TELKOMNIKA, Vol.10, No.2, June 2012, pp. 235~244
ISSN: 1693-6930
accredited by DGHE (DIKTI), Decree No: 51/Dikti/Kep/2010

Design of Lighting System for Surface Mine Projects

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Abstrak

Standar iluminasi pertambangan India adalah didasarkan pada cahaya khas tanpa memperhatikan rasio keseragaman, tetapi Komisi Internasional Iluminasi (CIE), Austria mempersyaratkan rasio keseragaman. Dalam sebuah pertambangan dengan reflektansi permukaan rendah, tingkat iluminasi sekitarnya lebih rendah dari standar iluminasi minimum yang ditetapkan oleh berbagai badan pengatur. Kecerahan permukaan akan mereduksi kondisi permukaan basah, dan menghasilkan visibilitas yang buruk. Pada penelitian ini, desain dibuat untuk keduanya, dalam mineral dan overburden benches berbasis cahaya terpantul minimum yang dapat diterima dan rasio keseragaman terpantul. Untuk tujuan perbandingan berbagai jenis sistem pencahayaan, sebuah bentangan sepanjang 1,0 km telah dipertimbangkan. Desain telah diupayakan dengan lima jenis luminer berbeda. Ketinggian pemasangan lampu divariasi pada lima langkah, yaitu 8 10, 12, 14 dan 16 m. Desain pada kondisi basah menimbulkan biaya lebih 9,4% untuk bangku mineral dan 50% untuk jalan angkut bangku overburden. Perancangan pada kondisi permukaan basah memastikan tingkat cahaya minimum, bahkan di dibawah kondisi terburuk reflektifitas permukaan, dengan peningkatan marginal dalam biaya.

Kata kunci: *haul roads, luminer, pantulan permukaan, standar iluminasi*

Abstract

Indian mining illumination standard is based on incident light without mentioning about uniformity ratio, but International Commission on Illumination (CIE), Austria insists uniformity ratio. In a mine with low surface reflectance, the surrounding illumination level is lower than the minimum lighting standard as specified by various regulatory bodies. The surface brightness further reduces in wet surface condition, and results in poor visibility. In the present study, design was made both in mineral and overburden benches based on the minimum acceptable reflected light and the reflected uniformity ratio. For the purpose of comparison of various types of lighting systems, a stretch of 1.0 km long haul road was considered. The design was attempted with five different types of luminaries. Lamp mounting heights were varied at five steps, namely 8, 10, 12, 14 and 16 m. Design under wet condition incurs an excess cost 9.4 % for mineral bench and 50 % for overburden bench haul roads. Designing under wet surface condition ensures the minimum light level even under the worst condition of surface reflectivity, with marginal increase in cost.

Keywords: *haul roads, illumination standards, luminaire, surface reflectance*

1. Introduction

Illumination is a very important factor to be understood properly and to be provided in mines where the activities are performed in night shift. An effective lighting installation is one, which has been designed and installed so that individual may work with safety and efficiency, and with reasonable comfort [1]. In general, vision is influenced by three main lighting design parameters: illuminance level on the surface, uniformity of light distribution and glare from sources. Luminous intensity of light source takes care of illuminance on visual tasks, whereas uniform distribution pattern depends on the technological aspects like luminaire layout, aiming angle and positioning of the light sources [2]. Glare is not a major problem in surface mine lighting as the lamps are, in general, mounted at considerable height. Moreover, bulb material selected to provide diffuse transmission causing scattering of lights. These two aspects reduce the burden on the designer as only illuminance level and uniformity ratio are to be taken into consideration for general lighting in surface mines.

Received December 19, 2011; Revised April 25, 2012; Accepted May 4, 2012

1.1 Reflectance of Surfaces

Physical behavior of light, such as reflection is very important in designing the illumination system. Because the light reflected from task has greater bearing on what is seen [3-4]. In general, the more light the surfaces reflect (the higher the reflectance) the easier they are to see [5].

Reflectance property of any surface, particularly a rock surface, is greatly influenced by the amount of moisture it contains. In case of dry surfaces, reflected light attribute materials color and scattered light from its surface texture [6]. When mineral surfaces, which are porous in nature is moistened, the scattering structures becoming coated with a thin layer of water. The light entering into the water and substance interface is scattered deep into the material, than when the material is dry. Due to this deeper penetration the light naturally strikes many more faces, and certain fraction of the light is absorbed, in the process. Thus the intensity of emerged out light decreases and it appears dimmer than its counterpart from dry surface.

Good road lighting design is not possible without knowledge of reflectance of road surface. It is clear that illumination of a dry haul road designed on reflected illuminance may not suffice when the roadway becomes wet. Measurements of this phenomenon are required so that the lighting installation can compensate for the absorption or reflectance characteristics of the surface.

1.2 Measurement of Reflectance

In general, there are four different techniques of reflectance measurements: reflected-incident light comparison, standard chips comparison, reflectance standard comparison and sphere reflectometry. Among these, the reflectance standard comparison method is though tedious but more accurate, and hence is generally employed for determining reflectance of mine surfaces. In this method experiments are conducted on specimens so that reflectance measurements can be performed in a laboratory where conditions are more accurately controlled. The reflectance values of haul road surfaces used in the present design have been obtained in the laboratory study [7].

1.3 Lighting Standards

In India provisions are made regarding mine lighting under Chapter XIII of The Coal Mines Regulations (CMR) 1957 [8]. In Regulation No. 154(2) (b), the Chief Inspector of Mines is authorized to prescribe the standards of lighting to be provided by notification in the official Gazette. In this context standards are prescribed for opencast mine illumination by Circular (Legis.) 1/1976 and Circular (Legis.) 3/1976 for coal and metal mines, respectively [9]. The standard of lighting specified is in terms of minimum required illuminance level.

The Commission Internationale de ‘Eclairage (CIE) i.e. International Commission on Illumination, Austria has brought out the Guide to the Lighting for Opencast Mines in the year 1987, which stresses upon uniformity as well [10]. CIE also suggests for average illuminance level instead of minimum illuminance level. Even the Bureau of Indian Standard (BIS) code of practice for lighting of public thoroughfares cites average illuminance level and overall uniformity ratio for traffic road lighting [11].

No doubt, the increase in lamp flux will increase the luminance of the surface. But wetting the surface changes its specular conditions abruptly [12]. Further, the average luminance of a surface increases when it becomes wet, which results in decrease of overall uniformity [13]. Hence, in present study the design has been made taking 0.5 lux as minimum acceptable reflected light (instead of incident light) and 0.3 as reflected overall uniformity ratio.

2. Research Method

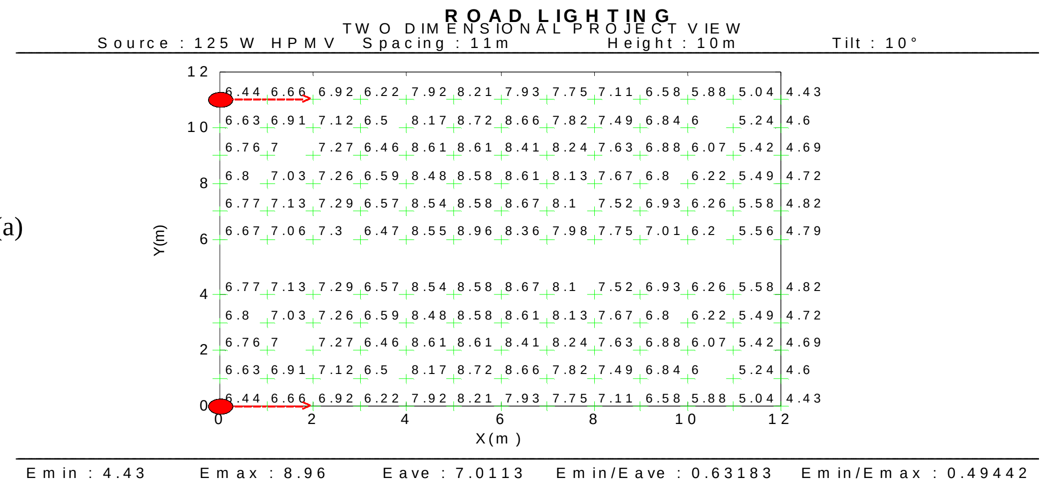
2.1. Development of Software

Software SURLux has been developed by the authors for designing surface mine illumination [14]. The software is developed on MATLAB, a high performance language for technical computing. The software is versatile in calculating light level at a grid point for any given set of parameters such as luminaire type and its characteristic, location of poles, spacing of poles, mounting height, tilt angle etc. A special feature of the software is that it can take directly into consideration of the reflectance factor of the surface [15]. Reflectance values under dry condition or wet condition can be fed to the software. Some standard values of reflectance under dry as well as wet condition have been incorporated in the program itself. The software is capable of calculating for any given area the minimum and maximum light level, average light level and uniformity ratio for deciding the feasibility of the illumination system. If cost data for all the components of lighting system are provided, then the software can calculate the cost of illumination (16). This would help in the selection of the optimum illumination design parameters.

2.2. Illumination Design Based on Reflectance of Road Surface

For the sake of comparison of various types of lighting systems, a stretch of 1.0 km long haul road was considered with 12 m width, which is quite common in surface mines. Design of the haul road was attempted with five different types of luminaries namely, 125 and 250 W high pressure mercury vapor (HPMV) lamps and 150, 250 and 400 W high pressure sodium vapor (HPSV) lamps. Lamp mounting heights have been varied in five steps, namely 8, 10, 12, 14 and 16 m. Tilt angle of luminaire was kept constant at 10º, as it gives best results at this angle [13]. Design of two different haul roads was considered in this study – one in iron ore bench and the other in lateritic overburden bench.

(a)



(b)

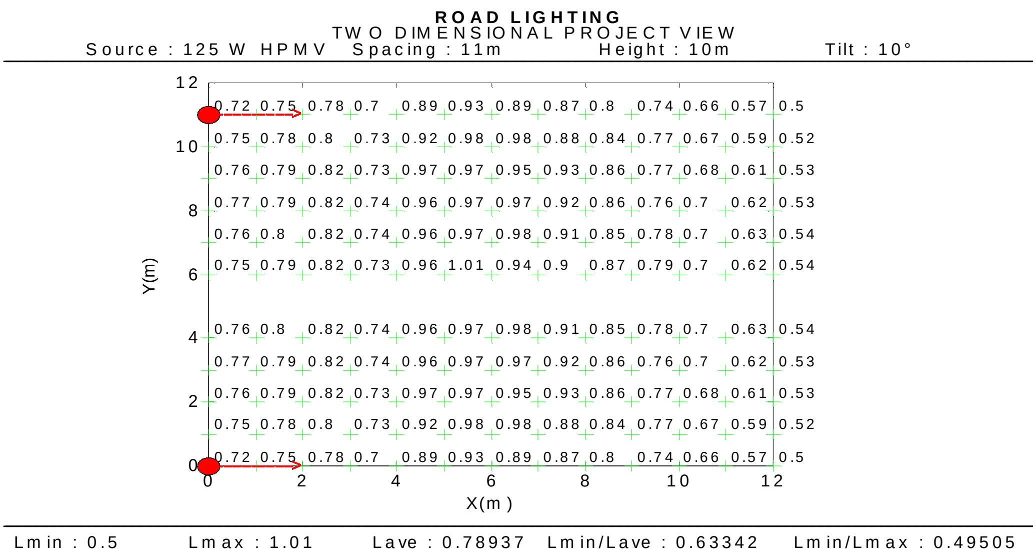


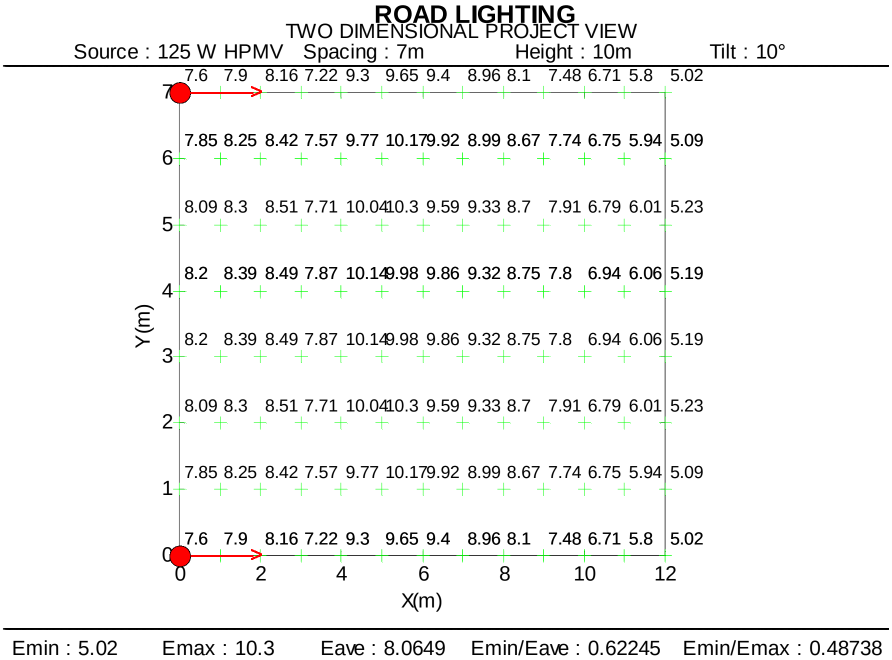
Figure 1. A Representative computer output showing at grid points for 125 W HPMV lamps with 10 m height, dry surface, (a) at luminance levels; (b) at illuminance levels

3. Results and Analysis

3.1. Haul road in mineral (iron ore) bench

The reflectance of haul road is 11.27 % for dry and 9.97 % for wet condition (as obtained from laboratory studies). By optimizing the pole spacing using the developed design model SURLux, the number of poles required for each type of sources to illuminate the entire length of road was calculated. While calculating the number of poles, fractional number has been rounded off to the nearest integer and it has been increased by one to have poles at the both ends of the road.

(a)



(b)

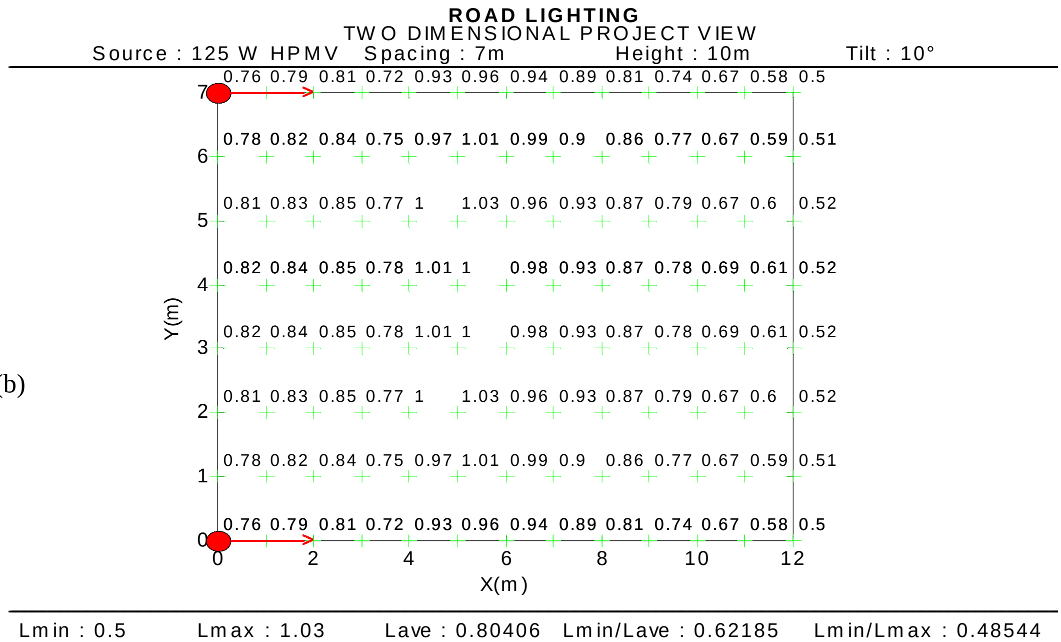


Figure 2. A representative computer output at grid points for 125 W HPMV lamps at 10 m height, wet surface. (a) for illuminance levels; (b) luminance levels

Table 1. Design parameters satisfying minimum standards in iron ore bench

Height of pole (m)	Surface condition	Pole spacing (m)	No. of poles	Minimum illuminance (lux)		Overall uniformity ratio	
				on surface	from surface	on surface	from surface
125 W HPMV							
8	dry	8	126	4.39	0.5	0.42	0.43
	wet *	-	-	-	-	-	-
10	dry	11	92	4.43	0.5	0.63	0.63
	wet	7	144	5.02	0.5	0.62	0.62
12	dry	10	101	4.45	0.5	0.78	0.78
	wet	5	201	4.98	0.5	0.77	0.78
14	dry	4	251	4.42	0.5	0.86	0.86
	wet *	-	-	-	-	-	-
16	dry *	-	-	-	-	-	-
	wet *	-	-	-	-	-	-
250 W HPMV							
8	dry	16	64	4.48	0.51	0.32	0.32
	wet	12	84	5.15	0.52	0.30	0.30
10	dry	19	54	4.43	0.5	0.42	0.42
	wet	16	64	5.11	0.51	0.42	0.42
12	dry	21	49	4.46	0.5	0.52	0.51
	wet	18	57	4.96	0.5	0.52	0.52
14	dry	21	49	4.54	0.51	0.60	0.60
	wet	16	64	5.03	0.5	0.57	0.57
16	dry	19	54	4.4	0.5	0.63	0.64
	wet	13	78	5.06	0.51	0.62	0.62
150 W HPSV							
8	dry *	-	-	-	-	-	-
	wet *	-	-	-	-	-	-
10	dry *	-	-	-	-	-	-
	wet *	-	-	-	-	-	-
12	dry	25	41	4.71	0.53	0.29	0.29
	wet	24	43	4.96	0.5	0.30	0.30
14	dry	32	32	4.54	0.51	0.35	0.35
	wet	27	38	5.06	0.5	0.35	0.35
16	dry	49	21	4.53	0.51	0.55	0.55
	wet	45	23	5.2	0.51	0.59	0.58
250 W HPSV							
8	dry	34	30	5.69	0.63	0.30	0.29
	wet	34	30	5.69	0.56	0.30	0.29
10	dry	43	24	4.81	0.54	0.35	0.34
	wet	41	25	5.32	0.54	0.37	0.37
12	dry	51	21	4.59	0.51	0.43	0.42
	wet	49	21	4.83	0.49	0.44	0.45
14	dry	54	20	4.49	0.51	0.49	0.49
	wet	51	21	5.03	0.51	0.52	0.53
16	dry	55	19	4.54	0.51	0.56	0.56
	wet	53	20	4.9	0.49	0.59	0.59
400 W HPSV							
8	dry	36	29	12.54	1.41	0.30	0.30
	wet	36	29	12.54	1.23	0.30	0.29
10	dry	44	24	9.06	1.01	0.30	0.30
	wet	44	24	9.06	0.92	0.30	0.31
12	dry	52	20	6.56	0.75	0.30	0.30
	wet	52	20	6.56	0.66	0.30	0.30
14	dry	60	18	4.93	0.57	0.29	0.30
	wet	58	18	5.37	0.53	0.31	0.30
16	dry	63	17	4.66	0.53	0.34	0.34
	wet	60	18	5.24	0.53	0.37	0.37

***** design parameters not satisfying minimum lighting standards

Figure 1(a) & 1(b) show the representative output of design program for illuminance and luminance layouts, respectively for 125 W HPMV lamps at 10 m pole height, for dry surface condition. Similarly Figure 2(a) & 2(b) show illuminance and luminance layouts respectively for wet surface condition. Table-1 gives the design parameters as obtained using the developed program, at five different stages of pole heights. It represents the maximum possible pole spacing for given height of pole to achieve minimum reflected illumination standards. As indicated in Table 1, in some of the cases, represented by asterisks, the design parameters do not satisfy the minimum lighting standards. In all other cases, the lighting design could fulfill the minimum illuminance level (0.5 lux minimum illuminance level and 0.3 overall uniformity ratio) reflected from the surface. For example from Table 1 it is seen that the optimum pole spacing for 150 W HPSV sources to meet the light requirements is 49 m for dry condition and 45 m for wet condition, both at 16 m pole heights.

Table 2 indicates cost of the illumination system for all the combinations mentioned in Table 1. Table 3(a) and 3(b) show the representative output of cost model for 125 W HPMV lamps at 10 m height pole, for both dry and wet conditions, respectively. It is seen that lowest cost for haul road illumination in iron ore bench is achieved with 150 W HPSV sources at 16 m pole heights, under both dry and wet conditions. Illumination cost under wet condition is more than under dry condition by

{(1,66,096 - 1,51,849) / 1,51,849} x 100 i.e. 9.4 %

Table 2. Total annual illumination cost in iron ore bench (for design parameters as given in Table 1)

Source	Height of pole (m)	Total annual cost (Rs.)	
		Dry surface	Wet surface
125 W HPMV	8	6,16,067	-
	10	4,89,069	7,64,222
	12	5,62,198	11,16,593
	14	14,58,799	-
	16	-	-
250 W HPMV	8	5,35,467	7,02,094
	10	4,74,829	5,62,341
	12	4,43,446	5,15,477
	14	4,56,137	5,95,080
	16	5,16,215	7,44,641
150 W HPSV	8	-	-
	10	-	-
	12	2,73,247	2,86,466
	14	2,22,050	2,63,261
	16	**1,51,849**	**1,66,096**
250 W HPSV	8	2,56,364	2,56,364
	10	2,15,621	2,24,511
	12	1,94,254	1,94,254
	14	1,90,291	1,99,693
	16	1,85,732	1,95,389
400 W HPSV	8	3,58,959	3,58,959
	10	3,07,537	3,07,537
	12	2,61,708	2,61,708
	14	2,40,425	2,40,425
	16	2,31,526	2,45,013

3.2. Haul Road in Over Burden (Lateritic) Bench

The reflectance of haul road is 9.55 % for dry and 5.25 % for wet condition (as obtained from laboratory studies). Table 4 gives feasible solutions for four types of sources namely, 250 W HPMV, 150 W HPSV, 250 W HPSV and 400 W HPSV. In case of 125 W HPMV lamps design parameters could not fulfill the minimum lighting standards for any pole height. In Table 4, the design parameters not satisfying the minimum required lighting standards, is represented by asterisk. The cost calculation given in Table 5 for respective design parameters as indicated in Table 4, shows that 400 W HPSV sources at 12 m height is offers minimum annual cost (Rs. 3,13,598) under wet condition. However, for dry condition 250 W HPSV lamps at 14 m height gives the optimum design. The percentage increase in cost under wet condition with respect to dry condition is

{(3,13,598 - 2,09,094) / 2,09,094} x 100 % i.e. 50 %.

Table 3 (a). A Representative computer output for cost calculation (for 125 W HPMV lamps at 10 m height pole, dry surface), (b). A Representative computer output for cost calculation (for 125 W HPMV lamps at 10 m height pole, wet surface)

COST CALCULATION
Fixed costs : Rs.264230
Lamp costs : Rs.22075
Energy costs : Rs.469003
Labour costs for lamp replacement : Rs.3154
Maintenance cost : Rs.5760
TOTAL ANNUAL COST : Rs.764222

(a)

COST CALCULATION
Fixed costs : Rs.264230
Lamp costs : Rs.22075
Energy costs : Rs.469003
Labour costs for lamp replacement : Rs.3154
Maintenance cost : Rs.5760
TOTAL ANNUAL COST : Rs.764222

(b)

Table 4. Design parameters satisfying minimum standards in laterite bench

Height of pole (m)	Surface condition	Pole spacing (m)	No. of poles	Minimum illuminance (lux)		Overall uniformity ratio	
				on surface	from surface	on surface	from surface
250 W HPMV							
8	dry *	-	-	-	-	-	-
	wet *	-	-	-	-	-	-
10	dry	15	68	5.25	0.5	0.42	0.42
	wet *	-	-	-	-	-	-
12	dry	15	68	5.27	0.51	0.49	0.50
	wet *	-	-	-	-	-	-
14	dry	15	68	5.19	0.5	0.57	0.57
	wet *	-	-	-	-	-	-
16	dry	12	84	5.29	0.51	0.63	0.63
	wet *	-	-	-	-	-	-
150 W HPSV							
8	dry *	-	-	-	-	-	-
	wet *	-	-	-	-	-	
10	dry *	-	-	-	-	-	-
	wet *	-	-	-	-	-	-
12	dry	22	46	5.4	0.51	0.31	0.31
	wet	7	144	9.9	0.51	0.39	0.38
14	dry	26	39	5.83	0.55	0.4	0.40
	wet	10	101	10.15	0.53	0.50	0.49
16	dry	33	31	5.81	0.55	0.53	0.53
	wet	15	68	9.49	0.5	0.62	0.62
250 W HPSV							
8	dry	25	41	7.03	0.68	0.29	0.29
	wet *	-	-	-	-	-	-
10	dry	41	25	5.32	0.51	0.37	0.37
	wet	17	60	9.54	0.51	0.35	0.36
12	dry	45	23	5.32	0.51	0.45	0.45
	wet	15	68	9.54	0.51	0.39	0.40
14	dry	47	22	5.42	0.51	0.53	0.52
	wet	14	72	9.61	0.51	0.45	0.46
16	dry	48	22	5.39	0.51	0.60	0.59
	wet	12	84	9.64	0.51	0.51	0.51
400 W HPSV							
8	dry	36	29	12.54	1.19	0.30	0.30
	wet	36	29	12.54	0.66	0.30	0.30
10	dry	44	24	9.06	0.88	0.30	0.30
	wet	42	25	10.16	0.53	0.33	0.32
12	dry	52	20	6.56	0.62	0.30	0.29
	wet	44	24	9.81	0.53	0.39	0.40
14	dry	58	18	5.37	0.53	0.31	0.32
	wet	43	24	9.99	0.53	0.44	0.45
16	dry	59	18	5.46	0.53	0.38	0.38
	wet	39	27	9.9	0.53	0.48	0.49

***** design parameters not satisfying minimum lighting standards

Table 5. Total annual illumination cost in laterite bench [for design parameters as given in Table 4.

Source	Height of pole (m)	Total annual cost (Rs.)	
		Dry surface	Wet surface
250 W HPMV	8	-	-
	10	5,97,347	-
	12	6,14,519	-
	14	6,32,131	-
	16	8,01,747	-
150 W HPSV	8	-	-
	10	-	-
	12	3,06,294	9,54,023
	14	2,70,129	6,95,974
	16	2,23,083	4,86,647
250 W HPSV	8	3,49,536	-
	10	2,24,511	5,35,664
	12	2,12,539	6,23,957
	14	**2,09,094**	6,79,176
	16	2,14,702	8,13,406
400 W HPSV	8	3,58,959	3,58,959
	10	3,07,537	3,20,257
	12	2,61,708	**3,13,598**
	14	2,40,425	3,19,814
	16	2,45,013	3,66,390

4. Conclusion

In mineral bench, illumination cost under wet condition is 9.4 % more than that under dry condition, whereas in an overburden bench the increase is 50 %. This increase in cost for haul road in overburden bench is mainly because of low reflectance of the surface and also large difference between dry and wet surface reflectivity.

In practice it is very difficult to design an installation such that it will take care of any wet weather condition. As per DGMS standards the light level to be maintained in haul roads is specified as the minimum horizontal illuminance level on the road surface. Whether this amount of light would produce visual acuity would depend on the nature of road surface. If the surface reflectivity is poor, illumination system designed on illuminance may not provide sufficient visibility. On the other hand, if minimum illuminance level is ensured by the system, it would always produce necessary visibility. Hence the authors incorporated the aspects of the reflectance of the surface as well as its wetness in the design considerations.

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