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COMPARISION OF REAL-WORLD ROADWAY LIGHTING, DYNAMIC SIMULATION AND CBE AND GLAREMARK PREDICTIVE SYSTEMS

BY

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INTRODUCTION

The main function of street lighting is to ensure that the efficiency of traffic movement at night shall approximate daylight conditions, with respect to safety, comfort and capacity. It is, of course, impossible to reproduce optimal daylight conditions, and the lighting research on public lighting has, therefore, been directed towards what minimum requirements must be fulfilled by public lighting in order to provide secure, safe,and comfortable night driving.

The most important factors in the quality of public lighting are:

For reliability of observation:

the quality, determined by the luminance of the background, and

For ease of perception:

the limitation of glare,

the uniformity of the luminance pattern on the road surface, and

the extent to which the lighting level exceeds that required for reliable perception.

The first factor determining visual comfort, after a suitable lighting level for reliable perception has been provided, is the glare from the light source. Glare from the roadway light sources may be defined as:

> "When the field of vision of an observer contains a light source whose luminance in the direction of the observer is appreciably greater than that of the other parts of

> his field of vision, this light source will give rise to glare. The glare produced increases with the luminance and apparent size of the light source, and with decreasing luminance of the background and the angle between the direction of observation and the direction to the light source" (DeBoer, 1967).

Glare is subdivided into two effects which are not completely independent.

> Disability Glare(which may not be apparent to the observer) acts to reduce the ability to see or spot an object. It is sometimes referred to as " blinding glare" or "veiling glare".
>
> Discomfort Glare which produces a sensation of discomfort but does not affect the visual acuity or the ability to discern an object.

While both forms of of glare reaction may be caused by the same light flux, the many factors involved in roadway lighting such as source size, displacement angle of the source, illuminance at the eye, etc. do not affect both forms of glare in the same manner, nor to the same degree. The only two factors common to both forms of glare are illuminance at the eye and the angle of flux enterance into the eye. It is generally true that when disability glare is reduced, there also will be a reduction in discomfort glare, but not necassarily in the same relative amount. However, if the discomfort glare is acceptable, hardly any effect on visual performance may be expected.

In this report the discussion is confined to discomfort glare aspect of roadway lighting.

Early Research On Discomfort Glare In Roadway Lighting

Research on discomfort glare has employed forms of apparatus in which the glare source could be varied in size and brightness, while the rest of the visual field remained exactly the same. One of the methods employed was that of Hopkinson (1940 et seq.), Hopkinson and Petherbridge (1954), and Petherbridge and Hopkinson (1950), in which the observer looked into a model room in which there were apertures corresponding to the glare sources under investigation. The luminance of these apertures was provided by an illuminating system outside the model itself. The luminance of the interior of the model was provided by lamps (hidden from the observer) under separate control. Various forms of optical systems were used in different investigations to ensure that any change in the luminance of the glare source would not result in any affect on the luminance of the general surrounding and vice versa.

The method of evaluation of discomfort glare has been to ask obsevers for their direct subjective impressions. In the earliest work (Luckiesh and Holladay, 1925) the procedure was to ask the observer to alter the luminance of the glare source to give in turn a series of sensations of discomfort or comfort. A very large number of sensations ranging from "painful" to "very pleasant" were used. Hopkinson (1940) developed a method which employed a series four criteria of discomfort glare ("just perceptible", "just acceptable", "just uncomfortable", "just intolerable"), associating with these criteria a method of 'calibrating' the human observer over a long period so that his evaluation could be improved in precision by experience, and the variance of these evaluation about a mean could be determined. Luckiesh and Guth (1949) used a single criterion of discomfort called the "borderline between comfort and discomfort" or "BCD", rather than a number of criteria.

Research on discomfort glare has, therefore, used "introspective" methods of evaluation. That is, the observer was asked to think about the situation, evaluate it, and make a setting of a controlled variable, such as the glare source luminance, until the glare sensation corresponded to a criterion which had been described to him and which he believed he could reproduce. No successful studies were made using specific visual tasks and the performance of them as the basis of evaluation. Attempts were indeed made to evaluate glare in this way (Bartlett and Pollock 1935, Stone and Groves 1968) but all the investigators who had attempted such a "behaviorist" approach found that acute subjective discomfort arises from situations which give rise to little or no decrement in visual performance. If such decrement does exist, it probably results from very long exposures.

It is necassary to mention here the difference in approach of one group of American researchers (Luckiesh 1925 et seq.) as compared with all others. Luckiesh and Guth,later his colleague, have insisted, from the earliest days of Luckiesh's work, on presenting the glare source momentarily rather than continuously. Luckiesh's argument was that glare is experienced when the observer looks from his work and sees the glare source for a second or so and then looks down at his work again. Other researchers have used continuous exposure of the glare source, on the basis that in a normal interior, the glare sources (like any other part of the field of view) are continuously exposed.

The results of various investigations into the discomfort glare phenomenon were; (a) all agreed that the magnitude of glare sensation is related directly to the luminance of the glaring source and its apparent size as seen by the observer, and (b) that the discomfort is reduced if the source is seen in a surrounding of high luminance. The glare sensation is also reduced, the further the glare source is off the line of sight. These findings were resulted in the following formula (Hopkinson, 1970):

$$\text{Glare constant} = (Bs^{1.6}\ w^{0.8})/Bb\ \theta^{2}$$

where Bs is the luminance of the source, Footlambert,

w is the solid angle subtended by the source, steradian,

Bb is the general background luminance, footlambert,and

θ is the angle between the direction of viewing and the direction of the glare source, degreea.

One of the consequences of the different experimental techniques used by Luckiesh and Guth (momentary exposure) and by other investigators (continuous exposure) was that the exponent of the glare source in the above formula was markedly different. The momentary exposure technique resulted in a higher influence of the luminance of the glare source (and therefore, a higher exponent of Bb) (Hopkinson 1957).

Such a formula enabled the magnitude of the glare sensation from a single source to be evaluated. However, it was shown that the effect of a number of luminaires can be obtained by suitable addition of the glare constants obtained for individual sources in the field of view. Hopkinson (1940) showed that the simple arithmetic addition of the glare constants gave a value of glare constant which corresponds closely to the sensation from the complete array of multiple sources. Hopkinson (1950) modified this proposal by showing that the glare from a number of sources is the same as that from a single source of equal apparent area placed at the centroid of the array. Later, Hopkinson (1957) showed, however, that the additive nature of glare was a highly complex phenomenon, the exact additivity function depended upon the luminance of the sources and their position in the field of view, among other things.

In Europe, de Boer and Schreuder (1967) conducted an experiment using a dynamic model of a normal street lighting installation. Here the average road surface luminance and its uniformity, and the size and number, light distribution, arrangement and luminous intensity of the street lighting lanterns could be varied independently of each other. A randomized sequence of street lighting installations was presented to the observer who had to choose in their appraisals between the following degrees of glare: "unbearable" glare (G=1); "disturbing" glare (G=3); "just admissible" glare (G=5); "satisfactory" glare (G=7); and "unnoticeable" glare (G=9). The number in bracket indicates the associated "Glaremarks" that were used for calculation. Their findings resulted in the system "Glaremark". A series of researches (at Kansas State University) relative to the BCD concept has shown that the cumulative effect of a number of equally bright sources can be combined (Bennett, 1979). The effect of several sources of differing brightness and location can be expressed in terms of a"Cumulative Brightness Effect" or "CBE" (Bennett, 1980).

Currently, in Europe, Glaremark is in use to prevent discomfort glare in the design of lighting for streets and highways. The Illuminating Engineering Society of North America (IESNA) has been working to add procedures for dealing with discomfort glare to future revisions of its Standard Roadway Lighting Practice. Moreover, North American tests have failed to show the validity or adaptibility of Glaremark (Keck and Odle, 1975). Further unpublished field tests were conducted by Gallagher in Philadelphia (Gallagher & Keck, 1981). The site consisted of a street served by luminaires mounted on opposite spaced poles 110.5 feet apart. Each pole was capable of carrying two luminaires and each luminaire could be switched independently. One type of luminaire was used in all the configurations. Two spacing--110.5 feet opposite and 221 feet opposite and seven light levels-- maximum about four times minimum, were used. Twenty-four subjects rode through each of the 10 configurations and scored each system in terms of brightness and overall quality. Ranking for the ten configurations was based on the "Glaremark" and "CBE" values computed by Merle Keck using photometric data and field data. Also, the ranking for the ten configurations was done by the observer rating. However, the Glaremark and North American "CBE" systems were equally unpredictive.

Research On Discomfort Glare At Kansas State University

In order to provide a basis for a North American system research is underway at Kansas State University. The first study was an extensive experiment based upon the pilot of work by Putnam and his coworkers (Bennett, 1977). A multiple regression model was developed for predicting glare sensitivity as a function of glare source size, position and background luminance for a single glare source. This study enabled prediction of an average response for a single, static glare source. Later probit analysis (Bennett and Rubinson, 1979) enabled prediction of an arbitrary percentile rather thean just the average. Further research extended this work to a number of static sources rather than a single source (Bennett, 1980). This research also has shown the declining influence of lights as one looks down the roadway and led to what Keck has called the "Cumulative Brightness Evaluation" or "CBE" model where summation of effects over successive lights are substitued for size, position, and background luminance in the previous multiple regression model. This currently is the CBE procedure.

Dynamic Simulator

Based upon an idea of Dr.Glenn Fry, a dynamic roadway simulator for discomfort glare was designed and built at Kansas

State University (Anantha, Dubbert, and Bennett, 1982). An experiment was conducted using this simulator in the summer of 1982 (Bennett, 1982). Seventy-four subjects were run each for three hours. In the experiment the conditions simulated were:

Car speeds of 30 mph and 60 mph,

Spacing of four mounting heights and eight mounting heights, (as spacing is defined to be a multiple of the mounting height),

One sided lighting and two sided staggered lighting,

Number of lights of 26, 10, 2, and 1,

A dynamic condition and a static condition.

Statistical results showed that the static condition was less uncomfortable than the dynamic conditions. Correspondingly, the annoyance level was greater for the higher speeds (60 mph vs. 30 mph). Spacing was a statistically significant variable. Observers were less sensitive to the eight MH conditions than the standard four MH conditions. No difference was found between lighting on one or both sides or the number of luminaires. The results showed, in general, that the Fry Simulator approach was a useful way to study discomfort glare from fixed roadway lighting. The main advantage is that it is much less expansive than field tests and is much more flexible.

An improved simulator was developed at Kansas State University (Easwer, Dubbert, and Bennett, 1983). Also a change in the direction for the research was planned. Rather than a "parametric study", a predictive-system-validation approach was planned.

A detailed study on the two predictive systems, namely Glaremark and CBE, was carried out in Fall 1983. Two computer programs were generated for these systems and standard data was used as suggested by Bill Lee Shelby of ITT Outdoor Lighting. The results of these systems revealed that:

- The first three luminaires in front of driver are the most important as far as the glare is concerned: the first luminaire contributes the major portion of this glare,
- As the spacing between the luminaires is increased, the effect of glare becomes less,
- An increase in the mounting height makes a particular installation more comfortable,
- By increasing the windshield cutoff angle, the importance of the first luminaire in front of the driver can be reduced.

An experiment was carried out in 1984, to see if there is a statistically significant difference between the glare responses of a driver and a passenger (Hussain, 1984). Seven pairs of subjects drove or rode through seven different roadway lighting installations in the City of Manhattan,Kansas. No statistically significant difference was found between the responses of drivers and passengers. In addition, it was found that all the lighting installations, studied except one, are comfortable using the New North American Glare Scale as the rating instrument. The levels of discomfort glare used in the North American Glare Scale are, "pleasant" (G=1), "satisfactory"

(G=3), "BCD" or "just admissible" (G=5), "disturbing" (G=7), and "intolerable" (G=9).

The above experiment was a pilot study for the present 1984 research. The objective of the research was to compare the real-world roadway lighting, dynamic simulation, and CBE and Glaremark predictive systems. Sixty subjects (30 pairs of subjects) drove or rode through six different lighting installations in the city of Manhattan and rated the quality of lighting using the North American Glare Scale. The same subjects also "drove" in the dynamic simulator, where the six real-world installations were simulated, and again rated the quality of lighting. The results of real-world and dynamic simulation were then compared with the Glaremark and CBE predictive systems.

PROBLEM

One objective of this study is to validate the dynamic simulator, developed at Kansas State University, by running 60 subjects through six simulated installations. The results the from the dynamic simulator then will be compared with the glare responses of subjects in the "same" real-world lighting installations. Since the dynamimc simulator is much less expensive and a more flexible way to study the discomfort glare from fixed roadway lighting, its validation will save expansive field tests.

The second objective of this study is to validate the European predictive system "Glaremark" and North American predictive system "CBE". This is planned to achieve by comparing the glare responses of 60 subjects, from the six real-world lighting installations, with the results of the above mentioned predictive systems. The validation of these predictive systems is important because it is the easiest approach to predict the discomfort glare from a particular roadway lighting installation without going into the trouble of preparing the simulator, time consuming subject running, or the expensive field tests. Moreover, these systems can be useful in predicting the comfort or discomfort of a lighting installation at the design stages, prior to the exsistance of the system.

METHOD

Procedure

The experiment was divided into three different parts. They are: real-world, simulator, and predictive systems.

Real-world

For the real-world part of the experiment, six different roadway lighting installations were selected in the City of Manhattan. The details of these installations are given in Table 1. These installations were selected in such a way that all the systems were different from each other in one way or another. For example, although both systems 3 and 5 (Table 1) were cobra-heads, with clear mercury lamps, and double-sided staggered installations, 5 is a 250 W lamp, whereas 3 is a 400 W lamp.

All the measurements relating to the roadway installations (Table 2) were taken by the experimentor. These measurements include:

Mounting height with the help of a theodolite,
Spacing and road width with a measuring tape,
Photometric brightness of all the installations with the help of a Spotmeter.

Since, in a real-world roadway lighting installation, the above mentioned parameters usually are not consistent, means of all the measurements taken for each installation and were used for the simulator as well as calculation purposes.

For the subject running in" real-world", five different orders of installations were selected. These orders are:

TABLE 1.

Details of the lighting installations.

No.	Location	Luminaire	Lamp	Wattage	Single or Double-sided	Driving
1.	McCall	CH	HPS	400	Single	Dynamic
2.	Claflin	CH	MV	400	Single	Dynamic
3.	Bluemont	CH	MV	400	Double	Dynamic
4.	Vet.Med	Gb	MV	250	Single	Dynamic
5.	N.Manhtn	CH	MV	250	Double	Dynamic
6.	AIB	CO	HPS	250	Single	Static

CH = Cobra Head

Gb = Globe (GE's Power Sphere)

CO = Cut-off

MV = Mercury Vapor

HPS = High Pressure Sodium

TABLE 2.

Measurements of lighting installations.

No.	Spacing (feet)	Mounting Height (feet)	Road Width (feet)	Overhang (feet)
1.	210	30	44	5
2.	190	27	35	5
3.	235	30	24	5
4.	70	10	48	0
5.	195	29	24	5
6.	104	35	36	2

6, 5, 4, 3, 2, 1 .... 6 pairs.
4, 5, 6, 3, 2, 1 .... 6 pairs.
5, 6, 4, 3, 2, 1 .... 6 pairs.
1, 5, 6, 4, 3, 2 .... 6 pairs.
1, 2, 3, 4, 5, 6 .... 6 pairs.

Although entirely different sequences of installation were possible for all 30 pairs of subjects, the above mentioned orders were used mainly to save the miles travelled by each pair.

A set of three instruction sheets (discussed later) were prepared for subjects to give them an understanding of the experiment and specific tasks.

Simulator

Principles of dynamic simulation: The basic concept of the simulation is that a disk is rotated in front of a light source. The disk has a clear spiral which increases in width as it spirals outward. The disk is opaque except for the clear spiral track. An occluder with a narrow open sector occludes most of the disk. As the disk rotates behind the occluder, the observer sees a series of "roadway lights" from the large first light above him to the ever more closely spaced small lights near the horizon. The basic concept is further developed in a new simulator.

The new concept is that two disks rotate in opposite directions (in proportion to the vehicle speed) behind an occluder. The disks are opaque except for clear double-spiral tracks on each of them as shown in Figure 1. The occluder is opaque except for the two narrow sectors. Both the disk and occluder are in front of

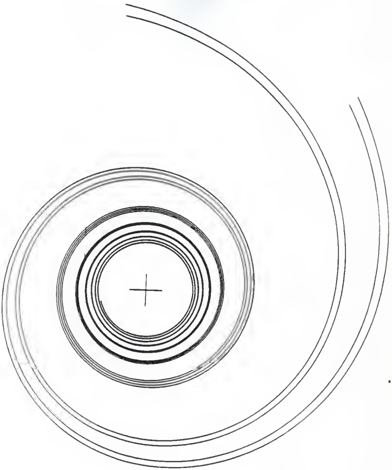


FIGURE 1: Double spiral track.

the light source. On the several places where the two sectors and the double-spirals on each disk intersect a series of road lights (Figure 2) occur. These appear to move toward and above the driver, getting larger.

The new concept was used in developing a dynamic simulator at Kansas State University (Easwer, Dubbert, and Bennett, 1983) and is currently in room 126, Durland Hall. A side view of this simulator is shown in Figure 3. It is a driver portion of an old car and is completely sealed from the outside ambient light, that is, light from outside cannot enter inside. The only light a subject can see is the background light and the simulated road lights.

Preparation of Simulator: The above mentioned simulator was used as the second part of the experiment, that is, 60 subjects "drove" this simulator where the six different roadway lighting installations were simulated.

As the first step of preparation, data for all the installations were collected (Table 2) from Kansas Power & Light, relevant manufacturers (General Electric Corporation, and ITT Outdoor Lighting), and the road itself.

Two computer programs were written to plot the double spiral for each type of luminaire; one program for double-sided installations and one for single-sided installations (Appendix 1). The spiral plots so obtained (diameter = 3 ft.) then were filled in along the spirals with a black marker pen. These plots then were sent to the Kansas Department of Transportation, Topeka, Kansas, to get the photonegatives as shown in Figure 4.

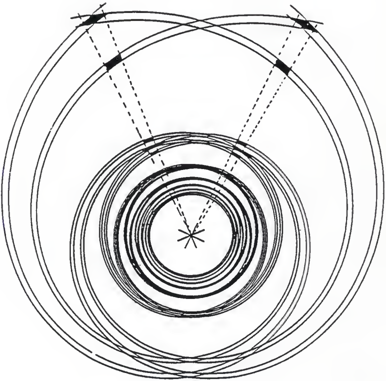


FIGURE 2: Intersecting double spirals.

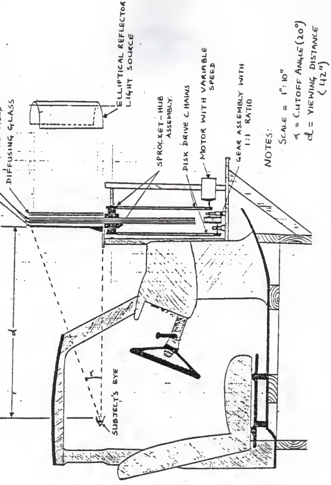


FIGURE 3: Roadway simulator diagram

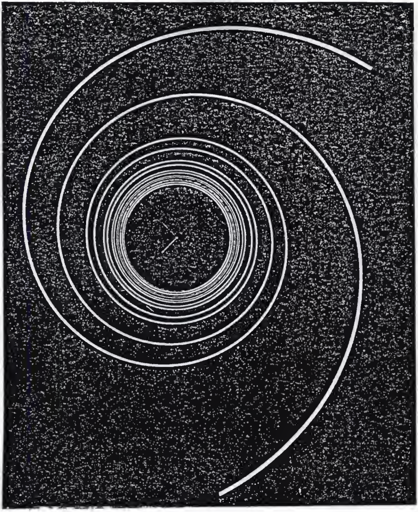


FIGURE 4: Photonegative of a double spiral plot

These phonogegatives were then "sandwiched" between two 3/8" plexiglass sheets of three feet diameter each. Thus, two disks having the same double spiral track, offset from one another by an angle of 52 degrees and rotated in the opposite direction simulated the roadway lights for a particular installation with opposite side lighting.

Two graduated sectors were made for each of the installations except for single-sided installations for which one of the sectors was kept completely opaque. The dimensions of these two sectors were determined separately for each luminaire by taking into account the dimension of each luminaire and using a linear relationship (assuming that as the driver moves toward the luminaire, the dimensions of the luminaire increases linearly).

Two light fixtures were used in line with the open sector to simulate the luminance of the real-world fixtures. Each light fixture used five 300 Watt quartzline lamps covered with a high heat resistant glass on the front side. All the lamps were arranged in the simulator in stacked configuration with the filament of each bulb positioned at the focus of the elliptical reflector made of a sheet of tin. The elliptical reflector increased the efficiency of the light source by concentrating the light from the quartzline lamp on a long, narrow piece of diffusing glass (Factorlite). The net effect was to provide a long narrow bar of intense and well diffused light. Intensities as high as 100,000 cd/m^{2}could be obtained by this system.

To simulate the brightness of each luminaire system luminance measurements on the roadway were taken with a Spotmeter. Each luminaire was measured at the cut-off angle (20 degrees) from the horizontal. Some luminaires were, however, measured at a closer distance in order to match the photometer reticule size with luminaire size. Also in the case of AIB, direct measurement technique was not used (Appendix 2) because of nonuniform distribution of light. Here, the illuminance was measured using a Vactec low level photometer. Each particular mean luminance was then matched with an equivalent level within the simulator using the Spotmeter or the Vactec photometer. These equivalent levels within the simulator were converted into "volts" with the help of a calibration curve (Figure 5), so that luminance level could be adjusted with the help of a voltmeter while simulating a lighting system.

Finally the rotational speed of the disk simulating the speed of the car was calculated, considering the fact that one revolution of the spiral corresponds to a distance travelled of one space between poles. If the pole spacing is considered to be a multiple of mounting height, then X(MH)/min. corresponds to 1 rpm of the spiral. Therefore, the rotational speed of the spiral, to simulate a driving speed of M mph is derived as follows:

$$1 \text{ rpm} = X(MH)/\text{min.} \qquad \text{MH is in feet.}$$

$$1 \text{ rpm} = X(MH)\,\frac{\text{ft}}{\text{min}} \times \frac{\text{miles}}{5280 \text{ ft.}} \times 60\,\frac{\text{min}}{\text{hour}}$$

$$= \frac{X(MH)}{88} \text{ miles/hour}$$

$$\text{Now, } \frac{X(MH)}{88} \text{ mph} = 1 \text{ rpm}$$

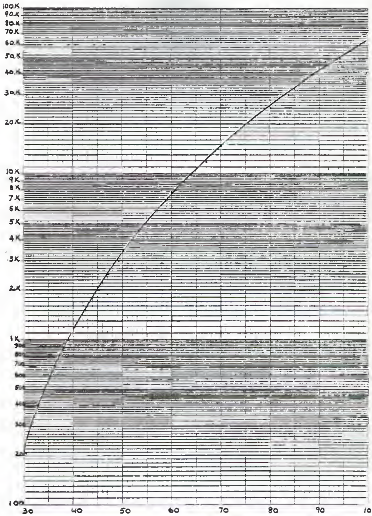


FIGURE 5: Calibration Curve

$$M \text{ mph} = \frac{88\ M}{X\ (MH)}$$

where M is the speed of the car in mph and MH is the mounting of the luminaire in feet.

Predictive Systems

Calculation of Glaremark: In this empirical model the observer's position along the roadway is not relevant; it makes no difference to Glaremark if the observer is in lane 1 or lane 6 or whether he is moving or is static. The calculation of Glaremark was done using the following empirical formula:

$$SLI = 13.84 - 3.31\log I\text{-}80 + 1.3\log(I\text{-}80/I\text{-}88)^{1/2} - 0.08\log(I\text{-}80/I\text{-}88) + 1.29\log F$$

$$GM = SLI + 0.97\log L + 4.41\log h - 1.46\log P.$$

Where,

GM = Glaremark.

SLI = Specific Lantern Index

I-80, I-88 = Luminous intensity of the lantern at an angle 80° and 88° respectively, to the vertical, candelas,

F = Flashed area of the luminaire as viewed from 76° to the downward vertical, m^2.

L = Average road surface luminance, cd/m^2.

h = Height of the luminaire above the road minus the observer's height, feet,

P = A quantity based on the number of luminaires per kilometer.

The purpose of this study is to compare the subject's rating (of quality of light of the real-world lighting installation) to the results of the Glaremark and CBE predictive systems. It is expected from these predictive systems that they should be able to predict the discomfort glare from any roadway lighting system and not only from the ideal lighting installations (such as perfectly clean and aligned). Only then would these predictive systems be useful for practical purposes. This is the reason calculations were made with the help of standard data provided by the concerned manufacturers.

Since the North American manufacturers do not provide the "flashed area" for a particular luminaire in their standard data, a linear relationship was developed for this purpose. The derivation of this formula is as follows:

This formula was basically developed for the "cobra-head" luminaire, assuming that the luminaire is approximately a rectangular box as seen by the observer. In the real-world roadway system the luminous area of a luminaire is not generally perpendicular to the line of sight. The luminous area varies as a function of the vertical angle as the observer moves towards the luminaire. In order to incorporate the luminous area as a function of vertical angle, the vertical dimension of the luminaire is assumed to vary linearly as the angle changes. It can be computed as follows:

Figure 6 shows the width (LHT2) and the vertical height (LHT1) of the luminaire. The following linear relationship is assumed:

At a long distance away from the luminaire:

when the viewing angle $\theta = 0^\circ$, the vertical dimension = LHT1

At the cut-off angle,

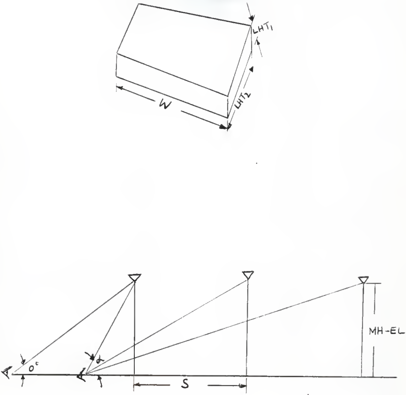


FIGURE 6: Profile of a luminaire and roadway

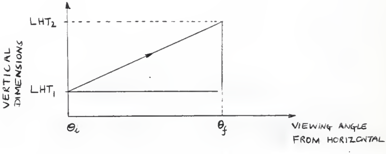


FIGURE 6 (contd:)

when the viewing angle $\theta = 20^\circ$, the vertical dimension = LHT2. As θ varies from 0 to the cut-off angle, the vertical dimension varies from LHT1 to LHT2, according to following equation,

$$LHT = m\theta + b \qquad (1)$$

where "m" is the slope of line and "b" is the intercept.

$$\text{Slope "m"} = \frac{LHT2 - LHT1}{\theta_f - \theta_i}$$

Substituting in equation (1)

$$LHT = \frac{(LHT2 - LHT1)\ .\ \theta}{\theta_f - \theta_i} + b$$

when $\theta = \theta_f$, LHT = LHT2

therefore,

$$LHT2 = \frac{(LHT2 - LHT1)}{(\theta_f - \theta_i)} \ .\ \theta_f + b$$

$$b = LHT2 - \frac{(LHT2 - LHT1)}{(\theta_f - \theta_i)} \ .\ \theta_f$$

Substituting the values of M and b in equation (1),

$$LHT = \frac{(LHT2 - LHT1)\ .\ (\theta - \theta_f)}{(\theta_f - \theta_i)} + LHT2$$

Therefore, the flashed area "F" can be calculated as:

$$F = LHT \times W$$

$$= \left[\frac{(LHT2 - LHT1)\ (\theta - \theta_f)}{(\theta_f - \theta_i)} + LHT2 \right] W.$$

where,

θ = 76° from the downward vertical, degrees

θ = wind-shield cut-off angle, degrees, and

θ_i = 0°; the viewing angle from infinity, degrees.

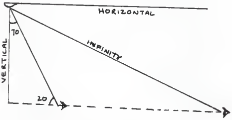
The above dimensions were obtained from the manufacturer for all the luminaires used in the experiment and are given in Appendix 3.

If we calculate the flashed area "F" for cobra-head (M400, General Electric), we would proceed as follows:

$\theta = 76^\circ$ from vertical,

$\theta = 90^\circ$ from vertical, if the distance between the observer and the pole is assumed to be infinite

$\theta = 90^\circ - 20^\circ$ from vertical.



Therefore,

$$F = \frac{(14.875 - 6.750)(76 - 70)}{(70 - 90)} + 14.875 \quad 18.375$$

$$= 228.54 \text{ in.} = 0.147 \text{ m}^2$$

For a cut-off luminaire:

$$F = W \times LHT2 \times \cos(\theta)$$

For a (General Electric) Power Sphere:

$$F = \pi r^2 .$$

where, r = radius of the sphere.

The values of I-80 and I-88 were calculated by linear interpolation from the candlepower data supplied by the manufacturer. A computer program was written to interpolate these values and calculate the Glaremark. The intensities were calculated assuming the horizontal angle to be 90 degrees. This angle was taken as 90 degrees because the convention used by the manufacturer is as shown in Figure 7. All the intensities (Appendix 4) were then multiplied by the "light loss factors" (Appendix 4-A) as follows:

Corrected Intensity = Original Intensity x LLD x LDD, candelas.

where LLD = Lamp Lumen Depreciation, and

LDD = Luminaire Dirt Depreciation.

All the above data (supplied by the General Electric Company) were then inserted in a computer program which reads the data, interpolates the value of intensity and then calculates the Glaremark.

<u>Cumulative Brightness Evaluation (CBE)</u>: The Cumulative Brightness Evaluation or "CBE" is an observer oriented system. Its value varies depending on the lane in which the observer is located and his position along that lane. The equation as developed, based on a suggestion by Dr. Glenn Fry using findings at Kansas State University is as follows:

$$CBE = \frac{(B1^{1.67})S1}{e^{0.0BA1}} + \frac{(B2^{1.67})S2}{e^{0.0BA2}} + \ldots\ldots\ldots\ldots\ldots\ldots$$

where, B = Photometric brightness of the glare source, fL

S = Source size, steradian

A = Source angle off the line of sight, degrees

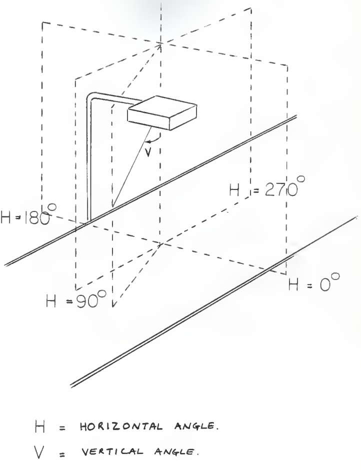


FIGURE 7: Convention for Horizontal Angle

Calculation of CBE

Calculation of CBE is, indeed, tedious but not complex. For an understanding as to how these calculations were made, complete detail is given as follows:

Figure 8 shows the geometry of roadway with the help of which calculations were made. In Figure 8-A, vertical dimensions are considered, whereas, in Figure 8-B, the luminaire has been projected downwards to the eye level to calculate the angles in the horizontal plane. Also it is assumed that the observer is halfway between two poles (position X in Figure 8).

Now,

$$\text{Brightness, } B = \frac{\text{Intensity(cd)}}{\text{Apparent bright area (in.}^2\text{)}} \times 452 = \text{Footlambert}$$

The intensity was obtained from the candlepower tables (Appendix 4) supplied by the manufacturer. The required vertical and horizontal angles were calculated as follows:

$$D = CD - O$$

where, CD = Distance of observer from the pole, feet

O = Overhang of the luminaire, feet.

Distance of the observer from the base of the pole,

$$Y = (D^2 + X^2)^{1/2}$$

where, X = Spacing / 2, feet.

Therefore, vertical angle, $V = \tan^{-1} (D^2 + X^2)^{1/2} / P$

Where Pole height, P(feet) = Mounting height (MH) - Eye level (EL)

Also distance of luminaire from the observer,

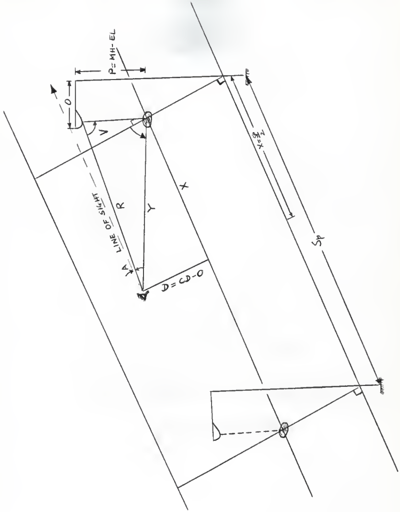


FIGURE 8A: Geomtry of Roadway (Horizontal)

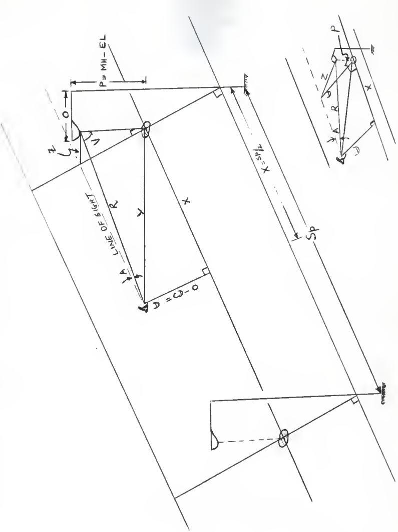


FIGURE 8B: Geomtry of Roadway (Vertical)

$$R = (P^2 + Y^2)^{1/2}$$

Now,

Horizontal angle, $H = 90 - \tan^{-1}(D/X)$, degrees.

With the help of V versus H, intensities were obtained, which were further multiplied by the "lamp loss factors". That is, Corrected Intensity, I(cd) = Original Intensity x LLD x LDD.

where, LLD = Lamp Lumen Depreciation,

LDD = Luminaire Dirt Depreciation.

These factors are given in Appendix 4-A, for the relevant luminaires, where needed.

The "apparent bright area" of the luminaire was calculated using the earlier mentioned linear relationship as follows:

$$\text{Apparent bright area,} \quad A = \left[\frac{(LHT2 - LHT1)}{(\theta_f - \theta_i)} (V - \theta_f) + LHT2 \right] W$$

Here for each successive luminaire the corresponding vertical angle "V" was used.

$$\text{Source size, } S = \frac{\text{Apparent bright area}}{R \times 144} = \text{steradian.}$$

The inclined distance from luminaire to the line of sight,

$$Z = \left((D + (MH - EL)^2\right)^{1/2} \text{, feet}$$

Angle off the line sight, $A = \tan^{-1}(Z/X)$, degrees

By putting the values of A, B, and S in the equation of CBE, we get CBE for the first luminaire.

For the second luminaire,

$$X = X + Sp$$

and the rest of the calculations are the same. The same geometry can be used for a double-sided installation except that, for the installation across the road:

$$X = Sp$$

Since the calculations of CBE are very tedious, a detailed computer program was written to calculate CBE. This program (Appendix 5) can be used for single-sided as well as double-sided installations. All one has to do is to insert the data for the relevant installation and indicate whether it is a single-sided or double-sided installation.

Task

Sixty subjects evaluated or rated the quality of light of six different lighting installations in the City of Manhattan, and of the same installations in the dynamic simulator. Therefore, the task for subjects was divided into two sub-tasks. They are:

Dynamic Simulator: The new dynamic simulator was developed at Kansas State University in Summer 1983, Durland Hall.

Once all the disks and graduated sectors were ready, a disk rpm calibration chart (Table 3) and a luminance calibration chart (Table 4) were prepared to simulate the driving speed and the luminance of the systems, respectively.

Room 132, Durland Hall, was used for the orientation of the subjects. Two subjects were called at one time. A "general instruction sheet" was prepared for the subjects (Figure 9) to make them familiar with the experiment in general, and also to

TABLE 3.

RPM Calibration Chart.

No.	Location	Speed (mph)	RPM
1.	McCall	30	13
2.	Claflin	30	10
3.	Bluemont	30	12
4.	Vet.Med	30	25
5.	N.Manhtn	30	14
6.	AIB	Static	Static

TABLE 4.

Luminance Calibration Chart.

No.	Location	Volts
1.	McCall	98.5
2.	Claflin	62.0
3.	Bluemont	63.0
4.	Vet.Med	32.5
5.	N.Manhtn	65.5
6.	AIB	95.0

Sheet No. 1

GENERAL INSTRUCTIONS

This is a study of street lighting quality. That is, we are interested in your impression of the quality of street lighting. More spcifically we are interested in your impressions as to whether any particular luminaire's installation is glaring enough to cause you any discomfort while driving. By street lighting we mean the overhead lights that light the streets and not the traffic signal, neon signs, luminaires used to light the houses, etc.

This study consists of two parts:

1) In one case you will drive through several roadway lighting installations, in the city of Manhattan, and
2) In the other case you will be driving under simulated conditions in the lab. That is, we have simulated real-world roadway conditions in the laboratory.

In both the situations we want you to rate the quality of lighting by using these forms (see attached rating forms). You are to rate the the lighting as if you were driving down the road alone and that you are not in an experimental setup. Don't look at the lights themselves, look along the roadway as you usually would.

You are to rate the quality of lighting according to the following criteria. There is a concept called "Borderline Between Comfort and Discomfort" or "BCD". If the intensity of light is at a high level, i.e. it is annoying or disturbing you in performing your task but not blinding you temporarily, then we would call

FIGURE 9: GENERAL INSTRUCTION SHEET

the light UNCOMFORTABLY GLARING. If the level of intensity is so much that you don't feel annoyed, then we call this light as COMFORTABLE. Now somewhere between these two extremes there should be a point of change where the light is at the borderline between comfort and discomfort. This is what we call BCD. This is the point where the light is not annoying or uncomfortable to you. But, if it is higher, it would be uncomfortable. Similarly if the intensity of light is very high i.e., it impairs your vision temporarily it is called INTOLERABLE or UNBEARABLE. There is a point between intolerable and uncomfortable which is called as DISTURBING. If the intensity of the light is so low that you hardly notice any glare but still can perform your task, then we call this as PLEASANT (UNNOTICEABLE). There is a point between comfortable and pleasant known as SATISFACTORY. At this point you can perform tasks without any difficulty.

For all the installations in both real-world and simulator you will be asked to rate the the glare criterion for each installation by using the attached North American Glare Scale.

Now, please read the glare scale carefully. If you have any questions regarding the glare criterion or regarding any other task, feel free to ask anything.

There is no risk involved in the experiment except that you will have to drive through different installations and you might notice occasional glare from the luminaires. However, you are free to withdraw from the research at anytime, but we hope that you will complete the session.

At the conclusion of this experiment you will be paid the amount promised.

give them an understanding of the North American Glare Scale (Figure 10). Once the subjects were fully familiar with the nature of the experiment, instruction sheet number two (Figure 11) was given to make them familiar with the specific task of the simulator. Moreover, the experimenter thoroughly explained details of the task in the simulator as well as in the real-world situation.

Sixty subjects were randomly divided into 30 pairs. For these 30 pairs, five different orders of six installations were selected for the simulated as well as the real-world condition. Each pair was asked to randomly select a sequence of installations, from a stack of rating forms (for a specimen rating form, see Figure 12).

Each pair went through each simulated installation at the same time. That is, one subject rated the quality of light of a particular installation in room 126; the other subject waited for his turn in room 132 so that his judgment would not become biased. Each subject went through each installation for 30 seconds. Also the simulated speed was maintained at 30 mph. At the end of each installation he was asked to come out of the simulator, take his time to consult the North American Glare Scale (Figure 10) and write down his rating on the form in front of the appropriate installation, along with some comment in his own words about his experience of the glare sources. Then he was asked to go in room 132 so that the second subject could go through the same installation. The second installation was mounted according to the particular sequence and the same

NEW NORTH AMERICAN GLARE SCALE

9	INTOLERABLE (UNBEARABLE)
8	
7	BORDER LINE BETWEEN UNCOMFORTABLE AND INTOLERABLE (DISTURBING)
6	
5	BORDER LINE BETWEEN COMFORT AND DISCOMFORT (BCD) (JUST ADMISSIBLE)
4	
3	BORDER LINE BETWEEN COMFORTABLE AND PLEASANT (SATISFACTORY)
2	
1	PLEASANT (UNNOTICEABLE)

FIGURE 10: NORTH AMERICAN GLARE SCALE

INSTRUCTION SHEET NO 2.

This simulator is designed to simulate an actual dynamic roadway lighting condition. You, as a subject will be performing an experiment with this simulator.

Take a seat in the car and make yourself comfortable. Locate the string with a metal strip tied to its end in front of you. Grab the metal strip and pull the string over the steering wheel towards you. Now with the other hand adjust your seat so that the tip of the metal strip touches your eye lashes. Now be ready to take-off. Keep your hand on the steering wheel. Also turn on the radio to your favorite channel.

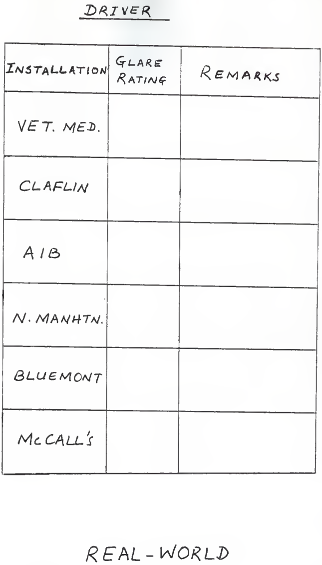
You will be driving the car under several different types of installations at a constant speed of 30 mph. Under each condition you will be asked to rate the glare criterion for luminance as per the North American Glare Scale (see attachment).

At the end of driving through a particular installation, I will change the installation on the simulator and once again you will rate the quality of lighting. Again please careful while rating for the best results.

There is neither any risk nor discomfort involved in taking part in the experiment. However, you are free to withdraw from the research at anytime, but we hope you will complete the session. Please feel free to ask any question at any time.

Thank you very much for your participation.

FIGURE 11: INSTRUCTION SHEET (SIMULATOR)



DRIVER

INSTALLATION	GLARE RATING	REMARKS
VET. MED.		
CLAFLIN		
AIB		
N. MANHTN.		
BLUEMONT		
McCALL'S		

REAL-WORLD

FIGURE 12: Rating Form

procedure was repeated. However, it should be noted that this procedure of subject running in the simulator was not true in the early stages of the subject running. That is, in the beginning one subject went through the simulator. Then he and his partner went through the real-world installations, and then after the real-world the other partner was run through the simulator. This procedure was continued with the first 24 subjects. The remaining 36 subjects were run first through the simulator and then through the real-world lighting installations.

Real-World This part of the experiment was conducted after sunset. Each pair was called again to drive or ride through six roadway lighting installations. A detailed instruction sheet (Figure 13) was prepared for this task also. Once again the same 30 pairs who rated the quality of lights in the simulator were asked to randomly select a sequence of roadway installations. If the order was the same as the one they went through in the simulator, they were asked to make another selection.

A 1976 Chrysler Cordoba car was used for the real-world experimentation. Since it was found that there is no statistically significant difference in the glare responses of a driver and a passenger (Hussain, 1984), two subjects rode or drove through the lighting installation at the same time. Once again, they used the North American Glare Scale to rate the quality of light, and the same type of rating forms were used. Also, all the subjects were accompanied by the experimenter through all the installations; it was made sure that the subjects

INSTRUCTION SHEET NO.3

First we will go on the road and drive through several different installations in the city of Manhattan. Please get into the car and fasten the seat belt.

While on the road you are required to strictly observe all the traffic laws e.g. speed limits (in all cases it will be 30 mph), road signs, etc. Try to be in the left or outside lane when I ask you to drive through a particular installation. At some instant I will ask you to rate the quality of lighting of a particular system. After some time I will ask you to pull over to the side of the road (if possible), and consult the North American Glare Scale to rate the quality of lighting.

In all the cases try to assume that you are driving alone and that you are not in experimental situation. When you rate a particular luminaire, please try to be careful and honest so that we get the best results.

There is neither any risk nor discomfort involved in taking part in the experiment. However, you are free to withdraw from the research at any time, but we hope that you will complete the session. Feel free to ask if there is any question or confusion.

Thank you very much for your participation.

FIGURE 13: INSTRUCTION SHEET (ROADWAY)

did not discuss the rating or their feelings with each other. In this case also, driving through each installation lasted 30 seconds on the average, and the driving speed was maintained at 30 mph.

Instructions and Informed Consent

Three instruction sheets were prepared for the subjects. Instruction Sheet No. 1 (Figure 9) was prepared to give a general idea of the experiment, to familiarize the subjects with the new North American Glare Scale (Figure 10), and the task. Instruction Sheet No. 2 (Figure 11) and Instruction Sheet No. 3 (Figure 13) were prepared for the specific tasks of the simulator and the real-world roadway installations.

Similarly, an Informed Consent (Figure 14) was prepared for each subject, which showed the conditions of the experiment and the willingness of the subjects to appear in the experiment.

Experimental Design

The two major hypotheses to be tested in this experiment were:

Ho1: Mean responses of subjects on the roadway =
Predicted values

versus

Ha2: Ho2 is not true.

Also, Ho3: Mean responses of driver = Mean responses of passenger

versus

Ha3: Ho3 is not true.

Ho4: $Q_1 = Q_2 = ... = Q_n$

versus

INFORMED CONSENT

1) There is neither risk or discomfort involved in taking part in the experiment except that you might find some lighting installations uncomfortable.

2) All the information regarding your participation in this research will be kept strictly confidential. Your performance as an individual will be treated as research data and will in no way be associated with you for other than identification purposes, thereby assuring anonymity of your responses and observations. Also, some public reports and articles may be made of the experiment, but in all cases your identity will be kept confidential.

3) Your participation in this project is voluntary. Your refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You will be permitted to leave at any time and/or may discontinue the experiment without any penalty. However, I hope that you will complete the session.

4) Mr. Arif Hussain is conducting this research at the University with Dr. Corwin Bennett as advisor. If you have any questions regarding the experiment of your rights as a test subject, injuries or emergencies resulting from your participation in the experiment, you can contact Dr. Corwin A. Bennett at 532-5606.

Thank you very much for your participation.

I have read the Instructions Sheets No. 1, 2, and 3, and the above statements and agree to voluntarily participate in the experiment.

-----------------   ----------------------------------
Date   Signature

FIGURE 14: INFORMED CONSENT

Ha4: Ho4 is not true.

Here, Q = Quality of light, and

n = 1,..., 6 different installations

In order to test the first hypothesis, the experimental design selected was two way classification with a completely randomized design. Six types of installations and two experimental setups (real-world and simulator) were the independent variables. The dependent variable was the subjects rating of the lighting installations based upon the North American Glare Scale.

To test the above hypotheses F-tests, t-tests, and LSD methods were employed.

All the conditions such as driving speed, installation to drive through, etc. were kept constant in the real-world as well as in the simulator. However, the order of installations through which each pair went was different in the real-world as well as in the simulator and the selection of these orders was randomized.

Subjects and Recruitment Procedure

Over 100 subjects signed up for the experiment during the Summer 1984 registration at Kansas State University. Out of these, an incidental sample of 60 subjects were recruited and were paid at the rate of $15.00 per subject. All the subjects went through each lighting installation for 15-20 seconds in the real-world as well as the same simulated installations.

RESULTS

The mean rating by subjects with means for each installation are listed in Appendix 6, for real-world as well as for the simulator (Table 5).

The SAS program was run to perform an F-test to test whether there is any significant difference in the subjects responses in the real-world and simulated conditions (hypothesis 1). Table 6 gives the ANOVA table for tests 1, 3 and 4. To test hypothesis 1 t-tests also were performed individually for all the installations. Table 7 gives the mean ratings for the simulated installations along with the corresponding standard deviations and critical values of t.

Table 8 gives the results of Glaremark and CBE predictive systems alongwith their ranking according to the comfort of the installation. That is, a rank of "1" was assigned to the most comfortable installation. It should be, however, noted that the values of Glaremark shown in Table 8 are converted values, that is, the values have been converted to the values used in the North American Glare Scale. This was done as follows:

10 - original Glaremark predicted value = converted Glaremark value

For all the installations (real-world and simulated) and the predictive systems, a rank of 1 is used for the lowest number or the most comfortable installation. If the Glaremark was not converted according to the North American Glare Scale, the rank order would have been opposite, that is, lowest number would

TABLE 5

Means of glare responses from real-world and simulator

Subjects	Installatios	Real-world		Mean	Simulator		Mean
		* D	* P		D	P	
30	McCall	5.7	5.1	5.4	6.8	6.5	6.7
30	Claflin	4.0	3.4	3.6	3.9	4.1	4.0
30	Bluemont	3.4	3.8	3.1	5.2	4.9	5.1
30	N.Manhtn.	3.7	3.7	3.7	4.6	4.8	4.7
30	Vet.med	2.8	2.8	2.8	3.6	3.4	3.5
30	AIB	3.9	3.6	3.7	5.3	4.8	5.2
Mean		3.9	3.7	3.8	4.9	4.7	4.8

Overall mean = 4.3

*
D = Driver, and

P = Passenger.

TABLE 6

ANOVA Table for hypotheses 1 and 3.

Source	DF	Sum Of Squares	Mean Square	F-Value	PR > F
Model	371	2028.57	5.47	2.18	0.0001
Error	348	872.32	2.51		
Corrected Total	719	2900.89			

Source	DF	ANOVA SS	F-Value	PR > F
Pair	29	319.10	4.39	0.0001
IType	5	541.01	43.17	0.0001
Setup	1	191.17	76.26	0.0001
IType*Setup	5	27.96	2.23	0.0504
Pair*IType *Setup	319	928.15	1.16	0.0867
Seat	1	4.84	1.93	0.1658
IType*Seat	5	5.87	0.47	0.8024
Setup*Seat	1	0.04	0.01	0.9064
IType*Setup *Seat	5	10.46	0.83	0.5277

Test of hypotheses using the ANOVA MS for Pair*IType*Setup as an error term.

Source	DF	ANOVE SS	F-Value	PR > F
IType	5	541.01	37.19	0.0001
Setup	1	191.17	65.70	0.0001
IType*Setup	5	27.96	1.92	0.0894

IType = Type of installation,
Seat = Driver or passenger,
Setup = Real-world or simulator.

TABLE 7

T-tests for hypothesis 1 (comparision of roadway and simulator)

Subjects	Installation	Real-world	Simulator	S	t*
60	McCall	5.40	6.63	1.61	-5.76
60	Claflin	3.68	4.03	1.90	-2.71
60	Bluemont	3.10	5.03	1.60	-7.03
60	N.Manhtn.	3.60	4.67	1.83	-4.60
60	Vet.Med	2.80	3.48	1.74	-3.27
60	AIB	5.17	5.17	1.92	-5.65

S = Standard deviation of roadway results.

$$t = \frac{(\text{Mean of roadway} - \text{Mean of simulation})\,(n)^{1/2}}{\text{Standard deviation of roadway}}$$

If $t > t_{\alpha/2.(n-1)}$, reject the hypothesis.

* If the absolute value of t is greater than 1.96, the hypothsis is rejected at the 0.05 significance level.

TABLE 8

Rating (and ranking) of installations according to comfort.

Installation	Real-world	Simulator	Glaremark	CBE*
McCall	5.38(6)	6.63(6)	6.15(5)	709.37(6)
Claflin	3.68(4)	4.03(2)	5.37(4)	319.15(4)
Bluemont	3.62(2)	5.03(4)	5.01(3)	199.66(3)
N.Manhtn	3.60(3)	4.67(3)	4.89(2)	93.99(2)
Vet.Med.	2.80(1)	3.48(1)	7.38(6)	3.56(1)
AIB	3.76(5)	5.17(5)	4.25(1)	401.22(5)
Mean	3.80	4.80	5.50	287.86

* Predicted BCD luminance, fL.

indicate the most comfortable installation.

In order to test if there is a significant difference in the real-world and predicted results (hypothesis 2) t-tests were performed individually for all the installations and the Glaremark predictive system. Table 9 gives the mean responses of the subjects on the roadway for each installation, their corresponding standard deviations, critical values of t and results of the predictive systems.

For all installations the "Spearman's Rank Correlation Coefficient" or r was determined (Table 10) using combinations of results of all the possible variables, for example, results of real-world and Glaremark, Glaremark and CBE, etc. The sign of r indicates the nature of the relationship between two variables. Positive values indicate a tendency for the variables to increase together, and negative values indicate a tendency for one variable to increase while the other decreases. A "zero" correlation implies no relationship, while -1 and +1 correlations imply perfect negative and positive relationships, repectively.

Table 11 shows the average measured luminance of six lighting installations at the cut-off angle as well as the calculated luminances of the same installations. These calculations were made using the approach used in the evaluation of CBE values.

TABLE 9

T-test for hypothesis 2 (comparision of roadway and Glaremark)

Installation	Roadway	S	GM	t*
McCall	5.38	1.68	6.15	- 3.55
Claflin	3.68	1.66	5.37	- 7.89
Bluemont	3.62	1.51	5.01	- 7.13
N.Manhtn	3.60	1.80	7.38	- 15.91
Vet.Med.	2.80	1.61	4.89	- 10.05
AIB	3.75	1.92	4.25	- 2.02
Mean	3.80		5.50	

S = Standard Deviation

GM = Glaremark

$$t = \frac{(\text{Mean of roadway} - \text{Predicted value})\ (n)^{1/2}}{\text{Standard Deviation of Roadway}}$$

If $t > t_{\alpha/2,(n-1)}$, reject the hypothesis

* If the calculated value of t is greater than 1.96, the hypothesis is rejected at the 0.05 significance level.

TABLE 10

Spearman's Rank Correlation Coefficient

	Real-world	Simulator	Glaremark	CBE
Real-world	-	-	-	-
Simulator	0.77	-	-	-
Glaremark	-0.257	-0.37	-	-
CBE	0.94	0.83	-0.2	-

TABLE 11

Measured and calculated luminances at cut-off angle.

Installations	Average measured luminance at cut-off angle, "fl"	Calculated luminance at cut-off angle, "fl"
McCall	79300	25698
Claflin	8940	13752
Bluemont	9500	13752
N.Manhtn.	11630	11183
Vet.Med.	427	421
AIB	52000	21000

DISCUSSION

An experiment was run at Kansas State University to see whether there is a statistically significant difference in the glare responses of a driver and a passenger (Hussain, 1984). It was found that there is no difference in the responses. The confirmation of this hypothesis was important because in the real-world situation the results of this hypothesis were used and two subjects were run at the same time through the lighting installations. As shown in Table 6, since the interaction effect is not significant, the presence or absence of the main effects can be investigated. At the 0.05 significance level hypothesis 3 could not be rejected this shows that there is no significant difference in responses to glare between a driver and a passenger.

It has been found, that at the 0.05 significance level, there is enough evidence to say that null hypothesis 1 cannot be accepted. This means that there is a statistically significant difference in the glare responses of subjects in the real-world and simulated conditions. Also, the t-tests showed that all the results of the simulated installations were significantly different from the corresponding real-world installation (Table 7).

For each installation, the mean rating of the subjects is on the higher side for the simulator (Table 8) as compared to the real-world. That is, the discomfort was stronger in the simulator than the corresponding real-world lighting installation. The reason for this strong effect of glare in the simulator could be attributed to the following two important factors:

In real-world lighting installations, the overall effect of glare is somewhat lowered by other light fixtures such as the headlights of other motor vahicals, neon signs, light from houses, etc. In other words the background luminance in the real-world situation is high in the city because of ths the subjects never felt too much discomfort during night driving. On the other hand, in the simulator all the background luminance was provided by a light source (which was adjusted to a maximum of 1 cd/m) and the dash light (which on an average provide 18.4 cd/m). This caused a darker background in the simulator as compared to the real-world, with the result of which the same simulated lighting installation was more uncomfortable in the simulator than in the real-world.

The luminaires of all the lighting installations were measured with the help of a Spotmeter. It was found that the installations have luminaires/lamps which vary significantly in intensity (Appendix 2). Moreover, most of the installations were found to be old, misalligned, and their lamps were somewhat dimmed because of years of usage, dirt, and soot, etc. All these factors resulted in an less intense systems. On the other hand, the simulation was ideal; that is, the light source was properly aligned and clean which resulted in a rating on the higher side as compared to the real-world installations.

The Spearman's Rank Correlation Coefficient (Table 10) for real-world and simulator ($r = 0.77$) results, however, showed a stronge positive correlation to the real-world ranking which means the ranks of lighting installations (on the basis of comfort) for the two setups are very close. The rank order of almost all the real-world lighting installations was found to be similar to those of the simulator except the Bluemont and Claflin Avenues. In the real-world their ranking was 4 and 2 respectively, whereas in the simulator they ranked as 2 and 4. Apparently Bluemont and Claflin Avenue have almost the same parameters except that Bluemont is a double-sided installation and Claflin is a single-sided installation which. Therefore, the only reason that can be given for the difference in the real-world and simulator rankings for these installations is that the simulated brightness of Bluemont's luminaire was 11630 fl whereas the brightness of Claflin Avenue was 8940 fl (Appendix 2). This difference of 2700 fl did not make a significant difference in the real-world driving but the ideal environment of the simulator caused more discomfort to the subjects and hence a higher rating for Bluemont Avenue.

A t-test was performed for each installation to test hypothesis 2; that is, to see whether the results of the roadway matched the results of Glaremark predictive system (Table 9). At the 0.05 significance level it was found that the null hypothesis for all the installations could not be accepted. This means that there were statistically significant differences in all real-world and Glaremark results. More importantly, Spearman's Rank Correlation Coeffecient for real-world and Glaremark came out to be -0.257. This shows that the predictive system is very poorly correlated to the real-world results. The reason for poor correlation of the Glaremark with the real-world results is that, although McCall, Claflin, Bluemont, and the North Manhattan Avenue showed a ranking quite close to the real-world results, the ranks of Vet.Med. and AIB caused a major decline in the correlation coefficient. This is primarily because Vet.Med. installation has very low mounting heights and the luminaires are very closely spaced, while on the other hand in case of AIB there are only two luminaires. According to the restrictions imposed by the Glaremark, an installation with these parameter is not at all acceptable for prediction. That is, Glaremark cannot be applied to these installations at all.

Glaremark cannot be applied to a broad range/variety of installations because of the following restrictions (Glare and uniformity in road lighting installations, CIE Publication 31 (TC-4.6), 1977):

It is applicable to systems longer than 300 meters with the following range of variables

$50 < I\text{-}80 < 7000$ (cd)

$1 < I\text{-}80/I\text{-}88 < 50$

$7\times10 < F < 4\times10$ (m)

$0.3 < L < 7$ (cd/m)

$5 < h < 20$ (m)

$20 < p < 100$

In other words, the predictive system is applicable to those systems only where, the intensity "I" of luminaire at 80 degrees from the vertical is greater or equal to 50 candelas or less than or equal to 7000 candelas; the ratio of intensities at 80 and 88 degrees from the vertical lies between 1 and 50; the flashed area

"F" of the luminaire lies between 7x10 and 4x10 square meter; the average road surface luminance "L" lies between 0.3 and 7 cd/m ; the difference of the mounting height and the eye level "H" should lie between 5 and 20 feet; the number of luminaires in one kilometer "P" should be between 20 and 100.

According to the researchers who developed the empirical relationship for Glaremark, these restrictions should be strictly observed in order to use Glaremark effectively. It is possible that in big cities more than one installation meet all the requirements of Glaremark but in Manhattan it was observed that all six installations which were selected for the experiment fell out of the range of at least one of these restrictions and, therefore, Glaremark did not prove to be a useful tool for predicting discomfort glare for these installations.

The basic concept of a predictive system is that it should be able to predict the discomfort glare (with reasonable accuracy) from all types of lighting installations and not only ideal systems, such as like those which are perfectly clean and alligned, with road surface properties constant, etc. So because of the restrictions Glaremark cannot be applied to a lot of practical situations like the ones selected for the experiment.

The lighting installations in the city of Manhattan are not ideal. The six lighting installations selected for the experiment are perhaps representative lighting installations of the United States. That is, everywhere one will find (for the same installation) different mounting heights, spacing, photometric characteristics, etc. Therefore, if Glaremark cannot predict the discomfort glare from these lighting installations then it is probably not suitable for North America. This predictive system was tested twice (Keck and Odle, 1975 and Gallagher, 1981) but unfortunately could not be validated. Therefore, instead of trying to validate Glaremark forever, research on the predictive systems should be diverted elsewhere.

A point, when the visual sensation experienced by the observer changes from comfortable to uncomfortable, called "Borderline Between Comfort and Discomfort" or "BCD" can be obtained by a properly instructed observer who has means to vary the luminance level of the light source. This concept of BCD was used to develop the equation for "Cumulative Brightness Evaluation" or "CBE" which combines the effect of several sources of differing brightness and location. Now, the predicted values of CBE cannot be compared with the results of real-world installations as was done in the case of Glaremark. This is because Glaremark uses the same ordinal scale for rating an installation as in the case of real-world, that is, the North American Glare Scale (as transformed above). The values of CBE can be compared directly only with the luminance at the BCD for each installation which is not possible because of the experimental design. It is, however, possible to predict from the mathematical combination of all the luminances in the field of view, which of the six installations is the most comfortable. The rankings so obtained can then be compared with the real-world rankings. Therefore, the Spearman's Rank Correlation Coeffecient for the results of real-world and CBE (Table 10) indicate a very strong positive correlation (0.94). The only difference in ranks was found in Bluemont and North Manhattan Avenue. In the real-world the results showed that Bluemont is more comfortable than North Manhattan Avenue, whereas CBE predicts the opposite. Logically CBE has predicted correctly because North Manhattan Avenue is a 250W installation whereas Bluemont is a 400W installation, and the higher the wattage, and, thus intensity of the system (keeping other factors constant) the more discomfort it can provide. However the subjects rating was not wrong either, because the actual luminance measurements for the two installations showed that even though North Manhattan is a 250W installation its average luminance is 11630 fl as compared to Bluemont's which is 9500 fl. Bluemont Avenue is one of the major and busiest roadways of Manhattan where traffic rush (and hence the disturbance from other light sources) even at midnight is higher then the North Manhattan Avenue, where the background luminance is considerably lower. Less traffic on North Manhattan means less disturbance from other light sources and less dirty luminaires (because of vehicle exhaust). Therefore, the overall effect on subjects was to give, on an average, the same rating for the two different installations. On the other hand CBE was not affected by these factors and predicted the ranking.

Another very interesting fact which was observed with CBE was the way it calculates the brightness of a particular luminaire.

$$\text{Brightness} = \frac{\text{Intensity (cd)}}{\text{Apparent bright area (in}^2)} \times 452 = \text{fl}$$

Where,

Intensity = Intensity (from data) x Light Loss Factors

Apparent bright area was calculated as mentioned in the method section.

Using this approach, the brightness of all the lighting installations was calculated at the cut-off angle. It was observed that the calculated values matched with at least one of the values obtained with the help of a Spotmeter for all the installations. For example, the calculated brightness at the cut-off angle for Claflin and North Manhattan Avenue were 13752 fL and 11183 fL respectively, and these values matched with atleast one observed value of each installation. In the case of Bluemont Avenue where the readings were fairly similar to the calculated value of 10,000 fl almost matched with the average observed value of 9500 fl. It was, however, noticed that the average measured luminance does not match the calculated values (Table 11). The reason that all the observed values did not match the calculated values is the varying luminances of the luminaires in the same installation. This shows that CBE system can be relied upon for predicting the discomfort glare, if the formula is somehow revised to give the reasonable numbers, that is, numbers which could be directly compared with the North American Glare Scale.

An F-test was performed (Table 6) to see if the quality of light is the same for all the lighting installations. It was found that all the lighting installations differ from each other in the quality of light. However,the mean ratings of the quality of light (on the basis of the North American Glare Scale) by 60 subjects showed that all but one of the real-world lighting installations selected for the experiment are comfortable for night driving. For example, the mean rating of all the lighting installations lies between 2.8 for Vet.Med. installation and 3.77 for AIB, which is very comfortable on the basis of North American Glare Scale. The mean rating for McCall road came out to be 5.38 which is slightly uncomfortable.

CONCLUSIONS

The effect of glare from a simulated lighting installation is found to be higher in the dynamic simulator as compared to the corresponding real-world lighting installation. However, on the basis of comfort, the rank orders of installations in simulator came out to very close to those of real-world. This shows that with the dynamic simulator can be used effectively for roadway lighting experiments.

The European system (Glaremark) proved to be inappropriate for predicting discomfort glare from roadway lighting in these cases.

The North American system (Cumulative Brightness Evaluation, or CBE) has shown a very strong correlation to the real-world rank orders on the basis of comfort. Further research in CBE is needed to develop it into a formula which gives predicted values compatible to the North American Glare Scale.

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APPENDIX I

Program for single and double spiral plots

```
//FORT.SYSIN DD *
C*************************************************
C--DYNAMIC DISK SPIRAL PLOT---------------BEGIN------------
C--VARIABLE DECLARATION
      REAL H.V,S,INRAD.CUTANG.LHT.EYELVL,X,Y,RADIUS,ANGLE.
     -   INITAN,HEIGHT,FINANG,SHIFT,SHFT,D,A2,B1,C1
      INTEGER COUNT.INIT.FINAL,REV.I
C--THIS SPACE IS RESERVED FOR VARIABLE ASSIGNMENT
C--MCCALL ROAD. SINGLE SIDED 400W COBRAHEAD. N°S.
      H = 41.0
C     H = MOUNTING HEIGHT (FEET)
      V = 42.
C     V = VIEWING DISTANCE IN THE SIMULATOR (INCHES)
      S = 210.0
C     S = LUMINARE LONGITUDINAL SPACING (FEET)
      INRAD = 2.
C     INRAD = INNER DISK HUB RADIUS (INCHES)
      REV = 8
C     REV = NUMBER OF PLOT REVOLUTIONS
      CUTANG = .349
C     CUTANG = CUT OFF ANGLE (RADIANS)
      LHT = 6.75
C     LHT = VERTICLE DIMENSION OF LUMINARE (INCHES)
      EYELVL = 3.5
C     EYELVL = EYE LEVEL OF THE OBSERVER (FEET)
      D = 14.875
C     D = DEPTH OF THE LUMINAIRE (INCHES)
      SHFT = 0.0
C     SHFT = SHIFT ANGLE BETWEEN TWO DOUBLE SPIRALS
C--PLOT INNER SPIRAL
      HEIGHT = H-EYELVL
      CALL PLTOPT('PAPERWIDTH=WIDE.COPIES=2#')
      CALL PLOTS
      CALL PLOT(25.0.17.0.23)
      SHIFT=-3.37
C-- PLOT INITIAL POINT
      RADIUS=V*TAN(CUTANG)
      INITAN = (2.*3.1416*HEIGHT*V)/(S*RADIUS) + SHIFT
      X=(RADIUS+INRAD)*COS(INITAN)
      Y=(RADIUS+INRAD)*SIN(INITAN)
      CALL  SMOOTH(X,Y,0)
C--FIND LOOP PARAMETERS
         INIT = INT((INITAN - SHIFT)*8. / 3.1416) + 1
         FINAL = 16*REV
C-- PLOT SPIRAL
      DO 10 COUNT = INIT,FINAL
         ANGLE = COUNT*3.1416/8. + SHIFT
         RADIUS = ((2.*3.1416*HEIGHT*V)/(S*(ANGLE-SHIFT))) + INRAD
         X = RADIUS*COS(ANGLE)
         Y = RADIUS*SIN(ANGLE)
         CALL SMOOTH(X.Y.2)
```

```
10    CONTINUE
C--PLOT FINAL POINT
      FINANG = (FINAL+1.)*3.1416/8. + SHIFT
         RADIUS = ((2.*3.1416*HEIGHT*V)/(S*(FINANG-SHIFT))) + INRAD
      X=RADIUS*COS(FINANG)
      Y=RADIUS*SIN(FINANG)
      CALL SMOOTH(X.Y,24)
C--PLOT OUTER SPIRAL
C-- PLOT INITIAL POINT
      RADIUS= V*TAN(CUTANG)*(1.+(D/(12.*HEIGHT)))-0.025
      X=(RADIUS+INRAD)*COS(INITAN)
      Y=(RADIUS+INRAD)*SIN(INITAN)
      CALL SMOOTH(X,Y,0)
C--PLOT SPIRAL
      DO 11 COUNT = INIT,FINAL
         ANGLE=COUNT*3.1416/8. + SHIFT
         LHTV = ((D-LHT)/(INITAN-2*3.1416*REV))*(ANGLE-INITAN)+D
         RADIUS=((2.*3.1416*HEIGHT*V)/(S*(ANGLE - SHIFT)))*
     -          (1.+(LHTV/(12.*HEIGHT)))+INRAD-0.025
         X = RADIUS*COS(ANGLE)
         Y = RADIUS*SIN(ANGLE)
         CALL SMOOTH(X,Y,2)
11    CONTINUE
C--PLOT FINAL POINT
         RADIUS=((2.*3.1416*HEIGHT*V)/(S*(FINANG-SHIFT)))*(1.+
     -          (LHT/(12.*HEIGHT)))-0.025
      X=(RADIUS+INRAD)*COS(FINANG)
      Y=(RADIUS+INRAD)*SIN(FINANG)
      CALL SMOOTH(X,Y,24)
      SHIFT = SHFT
C--PLOT CENTER LINES
      CALL PLOT(0.,1.,3)
      CALL PLOT(0..-1.,2)
      CALL PLOT(1.,0..3)
      CALL PLOT(-1..0..2)
C-- TERMINATE PLOT PROGRAM
      CALL PLOT(0.,0.,999)
      STOP
      END
/*
```

```
C***************************************************
C--DYNAMIC DISK SPIRAL PLOT----------------BEGIN------------
C--VARIABLE DECLARATION
      REAL H.V.S.INRAD.CUTANG.LHT.EYELVL.X.Y.RADIUS.ANGLE,
     -   INITAN.HEIGHT.FINANG.SHIFT.SHFT,D.A2.B1,C1
      INTEGER COUNT.INIT.FINAL,REV,I
C--BLUEMONT, DOUBLE SIDED 400W COBRAHEAD.
C--THIS SPACE IS RESERVED FOR VARIABLE ASSIGNMENT
      H = 30.5
C     H = MOUNTING HEIGHT (FEET)
      V = 42.
C     V = VIEWING DISTANCE IN THE SIMULATOR (INCHES)
      S = 236
C     S = LUMINARE LONGITUDINAL SPACING (FEET)
      INRAD = 2.
C     INRAD = INNER DISK HUB RADIUS (INCHES)
      REV = 8
C     REV = NUMBER OF PLOT REVOLUTIONS
      CUTANG = .349
C     CUTANG = CUT OFF ANGLE (RADIANS)
      LHT = 6.75
C     LHT = VERTICLE DIMENSION OF LUMINARE (INCHES)
      EYELVL = 3.5
C     EYELVL = EYE LEVEL OF THE OBSERVER (FEET)
```

```
      D = 14.875
C     D = DEPTN OF THE LUMINAIRE (INCHES)
      SNFT = 0.908 + 3.1415
C     SHFT = SNIFT ANGLE BETWEEN TWO DOUBLE SPIRALS
C--PLOT INNER SPIRAL
      HEIGHT = H-EYELVL
      CALL PLTOPT('PAPERWIDTH=WIDE,COPIES=2#')
      CALL PLOTS
      CALL PLOT(25.0,15.0,23)
      SHIFT=0
C--REPEAT TWICE FOR DOUBLE SPIRAL PLOT
      DO 20 I = 1,2
C-- PLOT INITIAL POINT
      RADIUS=V*TAN(CUTANG)
      INITAN = (2.*3.1416*HEIGHT*V)/(S*RADIUS) + SHIFT
      X=(RADIUS+INRAD)*COS(INITAN)
      Y=(RADIUS+INRAD)*SIN(INITAN)
      CALL  SMOOTN(X,Y,0)
C--FIND LOOP PARAMETERS
        INIT = INT((INITAN - SHIFT)*8. / 3.1416) + 1
        FINAL = 16*REV
C-- PLOT SPIRAL
      DO 10 COUNT = INIT.FINAL
         ANGLE = COUNT*3.1416/8. + SHIFT
         RADIUS = ((2.*3.1416*NEIGHT*V)/(S*(ANGLE-SHIFT))) + INRAD
         X = RADIUS*COS(ANGLE)
         Y = RADIUS*SIN(ANGLE)
         CALL SMOOTN(X,Y,2)
10    CONTINUE
C--PLOT FINAL POINT
      FINANG = (FINAL+1.)*3.1416/8. + SNIFT
         RADIUS = ((2.*3.1416*HEIGHT*V)/(S*(FINANG-SHIFT))) + INRAD
      X=RADIUS*COS(FINANG)
      Y=RADIUS*SIN(FINANG)
      CALL SMOOTH(X.Y.24)
C--PLOT OUTER SPIRAL
C-- PLOT INITIAL POINT
      RADIUS= V*TAN(CUTANG)*(1.+(D/(12.*HEIGHT)))-0.025
      X=(RADIUS+INRAD)*COS(INITAN)
      Y=(RADIUS+INRAD)*SIN(INITAN)
      CALL SMOOTH(X,Y.0)
C--PLOT SPIRAL
      DO 11 COUNT = INIT,FINAL
         ANGLE=COUNT*3.1416/8. + SHIFT
         LHTV = ((D-LHT)/(INITAN-2*3.1416*REV))*(ANGLE-INITAN)+D
         RADIUS=((2.*3.1416*HEIGNT*V)/(S*(ANGLE - SHIFT)))*
     -         (1.+(LHTV/(12.*HEIGNT)))+INRAD-0.025
         X = RADIUS*COS(ANGLE)
         Y = RADIUS*SIN(ANGLE)
         CALL SMOOTH(X,Y,2)
11    CONTINUE
```

```
C--PLOT FINAL POINT
         RADIUS=((2.*3.1416*HEIGHT*V)/(S*(FINANG-SHIFT)))*(1.+
     -             (LHT/(12.*HEIGHT)))-0.025
      X=(RADIUS+INRAD)*COS(FINANG)
      Y=(RADIUS+INRAD)*SIN(FINANG)
      CALL SMOOTH(X,Y,24)
      SHIFT = SHFT
20    CONTINUE
C--PLOT CENTER LINES
      CALL PLOT(0.,1.,3)
      CALL PLOT(0.,-1.,2)
      CALL PLOT(1.,0.,3)
      CALL PLOT(-1.,0.,2)
C-- TERMINATE PLOT PROGRAM
      CALL PLOT(0.,0.,999)
      STOP
      END
/*
```

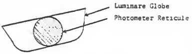
APPENDIX II

Dale's report

Manhattan Roadlight Measurements

To: Dr. Bennett
From: O. Dubbert

The following luminance measurements were taken with the portable spotmeter. Each luminare was measured at a cutoff angle of 20° from horizontal. Some luminares, however, were measured at a somwhat closer distance in order to match the photometer reticule size with the luminare size. The photometer reticule was centered on the luminare globe which allowed the reticule to cover better than 30% of the globe surface as the figure below illustrates.



Approximate Retácule Positioning on Luminare Globe

A total of six installations were measured, five with the spotmeter (luminance) and one with the Vactec photometer (illuminance).

Luminance Data

1. Claflin Road from Denison Ave. to N. Manhattan Ave., Single Sided with Cobrahead Fixtures.

Seven luminares measured:

13500 fL
6900 fL
11000 fL
20800 fL
3500 fL
3600 fL
3300 fL

Mean: 8940 fL

Standard Deviation: 6580 fL

2. N. Manhattan Ave. from Claflin Rd. to Bluemont Ave., Double sided, Staggered with Cobrahead fixtures.

   Four luminares measured:

   10500 fL
   10000 fL
   11000 fL
   15000 fL

   Mean: 11630 fL
   Standard Deviation: 2290 fL

3. Bluemont Ave. from N. Manhattan Ave. to Juliette Ave., Double Sided with Cobrahead Fixtures.

   Three luminares measured:

   8000 fL
   10000 fL
   10500 fL

   Mean: 9500 fL
   Standard Deviation: 1323 fL

4. McCall Rd. near Harding Glass Co., Single Sided H.P.S. with Cobrahead fixtures.

   Three luminares measured:

   150000 fL
   60000 fL
   28000 fL

   Mean: 79300 fL
   Standard Deviation: 63300 fL

5. Vet. Med. Center Parking Lot, Globe Luminares.

   Three luminares measured:

   400 fL
   280 fL
   600 fL

   Mean: 427 fL
   Stand Deviation: 162 fL

6. American Institute of Baking, Two H.P.S. Cutoff Luminares.

Because of the nonuniform distribution of light with the H.P.S. luminare the direct measurement technique was not used on this partucular installation. The Illuminance at the 20° cutoff angle was measured using the Vactec low level photometer. The surface illumination at the cutoff angle was found to be:

0.441 fc

Each particular mean lumination level was then matched with an equivalent level within the simulator by using the spotmeter or the Vactec photometer in the case of the A.I.B. installation.

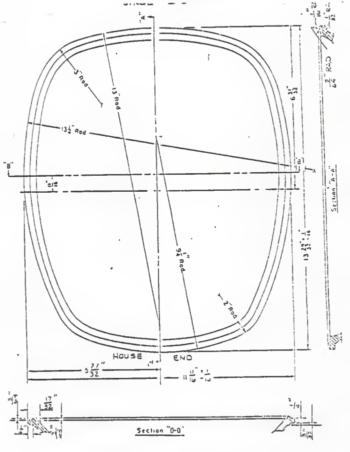
From simple observation of the installations, the nearest to ideal setups i.e. the straightest, most uniform and least ocluded rows of lights were found to be N. Manhattan Ave. and Bluemont Ave. The installations at Claflin Rd., Vet. Med Center , and McCall Rd. were found to be very nonuniform in luminance. The Claflin Rd. installation exhibited several different color temperatures indicating that different luminares were being used in the same installation. The McCall Rd. setup has luminares which vary up to five fold in brightness.

The Manhattan road light installations proved to be far from the near ideal lab simulation, however, due to the limits of the simulator parameters, a true simulation would prove to be far to complex and impractical.

Dale Dubbert 8-13-84

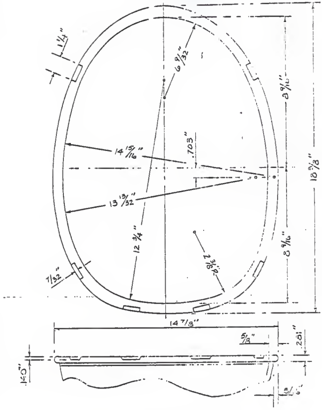
APPENDIX III

Diagram of Refractors



REFRACTOR FOR SMALL HORIZONTAL
BURNING HID LUMINAIRE
FIG. 41

All 100/175/250 W Outside depth = Glass 4⅝" Acrylic 5⅝"



REFRACTOR FOR MEDIUM HORIZONTAL
BURNING HID LUMINAIRE

FIG. #3

GE 400W

Outside depth = 6¾"

APPENDIX IV

Candelpower Tables

```
****ROADWAY PHOTOMETRIC CURVES AS OF  4/17/84 ****                PAGE NO  1

CURVE NO   LUMINAIRE LAMP      DIST-TYP  SOC.P. REV COMMENTS-------  AUT  OATE

 175822*  M-4000RA  H400A      M-N-III   1       1  NA                CRB  7901

CURVE LAST MOOIFIEO ON 790131

OIRECTORY RECORO         288
CD OATA FILE RECORO     1962
CANOLEPOWER CONSTANT      1.0000
LUMEN RATING              100000
HORIZONTAL INCREMENT      10.000
VERTICAL INCREMENT        10.000
CRIT. HOR. INCREMENT       5.000
CRIT. VER. INCREMENT       2.500
CRIT. HOR. START          52.500
CRIT. VER. START          60.000

                        CANDELA OATA  (02)

 HORZ    VERTICAL ANGLE >>---->
ANGLE    0.0    5.0   15.0   25.0   35.0   45.0   55.0   65.0   75.0   85.0   95.0  105.0
  0.0  13700  17850  22800  18400  12800   8545  10700   8150   3325   1265    764      0
  5.0  13700 1.7700  22500  19000  13900   9630  11200   9100   3670   1530    841      0
 15.0  13700  17400  21900  20200  16100  11800  12200  11000   4360   2060    994    382
 25.0  13700  17000  21600  21400  17400  12900  10800  12600   5430   2140   1070    382
 35.0  13700  16400  21100  21200  18700  15300  12500  14500   6650   2830   1220    841
 45.0  13700  15500  19700  21500  21500  21900  20100  18700  11200   6110   1610    382
 55.0  13700  14900  18000  21200  24500  26800  35500  27300  25800  12700   1990    841
 65.0  13700  14400  15500  19100  25800  31700  45600  42000  51300  15100   2060    459
 75.0  13700  13800  13400  16100  21700  34700  40200  48600  58700  11900   2060    841
 85.0  13700  13100  11500  12700  16300  28100  26500  36300  35800   6340   1760    841
 95.0  13700  12200   9550   9400  11800  18200  16300  19200  15300   2930   1150    459
105.0  13700  11400   7570   6800   8640  10800  10100   9550   5430   1450    917      0
115.0  13700  10500   6420   5430   6730   8480   8410   6500   2900   1220    459      0
125.0  13700   9940   5500   5120   6340   7800   8100   5270   2220    917    459      0
135.0  13700   9480   5040   5890   6110   6500   7640   4360   1910    917      0      0
145.0  13700   9170   4820   5200   5960   5660   6650   3820   1910    841      0      0
155.0  13700   8790   4890   4740   5960   5730   6270   3820   1680    841      0      0
165.0  13700   8560   4890   5730   6190.  5810   6340   4130   1450      0      0      0
175.0  13700   8640   5040   5730   6340   5890   6110   4200   1610      0      0      0

                        CRITICAL CANDELA OATA  (04)

         60.0   62.5   65.0   67.5   70.0   72.5   75.0   77.5   80.0   82.5   85.0   87.5
 52.5   28100  25500  23200  23200  21500  21100  19900  19600  17900  14300  10600   6570
 57.5   33000  31800  25200  30200  30200  31700  30300  30700  25800  18700  13100   7800
 62.5   37700  37400  37900  38500  41300  44300  44900  39400  32600  21700  14300   8330
 67.5   40000  42200  44000  47600  52400  55600  55300  45300  35300  21300  13800   7950
 72.5   40200  44100  46100  52900  59200  62300  59000  45900  32600  12100  12100   7030
 77.5   37700  42400  47200  51500  58100  60200  53700  39100  27300   7950   9550   5730
 82.5   32900  37300  41400  45600  50400  50000  41900  31000  20700   4820   7030   4590
 87.5   27400  29900  32200  35500  37800  37300  28300  21800  13900   2900   4740   2980
 92.5   21600  22300  23000  24800  25100  23200  18600  13700   8480  12200   3060   2450
 97.5   15800  16400  16400  16600  15600  14400  11000.  8560   5270  10900   2060   1680
102.5   12300  12700  11500  10200   9170   8180   6270   4740   3060   8640   1450   1380
107.5   10500  10400   8480   6960   5730   5270   3900   3290   2140   6420   1300   1070
112.5    9710   9860   6880   5200   4130   3820   3060   2680   1910   1380    994    994
117.5    9400   9100   6420   4280   3520   2830   2520   2060   1530   1300    917    841
122.5    9020   8100   5660   3820.  3130   2600   2290   1910   1530   1070    917    917
127.5    8560   7870   5270   3670   2830   2220   1990   1610   1150   1070    841    841
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****ROADWAY PHOTOMETRIC CURVES AS OF 10/ 3/84 ****                 PAGE NO  1

CURVE NO   LUMINAIRE LAMP      DIST-TYP  SOC.P. REV COMMENTS-------  AUT  DATE

 176537* / M-250R    H250A      L-N-III   8H      0                   NCP  8008

CURVE LAST MODIFIED ON 800811

DIRECTORY RECORD        487
CD DATA FILE RECORD    3331
CANDLEPOWER CONSTANT      1.0000
LUMEN RATING              10000
HORIZONTAL INCREMENT     10.000
VERTICAL INCREMENT       10.000
CRIT. HOR. INCREMENT      5.000
CRIT. VER. INCREMENT      2.500
CRIT. HOR. START         52.500
CRIT. VER. START         60.000

                          CANDELA DATA   (02)

 HORZ    VERTICAL ANGLE >>---->
ANGLE    0.0    5.0   15.0   25.0   35.0   45.0   55.0   65.0   75.0   85.0   95.0  105.0
  0.0   1705   1905   2304   2284   1089    707    550    483    324    206    164    129
  5.0   1705   1894   2289   2335   1232    713    506    529    380    257    190    139
 15.0   1705   1883   2274   2306   1375    719    562    575    436    308    216    149
 25.0   1705   1837   2258   2412   1642    847    821    718    498    304    267    149
 35.0   1705   1812   2243   2433   1950   1150   1057    875    518    349    257    144
 45.0   1705   1796   2155   2453   2335   1570   1329   1191    734    390    205    144
 55.0   1705   1755   2037   2294   2525   1858   1488   1488   1237    647    210    133
 65.0   1705   1740   1909   2104   2412   2109   1694   1919   2273   1032    241    154
 75.0   1705   1704   1760   1894   2109   1960   1837   2356   3166   1324    262    169
 85.0   1705   1678   1611   1658   1781   1740   1776   2273   2658   1170    241    164
 95.0   1705   1632   1488   1447   1540   1601   1560   1704   1499    801    216    159
105.0   1705   1601   1381   1288   1334   1540   1355   1242    965    539    205    149
115.0   1705   1570   1293   1196   1185   1386   1139    990    683    380    180    128
125.0   1705   1534   1216   1103   1032    996    847    713    544    287    185    123
135.0   1705   1504   1155   1011    847    713    672    616    457    339    190    118
145.0   1705   1493   1124    867    698    647    626    667    452    385    190    123
155.0   1705   1475   1083    780    621    611    600    672    436    293    195    128
165.0   1705   1468   1052    729    575    606    631    657    385    225    154     87
175.0   1705   1463   1032    693    565    585    683    754    405    190    128     87

                          CRITICAL CANDELA DATA   (04)

         60.0   62.5   65.0   67.5   70.0   72.5   75.0   77.5   80.0   82.5   85.0   87.5
 52.5   1432   1416   1406   1345   1237   1201   1042    872    770    667    565    421
 57.5   1540   1591   1581   1560   1504   1488   1437   1273   1078    929    734    529
 62.5   1683   1776   1791   1853   1889   1904   1955   1342   1493   1232    929    642
 67.5   1894   1981   2048   2238   2340   2438   2592   2438   1971   1550   1139    724
 72.5   2048   2155   2315   2510   2710   2864   3064   2925   2350   1832   1293    736
 77.5   2155   2263   2407   2628   2869   3084   3274   3033   2484   1940   1360    801
 82.5   2145   2253   2371   2566   2756   2894   2961   2756   2259   1731   1252    775
 87.5   2007   2089   2175   2243   2335   2392   2361   2202   1873   1499   1093    598
 92.5   1781   1637   1803   1827   1363   1332   1699   1581   1370   1124    878    600
 97.5   1550   1555   1545   1509   1524   1442   1293   1170   1032    867    734    534
102.5   1345   1329   1324   1309   1273   1170   1057    919    811    703    595    472
107.5   1196   1155   1170   1165   1093    991    878    749    657    559    485    400
112.5   1062   1057   1073   1073    960    847    734    621    529    457    411    344
117.5    919    893    913    960    857    729    636    534    446    411    354    303
122.5    795    760    770    780    739    657    575    428    400    347    298    257
127.5    703    667    657    542    595    570    518    452    375    318    282    257
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****ROADWAY PHOTOMETRIC CURVES AS OF  4/17/84 ****                    PAGE NO  1

CURVE NO   LUMINAIRE LAMP      OIST-TYP  SOC.P. REV COMMENTS-------  AUT  DATE

  175816*  M-4000RA  LU400200  M-N-III   2       1  NA                 WCP  7902

CURVE LAST MOOIFIED ON 790202

DIRECTORY RECORD        283
CD DATA FILE RECORO     260
CANOLEPOWER CONSTANT      1.0000
LUMEN RATING              10000
HORIZONTAL INCREMENT     10.000
VERTICAL INCREMENT       10.000
CRIT. HOR. INCREMENT      5.000
CRIT. VER. INCREMENT      2.500
CRIT. HOR. START         52.500
CRIT. VER. START         60.000

                   CANOELA OATA  (02)

 HORZ    VERTICAL ANGLE >>---->
ANGLE    0.0    5.0   15.0   25.0   35.0   45.0   55.0   65.0   75.0   35.0   95.0  105.0
  0.0   1349   1585   1832   1626   1426   1086   1255   1261    380    226    144    103
  5.0   1349   1575   1796   1652   1400   1009   1065   1086    427    226    144    103
 15.0   1349   1565   1760   1678   1374    932    875    911    474    226    144    103
 25.0   1349   1539   1770   1750   1508   1086    834    782    551    273    160    103
 35.0   1349   1503   1765   1868   1951   1616   1312   1101    329    540    226    113
 45.0   1349   1467   1729   1961   2141   2105   1868   1642   1441   1235    288    118
 55.0   1349   1431   1668   1791   2033   2239   2419   2779   2795   1894    314    129
 65.0   1349   1395   1570   1359   1755   2357   2897   4179   5496   1853    319    134
 75.0   1349   1354   1462   1034   1719   2162   2820   4220   6310   1390    283    139
 85.0   1349   1318   1318    839   1420   1673   2167   2872   3561    751    221    134
 95.0   1349   1256   1179    710   1153   1297   1559   1348   1379    360    165    118
105.0   1349   1220   1029    618    916    988   1070   1127    597    211    129     93
115.0   1349   1173    896    576    762    793    334    726    355    149    103     77
125.0   1349   1143    777    571    679    710    710    525    247    118     87     62
135.0   1349   1112    700    607    669    700    654    396    170    108     77     52
145.0   1349   1091    643    654    705    695    618    381    144     98     67     52
155.0   1349   1076    633    684    731    695    587    381    154     87     62     46
165.0   1349   1065    633    721    772    705    587    381    175     82     62     41
175.0   1349   1055    628    741    793    721    597    396    180     87     57     41

                   CRITICAL CANDELA OATA  (04)

         60.0   62.5   65.0   67.5   70.0   72.5   75.0   77.5   80.0   82.5   85.0   87.5
 52.5   2403   2429   2434   2434   2337   2290   2290   2306   2403   2409   1822   1235
 57.5   2892   2985   3129   3232   3186   3108   3304   3567   3664   2995   1971   1235
 62.5   3325   3587   3880   4055   3973   4143   4786   5172   4498   3186   1925   1209
 67.5   3685   4071   4477   4483   4658   5322   6212   5996   4508   2975   1786   1153
 72.5   3788   4302   4493   4472   5188   6268   6690   5651   3901   2506   1549   1024
 77.5   3567   3963   3953   4210   5342   6402   5939   4503   2980   1925   1235    834
 82.5   3047   3201   3201   3736   4966   5455   4344   3062   2028   1364    896    623
 87.5   2419   2439   2553   3175   4184   3999   2784   1930   1287    896    618    443
 92.5   1909   1889   2059   2614   3253   2671   1698   1158    793    582    422    324
 97.5   1518   1503   1642   2033   2311   1704   1060    731    515    396    304    242
102.5   1215   1199   1276   1467   1529   1096    695    494    371    293    237    196
107.5    993    978    983   1024   1009    746    504    376    288    232    190    160
112.5    870    839    787    746    690    546    391    299    237    196    165    139
117.5    777    741    664    561    494    412    319    247    206    170    144    134
122.5    726    674    566    432    355    324    268    221    185    149    129    113
127.5    674    623    484    350    273    252    226    185    154    139    118    108

CURVE NO   LUMINAIRE LAMP      OIST-TYP  SOC.P. REV COMMENTS-------  AUT  OATE
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****ROADWAY PHOTOMETRIC CURVES AS OF 10/ 3/84 ****                          PAGE NO  1

CURVE NO   LUMINAIRE LAMP      DIST-TYP  SOC.P. REV COMMENTS--------  AUT  DATE

 176930*  M-250R     H2500X    S-S-II    8H      0                     WCP  8008

CURVE LAST MODIFIED ON 800811

DIRECTORY RECORD       603
CD DATA FILE RECORD   5588
CANDLEPOWER CONSTANT     1.0000
LUMEN RATING             100000
HORIZONTAL INCREMENT     10.000
VERTICAL INCREMENT       10.000
CRIT. HOR. INCREMENT      5.000
CRIT. VER. INCREMENT      2.500
CRIT. HOR. START         52.500
CRIT. VER. START         60.000

                    CANDELA DATA  (02)

 HORZ    VERTICAL ANGLE >>---->
ANGLE    0.0   5.0  15.0  25.0  35.0  45.0  55.0  65.0  75.0  85.0  95.0 105.0
  0.0  16333 17192 16702 13950 10167  7074  5600  4568  3144  1965  1622  1276
  5.0  16333 17094 16947 14343 10708  7565  6337  5256  3540  2456  1818  1326
 15.0  16333 16996 17192 14736 11249  8056  7074  5944  4028  2947  2014  1376
 25.0  16333 16996 17143 15227 12035  9234  8351  7074  4765  3095  2309  1375
 35.0  16333 16849 17241 15763 13312 10954 10217  8301  5207  3340  2407  1621
 45.0  16333 16750 17094 16308 14884 12575 11740  9824  6434  3733  2211  1425
 55.0  16333 16750 17045 16701 16210 14490 13017 11591  8891  4962  2260  1425
 65.0  16333 16652 16701 17241 17192 15768 14735 14687 12378  6533  2358  1523
 75.0  16333 16455 16505 17290 17634 16603 16406 17331 15522  7467  2505  1523
 85.0  16333 16308 16210 16996 17241 16652 17241 19010 15768  7417  2456  1474
 95.0  16333 16112 15621 16210 16406 16112 16259 17290 13056  6336  2309  1523
105.0  16333 15964 15080 15276 15522 15080 14736 14490 10356  5060  2309  1523
115.0  16333 15817 14540 14049 14196 13558 12771 11445  8154  4225  2162  1376
125.0  16333 15719 13950 12771 12133 11445 10757  9038  6288  3438  2063  1425
135.0  16333 15571 13459 11151  9873  9481  8646  7565  5698  3291  2113  1277
145.0  16333 15424 12821  9775  8203  7860  7270  6631  4961  3488  2260  1228
155.0  16333 15424 12526  8940  7074  6533  6632  6189  4470  3242  2211  1179
165.0  16333 15277 12133  8449  6631  6091  6140  5797  4274  2751  1720  1130
175.0  16333 15129 12035  8154  6435  5944  5993  6091  4421  2407  1572   884

                    CRITICAL CANDELA DATA  (04)

         60.0  62.5  65.0  67.5  70.0  72.5  75.0  77.5  80.0  82.5  85.0  87.5
 52.5   11887 11642 11150 10512  9677  9033  8203  7123  6091  5256  4569  3732
 57.5   12963 12524 12280 11833 11249 10414  9628  8400  7319  6337  5354  4323
 62.5   14147 14097 13852 13056 13066 12378 11494 10021  8645  7417  6190  4765
 67.5   15375 15571 15522 15571 15178 14442 13312 11542  9972  8351  6926  5305
 72.5   15897 16996 17192 17438 16996 16259 14982 12919 10806  8939  7368  5600
 77.5   17929 18125 18469 18617 18273 17389 16112 13705 11347  9382  7663  5747
 82.5   18371 18764 19157 19108 18617 17683 16161 13901 11347  9333  7663  5551
 87.5   18273 18666 18362 18704 18273 17192 15424 13361 10954  8891  7172  5354
 92.5   17683 17850 17978 17684 16996 15817 14392 12280 10070  8252  6779  5050
 97.5   16652 16799 16701 16259 15522 14540 12919 11052  9136  7516  6091  4618
102.5   15375 15375 15178 14735 13951 13017 11544  9373  8203  6681  5354  4225
107.5   14147 13950 13852 13105 12428 11396 10217  8744  7172  5846  4363  3831
112.5   12771 12477 12250 11543 10807  9873  8793  7467  6238  5207  4421  3634
117.5   11642 11298 10659 10021  9235  8449  7565  6435  5452  4667  4028  3242
122.5   10561 10119  9579  8744  8252  7565  6563  5845  4863  4127  3635  3095
127.5    9530  9136  8645  7310  7368  6730  5793  5109  4372  3783  3439  2997
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LAMP DATA

[illegible] (See WARNING)

GE Ordering Abbreviation	ANSI Code	Finish	Light Center Length Inches	VERTICAL Lamp Lumen Depreciation Initial Lumens	Mean*	End of Relamping Period	Rated Average Life 10 Hours Per Start	HORIZONTAL Lamp Lumen Depreciation Initial Lumens	Mean*	End of Relamping Period	Rated Average Life 10 Hours Per Start
175-WATT (Enclosed Fixture Only) · Mogul Base											
MXR175/BU	M57	Clear	5	18 600	0.80	0.64	10 000	–	–	–	–
MXR175/BD	M57	Clear	5	18 600	0.80	0.64	10 000	–	–	–	–
MXR175/C/BU	M57	Diff	5	18 600	0.80	0.64	10 000	–	–	–	–
MXR175/C/BD	M57	Diff	5	18 600	0.80	0.64	10 000	–	–	–	–
MVR175/U	M57	Clear	5	14 000	0.74	0.67	10 000	12 000	0.58	0.57	8 000
MVR175/C/U	M57	Phos.	5	14 000	0.71	0.64	10 000	12 000	0.65	0.56	8 000
250-WATT (Enclosed Fixture Only) · Mogul Base											
MVR250/U	M58	Clear	5	20 600	0.83	0.69	10 000	19 800	0.72	0.64	10 000
MVR250/C/U	M58	Phos.	5	20 600	0.78	0.60	10 000	19 500	0.69	0.55	10 000
400-WATT · Mogul Base											
MVR400/U**	M59	Clear	7	36 000	0.80	0.68	20 000	32 000	0.74	0.68	15 000
MVR400/C/U**	M59	Phos	7	36 000	0.77	0.58	20 000	32 000	0.71	0.58	18 000
MVR400/VBU†	M59	Clear	7	40 000	0.80	0.64	20 000	–	–	–	–
MVR400/VBD	M59	Clear	7	40 000	0.80	0.64	20 000	–	–	–	–
MVR400/C/VBU†	M59	Phos	7	40 000	0.77	0.59	20 000	–	–	–	–
MVR400/C/VBD	M59	Phos	7	40 000	0.77	0.59	20 000	–	–	–	–
1000-WATT · Mogul Base											
MVR1000/U**	M47	Clear	9½	110 000	0.80	0.70	12 000	107 800	0.80	0.70	12 000
MVR1000/C/U**	M47	Phos	9½	105 000	0.78	0.65	12 000	100 000	0.76	0.65	12 000
MVR1000/VBU†	M47	Clear	9½	115 000	0.80	0.70	12 000	–	–	–	–
MVR1000/VBD	M47	Clear	9½	115 000	0.80	0.70	12 000	–	–	–	–
1500-WATT (Enclosed Fixture Only) · Mogul Base											
MVR1500/HBU/E	M48	Clear	9½	155 000	0.90	0.87	3 000	150 000	0.90	0.87	3 000
MVR1500/HBD/E	M48	Clear	9½	155 000	0.90	0.87	3 000	150 000	0.90	0.87	3 000

† SAF•T•GARD lamps are available. Lamp designation is changed from MVR to MVT. All other data remains the same. Also available as MVT400/I/U or MVT400/C/I/U
* 40% of rated life
** Vertical ±15° open fixture - all other enclosed fixture

[illegible]

MVR 400VBU or VBD MVR 1000VBU or VBD	Vertical burning only BU Base up ±15° BD Base down ±15°
MVR 175/U MVR 250/U MVR 400/U MVR 1000/U	U Universal burning
MVR 1500 HBU or HBD	HBU Base up to 15° below horizontal HBD Base down to 15° above horizontal
MXR 175 BU or BD	Vertical burning only BU Base up ±15° BD Base down ±15°
MVR 400/HOR	Horizontal burning only ±15°

MULTI-VAPOR LUMINAIRE LIMITATIONS VERTICAL LUMENS

	ANGLE OFF VERTICAL 0°	15°	30°	45°	60°	75°	90°
MV1000/U	100%	96	94	90	88	87	98
MV1500/HBD/E	100%	98	98	94	93	87	87

WARNING (All mercury and Multi-Vapor lamps)

This lamp can cause serious skin burn and eye inflammation from short wave ultraviolet radiation if outer envelope of the lamp is broken or punctured and the arc tube continues to operate. Do not use where people will remain for more than a few minutes unless adequate shielding or other safety precautions are used. Certain types of lamps that will automatically extinguish when the outer envelope is broken are commercially available from the General Electric Company

FILAMENT AND QUARTZLINE® LAMP DATA (120V Except As Noted)

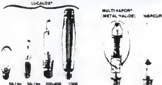
GE Ordering Abbreviation	Rated Watt	Max. Overall Length	Burning Position	Approximate Lumens Initial	Mean	Life Hours
Q300T3 CL	300	4-[illegible]	Horiz	5 950	5 780	2 000
Q425T3 CL	425	4-[illegible]	Horiz	8 900	8 600	2 000
Q500T3 CL (130V)	500	4-[illegible]	Horiz	10 950	10 600	2 000
Q600T3 CL	600	4-[illegible]	Horiz	11 100	10 250	2 000
Q1250T3 CL (208V)	1250	10-[illegible]	Horiz	28 000	27 100	2 000
Q1500T3 CL (240V)	1500	10-[illegible]	Horiz	35 000	34 700	2 000
Lamps for instant on automatic switched quartz						
Q150CL DC	150	2-[illegible]	Any	2 600	2 600	2 000
Q250CL DC	250	3	Any	5 000	4 850	2 000

MERCURY LAMP DATA (See WARNING on page H6 for SAF•T•GARD® Lamp.)

GE Ordering Abbreviation	ANSI Code	Finish	Light Center Length Inches	VERTICAL Initial Lumens	Lamp Lumen* Depreciation Mean	End of Relamping Period	HORIZONTAL Initial Lumens	Lamp Lumen* Depreciation Mean	End of Relamping Period
100-Watt – Life 24 000+ hours 10 hours/start – Mogul Base									
HR100A38	H38HT-R100	Clear	5	3 850	0.81	0.64	3 650	0.77	0.57
HR100DX38†	H38JA-R100 DX	Deluxe	5	4 200	0.84	0.69	4 000	0.79	0.63
175-Watt – Life 24 000+ hours 10 hours/start – Mogul Base									
HR175A39	H39KB-R175	Clear	5	7 950	0.94	0.58	7 570	0.90	0.81
HR175DX39†	H39KC-R175 DX	Deluxe	5	8 600	0.88	0.79	8 150	0.86	0.74
HR175WDX39	H39KC-R175 WDX	Warm DX	5	7 000	0.85	0.72	6 640	0.81	0.65
250-Watt – Life 24 000+ hours 10 hours/start – Mogul Base									
HR250A37	H37KB-R250	Clear	5	11 200	0.92	0.83	10 100	0.58	0.77
HR250DX37†	H37KC-R250 DX	Deluxe	5	12 100	0.88	0.75	11 500	0.82	0.65
HR250WDX37	H37KC-R250 WDX	Warm DX	5	10 000	0.84	0.63	9 540	0.78	0.56
400-Watt – Life 24 000+ hours 10 hours/start – Mogul Base									
HR400A33	H33CD-R400	Clear	7	21 000	0.91	0.83	20 000	0.87	0.75
HR400DX33†	H33GL-R400 DX	Deluxe	7	22 500	0.88	0.71	21 500	0.80	0.63
HR400WDX33	H33GL-R400 WDX	Warm DX	7	18 500	0.82	0.67	18 800	0.77	0.58
1000-Watt – Life 24 000+ hours 10 hours/start – Mogul Base									
HR1000A36	H36GV-R1000	Clear	9½	57 500	0.58	0.72	54 000	0.85	0.72
HR1000DX36†	H36GW-R1000 DX	Deluxe	9½	63 000	0.75	0.56	60 000	0.80	0.63
HR1000WDX36	H36GW-R1000 WDX	Warm DX	9½	58 000	0.83	0.48	54 000	0.73	0.58

* Mercury Lamp Lumen Depreciation based on 16 000 hours reactor ballast operation
† SAF•T•GARD lamps are available. Lamp designation is changed from HR to HT. All other data remains the same.

Data subject to change without notice
Registered trademark, General Electric Company



HIGH INTENSITY DISCHARGE LAMPS

High Intensity Discharge (HID) lamps are those which have a gaseous discharge arc tube operating at pressures and current densities sufficient to generate desired quantities of visible radiation within their arcs alone These lamp types have become popular primarily for three reasons

1 High efficacy — more lumens per watt of power consumed
2 Long lamp life and good lumen maintenance — reduces operating expenses
3 Compact source — permits good light control by use of reflectors and refractors resulting in high system efficiency

The three principal HID lamps now in common use are mercury metal halide (General Electric Multi-Vapor) and high pressure sodium (General Electric Lucalox)

HID WARMUP CHARACTERISTICS
(TIME TO REACH 80% LIGHT OUTPUT)

Mercury	5-7 minutes
Metal Halide	2-4 minutes
Lucalox	3-4 minutes

HID RESTRIKE CHARACTERISTICS

All HID lamps will deionize when there is a power interruption or if the lamp socket voltage drops below the amount required to sustain the arc for more than a few cycles Because it takes greater voltage to ionize the arc tube vapors while they are hot and under higher pressure the lamp will not re-start immediately

TIME TO RESTRIKE

Mercury	3-6 minutes	
Metal Halide	10-15 minutes	(MXR175 5-10 minutes)
Lucalox	1 minute	

STROBOSCOPIC EFFECT

HID lamp output tends to follow the alternating current waveform This can cause small moving objects to flicker To avoid this annoyance three phase power is suggested for mercury and Lucalox lamps Split phase ballasting can also be used with mercury lamps. Single phase power can be used with metal halide lamps

LIGHTING SYSTEM MAINTENANCE FACTOR

The lighting system maintenance factor (MF) is the product of the lamp lumen depreciation (LLD) and the luminaire dirt depreciation (LDD) The lamp lumen depreciation is given in the lamp tables for both the "mean" and "end of relamping period" The mean value is taken at approximately 40% life for Multi-Vapor and 50% life for Lucalox lamps For mercury lamps the value is taken at 8,000 hours This is due to the extreme long life of the mercury lamp A 16 000-hour economic life is suggested for this lamp The values for "end of relamping period" are taken at the end of the lamp's life The user may also use a more convenient group relamping period and should adjust the value accordingly

Luminaire dirt depreciation (LDD) is a function of the in service conditions and the type of luminaire Enclosed and filtered luminaires have built in maintenance characteristics which reduce the amount and effect of dirt accumulation While it is not possible to select one number to describe all conditions the following LDD values are suggested

OUTDOOR APPLICATIONS

Luminaire Type	Luminaire Dirt Depreciation (LDD)
Enclosed and filtered	0.95
Unfiltered	0.80

INDOOR APPLICATIONS

Luminaire Type	Luminaire Dirt Depreciation (LDD)		
	Light	Medium	Heavy
Enclosed and filtered	0.87	0.90	0.86
Enclosed	0.94	0.88	0.77
Open and ventilated	0.90	0.84	0.74

LUCALOX LAMP DATA

GE Ordering Abbreviation	Ballast ANSI Code	Finish	Light Center Length Inches	VERTICAL OR HORIZONTAL		
				Initial Lumens	Lamp Lumen Depreciation	
					Mean	End of Relamping Period
35-WATT Life 16,000 hours 10 hours/start Medium Base Only						
LU35/med	S76	Clear	3 7/16	2 250	0.90	0.73
LU35/D/med	S76	Diffuse	3 7/16	2 190	0.90	0.73
50-WATT Life 24,000+ hours 10 hours/start Mogul Base▲						
LU50	S68	Clear	5	4 000	0.90	0.73
LU50/D	S68	Diffuse	5	3 500	0.90	0.73
70-WATT Life 24,000+ hours 10 hours/start Mogul Base▲						
LU70	S62	Clear	5	5 500	0.90	0.73
LU70/D	S62	Diffuse	6	5 400	0.90	0.73
100-WATT Life 24,000+ hours 10 hours/start Mogul Base						
LU100	S54	Clear	5	9 500	0.90	0.73
LU100/D	S54	Diffuse	6	8 500	0.90	0.73
150-WATT Life 24,000+ hours 10 hours/start Mogul Base						
LU150/55	S55	Clear	5	16 000	0.90	0.73
LU150/55/D	S55	Diffuse	5	16 000	0.90	0.73
LU150/100	S56	Clear	6	15 000	0.70	0.73
200-WATT Life 24,000+ hours 10 hours/start Mogul Base						
LU200	S66	Clear	5¾	22 000	0.90	0.73
250-WATT Life 24,000+ hours 10 hours/start Mogul Base						
LU250	S50	Clear	5¾	27 500	0.90	0.73
LU250/D	S50	Diffuse	5	26 000	0.90	0.73
LU250/S	S50	Clear	5¾	30 000	0.90	0.73
LU250/DX*	S50	Clear	5¾	22 500	0.92	0.75
310-WATT Life 24,000+ hours 10 hours/start Mogul Base						
LU310	S67	Clear	5¾	37 000	0.90	0.73
400-WATT Life 24,000+ hours 10 hours/start Mogul Base						
LU400	S51	Clear	9¾	50 000	0.90	0.73
LU400/D	S51	Diffuse	7	47 500	0.90	0.73
1000-WATT Life 24,000 hours 10 hours/start Mogul Base						
LU1000	S52	Clear	9½	140 000	0.90	0.73

* Life 10 000 hours at 10 hours/start. CRI 60 color temp 2200°

[illegible]

Similar wattage clear and diffuse Lucalox lamps may not have the same bulb size or light center length If lamps are interchanged the socket position may need to be changed to obtain the desired photometric distribution

▲ Most Lighting Systems Department products will be furnished with Mogul Base Sockets Any exceptions will be noted on product pages

LU50/Med	LU70/Med	LCL 3-7/16 (Medium socket must be rated for 4KV)
LU50/D/Med	LU70/D Med	
LU100/Med	LU150/Med	
LU100/D/Med	LU150/D Med	

[illegible]

HRS/START	ESTIMATED AVG. LIFE▼
Cont	24 000+
10	24 000+
5	18 000
2.6	13 500
1.2	10 000

▼ Does not apply to 35W Lucalox nor E-Z Lux* lamps

Data subject to change without notice
* Registered Trademark of General Electric Company

APPENDIX V

Computer programs for Predictive Systems

```
$JOB
(*$B+*)
(* NORTH MANHATTAN AVENUE *)
PROGRAM CBE(INPUT,OUTPUT):
CONST
  EL = 4.0;     (* EYE LEVEL *)
  MH = 29:      (* MOUNTING HEIGHT *)
  O = 5.0;      (* OVERHANG OF THE LUMINAIRE *)
  CUTOFF = 70.0;  (* WIND-SHIELD CUT-OFF ANGLE  =  90 - 20 DEGREE *)
  IANGLE = 90.0:  (* INITIAL ANGLE *)
  LHT1 = 11.686;  (* HEIGHT OF THE LUMINAIRE*)
  LHT2 = 4.625;   (* WIDTH OF THE LUMINAIRE *)
  W = 13.910;     (* LENGHT OF THE LUMINAIRE *)
  E = 1.070;      (* A FACTOR. INITIAL LUMENS/ RATED LUMENS *)
```

```
  LDD = 0.95;       (* LUMINAIRE DIRT DEPRECIATION *)
  LLD = 0.77;       (* LAMP LUMEN DEPRECIATION *)
  SP  = 195:        (* SPACING BETWEEN THE LUMINAIRES *)
  SIDES = 2:        (* '1' FOR SINGLE-SIDED,'2' FOR DOUBLE-SIDED *)
  ROUTE = 3:        (* WE USED 1,2,3.4.5,AND 6 ROUTES *)
TYPE
  INT_ARRAY = ARRAY(.1..5.1..7,1..11.) OF INTEGER:

VAR
  P,D,CD.X,TOTCBE.CBE,V,H.R.B.A.AREA.INT,Z.S:REAL:
  TABLE : INT_ARRAY:

PROCEDURE READ_DATA:
VAR
  I.J,K : INTEGER:
BEGIN
  READLN(I);
  WHILE I <> 0 DO
  BEGIN
    FOR J := 1 TO 7 DO
    FOR K := 1 TO 11 DO
      READ (TABLE(.I.J.K.));
    READLN(I);
  END;
END:
PROCEDURE INITIALIZE:
BEGIN
    CD := 21.0;
    X := SP/2;
    P := MH - EL;
    D := CD - O;
    TOTCBE := 0.0;
END:
PROCEDURE RE_INITIALIZE:
BEGIN
    CD := 27.0;
    X := SP;
    D := CD - O;
END;
PROCEDURE INTENSITY;

VAR
  CHECK,VALUE1,VALUE2,VALUE3,VALUE4.PREVH,NEXTH.PREVV.NEXTV: INTEGER;
  TEMP1, TEMP2, TEMP3, TEMP4 : INTEGER;
  INT1,INT2 : REAL:
BEGIN
    CHECK := 0:
    PREVH := 45;
    NEXTH := 55:
    TEMP1 := 1:
    TEMP2 := TEMP1 + 1:
```

```
    WHILE(CHECK = 0) DO
    BEGIN
      IF ((H >= PREVH) AND (H < NEXTH)) THEN
        CHECK := 1
      ELSE
      BEGIN
         PREVH := PREVH + 10:
         NEXTH := NEXTH + 10;
         TEMP1 := TEMP1 + 1;
         TEMP2 := TEMP2 + 1:
      END
    END;
    CHECK := 0;
    PREVV := 5;
    NEXTV := 15:
    TEMP3 := 2:
    TEMP4 := TEMP3 + 1;
    WHILE (CHECK = 0) DO
    BEGIN
      IF ((V >= PREVV) AND (V < NEXTV)) THEN
        CHECK := 1
      ELSE
      BEGIN
        PREVV := PREVV + 10;
        NEXTV := NEXTV + 10;
        TEMP3 := TEMP3 + 1:
        TEMP4 := TEMP4 + 1;
      END
    END:
    VALUE1 := TABLE(.ROUTE,TEMP1,TEMP3.);
    VALUE2 := TABLE(.ROUTE,TEMP2,TEMP3.);
    VALUE3 := TABLE(.ROUTE,TEMP1.TEMP4.);
    VALUE4 := TABLE(.ROUTE,TEMP2,TEMP4.);
    INT1 := VALUE1 - ((VALUE1 - VALUE2)*(H - PREVH)/(NEXTH - PREVH)):
    INT2 := VALUE3 - ((VALUE3 - VALUE4)*(H - PREVH)/(NEXTH - PREVH));
    INT := INT1 - ((INT1 - INT2)*(V-PREVV)/(NEXTV - PREVV))
END;
PROCEDURE CALCULATE;
VAR
 V1, H1: REAL;
BEGIN
    V1:= ARCTAN((SQRT(SQR(X) + SQR(D)))/P);
    V := 180 * V1/3.142;
    H1:= 180*(ARCTAN(D/X))/3.142;
    H := 90 - H1;
    R := SQRT(SQR(X) + SQR(D) + SQR(P));
    B := SQRT(SQR(D) + SQR(P));
    A := (ARCTAN(B/X))*180/3.142;
    AREA := (((LHT1 - LHT2)/(CUTOFF - IANGLE)*(V - CUTOFF)) + LHT1) *W;
    INTENSITY:
    Z :=INT*E*LLD*LDD*452/AREA;
```

```
    S := AREA/(144*SQR(R));
    CBE := ((Z**1.67)*S)/(EXP(0.08*A));
    TOTCBE := TOTCBE + CBE;
END;
PROCEDURE PRINT_RESULTS;
BEGIN
    WRITELN(´ R    =´,R:10:2);
    WRITELN(´ V    =´,V:10:2);
    WRITELN(´ H    =´,H:10:2);
    WRITELN(´ I    =´,INT:10:2);
    WRITELN(´ A    =´,A:10:2);
    WRITELN(´ Z    =´,Z:10:2);
    WRITELN(´ S    =´,S:10:8);
    WRITELN(´ AREA =´,AREA:10:2);
    WRITELN(´ CBE  =´,CBE:10:2);
    WRITELN(´-´);
END;
PROCEDURE LOOP1;
VAR
I : INTEGER;
BEGIN
    FOR I := 1 TO 8 DO  (* WE USED 8 LUmINAIRES IN FRONT OF DRIVER *)
      BEGIN
         CALCULATE;
         PRINT_RESULTS;
         X := X+SP
      END
END;
(*MAIN PROGRAM*)
BEGIN
    READ_DATA;
    INITIALIZE;
    PAGE;
    WRITELN(´ THE FOLLOWING IS THE ANSWER FOR ROUTE´,ROUTE:2);
    WRITELN(´-´);
    WRITELN (´ THE FOLLOWING IS FOR SIDE 1´);
    WRITELN(´-´);
    LOOP1;
    IF(SIDES = 2) THEN
      BEGIN
         WRITELN (´ THE FOLLOWING IS FOR SIDE 2´);
         WRITELN(´-´);
         RE_INITIALIZE;
         LOOP1;
      END;
    WRITELN(´ THE TOTAL CBE VALUE IS´, TOTCBE:10:2);
END.
$ENTRY
1
1349 1467 1729 1961 2141 2105 1868 1642 1441 1235 288
1349 1431 1668 1791 2033 2239 2419 2779 2795 1894 314
```

```
1349 1395 1570 1359 1755 2357 2897 4179 5496 1853 319
1349 1354 1462 1034 1719 2162 2820 4220 6310 1390 283
1349 1318 1318 839  1420 1673 3167 2872 3561 751  221
1349 1256 1179 710  1153 1297 1559 1848 1379 360  165
0000 0000 0000 000  0000 0000 0000 0000 0000 000  000
2
13700 15500 19700 21500 21500 21900 20100 18700 11200 6110  1610
13700 14900 18000 21200 24500 26800 35500 27300 25800 12700 1990
13700 14400 15500 19100 25800 31700 45600 42000 51300 15100 2060
13700 13800 13400 16100 21700 34700 40200 48600 58700 11900 2060
13700 13100 11500 12700 16300 28100 26500 36300 36800 6340  1760
13700 12200 9550  9400  11800 18200 16300 19200 15300 2980  1150
00000 00000 0000  0000  00000 00000 00000 00000 00000 0000  0000
3
1705 1796 2155 2453 2335 1570 1329 1191 734  390  205
1705 1755 2037 2294 2525 1858 1488 1488 1237 647  210
1705 1740 1909 2104 2412 2109 1694 1919 2273 1032 241
1705 1704 1760 1894 2109 1960 1837 2356 3166 1324 262
1705 1687 1611 1658 1781 1740 1776 2273 2658 1170 241
1705 1632 1488 1447 1540 1601 1560 1704 1499 801  216
0000 0000 0000 0000 0000 0000 0000 0000 0000 000  000
4
16333 16849 17241 15768 13312 10954 10217 8301  5207  3340 2407
16333 16750 17094 16308 14884 12575 11740 9824  6484  3733 2211
16333 16750 17045 16701 16210 14490 13017 11691 8891  4962 2260
16333 16652 16701 17241 17192 15768 14785 14687 12378 6533 2358
16333 16455 16505 17290 17634 16603 16406 17831 15522 7467 2505
16333 16308 16210 16996 17241 16652 17241 19010 15768 7417 2456
16333 16112 15621 16210 16406 16112 16259 17290 13656 6386 2309
5
7089 7745 8558 8472 8473  8900  9242  8429  12109 86 0
7089 7702 8344 8558 8943  11895 15490 10826 12024 86 0
7089 7531 8044 8515 9414  15361 20410 14848 9456  86 0
7089 7488 7574 8472 10612 19640 20410 22849 5135  86 0
7089 7317 7213 7745 9884  18271 19897 22293 4193  86 0
0000 0000 0000 0000 0000  00000 00000 00000 0000  00 0
0000 0000 0000 0000 0000  00000 00000 00000 0000  00 0
0
```

```
THE FOLLOWING IS FOR SIDE 1

R    =    101.92
V    =     75.79
H    =     80.68
I    =   2747.59
A    =     16.93
Z    =   7247.95
S    = 0.00008966
AREA =    134.11
CBE  =     64.71

R    =    294.00
V    =     85.11
H    =     86.87
I    =   1091.42
A    =      5.79
Z    =   4370.74
S    = 0.00000710
AREA =     88.34
CBE  =      5.36

R    =    488.40
V    =     87.05
H    =     88.12
I    =    886.04
A    =      3.48
Z    =   3978.06
S    = 0.00000229
AREA =     78.80
CBE  =      1.78

R    =    683.15
V    =     87.89
H    =     88.66
I    =    802.82
A    =      2.49
Z    =   3802.73
S    = 0.00000111
AREA =     74.69
CBE  =      0.87

R    =    878.00
V    =     88.36
H    =     88.96
I    =    757.86
A    =      1.94
Z    =   3703.15
S    = 0.00000065
AREA =     72.40
CBE  =      0.51
```

```
R    =   1072.91
V    =     88.65
H    =     89.15
I    =    729.74
A    =      1.59
Z    =   3638.88
S    = 0.00000043
AREA =     70.95
CBE  =      0.33

R    =   1267.85
V    =     88.86
H    =     89.28
I    =    710.49
A    =      1.34
Z    =   3593.96
S    = 0.00000030
AREA =     69.94
CBE  =      0.24

R    =   1462.80
V    =     89.01
H    =     89.37
I    =    696.49
A    =      1.16
Z    =   3560.79
S    = 0.00000022
AREA =     69.20
CBE  =      0.17

THE FOLLOWING IS FOR SIDE 2

R    =    197.82
V    =     82.73
H    =     83.56
I    =   1541.57
A    =      9.69
Z    =   5451.60
S    = 0.00001775
AREA =    100.04
CBE  =     14.21

R    =    391.42
V    =     86.33
H    =     86.77
I    =    989.45
A    =      4.88
Z    =   4249.59
S    = 0.00000373
AREA =     82.37
```

```
CBE  =      2.90

R    =    585.95
V    =     87.54
H    =     87.85
I    =    853.59
A    =      3.26
Z    =   3952.78
S    = 0.00000155
AREA =     76.40
CBE  =      1.21

R    =    780.71
V    =     88.15
H    =     88.38
I    =    788.86
A    =      2.44
Z    =   3802.17
S    = 0.00000084
AREA =     73.40
CBE  =      0.65

R    =    975.57
V    =     88.52
H    =     88.71
I    =    751.07
A    =      1.96
Z    =   3711.03
S    = 0.00000052
AREA =     71.60
CBE  =      0.41

R    =   1170.47
V    =     88.76
H    =     88.92
I    =    726.31
A    =      1.63
Z    =   3649.93
S    = 0.00000036
AREA =     70.40
CBE  =      0.28

R    =   1365.41
V    =     88.94
H    =     89.08
I    =    708.85
A    =      1.40
Z    =   3606.11
S    = 0.00000026
AREA =     69.54
CBE  =      0.20
```

```
R    =   1560.36
V    =     89.07
H    =     89.19
I    =    695.87
A    =      1.22
Z    =   3573.15
S    = 0.00000020
AREA =     68.90
CBE  =      0.15

THE TOTAL CBE VALUE IS      93.99
```

APPENDIX VI

Data from Roadway and Simulator

McCall Road

Subject	Simulator (Driver)	Simulator (Passeng)	Roadway (driver)	Roadway (Passeng)
1	8	7	7	5
2	7	8	7	3
3	7	7	3	5
4	7	7	7	7
5	7	6	6	2
6	7	9	5	7
7	7	3	7	6
8	4	7	3	5
9	5	7	6	8
10	8	3	5	6
11	6	6	5	4
12	6	7	6	7
13	5	4	5	3
14	7	8	6	3
15	6	3	5	4
16	7	7	5	8
17	7	9	3	3
18	5	2	5	6
19	7	7	7	7
20	7	4	5	4
21	9	8	5	6
22	8	6	4	5
23	5	9	6	4
24	6	7	8	7

25	8	4	5	3
26	8	7	2	5
27	9	8	8	5
28	7	8	8	4
29	6	7	7	4
30	8	9	9	7
Total	204	194	170	153
Mean	6.8	6.5	5.7	5.1
	6.7		5.4	

Claflin Road

Subject	Simulator (Driver)	Simulator (Passeng)	Roadway (Driver)	Roadway (Passeng)
1	4	4	3	4
2	1	6	7	6
3	8	3	4	3
4	6	3	3	2
5	1	5	5	6
6	4	3	8	6
7	8	4	3	1
8	3	4	2	2
9	6	4	5	6
10	5	5	3	3
11	5	2	5	2
12	5	5	5	3
13	1	2	1	5
14	3	1	4	4
15	5	6	1	2
16	3	7	5	6
17	2	5	1	1
18	2	3	5	4
19	5	5	6	3
20	2	1	5	1
21	3	8	3	3
22	4	3	5	1
23	3	5	3	4
24	4	3	3	2

26	3	5	3	4
27	2	6	3	4
28	6	6	5	3
29	5	3	6	4
30	5	1	5	4
Total	118	124	119	102
Mean	3.9	4.1	4.0	3.4
	4.0		3.7	

Bluemont Avenue

Subject	Simulator (Driver)	Simulator (Passeng)	Roadway (Driver)	Roadway (Passeng)
1	8	6	5	4
2	4	5	4	2
3	6	5	5	3
4	7	2	1	1
5	7	7	4	3
6	3	7	3	3
7	6	2	4	4
8	5	5	2	3
9	6	7	5	6
10	5	4	3	4
11	5	5	4	3
12	5	6	4	3
13	2	2	1	4
14	5	5	4	5
15	4	4	3	3
16	5	7	5	6
17	3	7	1	3
18	4	5	3	5
19	6	5	4	4
20	6	6	4	4
21	5	2	1	8
22	2	4	1	1
23	7	7	4	3
24	4	4	3	5

25	6	3	3	5
26	5	5	2	3
27	7	2	2	3
28	6	5	5	3
29	5	4	7	4
30	7	8	5	6
Total	156	146	102	114
Mean	5.2	4.9	3.4	3.8
	5.1		3.6	

North Manhattan Avenue

Subject	Simulator (Driver)	Simulator (Passeng)	Roadway (Driver)	Roadway (Passeng)
1	7	6	3	4
2	6	6	8	5
3	7	5	4	1
4	5	3	7	1
5	8	5	4	5
6	3	9	5	2
7	5	2	3	3
8	7	5	4	4
9	3	5	3	6
10	3	2	2	4
11	4	3	4	2
12	5	6	4	4
13	2	3	1	4
14	4	6	3	5
15	2	5	1	3
16	3	5	1	4
17	3	6	1	3
18	2	5	3	4
19	6	6	5	4
20	6	7	6	2
21	5	3	5	1
22	3	3	1	1
23	4	7	2	4
24	3	3	4	4

25	5	3	3	6
26	3	4	3	4
27	3	4	4	2
28	8	7	3	3
29	4	2	8	6
30	8	7	5	6
Total	137	143	110	107
Mean	4.6	4.8	3.7	3.6
	4.7		3.7	

Veterniary Medicine Building

Subject	Simulator (Driver)	Simulator (Passeng)	Roadway (Driver)	Roadway (Passeng)
1	2	3	1	2
2	1	2	1	2
3	2	7	2	4
4	3	4	1	3
5	4	3	3	4
6	2	3	2	1
7	6	5	2	1
8	6	3	1	4
9	2	4	3	2
10	7	5	2	2
11	3	1	3	1
12	5	3	5	3
13	3	3	3	1
14	6	3	2	2
15	2	2	2	2
16	5	5	3	4
17	5	7	1	1
18	5	2	2	3
19	4	4	5	2
20	3	1	3	3
21	5	6	1	6
22	2	2	7	7
23	7	3	3	2
24	1	3	6	4

25	1	5	2	4
26	2	1	1	2
27	3	1	1	3
28	2	2	7	2
29	3	3	5	3
30	6	5	3	5
Total	108	101	83	85
Mean	3.6	3.4	2.8	2.8
	3.5		2.8	

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Subject	Simulator (Driver)	Simulator (Passeng)	Real-world (Driver)	Real-world (Passeng)
1	9	5	3	5
2	3	4	3	2
3	8	3	2	3
4	4	3	1	3
5	5	5	3	1
6	5	5	6	4
7	9	7	2	4
8	8	4	5	3
9	4	4	6	3
10	5	3	2	5
11	6	2	6	3
12	6	5	5	4
13	3	3	3	3
14	4	6	5	3
15	5	3	4	3
16	5	6	3	7
17	5	3	1	1
18	4	4	5	3
19	8	6	8	4
20	7	2	2	3
21	7	3	5	5
22	6	5	6	3
23	3	9	2	3
24	5	5	6	7

25	4	8	3	7
26	2	8	1	1
27	2	5	1	3
28	5	3	2	2
29	5	6	7	5
30	8	8	9	6
Total	160	143	117	109
Mean	5.3	4.8	3.9	3.6
	5.1		3.8	

COMPARISION OF REAL-WORLD ROADWAY LIGHTING, DYNAMIC SIMULATION, AND CBE AND GLAREMARK PREDICTIVE SYSTEMS

BY

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An experiment was conducted , in Summer 1984 at Kansas State University to compare the glare responses of subjects from the roadway lighting installations, with the simulation of the same lighting installations, and with the predicted values of the glare by Glaremark and CBE predictive systems. Sixty subjects rode or drove through six different lighting installations in the city of Manhattan, to rate the quality of light on the basis of North American Glare Scale. The same subjects "drove" through the dynamic simulation of the same six lighting installations. At 0.05 significance level significant differences were found in the results of real-world and dynamic simulation. However, on the basis of comfort, a very stronge positive correlation was found in the rank orders of real-world and simulated installations. At 0.05 significance level, both the predictive systems showed significant differences in the real-world and predicted results. However, the rank orders predicted by CBE showed a very strong~~e~~ positive correlation with the rank orders of real-world installation.