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Design of haul road lighting system. Part II: design based on optimal cost considerations

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The proper selection of lighting installations is very important for the provision of cost-effective lighting systems without compromising light quality. In this study a computer program was developed to evolve a cost-effective lighting system for haul roads in surface mines. This program is beneficial in assessing the viability of various lighting installations in order to achieve cost-effective solutions. Using the program, illumination design was studied for an 800 m long stretch of haul road. Nine different types of light sources were considered at mounting heights of 12 m and 16 m. The study shows that at a 12 m mounting height, 100 W high-pressure sodium vapour (HPSV) lamps offer the most cost-effective design, followed by 250 W HPSV lamps. In the case of 16 m pole heights the annual lighting cost is minimum for 150 W HPSV lamps, followed by 250 W HPSV lamps. This work also shows that optimum design based on energy consumption need not be the same as design based on optimum cost considerations as cost parameters may vary widely with location.

Keywords: Lighting; Haul road; Design; Cost optimization

1. Introduction

Financial cost is a very important factor in any lighting project and especially in mining industries that are spread over areas of several square kilometres and require good artificial illumination at night. In many projects, lighting is often the last thing to be considered in costings; because of low budgetary provision, the lighting installation may result in poor working environments. This in turn may decrease efficiency and increase accident rates, thus affecting the expected performance of the project overall. The design of a proper and cost-effective lighting system in the early phase of any project is therefore essential. In general, the cost of mine lighting is small compared to other cost components. The cost of lighting in Indian coal mines is of the order of Rs 1.20 to 1.75 (1 US$ = approx. 45.00 INR Rs) per tonne of coal production, which is about 0.35 to 0.4% of

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total production costs (Karmakar and Chauhan 2002, 2004). A scientific approach to illumination design would therefore contribute to efficient lighting without exorbitant increases in the total investment in illumination.

2. Economics of lighting

Various studies have shown that improved road lighting can help reduce the number of night time accidents (Bell 1972, Chironis 1974, CIE 1979). Any improvement in lighting quality is an economic decision and efficient road lighting can be made economically feasible. In any lighting system, the cost of energy consumption is a major component, however, one cannot say that an energy-efficient lighting system is always a cost-effective one.

Once a lighting system has been installed its running cost (other than labour on maintenance) is made up of two principal items—the cost of lamps and the cost of the electrical power consumed by them (Lighting Service Bureau 1948). However, in general, many other factors play a role in determining the cost of a road lighting installation. Among these, lamp efficiency and lamp life affect the whole economics of the lighting installation. Other factors, such as lamp price, number of particular type of luminaires required, pole type and arrangement, type of control gear employed, location of the electricity supply cables, depreciation cost, rates of interest and cost of labour and maintenance, are also significant. The relation between these items varies with the local tariff but, in general, the current consumed during lamp life costs several times as much as the lamp itself. So when considering the quality of a particular type of lamp, only lamps that consume the least possible amount of electricity to give the required light should be used. In other words, the most efficient lamps are the cheapest in the long run. Using lamps with a high luminous efficacy and suitable light distribution can reduce the overall costs of a lighting installation. Sources with a longer life are always desirable, since this reduces replacement costs (Mehtha 2003). In practice, for an economic evaluation of lighting systems, the annual cost of the system is considered because the replacement cost component is high during the whole life of the project.

The difference between lamps' colour, shape and size also affects lantern design to make best use of their light (Homes 1975). High-intensity discharge (HID) lamps are generally used in exterior lighting. High-pressure sodium vapour (HPSV) lamps give very good performance in surface mine lighting because of their long life and efficient penetration in dusty and foggy environments (Aruna *et al*. 2003, 2004). The colour and monochromatic character of HPSV lamps are not particularly important in roadway and area lighting installations. The lower power consumption for a given amount of light, in spite of the higher initial lamp cost, might make the overall cost of an installation using discharge lamps less than that of a filament lamp system.

3. Mathematical model development

The cost of any lighting project is calculated under two major heads, i.e. initial investment cost and total annual cost. The total initial investment cost TI is:

$$\mathrm{TI} = \left(\sum \mathrm{NLT}[\mathrm{PL} + (\mathrm{LP} \times \mathrm{NL})]\right) + \mathrm{INSTC} \qquad (1)$$

where Σ indicates (throughout this paper) summation over all types of luminaires, NLT is the number of luminaires (i.e. fixtures) of a particular type, PL is the luminaire unit price, NL is the number of lamps in the particular fixture, LP is the unit lamp price and INSTC is the installation cost, which is calculated as:

$$\mathrm{INSTC} = (\mathrm{PC} + \mathrm{PIC} + \mathrm{PFC} + \mathrm{PFIC}) \times \mathrm{TP} + \mathrm{CC} \tag{2}$$

where PC is the unit pole cost, PIC is the unit pole installation cost, PFC is the unit pole fittings cost, PFIC is the unit pole fittings installation cost, TP is the total number of poles and CC is the total cabling cost, calculated as:

$$\mathrm{CC} = (C \times \mathrm{TL}) + (\mathrm{CL} \times \mathrm{TL}) \tag{3}$$

where C is the cable cost per km, TL is the total length of cable in km and CL is the cable laying cost per km. The total annual cost, TAC, is calculated by:

$$\mathrm{TAC} = \mathrm{EN} + \mathrm{AI} + \mathrm{LC} + \mathrm{MC} \tag{4}$$

where EN is the energy cost per year, which is calculated as:

$$\mathrm{EN} = \frac{\mathrm{KWHPR}}{1000}\left(\sum[\mathrm{NLT}(\mathrm{WNLT} + \mathrm{BL})]\right) \times \mathrm{BH} \tag{5}$$

where KWHPR is the kWh price, WNLT is the total watts per luminaire for a particular luminaire type, BL is the ballast loss per luminaire and BH is the burning hours per year of the switching mode.

In equation (4) AI is the annual investment cost for luminaries, which is calculated as:

$$\mathrm{AI} = \mathrm{AF}\left(\sum (\mathrm{NLT} \times \mathrm{PPL})\right) + \mathrm{INSTC} \tag{6}$$

where PPL is the price per luminaire for a particular luminaire type and AF is the annuity factor. Here, INSTC is the installation cost per year. The annuity factor depends on the interest rate and the amortization period, which is calculated as:

$$AF = \frac{R/100}{1 - [1/(1 + R/100)]^N} \tag{7}$$

where R is the interest rate (%) and N is the amortization period (in years).

As in equation (2) the installation cost per year is calculated as:

$$\mathrm{INSTC} = (\mathrm{PC} + \mathrm{PIC} + \mathrm{PFC} + \mathrm{PFIC}) \times \mathrm{TP} + \mathrm{CC} \tag{8}$$

where the parameters here represent the per-year values. Thus, CC is the total cabling cost per year, which is calculated as before:

$$\mathrm{CC} = (C \times \mathrm{TL}) + (\mathrm{CL} \times \mathrm{TL}) \tag{9}$$

Lamp replacement cost per year, LC, is:

$$\mathrm{LC} = \sum \frac{(\mathrm{NLT} \times \mathrm{NL} \times \mathrm{LP})}{\mathrm{RP}} \tag{10}$$

where RP is the relamping period (in years) for a particular luminaire type. MC is the maintenance cost per year, which is calculated as:

$$\mathrm{MC} = \sum \frac{\mathrm{NT} \times \mathrm{MCL}}{\mathrm{RP}} \tag{11}$$

where NT is the total number of luminaires and MCL is the maintenance cost per luminaire, which can be calculated as:

$$\mathrm{MCL} = \frac{\text{Total salary/year of electrical staff}}{\text{Number of luminaires}} \tag{12}$$

4. Computer model development

A computer program was developed in MATLAB to perform economic analyses of lighting systems, the simplified flow chart of which is given in figure 1. Using this model one can easily compute the total costs of a roadway lighting system (i.e. initial investment and total annual costs), which may involve different types and wattages of lamps. Part I of this paper (Karmakar *et al.* 2006) considered the optimum pole spacing for different types of luminaries mounted at different heights. Knowing the optimum spacing between the poles, one can determine the number of poles to be installed in a haul road. The initial and total annual costs for the lighting system can then be calculated using the developed program.

5. Selection of optimum design based on lighting system cost

For the economic analysis, a haul road of length 800 m and width 12 m was considered. Nine different types of sources were considered and their optimum pole spacing was determined as described in Part I of this paper (Karmakar *et al.* 2006). The minimum number of poles needed to illuminate the full length of road with each type of source was computed and their respective initial and annual costs were calculated with the help of the developed program. A typical output for various cost components for 100 W HPSV sources is given in table 1. The cost comparison of different lighting systems using 12 m and 16 m height poles is presented in table 2. Total annual cost (TAC) takes into consideration the annual running cost as well as a suitable part of the initial investment cost. Hence TAC is the single parameter used for cost comparison of different lighting systems in this work.

For a system using 12 m poles, the minimum annual cost is for 100 W HPSV lamps, followed by 250 W HPSV lamps. The cost is very high with the use of fluorescent tube lamps (FTLs) and high-pressure mercury vapour (HPMV) lamps mainly because of their shorter life and requirement for a greater number of poles. The energy consumption of 70 W HPSV lamps is less than that of 250 W HPSV sources, but the running cost of a 70 W system is around 2% more than that of 250 W HPSV sources. With 16 m poles, the minimum annual cost of a lighting system is for a 150 W HPSV lamp system; this system also has the lowest energy consumption. The annual cost of a system with 250 W HPSV sources is less than that of a 100 W system despite its minimum energy consumption. This is mainly because of the increased number of poles required in a 100 W HPSV 16 m pole system.

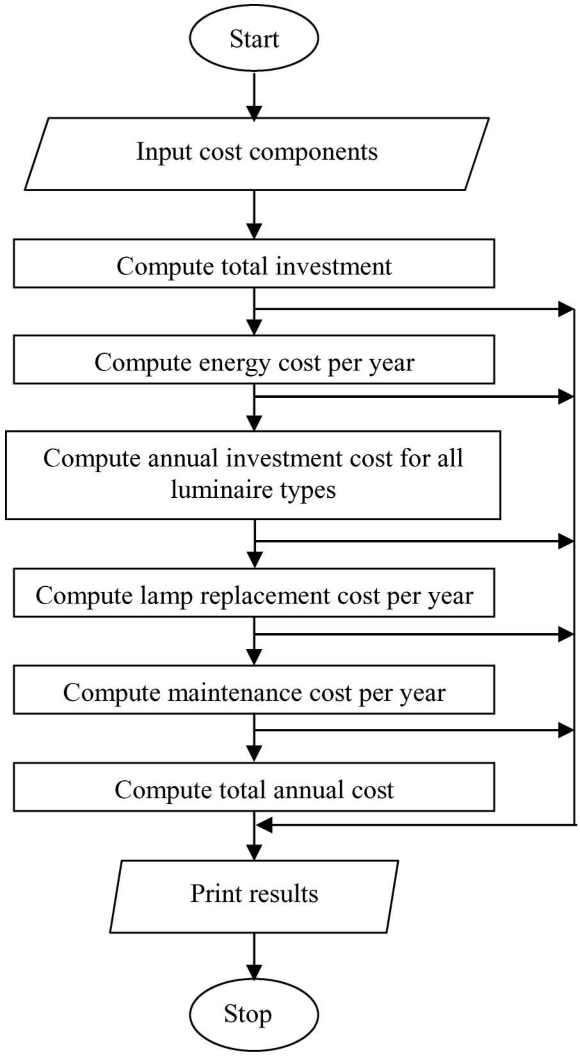

Figure 1. Simplified flow chart for cost calculations.

Table 1. Cost calculations for 100 W HPSV source at 12 m height (1 US$ = approx. 45.00 INR Rs).

Cost Calculation
Investment cost (Rs) 275742
Energy cost per year (Rs) 50631
Annual Investment cost for all luminaire types (Rs) 49645
Lamp replacement cost per year (Rs) 3331
Maintenance cost per year (Rs) 96000
Total annual cost (Rs) 199607

Table 2. Cost comparison of different lighting systems with 12 m and 16 m height poles (1 US$ = approx. 45.00 INR Rs).

	Pole height (m)			
	12		16	
Type of source	Initial investment cost (Rs)	Total annual cost (Rs)	Initial investment cost (Rs)	Total annual cost (Rs)
2×36 W FTL	600,898	522,733	190,810	362,595*
80 W HPMV	281,611	389,784*	268,787	385,055*
125 W HPMV	540,141	529,475	205,417	377,906*
250 W HPMV	268,699	455,774	311,431	483,326
70 W HPSV	406,927	232,601	683,161	326,498
100 W HPSV	275,742	199,607	358,932	231,548
150 W HPSV	326,152	229,840	161,757	165,708
250 W HPSV	228,173	227,502	181,916	199,850
400 W HPSV	267,811	306,565	203,935	254,539

*Not acceptable as the average values are less than the minimum standards of 4 lux.

6. Conclusions

Many factors play a role in determining the costs and energy effectiveness of a road lighting installation. The relative importance given to each of the factors will depend upon the prevailing local circumstances. For example, the cost of labour will vary widely from place to place. There is therefore no common optimum design applicable for a mine located anywhere in the country. Case-specific calculations need to be carried out in order to obtain a cost-effective haul road design.

References

Aruna, M., Karmakar, N.C. and Rao, Y.V., Problems in surface mine lighting and factors to be considered in lighting design. *J. Inst. Public Health Eng., India*, 2004, Special Issue, 34–40.

Aruna, M., Rao, Y.V. and Karmakar, N.C., Design of illumination system in opencast mines, in *19th World Mining Congress,* 2003, pp. 1149–1157.

Bell, B.W., Lighting in coal mines, in *Proceedings of the Symposium on Environmental Engineering in Coal Mining,* 1972, pp. 63–71.

Chironis, P.N., Underground mine lighting—a look at what's new in concepts and equipment. *Coal Age*, 1974, **63**, 66–74.

CIE (Commission Internationale de L'Eclairage, Austria). *Street Lighting and Accidents,* Publication No. 8/2 (TC-4.6), 1979.

Homes, J.G., *Road Lighting, Essays on Lighting,* 1975 (Adam Higher: London).

Karmakar, N.C. and Chauhan, B.S., Illumination survey and cost analysis for large scale opencast coal mine. *Ind. Mining Eng. J.*, 2002, **41**, 29–32.

Karmakar, N.C. and Chauhan, B.S., An economic analysis on lighting of small opencast mines by light-tower. *Minetech*, 2004, **25**, 18–27.

Karmakar, N.C., Aruna, M., Rao, Y.V. and Yaragatti, R.U.K., Design of haul road lighting system. Part I: design based on optimal energy considerations. *Int. J. Surf. Mining Reclam. Environ.*, 2006 (in press).

Lighting Service Bureau. *Illumination Design for Interiors,* LSB, London, 1948.

Mehtha, L., Energy saving and latest trend in road lighting. *Light Newsletter*, 2003, **III**, 26–27.