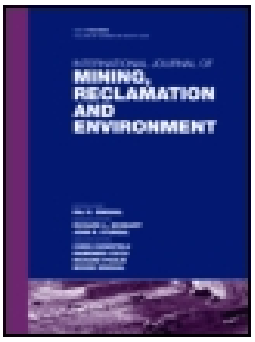

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Design of haul road lighting system. Part III: application

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The design of haul road illumination systems based on a scientific approach is very important. Improperly planned lighting systems may provide unsatisfactory illumination and may also incur higher costs. This paper describes illumination systems designed for two haul roads using the computer programs developed in earlier stages of this work. System performances and cost are compared with the existing illumination system. Designs based on the developed programs show total potential cost savings of approximately 26% and 48% for the two systems.

Keywords: Lighting; Haul road; Design; Illumination standards; Illumination survey

1. Introduction

Haul roads in surface mines are typically illuminated by single-sided lighting arrangements. Within the pit limit, lighting installations cannot be permanent due to regular advancements of the working face (Bandhopadhyay 1989); it is thus very difficult to maintain lighting standards in haul roads within the pit. Uniformity of light levels is very important, especially where there is a sudden change in road configuration. However, because of typical working patterns in mines, proper orientation of lamps and hence a uniform distribution of light are difficult to achieve (Aruna *et al.* 2004).

Indian mine lighting standards have specified only the minimum light level. But, as discussed in Part I of this work (Karmakar *et al.* 2006a), the average light level and the uniformity ratio are also important aspects in proper lighting design. Taking into account Indian lighting standards and CIE (International Commission on Illumination, Austria) guidelines, haul road lighting should be based on a minimum light level of 0.5 lux, an average light level of 4.0 lux and a uniformity ratio of 0.3 (for details see Karmakar *et al.* (2006a)).

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In general, Indian practice is a single-sided haul road lighting arrangement with light sources mounted at heights of 9 to 12 m. In most mechanized mines high-intensity discharge (HID) lamps (e.g. high-pressure sodium vapour (HPSV) and high-pressure mercury vapour (HPMV) lamps) are used for illumination; in small semi-mechanized mines, fluorescent tube lamps (FTLs) with HID lamps at junctions are preferred.

Part I of this work (Karmakar *et al.* 2006a) dealt with the development of a computer program for optimum lighting design based on energy consumption; Part II (Karmakar *et al.* 2006b) described a cost analysis. Here the developed models are applied to the real-life case study of an iron ore mine in the Goan region of India where about 13 segments of haul road were in operation within the pit. Two of the in-pit roadways were considered for the present study—one where only a single type of lamp was used and the other where different combinations of lamps were employed. Using the developed program, a theoretical optimum design was obtained for both the haul roads using only a single type of lamp (similar types of lamps were used so as to achieve a uniform distribution of light, i.e. overlapping isolux contours (Lyons 1981)). The designed lighting system was compared with the existing system in terms of both illumination level and cost.

2. Lighting system and illumination survey

The two haul roads considered in the present study were of length 720 m (Road A) and 292 m (Road B), both 12 m width. Road A was illuminated with 250 W HPSV lamps mounted at 9.0 m height. A total of 15 lamps were used at irregular spacings, varying from 43 to 50 m. The light arm angle, i.e. lamp tilt angle, was 35°. There was no overhang, i.e. lamps were vertical above the road edge.

Road B was illuminated with five different kinds of lamps. Altogether eight lamps (2 × 250 W HPSV, 2 × 400 W HPSV, 2 × 400 W HPMV, 1 × 250 W HPMV and 1 × 70 W HPSV) were used at a tilt angle of 45°. A survey among mine personnel revealed that the combination of lamps was not used to serve any specific purpose—rather it had developed depending on the availability of lamps at the time of replacement. All the lamps were mounted at 6.5 m height and the lamps were 2 m offset from the edge of the road.

An illumination survey for the haul roads was conducted as per the methodology proposed by Mine Safety and Health Administration (MSHA) (USBM 1976, 1982). Grids were marked along the length of the haul roads at 5 m intervals. Horizontal illumination levels were measured at three points (two at the edges and one at the centre) of each grid line using a digital luxmeter. Table 1 highlights the existing lighting installations in both roads.

3. Survey results and cost estimation

For brevity, only the salient features of the detailed survey carried out are provided here. In general, illumination in the 'houseside' (i.e. the side of the road nearest to the pole) was higher than that in the 'roadside' (i.e. the side of the road furthest from the pole), due to the low height of the poles compared with the road width. Dark areas with light levels much less than the standards recommended were noted; these are a result of the irregular pole spacing and also, perhaps, their low height. Mine personnel tried to compensate for the effect of low pole height by increasing the tilt angle, but this diffused the light resulting in glare problems for the operator as the lamp came in his field of vision. Overall it was felt that the illumination systems for both roads were not satisfactory.

The costs of the existing illumination systems in Roads A and B were calculated using the program described in Part II (Karmakar *et al.* 2006b), and the results are presented in table 1.

4. Cost-effective design of a new illumination system

Designs were considered for mounting heights of 12 m and 16 m (as the existing road width is 12 m). Only HPSV lamps were considered as they are more effective for haul road illumination than HPMV lamps (Karmakar *et al*. 2006b). Tilt angle was kept at 10° (Karmakar *et al*. 2006a). For both roads, designs were studied for systems using lamps of 70, 100, 150, 250 and 400 W. The design parameters and costs involved are given in tables 2 and 3. All these designs satisfy the minimum lighting standards (as discussed earlier) involving optimum total annual cost for each system.

Table 2 shows that for Road A, an economic design is achieved with 100 W HPSV lamps mounted at 12 m height, whereas 150 W lamps at 16 m height give the minimum cost. Similarly, 150 W lamps at 16 m height give the most economic design for Road B (table 3). Comparing the

Table 1. Details of existing lighting installations in Roads A and B (1 US$ = approx. 45.00 INR Rs).

	Road A	Road B
Source	15 × 250 W HPSV	2 × 250 W HPSV 2 × 400 W HPSV 2 × 400 W HPMV 1 × 250 W HPMV 1 × 70 W HPSV
Road length (m)	720	292
Height of pole (m)	9	6.5
Spacing (m)	Not regular	Not regular
No. of poles	15	8
Tilt angle (deg.)	30	45
Initial investment cost (Rs)	476,871	81,003
Total annual cost (Rs)	223,375	244,530

Table 2(a). Cost comparison of lighting systems in Road A; 12 m height poles and tilt angle of 10° (1 US$ = approx. 45.00 INR Rs).

Source	70 W HPSV	100 W HPSV	150 W HPSV	250 W HPSV	400 W HPSV
Spacing (m)	28	45	40	62	52
No. of poles	27	17	19	13	15
Initial investment cost (Rs)	366,234	246,781	295,088	211,523	250,611
Total annual cost (Rs)	218,941	**188,714**	225,849	218,039	293,312

Table 2(b). Cost comparison of lighting systems in Road A; 16 m height poles and tilt angle of 10° (1 US$ = approx. 45.00 INR Rs).

Source	70 W HPSV	100 W HPSV	150 W HPSV	250 W HPSV	400 W HPSV
Spacing (m)	16	34	89	80	70
No. of poles	46	22	9	10	11
Initial investment cost (Rs)	777,160	393,106	177,081	200,266	225,235
Total annual cost (Rs)	336,095	230,731	**165,038**	197,393	248,986

Table 3(a). Cost comparison of lighting systems in Road B; 12 m height poles and tilt angle of 10° (1 US$ = approx. 45.00 INR Rs).

Source	70 W HPSV	100 W HPSV	150 W HPSV	250 W HPSV	400 W HPSV
Spacing (m)	28	45	40	62	52
No. of poles	11	7	8	6	7
Initial investment cost (Rs)	149,155	101,516	124,021	96,975	116,244
Total annual cost (Rs)	146,077	**134,156**	150,690	152,195	187,937

Table 3(b). Cost comparison of lighting systems in Road B; 16 m height poles and tilt angle of 10° (1 US$ = approx. 45.00 INR Rs).

Source	70 W HPSV	100 W HPSV	150 W HPSV	250 W HPSV	400 W HPSV
Spacing (m)	16	34	89	80	70
No. of poles	19	10	4	5	5
Initial investment cost (Rs)	320,887	178,111	78,241	99,056	101,806
Total annual cost (Rs)	195,147	157,127	**126,591**	146,478	165,425

total annual cost of the existing system with that of the designed system, the tables show that the costs for all five designs for Road A are less than that of the existing system. For Road B most of the new designs are cheaper than the existing system. The existing lighting systems thus not only fall short of the recommended standards, but they also involve higher costs. The cost savings involved using the new illumination systems are:

$$\begin{aligned} \text{Road A: Cost saving} &= [(223,375-165,038)/223,375] \times 100 = 26.1\% \\ \text{Road B: Cost saving} &= [(244,530-126,591)/244,530] \times 100 = 48.2\% \end{aligned}$$

5. Conclusions

In haul road lighting designs, the height and spacing of the poles are two important factors for efficient illumination, which in turn depend upon the type of luminaire used. In general, a uniform distribution of light is achieved with similar light sources spaced at regular intervals. In both the haul roads considered in this case study, the mounting height was less than the road width, illumination levels were not satisfactory between the poles and the cost of the existing system proved to be more than the optimum designed cost. The cost comparison carried out in this work shows that the roads could have been properly illuminated at costs of approximately 26% and 48% less than the cost of the systems currently in place.

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