

Visibility Based Lighting Design



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Why do Roadway Lighting Research?

- We have been lighting roadways since 1852.
- The first lighting specification was in 1889 in Paris.

Gas Light-Mean Illumination on Paris Streets in 1889

■ Mean Illumination

- Rue Royale1.6 lux
- Rue de la Paix1.5 lux
- Place de POpera0.7 lux
- Ave. de POpera0.43 lux
- Rue du Quatre-Septembre....0.43 lux
- All Paris.....0.05 lux

DISTRIBUTION AND MEASUREMENT OF ILLUMINATION.

DISTANCE BETWEEN TWO LIGHTS IN METERS.

Minimum Intensity of Horizontal Illumination in Luxes.	$I=500$ Dec. Candles. h			$I=600$ Dec. Candles. h			$I=700$ Dec. Candles. h			$I=800$ Dec. Candles. h			$I=900$ Dec. Candles. h			$I=1000$ Dec. Candles. h		
	6	10	14	6	10	14	6	10	14	6	10	14	6	10	14	6	10	14
	0.5	44	50	54	47	54	58	50	57	62	52	60	67	54	64	68	56	65
1	34	38	39	37	41	43	39	44	46	41	46	49	43	48	52	44	50	54
2	26	28	26	28	30	30	30	33	32	32	35	35	31	36	37	34	38	39

Question

- After 115 years of lighting roads why do we need to keep looking at Roadway Lighting?
 - Haven't we got it right yet?

Top 10 Leading Causes of Death in the United States for 2001, by Age Group¹

R A N K	Cause and Number of Deaths											Years of Life Lost ²
	Infants Under 1	Toddlers 1-3	Young Children 4-7	Children 8-15	Youth 16-20	Young Adults 21-24	Other Adults			Elderly 65+	All Ages	
							25-34	35-44	45-64			
1	Perinatal Period 13,734	Congenital Anomalies 496	MV Traffic Crashes 533	MV Traffic Crashes 1,546	MV Traffic Crashes 5,979	MV Traffic Crashes 4,136	MV Traffic Crashes 6,759	Malignant Neoplasms 16,569	Malignant Neoplasms 139,785	Heart Disease 582,730	Heart Disease 700,142	Malignant Neoplasms 23%(8,614,131)
2	Congenital Anomalies 5,513	MV Traffic Crashes 421	Malignant Neoplasms 400	Malignant Neoplasms 829	Homicide 2,414	Homicide 2,738	Homicide 5,204	Heart Disease 13,326	Heart Disease 98,885	Malignant Neoplasms 390,214	Malignant Neoplasms 553,768	Heart Disease 22%(8,110,571)
3	Heart Disease 479	Accidental Drowning 393	Exposure to Smoke/Fire 178	Suicide 447	Suicide 1,879	Suicide 1,924	Suicide 5,070	MV Traffic Crashes 6,891	Stroke 15,518	Stroke 144,486	Stroke 163,538	MV Traffic Crashes 5%(1,700,952)
4	Homicide 332	Homicide 362	Congenital Anomalies 168	Homicide 391	Malignant Neoplasms 814	Accidental Poisoning 771	Malignant Neoplasms 3,994	Suicide 6,635	Diabetes 14,913	Chronic Lwr. Resp. Dis. 106,904	Chronic Lwr. Resp. Dis. 123,013	Stroke 5%(1,687,683)
5	Septicemia 312	Malignant Neoplasms 321	Accidental Drowning 164	Congenital Anomalies 324	Accidental Poisoning 566	Malignant Neoplasms 768	Heart Disease 3,160	HIV 5,867	Chronic Lwr. Resp. Dis. 14,490	Influenza/ Pneumonia 55,518	Diabetes 71,372	Chronic Lwr. Resp. Dis. 4%(1,444,745)
6	Influenza/ Pneumonia 299	Heart Disease 200	Homicide 133	Accidental Drowning 293	Heart Disease 398	Heart Disease 543	Accidental Poisoning 2,507	Accidental Poisoning 5,036	Chronic Liver Disease 13,009	Diabetes 53,707	Influenza/ Pneumonia 62,034	Suicide 3%(1,079,822)
7	MV Traffic Crashes 139	Exposure to Smoke/Fire 170	Heart Disease 82	Heart Disease 273	Accidental Drowning 326	Accidental Drowning 211	HIV 2,101	Homicide 4,268	Suicide 9,259	Alzheimer's 53,245	Alzheimer's 53,852	Perinatal Period 3%(1,070,154)
8	Nephritis/ Nephrosis 133	Septicemia 96	MV NonTraffic Crashes 51	Exposure to Smoke/Fire 140	Congenital Anomalies 244	Congenital Anomalies 206	Stroke 601	Chronic Liver Disease 3,336	MV Traffic Crashes 8,750	Nephritis/ Nephrosis 33,121	MV Traffic Crashes 42,443	Diabetes 3%(1,014,201)
9	Stroke 108	Influenza/ Pneumonia 92	Benign Neoplasms 46	MV NonTraffic Crashes 125	Accidental Falls 114	HIV 167	Diabetes 595	Stroke 2,491	HIV 5,437	Septicemia 25,418	Nephritis/ Nephrosis 39,480	Homicide 3%(924,263)
10	Meningitis 78	Perinatal Period 63	Septicemia 33	Chr. Lwr. Resp. Dis. 102	Acc. Dischg. Of Firearms 114	Accidental Falls 134	Congenital Anomalies 458	Diabetes 1,958	Nephritis/ Nephrosis 5,106	Hypertension Renal Dis. 16,397	Septicemia 32,238	Chronic Liver Disease 2%(623,998)
ALL ³	27,568	4,288	2,703	6,672	15,851	14,940	41,683	91,674	412,204	1,798,420	2,416,425	All Causes 100%(36,866,317)

¹When ranked by specific ages, motor vehicle crashes are the leading cause of death for age 2 and every age 4 through 33.

²Number of years calculated based on remaining life expectancy at time of death; percents calculated as a proportion of total years of life lost due to all causes of death.

³Not a total of top 10 causes of death.

Source: National Center for Health Statistics (NCHS) CDC, Mortality Data 2001

Note: The cause of death classification is based on the National Center for Statistics and Analysis (NCSA) Revised 68 Cause of Death Listing. This listing differs from the one used by the NCHS for its reports on leading causes of death by separating out unintentional injuries into separate causes of death, i.e., motor vehicle traffic crashes, accidental falls, motor vehicle nontraffic crashes, etc.

Accordingly, the rank of some causes of death will differ from those reported by the NCHS. This difference will mostly be observed for minor causes of death in smaller age groupings.



Driver Issues

- Night driving has been described as a situation for which humans have not evolved, leaving our visual system inadequate and inefficient for certain tasks (Rumar, 1990).

The Current Issue - Visibility



What is Visibility?

- It is the quality or the state of just being visible to the eye
 - For outdoor applications, visibility is defined as the distance at which something can just be perceived by the eye.
 - IESNA Handbook Volume 9, 2000

Object Visibility



Visibility with Glare



Visibility with Extreme Glare





ANSI/IESNA Roadway Lighting Practice

- ANSI/IESNA RP-8 allows for three different design methodologies for roadway lighting design:
 - Illuminance design.
 - Luminance design.
 - Small target visibility design.

Roadway Calculations

- The calculation methods for each of these design methods are related to each other:
 - Calculate illuminance first.
 - Calculate luminance second.
 - Calculate STV third.

Visibility

- Visibility is related to the contrast of the object to its background.
 - There is a threshold contrast at which the eye can just perceive an object.
 - This threshold contrast depends on the size of the object, the viewing time, contrast polarity, and the background luminance.

Visibility Level

- The visibility level is used to establish the elevation of the actual condition to that of the threshold condition:
 - The ΔL_{th} is calculated with the Adrian Model.
 - ΔL_{Actual} is calculated from the actual condition.

$$VL = \frac{\Delta L_{Actual}}{\Delta L_{Threshold}} = \frac{L_{Target} - L_{Background}}{\Delta L_{Threshold}} = \frac{C_{Actual}}{C_{Threshold}}$$

Adrian Model

- A model of the threshold luminance difference required for visibility developed by Dr. W. K. Adrian (Professor Emeritus, University of Waterloo, Ontario, Canada).
 - The Adrian model is used to derive the visibility level and the small target visibility (STV) quality criterion for roadway lighting, as prescribed by the IESNA RP-8.

Small Target Visibility

- The small target visibility (STV) is a quality criterion developed to evaluate the performance of roadway lighting design.
 - The STV is the weighted average of the visibility level calculated for a grid of targets on the road surface.
 - The current Target is a 7" gray flat square with 50% reflectance
 - An STV value of 2.6 to 3.8 is prescribed by the IESNA RP-8 (2000).
- The relationship of STV to actual driver performance remains a point of research and discussion.



CoolWe can see....

The World's a better place right?

- One of the difficulties in adopting the STV has been that like illuminance and luminance, STV is not correlated to accidents (Mace 1996)

What can the matter be?

- The problems with STV are multiple:
 - Headlamps are not accounted for
 - The reflected light from the pavement onto the target is not accounted for
 - The levels do not represent the actual requirements of the driver
 - Others
 - The target is flat and shows only two dimensions
 - The weighting of the various Visibility Levels does not relate to reality

Headlamps and STV

- One of the difficulties in adopting the STV has been that like the illuminance and the luminance, STV is not correlated to accidents (Mace 1996)
- Vehicle headlamps have been left out of the calculations
 - The assumption has always been that headlights will just improve the situation.
 - Mace and Keck have started to consider headlamps

FRL Results

■ Mace found that:

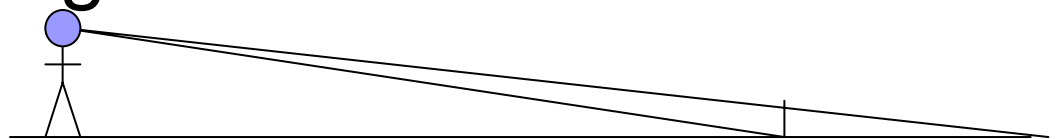
- Higher pavement luminance does not necessarily increase visibility
- Object Visibility is greater with greater pavement luminance non-uniformity
- Participants however found highly uniform surfaces more acceptable
 - Less fatigue
 - No Transient Adaptation
- Lower pavement luminance values can be used with higher non-uniformity to achieve the same visibility
- The STV calculation does loosely correlate to the visibility distance

Visibility Level Definitions

- For the purposes of RP-8, the target luminance is calculated as:

$$L_T = \frac{I \cdot \cos^2(\gamma) \cdot \sin(\gamma) \cdot \cos(90 - \phi)}{h^2 \cdot A_{Target}}$$

- Note that light reflected from the pavement to the target is not included.
- The target background luminance is the average of the pavement luminance just above and just below the target.



Pavement Reflection



Pavement Reflection

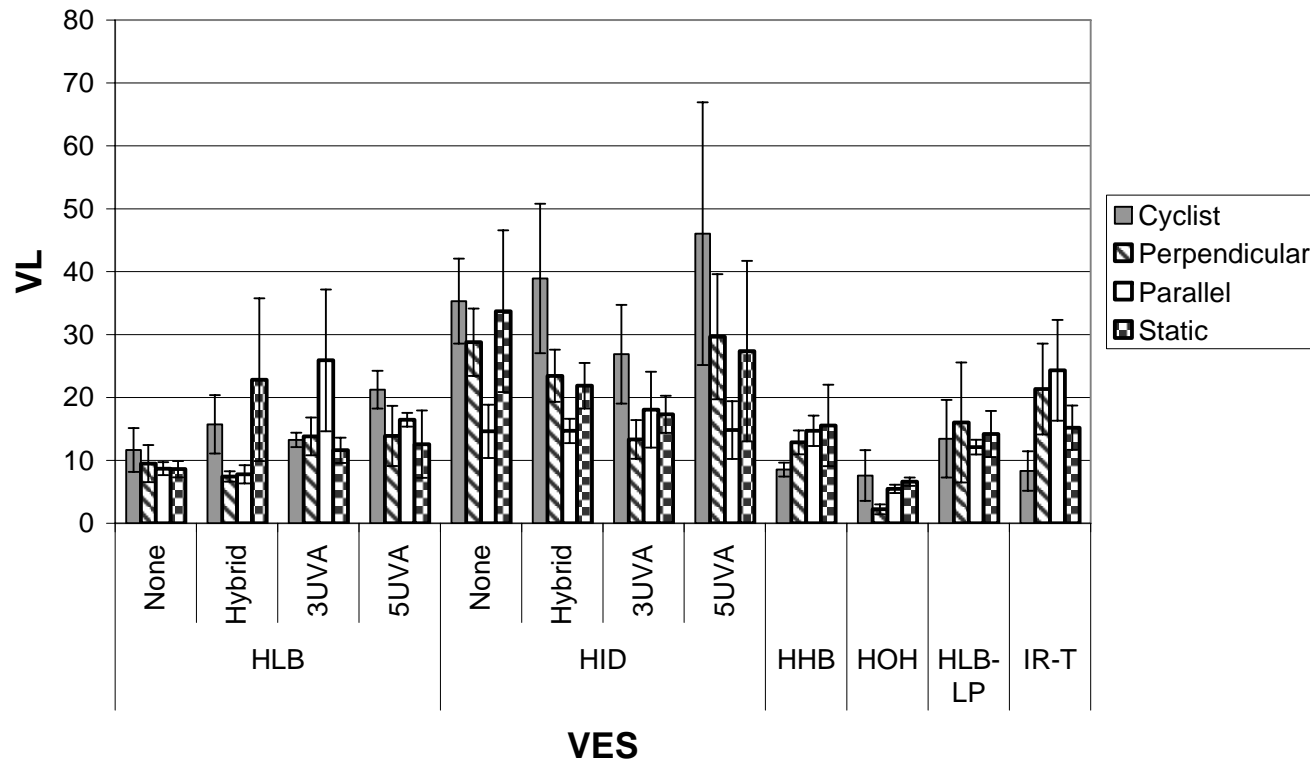


Pavement Reflection



Threshold VL Levels

Visibility Level At Threshold: White Clothed Objects



Just a thought....

- Vertical Illuminance is “King”
 - Vertical illuminance represents the amount of light striking the facing surface of an object
 - It may most closely represent the visibility of an object
 - Research is continuing....



Pedestrian Area Lighting

Pedestrian Accidents: How big is this problem?

- In Orlando:
 - 51.6% of vehicle and pedestrian accidents happen at night.
 - Evenly distributed on Lighted and Unlighted Roads
 - Of Fatal Crashes
 - 58.6% of incidents happen on unlighted roads
 - 25.3% of incidents happen on lighted roads
 - Result: The accidents on unlighted roads are more serious than those on lighted roads.

Why?

- The driving task is 90% visual.
 - In order to drive we must be able to see:
 - Road
 - Road Markings
 - Signs
 - Other Vehicles
 - Anything that can enter the roadway
 - Pedestrians, Cyclists, Dogs, Deer
 - At night, lighting is required to see these objects.

Aren't headlights good enough?

Halogen Low Beam Headlamps		Total Distance Needed in feet (Speed in mi/h)					
Type of Object	Detection	126 (25)	197 (35)	278 (45)	370 (55)	474 (65)	529 (70)
Tire Tread	240			X	X	X	X
Parallel Pedestrian-Black Clothing	386					X	X
Perpendicular Pedestrian-Black Clothing	409					X	X
Child's Bicycle	464					*	*
Cyclist-Black Clothing	566						
Perpendicular Pedestrian-White Clothing	828						
Parallel Pedestrian-White Clothing	839						
Static Pedestrian-White Clothing	858						
Cyclist-White Clothing	862						

X = stopping distance might be compromised

• = exceeds distance, but the scenario is not likely

• Source – Blancho et al. 2003

Yes, but there are new HID Headlamps.....

High Intensity Discharge		Total Distance Needed in feet (Speed in mi/h)					
Type of Object	Detection	126 (25)	197 (35)	278 (45)	370 (55)	474 (65)	529 (70)
Tire Tread	212			X	X	X	X
Perpendicular Pedestrian-Black Clothing	275			X	X	X	X
Parallel Pedestrian-Black Clothing	282				X	X	X
Child's Bicycle	417					*	*
Cyclist-Black Clothing	444					X	X
Cyclist-White Clothing	683						
Parallel Pedestrian-White Clothing	713						
Perpendicular Pedestrian-White Clothing	734						
Static Pedestrian-White Clothing	796						

X = stopping distance might be compromised

•= exceeds distance, but the scenario is not likely

•Source – Blancho et al. 2003



What is the required lighting level?

- The IESNA has two recommendations:
 - RP 33-99
 - RP 8-00

Current Pedestrian Lighting Recommendations

- IESNA RP-33-99
 - Commercial Areas
 - 20 vertical lux
 - Residential Areas
 - 5 vertical lux

RP 8 – 00 Bikeway Recommendations

Maintained Illuminance Values for Walkways/Bikeways – High Conflict Areas			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min} *
Mixed Vehicle and Pedestrian**	20.0/2.0	10.0/1.0	4.0
Pedestrian Only	10.0/1.0	5.0/0.5	4.0
Maintained Illuminance Values for Walkways/Bikeways – Medium Conflict Areas			
Pedestrian Areas	5.0/0.5	2.0/0.2	4.0
Maintained Illuminance Values for Walkways/Bikeways – Low Conflict Areas			
Rural/Semi-Rural Areas	2.0/0.2	0.6/0.06	10.0
Low Density Residential	3.0/0.3	0.8/0.08	6.0
Medium Density Residential	4.0/0.4	1.0/0.1	4.0

Why the Disparity?

- There has not been a significant study on Crosswalk Lighting since 1973.
 - In this study, a lighting level of vertical 40 lx was found to be significant.
 - A special luminaire was defined that could be used for lighting of the crosswalks.
 - This luminaire used Low Pressure Sodium, as it provided an aspect of highlighting in the crosswalk.
- These recommendations were never put into general practice.

What is a safe lighting level?

- In an FHWA Scan tour, it was found that in Switzerland, a level of 40 vertical lx was used in all crosswalks.
 - This level reduced nighttime vehicle to pedestrian crashes by 66%.

Crosswalk Lighting Study at Virginia Tech



Purpose

- The purpose of this study was to:
 - Develop a recommendation for the required lighting level for crosswalks.
 - Develop a design surrogate.
 - The surrogate can be used to simulate pedestrians in design software.

Pedestrian Detection Objects

(Students don't like to be called Targets)

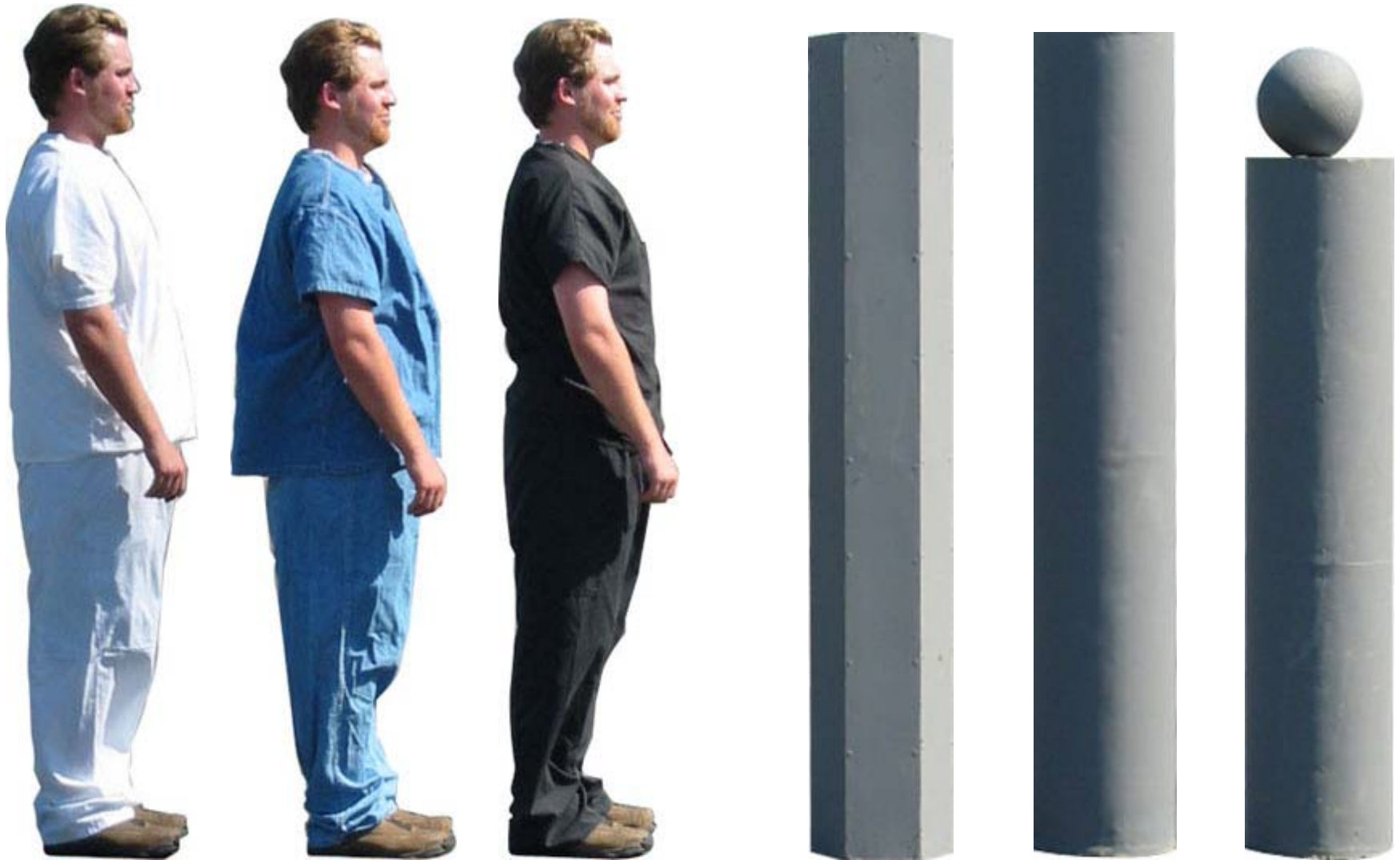
■ Surrogates

- Three Surrogates were chosen for the project each with varying degrees of internal contrast.
 - Surrogate 1 – Extruded Octagon
 - Surrogate 2 – Cylinder
 - Surrogate 3 – Cylinder with Ball

■ Pedestrians

- Three Pedestrians were used for comparison.
- Each was dressed differently.
 - White, Denim, and Black Clothing

Objects



Experimental Design

The Study will considers the following variables for the Lighting Designs:

- Illuminance Level High (60 lux), 40 lx, 20 lx, Low (5lx) vertical Illuminance
- Lamp Type Metal Halide, High Pressure Sodium
- Glare On, Off
- Fixed Overhead Lighting On, Off

Lighting Designs

- 16 Lighting Designs were developed and implemented in the Virginia Smart Road.
 - To achieve the lighting levels required, 3 different luminaires were used.
 - The luminaires are all Semi-Cutoff, Type II luminaires from 2 different Manufacturers.
 - 400 Watt HPS – For 20, 40 and 60 lx Conditions
 - 150 Watt HPS – For 5 lx Condition
 - 400 Watt MH – For All MH Conditions

Smart Road Experimental Lighting Testbed



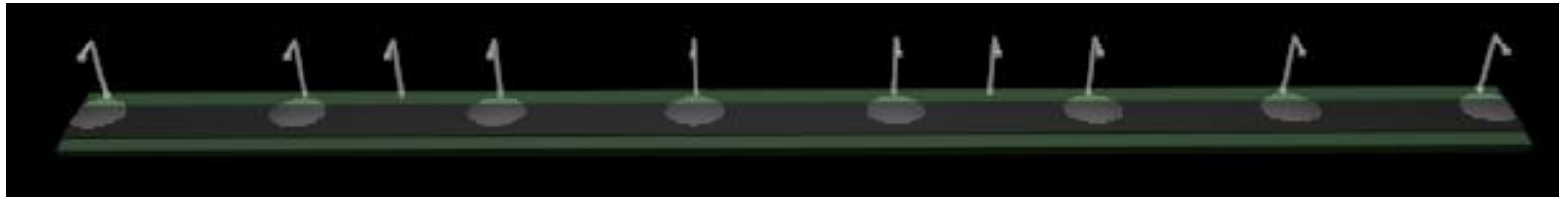
Experimental Lighting Testbed

■ Summary

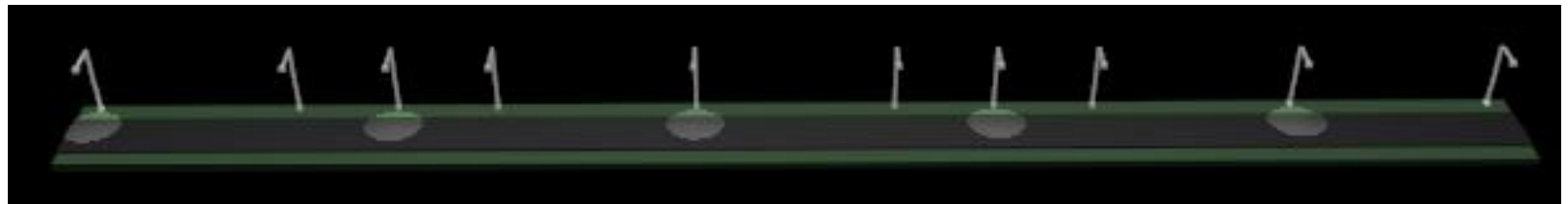
- FHWA designed a patterned spacing that allows simulation of 40, 60, and 80 meter light pole spacing (130-260 ft)
- Three luminaires per adjustable height pole
- Separate dimmers for asphalt and concrete roadway sections
- Computer control allows for individual light pole (on/off) and luminaire control (1 of 3 selected & brightness level)

Experimental Lighting Testbed

■ 40 meter



■ 60 meter



■ 80 meter



Spacing: 40m-20-20-40-40-20-20-40-40.....

Experimental Lighting Testbed

Most Towers have:

- 400w HPS luminaire w/M-S-II distribution
- 400w HPS luminaire with flat glass w/ M-C-II
- 150w HPS luminaire with flat glass w/ M-C-II

Specials:

- Some towers have 400W MH Probeam Luminaires
- 400w MH luminaire with flat glass w/ M-C-II

- Variable Bracket Height



All Weather Testing



All Weather Testing

■ Summary

- 1/2 mile of snow/rainmaking capability
- 75 snow/rain towers spaced at 10m (33 ft) intervals along asphalt and concrete pavements
- Automated control of water pumps, air compressors, and individual water & air hydrants
- Capable of 3000 gallons per minute, fed by a 500,000 gallon tank, plus 6400 CFM airflow during snowmaking

Snowmaking

- Snow
- at $< 28^{\circ}$ Wet Bulb
- Variable intensities based on water flow, air flow, and nozzles



Fog Making

- Water and Air mixing at Fog Nozzle
 - Visibility can be measured and controlled based on Wind Speed, Temperature, Dew Point, and Relative Humidity



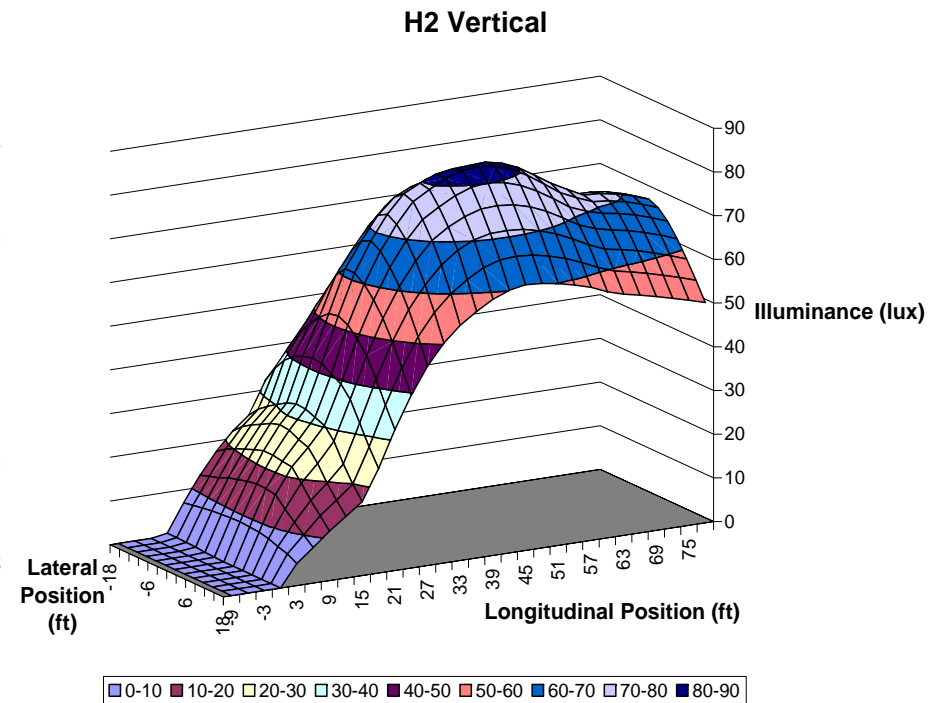
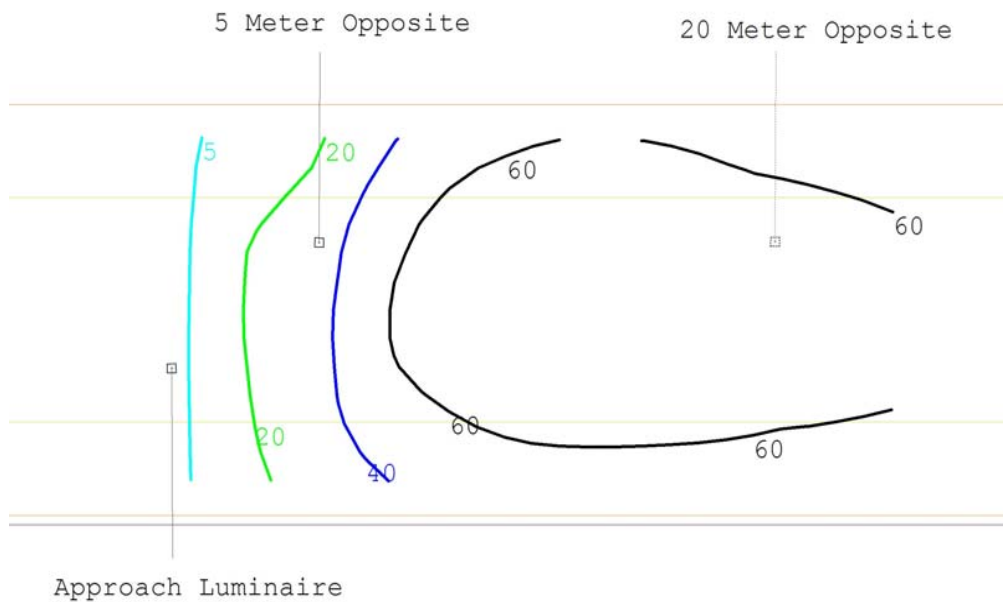
Don't Mess with the Fog Experimenters!



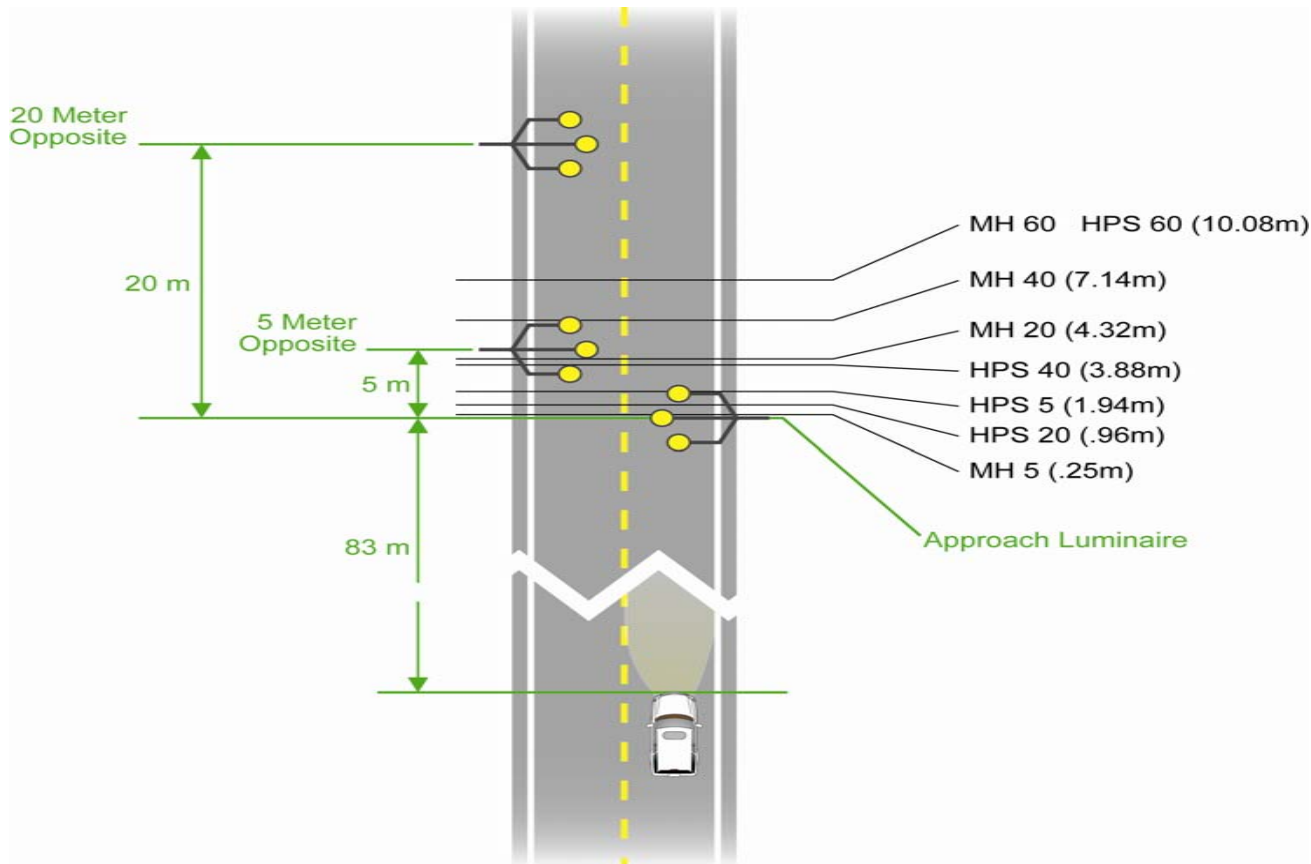
Crosswalk Placement

- The luminaires were laid out so that the crosswalk would be placed equally between 2 luminaires.
 - This simulates the lighting of the crosswalk for both directions.
 - The exact location of the crosswalk was moved with respect to the luminaires to achieve the desire lighting level.

Illuminance Performance

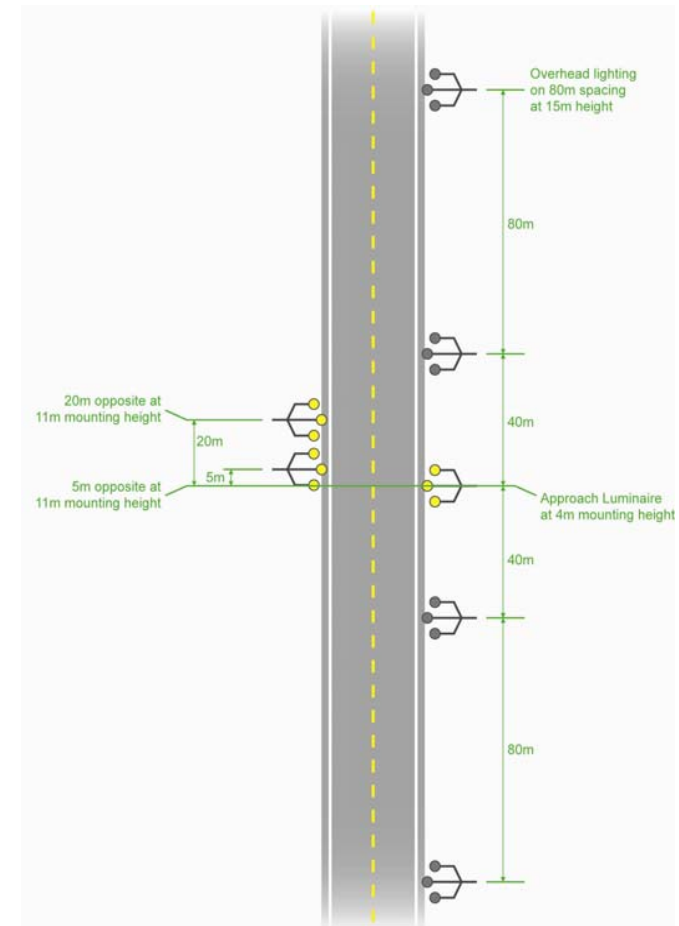


Experimental Layout



Overhead Lighting

- The overhead lighting factor is the addition of the roadway lighting to the specialized crosswalk lighting.



Glare

- A glare condition was created using a portable headlight frame.
 - Halogen Low Beam lamps were placed on the frame.
 - The frame was located on the shoulder of the oncoming traffic lane, 60 m from the experimental vehicle.

The Hot Dog Wagon



Occlusion Glasses

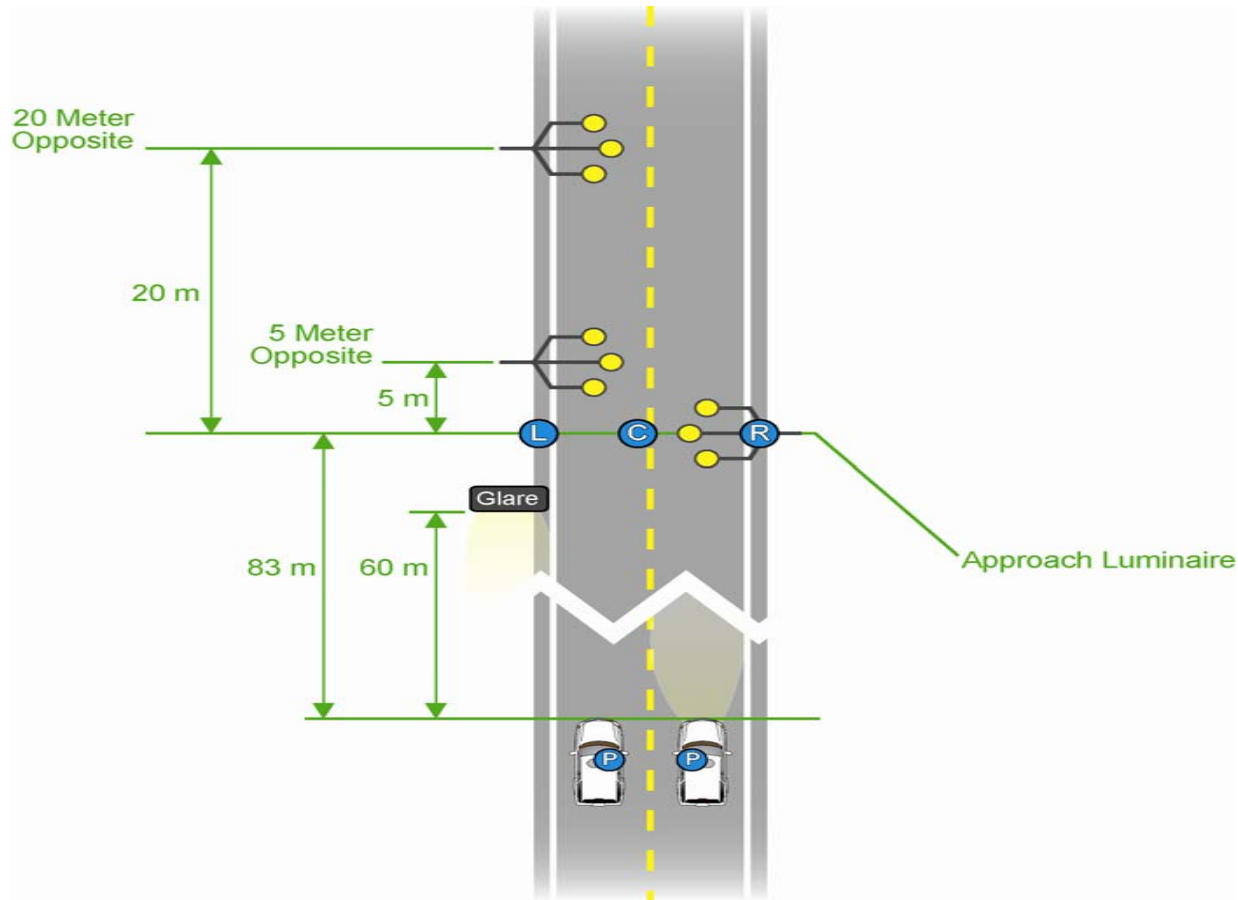
- Each participant was wearing a pair of occlusion glasses.



Static Experimental Process

- An object was placed in the crosswalk.
 - White, Blue Black Pedestrian
 - Surrogate 1, 2, or 3
- When ready, the occlusion glasses would flash.
- The participant would stop the flashing with a button press after they have identified the object.
- The number of flashes for correct identification were counted and used as the metric.
- Each object is presented in 1 of 3 locations in the crosswalk.
 - 20 Object presentations are given for each lighting design and glare condition

Experimental Area



Participants

- 16 Participants were used in each condition.
- Participants were all 65 or older.
- 2 participants were tested simultaneously.

Results

- The results for missed objects and time to detect were analyzed looking for significant factors.

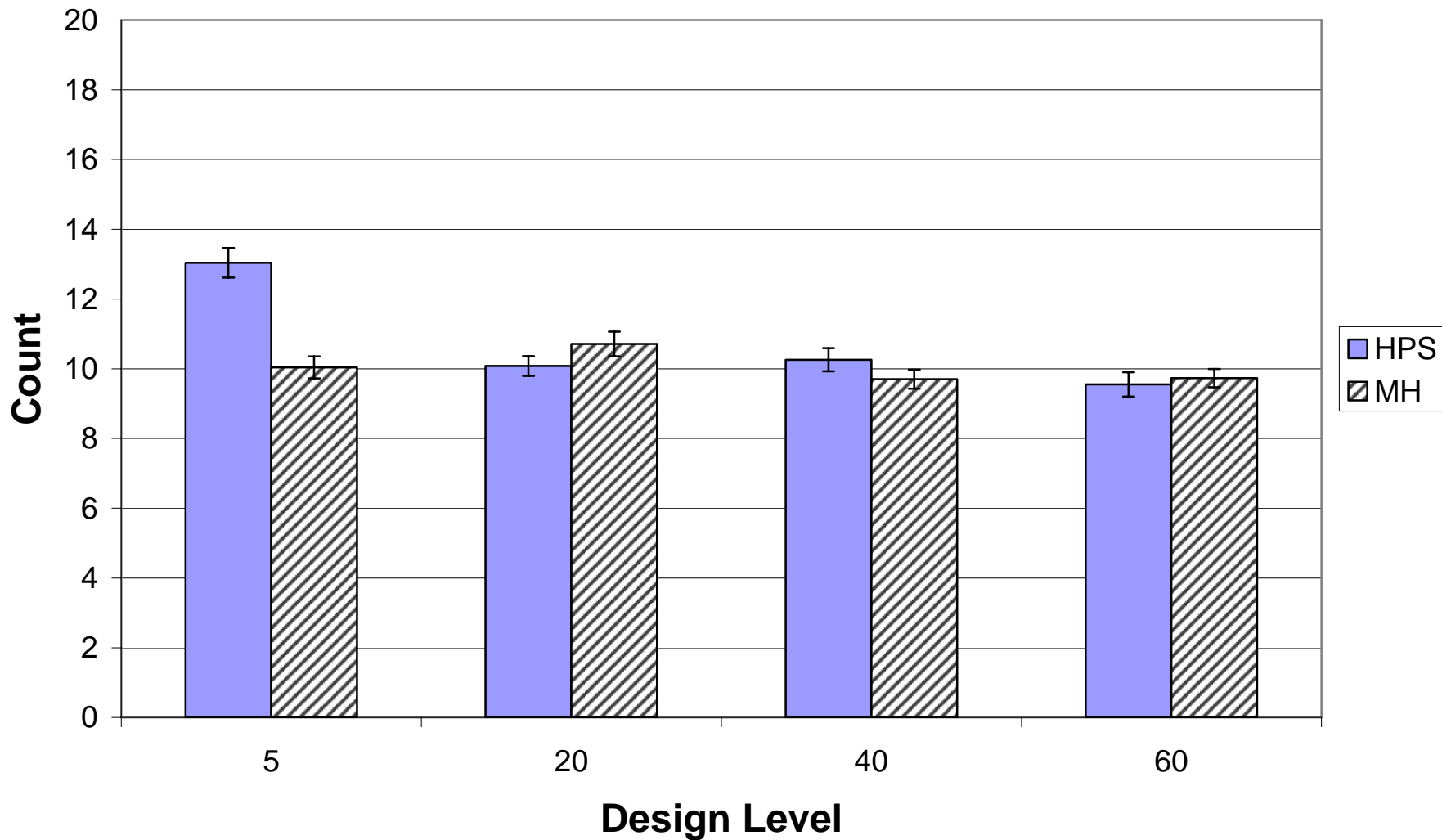
Missed Objects

- Less than 2% of the objects were missed without glare.
- 30.6% of the objects were missed with the glare turned on.
- The greatest influence on this parameter was the position of object with respect to the glare source.
 - The object closest to the glare was missed the most.

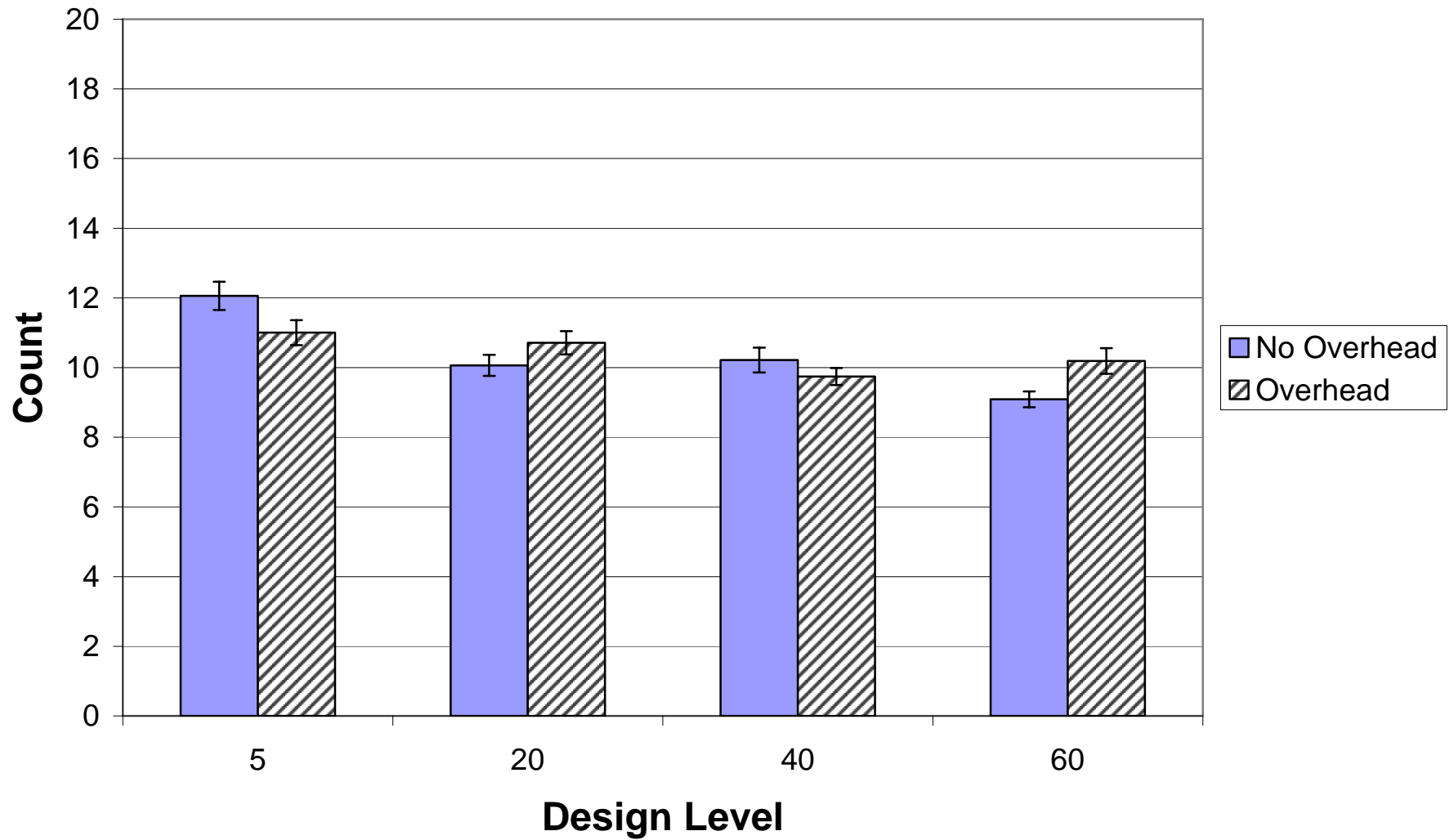
Timed Response

- The general relationship showed an influence of the lighting design level, the lamp and level interaction and the level and overhead interaction.
- For the timed response, the white clothed pedestrian was never influenced by the lighting design.
 - Object Always appeared Suprathreshold
- The black clothed object was influenced by the addition of the overhead lighting and the design level.
- The denim pedestrian was influenced by the lamp type as well as the other factors.

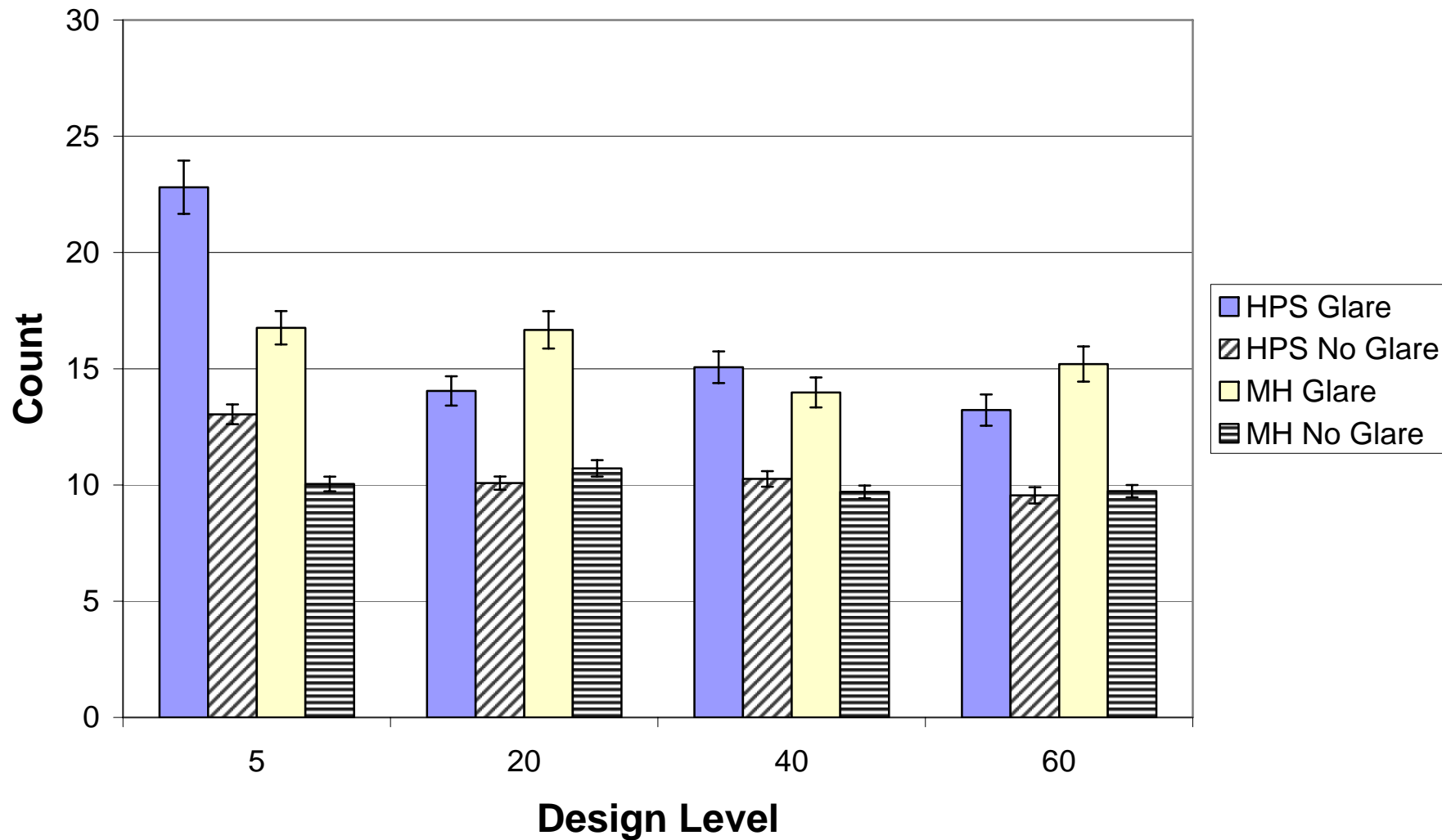
Lamp by Design Level



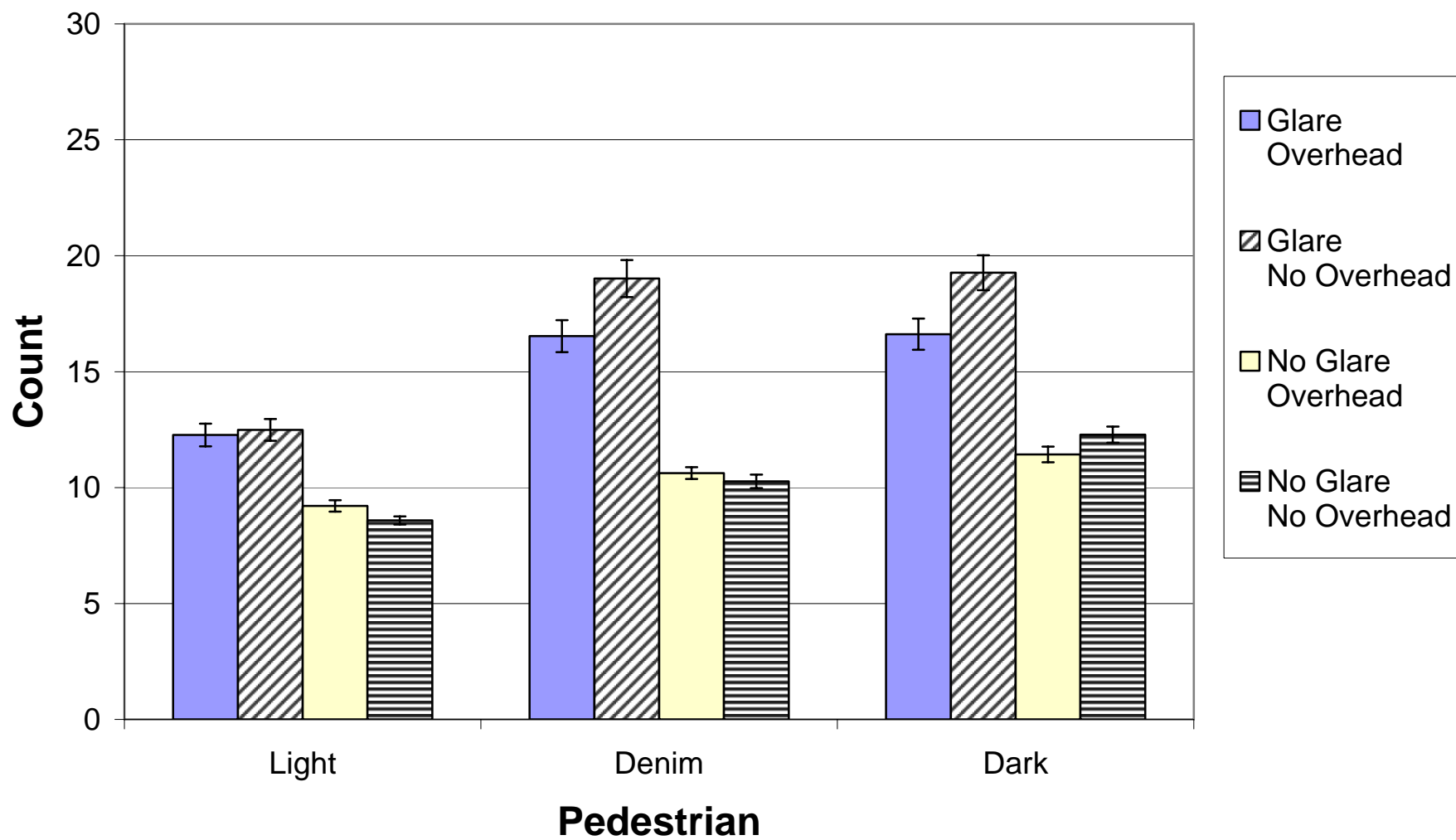
Overhead by Design Level



Lamp Type and Glare by Design Level



Glare and Overhead by Pedestrian



Contrast



Object Luminance Characterization

- All of the objects in the study were characterized for their photometric appearance
- Using a CCD photometer, a new world has been opened which allows for greater depth of analysis
 - 1024x1024 full color CCD
 - 1,000,000 measurements vs. 1 with a conventional photometer
- A Radiant Imaging ProMetric 1600 is owned by the Federal Highway Administration and is on generous loan to VTTI - LIT



CCD Photometry



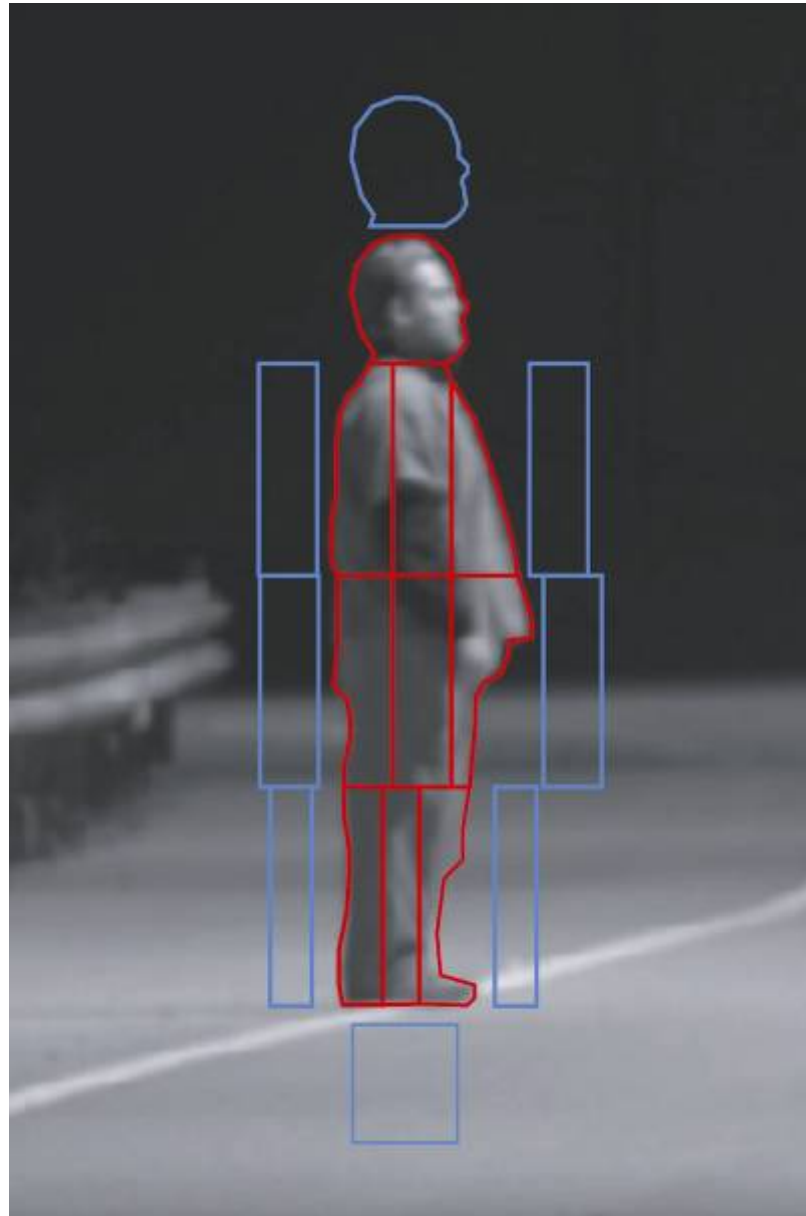
- “This is not your Parent’s photometry”
- We have barely started to touch the surface of how this instrument will change the way we look at lighting



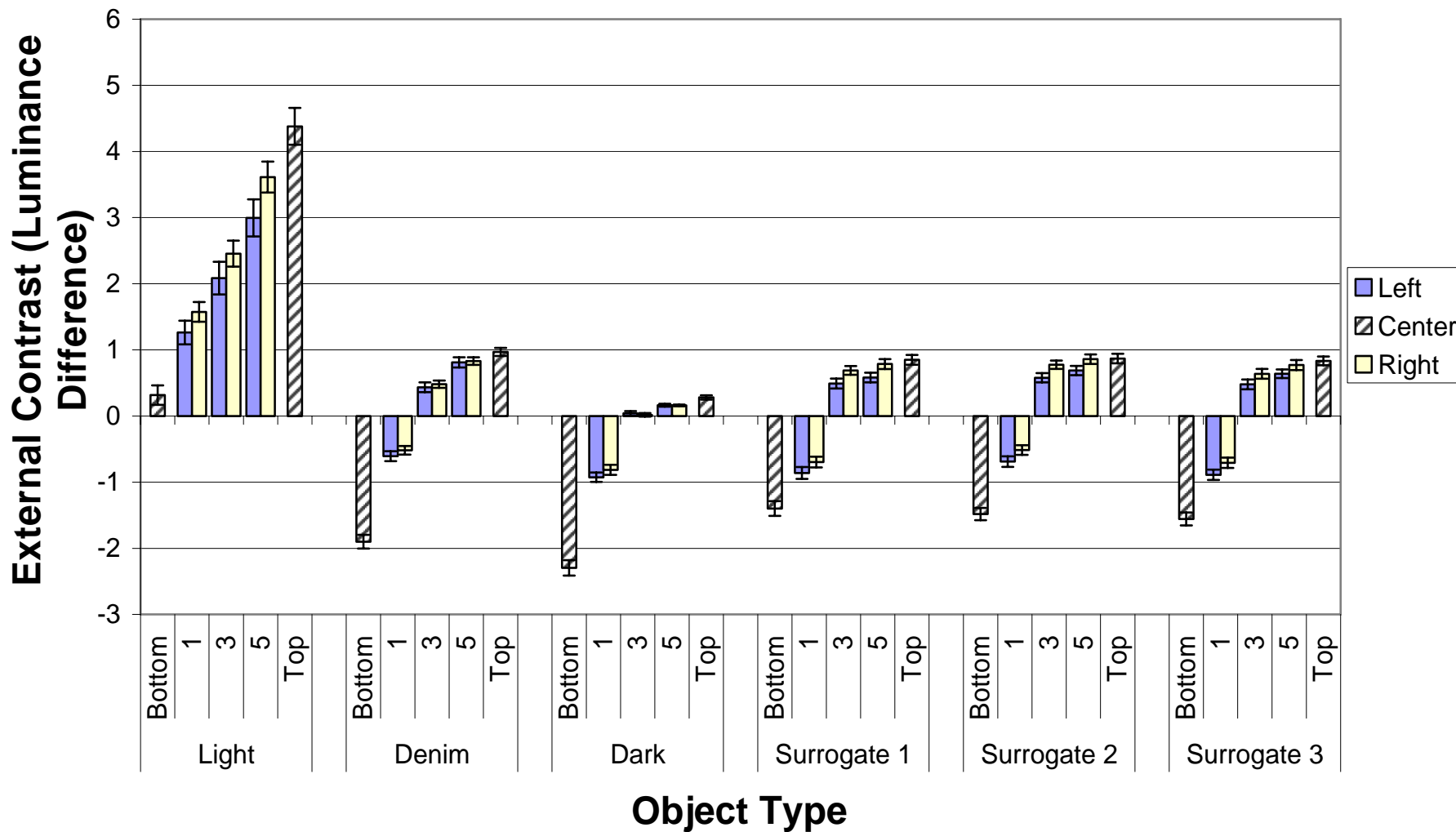
Photometric Characterization

- Each of the experimental conditions was photometered with a CCD Photometry System.
 - From the images, the luminance of the object and the background were taken.
 - The foreground was in a grid of 9 (3 horizontal and 3 vertical).
 - The background was taken adjacent to the vertical positions.

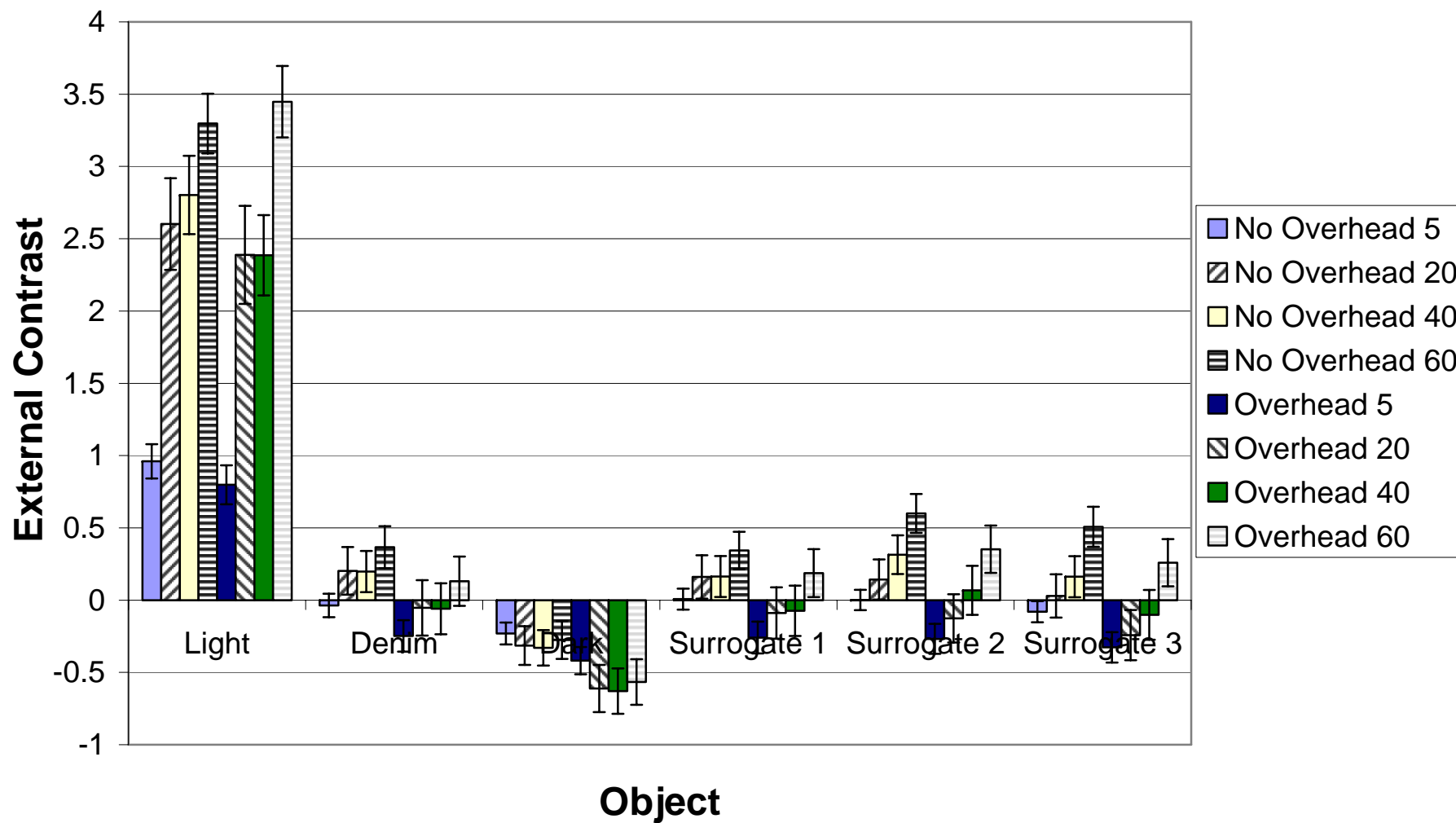
Photometric Grid



Object Type vs External Contrast



Overhead and Design Level by Object



Contrast Relationship

- The highest correlation to the object visibility was the logarithm of the absolute value of the external contrast.
- This can be related back to the vertical illuminance through the following

equation:

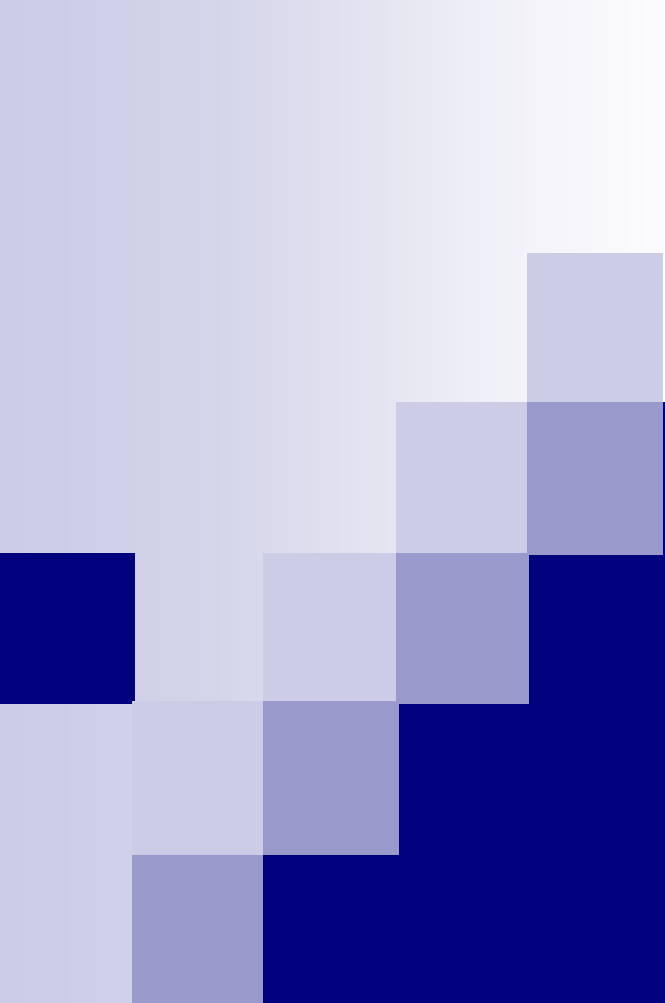
$$\log(abs(C_{External})) = \text{Log} \left(abs \left(\frac{\rho_{Object} \cdot E_{Vertical}}{\pi} - L_{Background} \right) \right)$$

Static Testing Summary

- A lighting level of 20 vertical lux seems sufficient for crosswalks with the following limitations:
 - This is a static test, but dynamic testing may prove that this level needs to be higher.
 - This was a rural road, but an urban area with a complex background may require a higher lighting level.
 - The addition of overhead lighting does not seem to mitigate the impact of glare.

Static Testing Summary

- Surrogates all performed equally well.
 - The simplest surrogate should be chosen.
 - The extruded cylinder is likely the easiest to implement in design software.



Another Thought

Maintained Intensity

- All lighting recommendations in IESNA RP-8 are for maintained levels.
- This means that the intensity used in all calculations is scaled by the light loss factor (LLF).
 - $LLF = \text{Lamp Lumen Depreciation} \times \text{Luminaire Dirt Depreciation}$.
 - For the equations, intensity (I) is equated as $\text{Lamp Intensity} \times LLF$.

Dirt Depreciation

- Method

- Photometer Dirty Luminaire
- Clean the Luminaire
- Photometer Again

- Spatially Distributed Dirt Depreciation

Before Cleaning



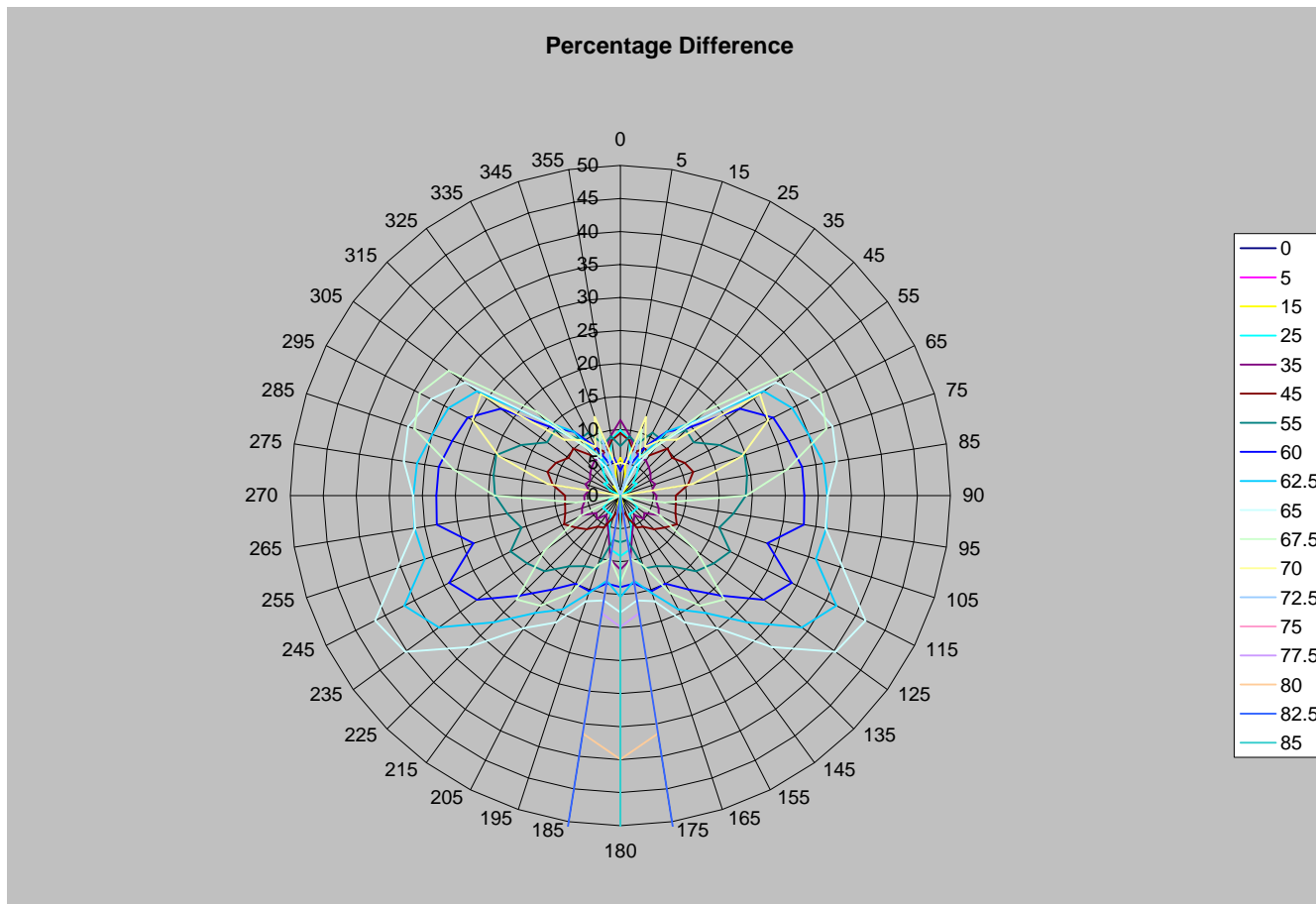
I-Table Dirty

	0	5	15	25	35	45	55	60	62.5	65	67.5	70	72.5	75	77.5	80	82.5	85	90
0	8867	9068	11617	16575	17870	11432	7044	4588	3433	2927	2568	2201	1709	1147	749	546	390	256	0
5	8867	9068	11543	15095	15465	11062	7607	4937	3580	3023	2645	2311	1787	1189	766	556	398	263	0
15	8867	9065	10794	12542	12505	9296	6778	4917	3898	3367	3049	2520	1857	1242	798	547	395	261	0
25	8867	8985	10511	13264	11617	9988	7544	5398	4331	3615	3065	2594	1894	1178	751	578	423	277	0
35	8867	8928	10681	11932	12209	10249	8478	6674	5624	4484	3554	2901	1896	1041	789	606	435	280	0
45	8867	8850	10271	11488	11691	11802	10852	9222	8241	6641	5552	3679	1965	1210	919	696	496	314	0
55	8867	8811	9869	11055	12265	12653	12949	15502	16094	15132	12505	7056	2893	1571	1101	813	562	345	0
65	8867	8802	9342	10406	11950	14429	16131	20645	21644	20127	14189	7335	3335	1796	1223	887	602	367	0
75	8867	8776	8994	9594	11094	14762	18259	22143	22643	19091	11654	5690	2804	1698	1193	868	597	364	0
85	8867	8757	8820	9066	9999	11784	15983	21570	21607	17630	10138	4849	2510	1589	1117	818	562	344	0
90	8867	8767	8754	8924	9603	10580	13430	18666	18425	13845	7204	3618	2146	1415	1042	753	511	312	0
95	8867	8743	8763	8898	9226	9583	10628	14411	13467	9153	4614	2782	1835	1310	989	730	504	313	0
105	8867	8730	8672	8848	8743	8354	7305	7377	5483	3953	2473	1874	1428	1103	838	621	432	269	0
115	8867	8706	8567	8691	8308	7303	6112	5023	4253	3339	2077	1630	1265	1002	774	579	406	260	0
125	8867	8691	8441	8613	7751	6576	5476	4440	3774	2817	1796	1408	1136	888	689	514	362	230	0
135	8867	8683	8351	8367	7477	6140	5037	4003	3465	2734	1837	1325	1066	853	659	498	353	229	0
145	8867	8676	8308	8223	6972	5836	4516	3630	3150	2549	1822	1323	1108	861	628	463	328	212	0
155	8867	8706	8363	8178	6847	5640	4373	3557	3088	2477	1839	1291	1047	839	641	473	333	219	0
165	8867	8691	8495	8461	7006	5195	4275	3716	2943	2368	1767	1265	1053	901	718	505	326	208	0
175	8867	8739	8641	9172	7401	5346	4116	3913	3252	2840	2016	1411	1115	972	802	593	394	229	0
180	8867	8791	8683	9305	7444	5779	4203	4003	3437	3078	2083	1424	1123	951	791	596	394	219	0

I-Table Clean

	0	5	15	25	35	45	55	60	62.5	65	67.5	70	72.5	75	77.5	80	82.5	85	90
0	8624	8783	12061	18129	19905	12357	7352	4514	3160	2619	2346	2061	1532	834	356	210	129	64	0
5	8624	8813	11839	16261	16760	11821	8099	4978	3298	2708	2425	2172	1624	903	335	192	115	67	0
15	8624	8782	10794	12968	13227	9716	7113	4915	3755	3217	3136	2603	1769	951	397	168	110	64	0
25	8624	8689	10413	13985	12154	10606	8175	5624	4360	3548	3015	2564	1739	789	241	168	115	71	0
35	8624	8606	10624	12228	12808	10820	9201	7302	6112	4673	3657	2967	1669	394	236	176	120	71	0
45	8624	8521	10106	11562	12191	12857	12339	10502	9501	7572	6471	3903	1392	482	282	200	134	80	0
55	8624	8471	9590	11155	12746	13745	14725	19665	21681	21015	18074	9225	2473	716	382	238	144	84	0
65	8624	8434	8978	10341	12339	15928	19110	27564	30228	29303	21163	9472	3119	954	455	264	159	90	0
75	8624	8426	8611	9427	11488	16427	22458	29913	31985	28470	16982	6756	2286	869	435	260	159	91	0
85	8624	8413	8441	8835	10249	12875	19535	29562	31042	26028	13301	5183	1857	820	443	268	159	91	0
90	8624	8412	8388	8717	9903	11283	16279	25547	26491	19831	8602	3395	1522	735	426	258	152	88	0
95	8624	8417	8397	8722	9505	10206	12567	19720	19332	13005	4690	2290	1221	679	433	280	162	92	0
105	8624	8406	8325	8745	9053	8891	8382	9314	7612	5748	2107	1437	992	615	389	245	147	85	0
115	8624	8412	8227	8641	8626	7808	7217	6743	6340	5309	1968	1317	936	583	395	251	148	88	0
125	8624	8406	8079	8650	7864	6904	6342	5737	5348	4310	1811	1018	747	489	325	206	130	77	0
135	8624	8434	8001	8384	7611	6356	5722	4784	4423	3687	2050	886	655	452	287	186	120	74	0
145	8624	8441	7999	8238	6983	5938	4926	4109	3726	3067	1989	970	766	533	288	170	106	62	0
155	8624	8493	8112	8191	6908	5709	4693	3898	3528	2849	1913	988	687	515	338	193	112	65	0
165	8624	8511	8354	8689	7181	5126	4562	4098	3197	2555	1713	976	728	672	542	351	139	59	0
175	8624	8585	8591	9745	7936	5219	4157	4242	3461	3095	1963	1130	839	779	682	551	343	80	0
180	8624	8646	8691	9978	8110	5816	4262	4366	3774	3445	2120	1177	842	763	684	588	379	77	0

Percentage Difference (Clean – Dirty)/Clean





The Future of Research

Where to Now?

- Visibility Research in the Future





Overview

- Pieces of the Puzzle:
 - Who, Why & How?
 - Where to Now?
- The Shape of Future Research:
 - Driver Requirements
 - Sensors, Metrology & Modeling
 - Lighting Technology
- The Roadmap Ahead:

Refining Visual Requirements —Lighting Design—

- Roadway Lighting shown to reduce crashes
 - However, no correlation between “goodness” of lighting design and safety
 - Cannot develop crash modification factors for specific roadway types
 - Cannot optimize cost/benefit of roadway lighting

The Shape of Future Research —Driver Needs—

- Refining Visual Requirements:
From Threshold to Information & Decision Making
 - Performance under mesopic lighting levels
 - Impact of non-uniform field
 - ETAL
- Impact of Aging Drivers
 - Vision limitations
 - Increased crash risk

Demographic Trends: — The Aging Driver Population

- 18.9 million drivers age 70 and older in 2000:
 - 36 percent increase from 1990 to 2000
 - 1990—8 percent of drivers were age 70 and over
 - 2000—10 percent of drivers were age 70 and over
- “Older” driver population will continue to grow as baby-boomers age

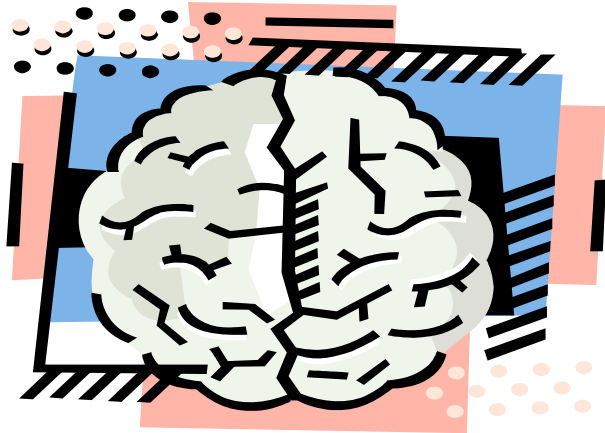


The Roadmap Ahead... (and other considerations)

(Photo by the Alaska Road Commission)



Development of a Driver Model



- How does a driver process visual information?
- Is that process different under mesopic levels?
- What is the impact of non-uniform lighting?



Energy Consumption

- How can we reduce consumption while improving roadway visibility?
- Can we show a connection between the lighting level and improved safety of roadway users and mobility of people and goods?

Environmental Concerns

- Sky glow – reflection of light by the atmosphere, such that a discernable glow is present.
- Light trespass – direct emission of light into areas where it is not required or desired.



Cost Effectiveness

- Identify funds
- Evaluate risk
- Assess regional needs;
allocate resources
appropriately
- Master Lighting Plans



Alternatives to Roadway Lighting

- Advanced headlight technologies: target the road, not the oncoming driver
- Self-luminous signs: less “wasted” light (especially uplight)
- In-roadway lighting: all-weather guidance, and/or changes in alignment



The Challenge....

- As the driving population ages, there is an increased need for improving roadway visibility.
- Lighting is an important means by which to meet this need, but must be balanced against environmental concerns and energy constraints.
- How will industry address this potential conflict?

Any Questions?

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