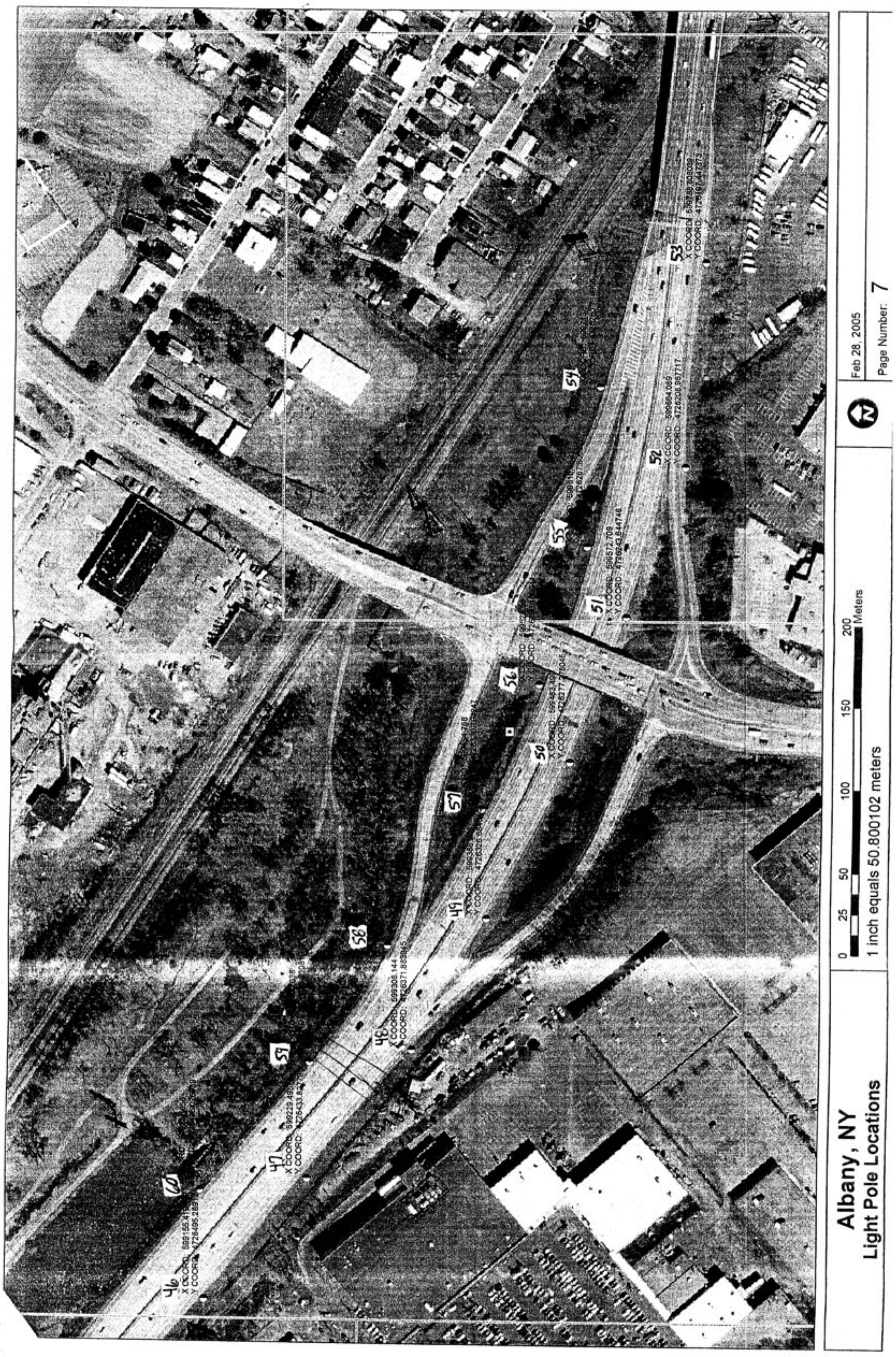
I220


Albany, NY
Light Pole Locations
0 25 50 100 150 200 Meters
1 inch equals 50.800102 meters
Feb 28, 2005
Page Number: 7

musco Lighting

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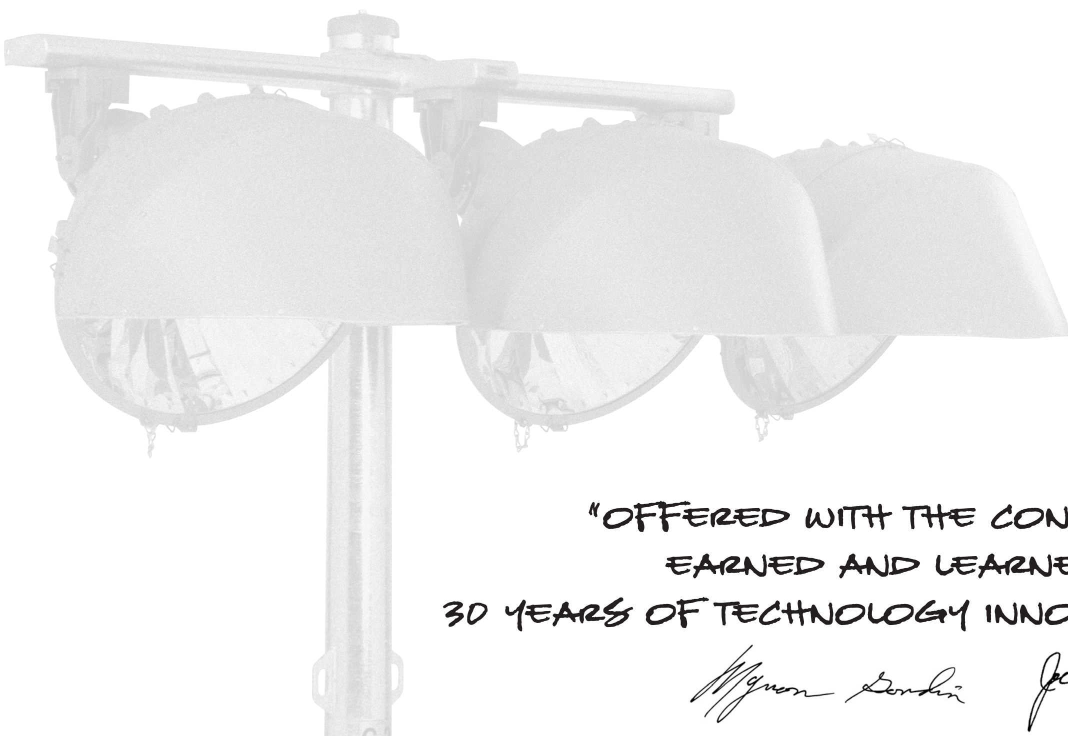
Light·Structure GREEN™

For your budget, for the environment.



"OFFERED WITH THE CONFIDENCE
EARNED AND LEARNED FROM
30 YEARS OF TECHNOLOGY INNOVATION."

Musco's Light-Structure GREEN™

Musco's Green friendly system will reduce by half or more, the cost of operating and maintaining your ballfield lighting system.

For Your Budget

Innovative photometric improvements of the luminaire result in substantially more efficient light control.

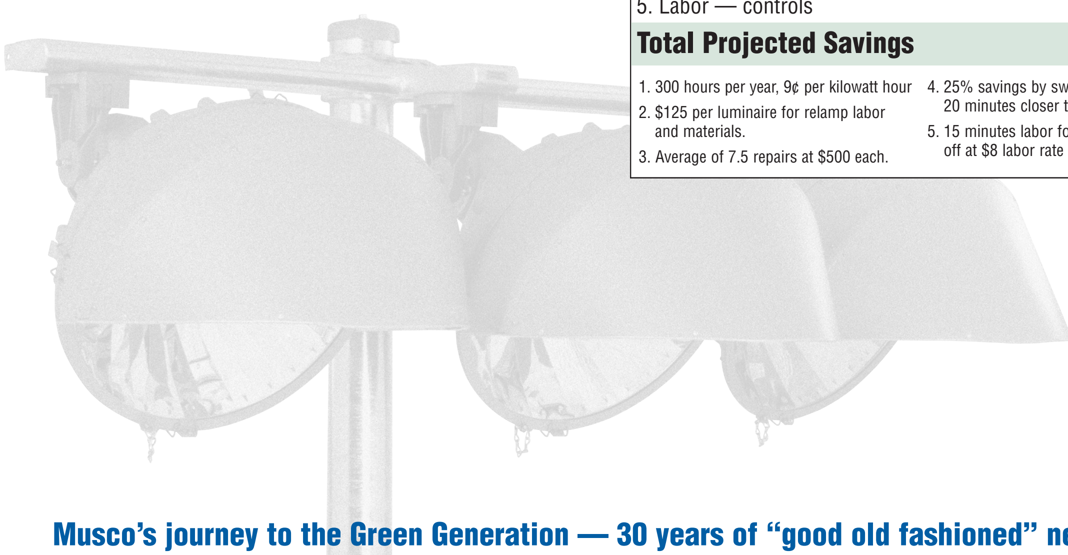
Musco's evolution of fundamental lamp principles creates a new operating system — Smart Lamp™.

Savings

25 Year Life Cycle Cost Savings

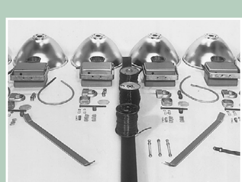
Prior Technology Fixture Quantity	52
Light·Structure Green™ Fixture Quantity	32
1. Energy — photometric improvement	$23,080
2. Group Relamp	$16,250
3. Lamp Maintenance	$3,750
4. Energy — controls	$5,770
5. Labor — controls	$10,000
Total Projected Savings	**$58,850**

1. 300 hours per year, 9¢ per kilowatt hour
2. $125 per luminaire for relamp labor and materials.
3. Average of 7.5 repairs at $500 each.
4. 25% savings by switching on and off 20 minutes closer to actual usage time.
5. 15 minutes labor for turning on and for off at $8 labor rate — 1000 operations.



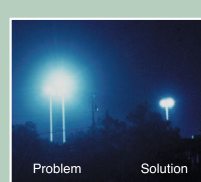
Musco's journey to the Green Generation — 30 years of "good old fashioned" new technology

1976
Existing technology



1977
Factory assembled and wired light cluster — SportsCluster®. Predictable results, easier installation.

1981
Glare control research



1982
Temporary lighting service and rolling lab — Mobile Lighting System

1987
Easier maintenance — remote ballasts

. . . for a More Energy Conscious Generation.

Amazing new technology . . . big cost benefits.

And best of all, it does wonderful things for the adjoining environment. It puts much less light on nearby properties. It protects the beauty of the dark night skies.

For The Environment

Spill and glare control features are now a standard part of every luminaire at no extra cost.

This green generation luminaire system cuts spill by half or more, even when compared to Musco's prior industry-leading technology.

Less Spill

360' x 225' Soccer Field

30fc Average Maintained		**30fc Constant Illumination**
Light·Structure with Total Light Control™ photometric option	**Fixture Type**	**Light·Structure Green™**
1500W MZ	**Lamp Type**	1500W MZ
	Vertical Illumination	
0.50 fc	**Average**	**0.15 fc**
0.74 fc	**Maximum**	**0.26 fc**
52	**# of Luminaires**	**32**

Now 25 years of unprecedented, trouble-free operation

Musco's *Constant 25*™ warranty and maintenance program guarantees:

- Constant light levels and group lamp replacements at the end of rated lamp life
- Reduced energy consumption
- Monitoring, maintenance and remote on/off control services
- System structural integrity

1989

Glare control with efficiency — SportsCluster·2®

1991

Complete lighting and electrical system from foundation-to-poletop, Light·Structure System™

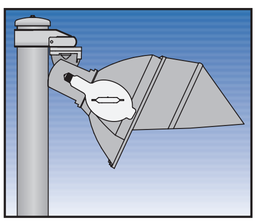
1997

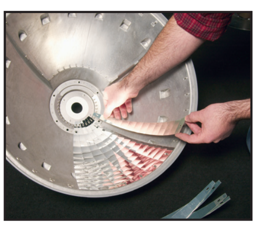
Facility management services — 10 Club Service® and Control·Link®

2005

Energy, environment . . . today's prices — Light·Structure Green™

Light·Structure Green™ System — still Five Easy Pieces™ plus:





Improved Luminaire Efficiency

1. **Reflector system:** More than 2000 photometric patterns provide optimal energy efficiency and minimal spill light for each project.
2. **Visor System:** Several visor choices provide energy efficient light on the field and minimal spill light. The aerodynamics reduce wind load on the poles.
3. **Side Shift Beam Control:** Beams can be adjusted within the luminaire horizontally as well as vertically. We can now custom fit the light to the corners.

Smart Lamp™ Operating System

1. **Lamp:** 30 years of lamp experience has taught Musco how to operate the lamp with less energy and extend its life with a system of timed power adjustments.
2. **Geared tilt adjustment:** With a geared leveling mechanism, the lamp arc tube operates in the energy advantageous horizontal position.

Increased Durability, Assured Results

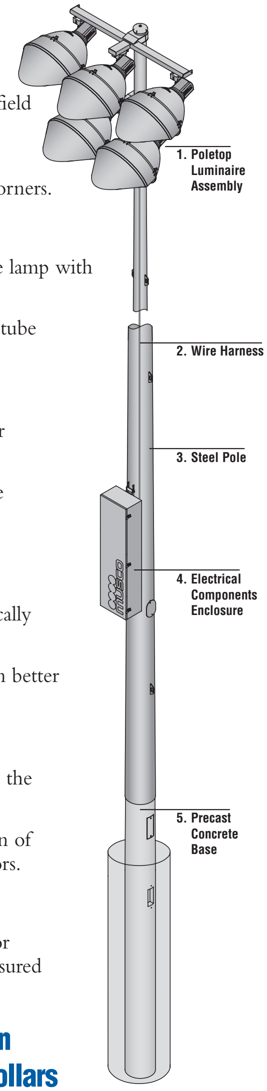
1. **Die-Cast aluminum reflector housing:** Provides a rugged foundation for building and maintaining a sophisticated photometric unit.
2. **Gasketing:** Improved material and gasket system design virtually eliminate “outgasing” and other contamination of the reflectors and lens.
3. **Factory Assembled Luminaires:** The luminaire ships totally assembled: avoids contaminants, saves time, improves aiming accuracy.
4. **Attaching Mechanism:** The factory assembled luminaire connects electrically and structurally to the crossarm with one simple attachment.
5. **Factory Aiming:** Musco’s well established service of factory aiming is even better with Light-Structure Green™ . . . field changes can still be done.

Solid control and flexible management

1. **Controls and monitoring:** This system, in one simple cabinet, included in the base price, saves energy and gives you a solid, flexible management tool.
2. **Control Link Central™:** Real people at Musco, 24/7, support the operation of your lights….from office, field or home . . . benefits field users and neighbors.

Ultimate guarantee

With **Green Generation Lighting,** Musco’s Constant 25™ guarantees it all for 25 years, plus free relamping at the end of the lamps rated life. All of this is assured by Musco’s field service department and their technicians.



Light Structure Green™ is the result of more than a dozen inventions and innovations from more than 10 million dollars of research and capital investment by Musco.

Musco Lighting®

We Make It Happen®

800/825-6030
www.musco.com
e-mail: lighting@musco.com

J275UC DIESEL GENSET

MODEL	J275UC
Stand-by Power @ 60Hz	***275kW / 344 kVA***
Prime Power @ 60Hz	***250 kW / 313 kVA***

Standard Features

General features :

- Engine (JOHN DEERE , 6081HF070-318)
- Engine EPA Carb Charge alternator 12 V , Governor:Elec
- Alternator (LEROY SOMER , LSA462L9)
- Single bearing alternator IP 23 , insulation class H /H
- Radiator 50°C [122°F]°C max. T° air inlet with coolant cap
- Skid and vibration isolators
- Dry type air filter
- Main line circuit breaker
- Microprocessor control panel
- 12 V battery, rack and cable
- Industrial silencer (loose)
- User manual ^pCSA Certified (consult us)

Generator Ratings

Voltage	HZ	Phase	P.F	Standby Amps	Standby Ratings kW/kVA	Prime Ratings kW/kVA
480/277	60	3	0.8	414	275 / 344	250 / 313
440/254	60	3	0.8	451	275 / 344	250 / 313
380/220	60	3	0.8	523	275 / 344	250 / 313
240/120	60	3	0.8	828	275 / 344	250 / 313
230/115	60	3	0.8	864	275 / 344	250 / 313
220/127	60	3	0.8	903	275 / 344	250 / 313
208/120	60	3	0.8	955	275 / 344	250 / 313
600/347	60	3	0.8	331	275 / 344	250 / 313

PRP : Prime Power is available for an unlimited number of annual operating hours in variable load applications, in accordance with ISO 8528-1. A 10% overload capability is available for a period of 1 hour within 12-hour period of operation, in accordance with ISO 3046-1
ESP : The standby power rating is applicable for supplying emergency power in variable load applications in accordance with ISO 8528-1. Overload is not allowed.

Conditions of sale

- SDMO provides a full line of products with high quality recognized engines and alternators.
- Service and parts are available from SDMO distributors as a single source of responsibility.
- Each and every units is factory tested. All generator sets are also prototype tested.
- Warranty according to our standard conditions. Five years extended also available

ENGINE DATA

Manufacturer / Model	JOHN DEERE 6081HF070-318 , 4-cycle, Turbo , Air/Water SC
Cylinder Arrangement	6 X L
Displacement	8.1L [494.3C.I.]
Bore and Stroke	116mm [4.6in.] X 129mm [5.1in.]
Compression ratio	15.7 :1
Rated RPM	1800 Rpm
Piston Speed	7.74m/s [25.4ft./s]
Max. stand by Power at rated RPM	298kW [399BHP]
Frequency regulation, steady state	+/-0.5%
BMEP	21.6bar [313psi]
Governor : type	Elec
Exhaust System	
Exhaust gas flow	953L/s [2019cfm]
Exhaust temperature	448°C [838°F]
Max back pressure	750mm CE [30in. WG]
Fuel System	
110% (Stand By power)	74L/h [19.6gal/hr]
100% (of the Prime Power)	63.6L/h [16.8gal/hr]
75% (of the Prime Power)	47.4L/h [12.5gal/hr]
50% (of the Prime Power)	32.8L/h [8.7gal/hr]
Total fuel flow	316L/h [83.5gal/hr]
Oil System	
Total oil capacity w/filters	32L [8.5gal]
Oil Pressure low idle	2.1bar [30.4psi]
Oil Pressure rated RPM	2.75bar [39.8psi]
Oil consumption 100% load	0.12L/h [0.0gal/hr]
Oil capacity carter	31L [8.2gal]
Thermal balance 100% load	
Heat rejection to exhaust	232kW [13192Btu/mn]
Radiated heat to ambiant	37.5kW [2132Btu/mn]
Heat rejection to coolant	105kW [5970Btu/mn]
Air intake	
Max. intake restriction	625mm CE [25in. WG]
Engine air flow	338L/s [716cfm]
Coolant System	
Radiator & engine capacity	40L [10.6gal]
Max water temperature	105°C [221°F]
Outlet water temperature	93°C [199°F]
Fan power	10 kW
Fan air flow	7m3/s [14834cfm]
Available restriction on air flow	20mm CE [0.8in. WG]
Type of coolant	Gencool
Thermostat	82-94 °C
Emissions	
HC	4.48 gr/bhp/h
CO	0.52 gr/bhp/h
Nox	4.48 gr/bhp/h
PM	0.10 gr/bhp/h

ALTERNATOR SPECIFICATIONS

GENERAL DATA

- Compliance with NEMA MG21, UTE NF C51.111, VDE 0530, BS 4999, CSA standards.
- Vacuum-impregnated windings with epoxy varnish.
- IP21 drip proof.

ALTERNATOR DATA

Manufacturer / Type	LEROY SOMER LSA462L9
Number of phase	3
Power factor (Cos Phi)	0.8
Altitude	< 1000 m
Overspeed	2250 rpm
Pole : number	4
Exciter type	SHUNT
Insulation : class, temperature rise	H / H
Voltage regulator	R230
Sustained short circuit current	N/A
Total harmonics (TGH/THC)	< 4%
Wave form : NEMA = TIF – TGH/THC	< 50
Wave form : CEI = FHT – TGH/THC	< 2%
Bearing : number	1
Coupling	Direct
Voltage regulation 0 to 100% load	+/- 1%
Recovery time (20% Volt dip) ms	< 500 ms
SkVA with 90 % of nominal sustained voltage (at 0.4 PF)	N/A

OTHER ALTERNATOR DATA

Continuous nominal rating @ 40°C	343 kVA
Standby rating @ 27°C	375 kVA
Efficiencies @ 4/4 load	93.2 %
Air flow	0.51m3/s [1080.62cfm]
Short circuit ratio;50 (Kcc)	0.49
Direct axis synchro reactance unsaturated (Xd)	290 %
Quadra axis synchro reactance unsaturated (Xq)	174 %
Open circuit time constant;50 (T'do)	2180 ms
Direct axis transient reactance saturated (X'd)	13.3 %
Short circuit transient time constant (T'd)	105 ms
Direct axis subtransient reactance saturated (X''d)	8 %
Subtransient time constant (T''d)	10 ms
Quadra axis subtransient reactance saturated (X''q)	9.9 %
Zero sequence reactance unsaturated (Xo)	0.4 %
Negative sequence reactance saturated (X2)	8.9 %
Armature time constant (Ta)	16 ms
No load excitation current (io)	1.1 A
Full load excitation current (ic)	3.8 A
Full load excitation voltage (uc)	34 V
Recovery time (Delta U = 20% transitoire)	< 500 ms
Motor start (Delta = 20% perm. Or 50% trans.)	840 kVA
Transient dip (4/4 charge) – PF : 1.8 AR	14.5 %
No load losses	6.6 kW
Heat rejection	19 kW

Control Panels

NEXYS

Specifications :

Frequency meter, Ammeter, Voltmeter

Alarms and faults Oil pressure, water temperature, Overcrank, Overspeed (>60 kVA), Min/max alternator, Low fuel level, Emergency stop

Engine parameters Hours counter, Engine speed, Battery voltage, Fuel level, AIr preheating

TELYS

Specifications :

Frequency meter, Ammeter, Voltmeter

Alarms and faults Oil pressure, water temperature, No start-up, Overspeed, Min/max alternator, Min/max battery voltage, Low fuel level, Emergency stop

Engine parameters Hours counter, Oil pressure, Water temperature, Engine speed, Battery voltage, Fuel level

Options

Engine and Radiator

- Heat shield protection
- Oil drain extension
- Heavy duty air filter
- Lube oil drain pump
- Radiator core guard
- Battery charger
- Block heater

Alternator

- Anti condensation heater
- Enforced impregnation
- Oversized alternator

Exhaust

- Residential silencer
- Critical silencer
- Flexible exhaust conn.

Control panel

- NFPA 110 level 1
- Paralleling system
- Remote annunciator
- Oil temperature shutdown
- Key start panel

Literature

- Parts
- Maintenance

Fuel

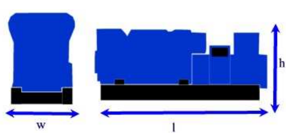
- Day tank
- Subbase fuel tanks UL
- Water separator fuel filter

Enclosure

- M227
- Silent 71.3 db @ 7m [23 Ft] (stby)

Weight and Dimensions

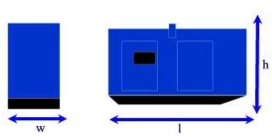
Open Model Excluding option



Overall size l x w x h :
2900mm [114in] x 1300mm [51in] x 1675mm [66in]

Weight :
2280kg [5025lbs] Net 2350kg [5179lbs] Brut

With Optional Enclosure



Overall size l x w x h :
4004mm [158in] x 1380mm [54in] x 2125mm [84in]

Weight :
3230kg [7119lbs] Net 3300kg [7273lbs] Brut

SDMO industries - Head Office **–** 12bis, rue de la Villeneuve – CS 92848 - 29228 BREST cedex 2 - FRANCE - www.sdmo.com

APPENDIX 2

PHOTOGRAPHIC RECORD OF HIGH-MAST LIGHTING SYSTEM

Figure A-2.1. Different general views of the I-90 stretch under construction as it was illuminated with a semi-permanent high-mast lighting system. *[Photo credits: Dennis Guyon, Lighting Research Center]*

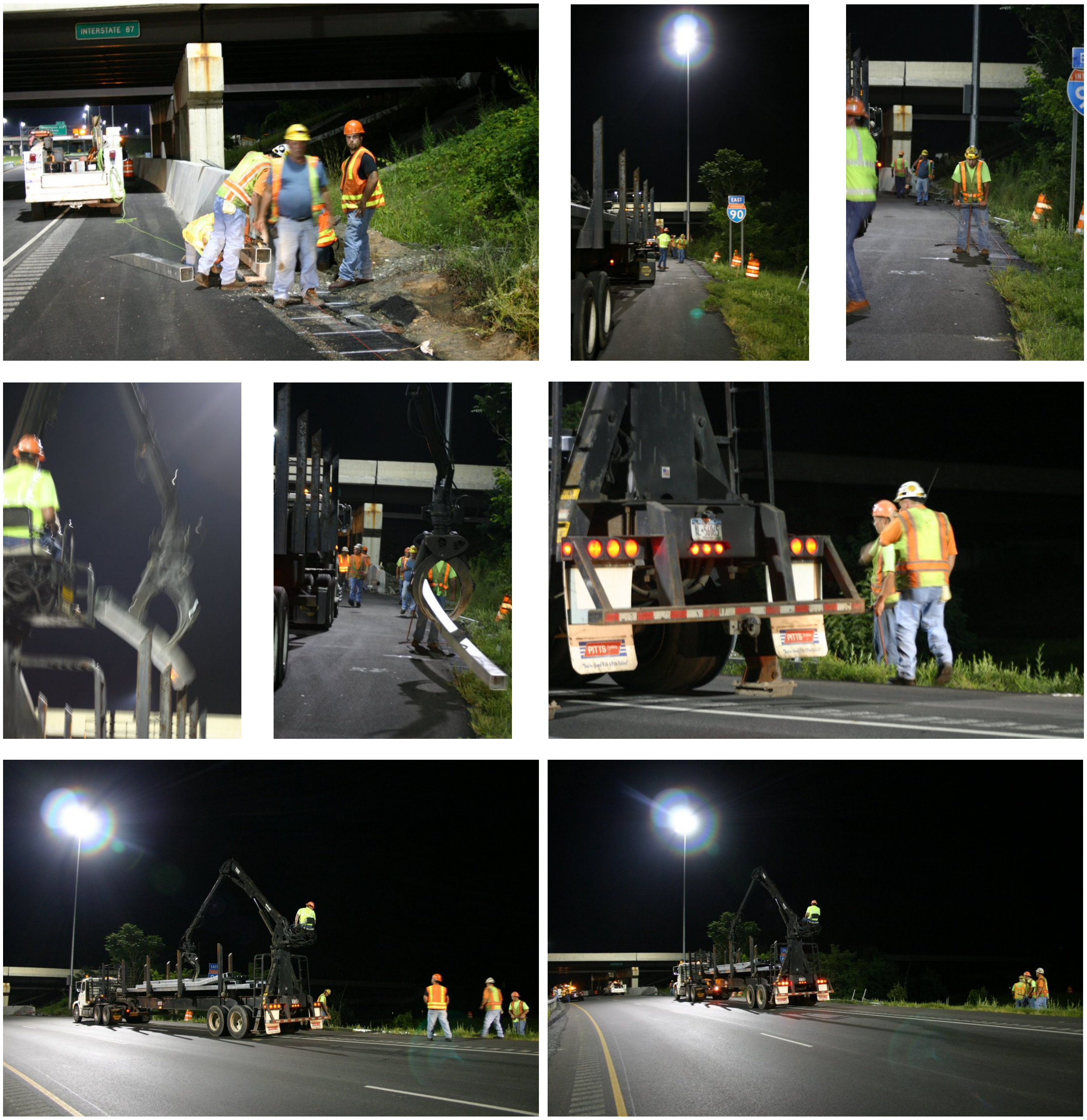


Figure A-2.2. Crew working on the installation of guard rails. It can be appreciated in the photographs the high light levels and uniformity provided by the lighting. *[Photo credits: Dennis Guyon, Lighting Research Center]*

Figure A-2.3. Crew working on the installation of guard rails. It can be appreciated in the photographs the high light levels and uniformity provided by the lighting and how the coverage beyond the clear zone was also helpful with some of the maintenance tasks. *[Photo credits: Dennis Guyon, Lighting Research Center]*

Figure A-2.4. Detail of the control boxes mounted to the poles and sequence during removal of the poles. See Figure A-2.5 for the rest of the removal steps. *[Photo credits: Dennis Guyon, Lighting Research Center]*

Figure A-2.5. Final removal steps of one pole at the end of the project. [Photo credits: Dennis Guyon, Lighting Research Center]

Figure A-2.6. Detail of one luminaire top being disassembled and packed for shipping at the end of the project. *[Photo credits: Dennis Guyon, Lighting Research Center]*

APPENDIX 3

SAMPLE LIGHTING CALCULATIONS

Semi-permanent high-mast lighting for construction
NYDOT - C-05-06
Sample calculation area (1000-ft by 165-ft)
High-mast_1500W_5x6_70ft

LUMINAIRE SCHEDULE

Symbol	Label	Qty	Catalog Number	Description	Lamp	File	Lumens	LLF	Watts
	E	20	TV 1000M GP/HD6	SPUN PARABOLIC FLOODLIGHT - NEMA 6 DISTRIBUTION	ONE 1500-WATT CLEAR BT-56 METAL HALIDE, HORIZONTAL POSITION.	19732_6.IES	170000	1.00	1080

Semi-permanent high-mast lighting for construction
NYDOT - C-05-06
Sample calculation area (1000-ft by 165-ft)
High-mast_1500W_5x6_70ft

STATISTICS

Description	Symbol	Avg	Max	Min	Max/Min	Avg/Min
Calc Zone #5	+	164 lux	264 lux	80 lux	3.3:1	2.1:1

Semi-permament high-mast lighting for construction
NYDOT - C-05-06
Sample calculation area (1000-ft by 165-ft)
High-mast_1500W_5x6_70ft

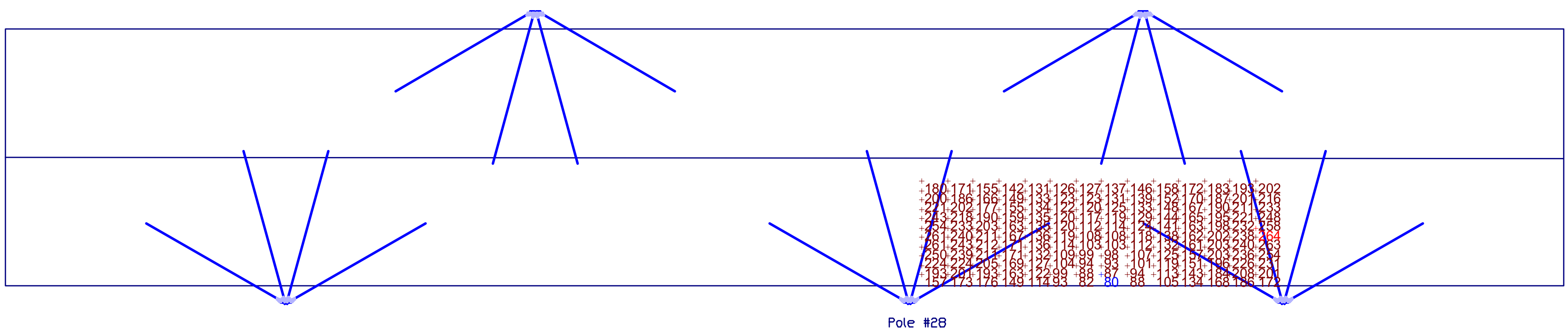
LUMINAIRE LOCATIONS

			Location						Aim	
No.	**Label**	**X**	**Y**	**Z**	**MH**	**Orientation**	**Tilt**	**X**	**Y**	**Z**
1	E	177.0	-10.0	70.0	70.0	-60.0	55.0	90.4	40.0	0.0
2	E	179.0	-10.0	70.0	70.0	-15.0	55.0	153.1	86.6	0.0
3	E	181.0	-10.0	70.0	70.0	15.0	55.0	206.9	86.6	0.0
4	E	183.0	-10.0	70.0	70.0	60.0	55.0	269.6	40.0	0.0
5	E	577.0	-10.0	70.0	70.0	-60.0	55.0	490.4	40.0	0.0
6	E	579.0	-10.0	70.0	70.0	-15.0	55.0	553.1	86.6	0.0
7	E	581.0	-10.0	70.0	70.0	15.0	55.0	606.9	86.6	0.0
8	E	583.0	-10.0	70.0	70.0	60.0	55.0	669.6	40.0	0.0
9	E	817.0	-10.0	70.0	70.0	-60.0	55.0	730.4	40.0	0.0
10	E	819.0	-10.0	70.0	70.0	-15.0	55.0	793.1	86.6	0.0
11	E	821.0	-10.0	70.0	70.0	15.0	55.0	846.9	86.6	0.0
12	E	823.0	-10.0	70.0	70.0	60.0	55.0	909.6	40.0	0.0
13	E	733.0	175.0	70.0	70.0	120.0	55.0	819.6	125.0	0.0
14	E	731.0	175.0	70.0	70.0	165.0	55.0	756.9	78.4	0.0
15	E	729.0	175.0	70.0	70.0	195.0	55.0	703.1	78.4	0.0
16	E	727.0	175.0	70.0	70.0	240.0	55.0	640.4	125.0	0.0
17	E	343.0	175.0	70.0	70.0	120.0	55.0	429.6	125.0	0.0
18	E	341.0	175.0	70.0	70.0	165.0	55.0	366.9	78.4	0.0
19	E	339.0	175.0	70.0	70.0	195.0	55.0	313.1	78.4	0.0
20	E	337.0	175.0	70.0	70.0	240.0	55.0	250.4	125.0	0.0

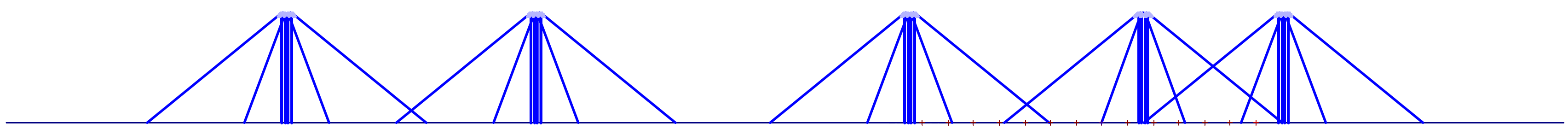
Semi-permanent high-mast lighting for construction
NYDOT - C-05-06
Sample calculation area (1000-ft by 165-ft)
High-mast_1500W_5x6_70ft

STATISTICS

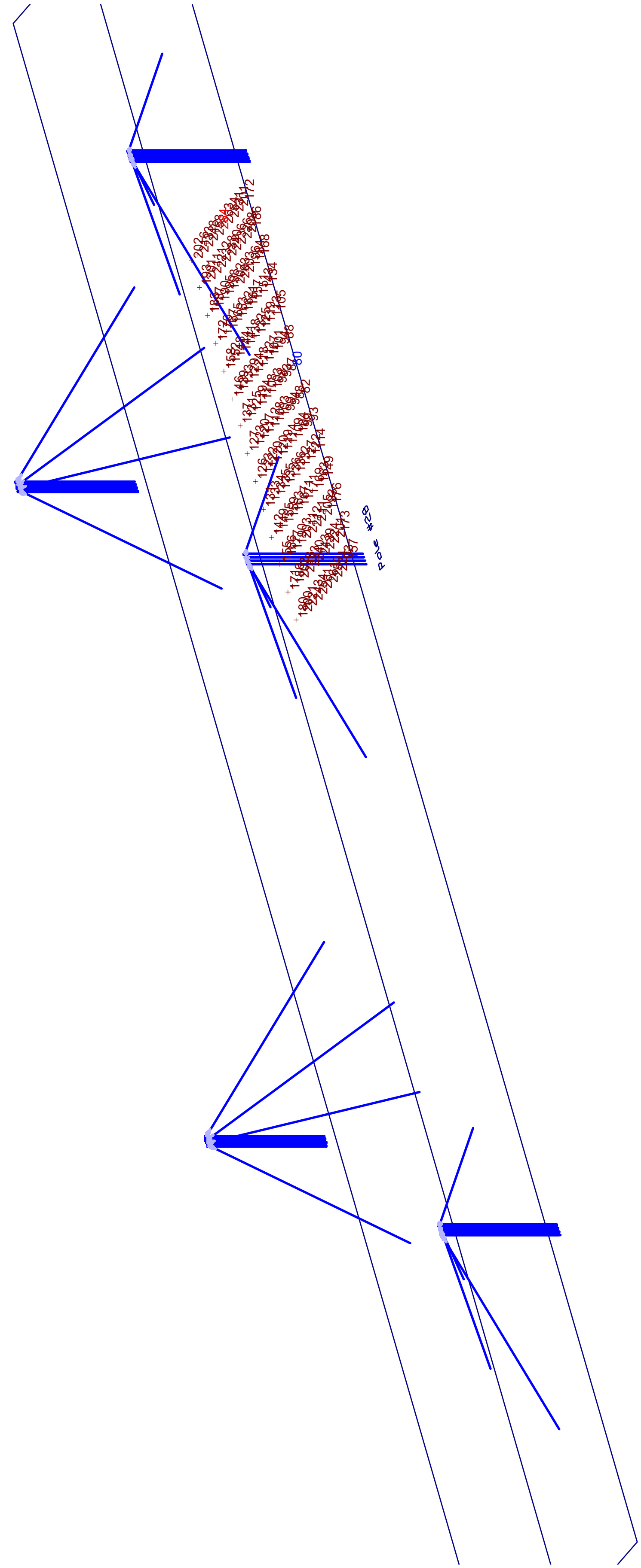
Description	Symbol	Avg	Max	Min	Max/Min	Avg/Min
Calc Zone #5	+	164 lux	264 lux	80 lux	3.3:1	2.1:1



Plan View
Scale 1" = 80'



South Elevation
Scale 1" = 80'



Southwest View

Not to Scale

APPENDIX 4

TABULATED SUMMARY OF RESULTS OF
OPTIMIZATION/SENSITIVITY CALCULATIONS

Case		Horizontal aiming				Vertical aiming				Beam	Lamp	Pole	Pole	Illuminance metrics (lx)					Number of poles for a	Total power
		Lum 1	Lum 2	Lum 3	Lum 4	Lum 1	Lum 2	Lum 3	Lum 4	distribution	power	height	spacing	Average	Maximum	Minimum	Max/min	avg/min	1000-ft stretch of road	(@ 1650 W per pole)
1	Base case (Manuf 1)	-60°	-15°	15°	60°	55°	55°	55°	55°	5x6	1,500 W	70-ft	320-ft	128	255	46	5.5	2.8	28	46,200 W
2	Manuf 2	-60°	-15°	15°	60°	55°	55°	55°	55°	4x4	1,500 W	70-ft	320-ft	144	296	43	6.9	3.3	28	46,200 W
3	Manuf 3	-60°	-15°	15°	60°	55°	55°	55°	55°	4x4	1,500 W	70-ft	320-ft	128	248	47	5.3	2.7	28	46,200 W
4	Manuf 2	-60°	-15°	15°	60°	55°	55°	55°	55°	5x5	1,500 W	70-ft	320-ft	112	159	64	2.5	1.8	28	46,200 W
5	Manuf 3	-60°	-15°	15°	60°	55°	55°	55°	55°	4x4	1,000 W	70-ft	320-ft	83	161	30	5.4	2.8	28	46,200 W
6	Manuf 2	-60°	-15°	15°	60°	55°	55°	55°	55°	5x5	1,000 W	70-ft	320-ft	66	94	38	2.5	1.7	28	46,200 W
7	Manuf 1	-60°	-15°	15°	60°	55°	55°	55°	55°	6x6	1,000 W	70-ft	320-ft	83	165	30	5.5	2.8	28	46,200 W
8	Manuf 2	-60°	-15°	15°	60°	50°	50°	50°	50°	5x5	1,500 W	120-ft	320-ft	56	90	21	4.3	2.7	16	26,400 W

Notes:

1. The calculations of this summary were conducted using a sample section of the I-90 road of 1000-ft by 165-ft - a sample of the layout is shown in the diagram below (base case).

2. The illuminance calculations represent initial values. No lumen depreciation factors have been added to the calculations.