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# Effect of Illumination on Productivity, Safety, and Health of Opencast Mine Operators

Aditya Prakash[1)] and *Dr. Hrushikesh Naik[2)]

[1), 2)] *Department of Mining Engineering, National Institute of Technology, Rourkela-769008, India*
[2)] *hknaik@nitrkl.ac.in*

## ABSTRACT

Mine illumination is a matter of great concern to the mining industry. The safe movement of men and machinery is determined by the lighting environment in the mines. Any lack in the illumination system reflects in the productivity and safety status of the mine. The main objective of this work was to assess the illuminance level in mines at different strategic locations as mentioned in statutory circulars by the Directorate General of Mines Safety (DGMS), Ministry of Mines, and Government of India. The research work consists of detailed field observations for assessment of the existing lighting condition of a mine and to quantify the effect of poor lighting on the productivity of different Heavy Earth Moving Machineries. The second part of the research work was to find out inherent problems associated in the illumination system of mines. The safety and health aspects were also included in this research work. There were three mines namely Mine1, Mine2, and Mine3 chosen for field observation. The safety status of different locations inside mines was examined by comparing illuminance levels at those locations with what was set by DGMS and by various typical issues faced by operators in those mines. The illuminance level was measured using a lux meter present in respective mines. Illumination survey was conducted at locations like haul roads, loading points, unloading points, operator's cabins, workshops, and substations. After analysis of the illumination survey, it was found that though haul roads of some mines have an illuminance level more than set standards issues of glare in Mine1 cannot be ignored. Productivity analysis in Mine1 and Mine3 shows that the productivity of both dumpers and excavators was reduced in artificial illumination.

**Keywords:** Dark Zone, Flood Light, Glare, Illuminance, Lighting Ergonomics, Luminance, Productivity, Reflectance

## 1. INTRODUCTION

[1)] Undergraduate Student
[2)] Associate Professor

Illumination in opencast mines plays an important role in ensuring the safety of employees and production. The movement of men and machinery at night-time is affected by the illuminance of the mine. Insufficient light causes a situation of non-visibility of objects in front of machine operators. This inability to clearly see the objects by these operators is the prime reason behind accidents at night-time. Secondly, to avoid such accidents in mines, operators slow down their speed to avoid accidents due to collisions and crushing. The result is that this reduced speed increases the cycle time and thus productivity of different types of machinery. It is evident from above that sufficient light in mine is vital from both safeties as well as productivity point of view. Furthermore, the excess light in the mine can cause glare which makes operators momentarily blind person and they are not able to see any objects for a while. This situation is worst and can potentially cause disastrous accidents in mines. Thus, it is extremely important to properly assess the lighting condition in mines through periodic illumination surveys and to improve the illuminance wherever necessary, especially at strategic mine locations. Not only improvement in an existing lighting system is required but also to design an optimum lighting system that should meet all statutory provisions and be competent enough from the cost point of view.

## 2. METHODOLOGY ADOPTED FOR THE STUDY

Measurement of the illuminance of a mine is a must to assess the lighting condition. It is measured using photometers. Many countries including India have illumination standards keeping illuminance as the basis. Therefore, illuminance measurement is needed to comply with established regulatory provisions and to improve mine lighting. Our eyes cannot see the luminous flux coming out of the source. Though many photometers can measure lux, our eyes do not function in that manner. What we see is the reflected light coming out of some objects. Since luminance measurement is more appropriate to simulate the way, our eyes behave. Thus, many countries specify luminance as a standard parameter of lighting. The measurement of reflectance can give a lot of insights into the behavior of the surface with light incidents on it. The mine surface neither has high reflectance nor has uniformity of nature of the surface. These variations lead to non-uniform lighting conditions in mines despite the same luminary wattage and type.

## 3. FIELD OBSERVATIONS, RESULTS, AND DISCUSSIONS

The field observation was done to assess the existing lighting condition of the mine for a multiple illuminance survey was conducted in three mines namely Mine1, Mine2, and Mine3. Cycle time was also noted in Mine1 and Mine3 for quantifying the effect of illumination on the Productivity of Dumpers and Excavators. Illumination level was measured by Lux meter available in respective Mines. In all the mines the lux meter used was oval in shape.

### 3.1 Illumination Survey and Field Observation in Mine1

Mine1 is a mechanized opencast metalliferous mine. The average Stripping ratio (waste: ore) $m^3/m^3$ is 1:0.7 and the waste was removed by long-hole blasting with SME & ANFO explosives. The ore was also extracted by blasting of in-situ ore by SME & ANFO explosive. Loading was done by Hydraulic excavators. The excavator loads the ore on a dump truck of matching capacity. Transportation from working face to crusher was carried out by the same dump truck (Dumper).

### 3.2 Illumination Survey on Haul Roads of Mine1

The safe movement of a dumper on haul roads at night depends on the lighting environment. Adequate lighting provides smooth and faster movement whereas insufficient lighting causes risk-laden movement. Assessment of illumination level was done using a lux meter. Reading was taken in a grid pattern.

***Field Conditions and Manner of Illuminance Survey***

The reading was taken at a 5m interval along the length as shown in the illumination survey profile (Fig. 1). The reading in line with a pole was taken at the end of the berm, which was on an average of 2m from the poles. Readings were also taken on the middle of haul roads and along the opposite edge of haul roads near the raised ground.

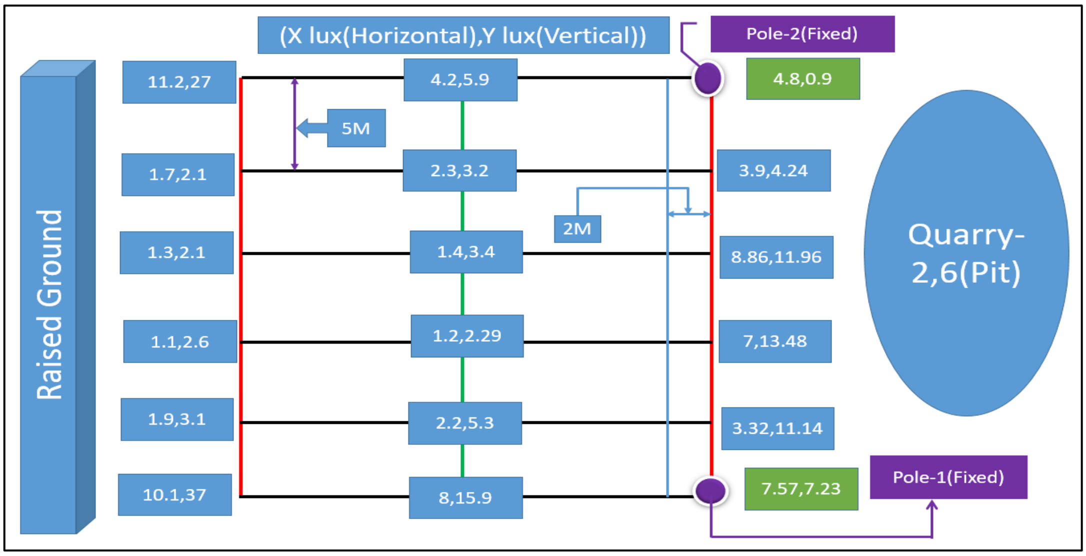


Fig. 1 Grid Pattern Illumination Survey Profile of Haul Road of Quarry-2, 6 in Mine1

#### 3.2.1 Illumination Survey at Intersection of Haul Roads

From the safety point of view, the intersection of haul roads is a potential site where collision is likely to occur. In the daytime, natural light allows the operator to easily track the movement of other machinery, but the case is not so at night-time, it is required that sufficient light should be available at every location inside the mine especially the site of potential accident areas. In Mine1, the rate of installation of fixed LED lighting was lagging much behind the rate of face advance. To facilitate the movement of men and machinery in these lagged zones, the portable DG tower was provided at strategically important locations like the intersection of haul roads (Fig. 2). This temporary setup is fulfilling the demand, but it is not safer as it produces glare, which causes eye strain to dumper operators. An illumination survey was conducted in front of the portable DG tower to check the illumination status at the intersection of haul roads. The illumination survey profile is shown in Fig. 3.

***Field Conditions and Manner of Illuminance Survey***

An illumination survey was carried out to check excess and lack of light around 15m from the intersection point of haul roads. Readings were taken at 5m intervals, and the first reading was taken at 5m from the portable DG tower, the last reading was taken at 15m from the DG tower. The Mine1 intersection had blind curves, which necessitates not only adequate illuminance but also a convex mirror that can give a view of incoming machinery from another side of the haul road. After the implementation of the above two suggestions, the accident in mines can be averted.

### 3.3 Illumination Survey Inside Dumper's Cabin in Mine1

The operator who operates the dumper must be able to clearly see the different arrangements to control the dumper. To maneuver the equipment without any glitches, there should be sufficient illuminance in the machine's cabin. Since horizontal illuminance allows the operator to clearly see the switches, gear, and speed meter, thus a measurement of horizontal illuminance is needed to improve the safety and visual health of the operator. The extent of seriousness to health and safety can be understood with the fact that wrongly pressing the switch can make the machine behave against the wish of the operator. This can potentially cause an accident in mines. Thus, it is extremely important to assess the level of illuminance inside the cabin (Fig. 4).

Fig. 2 Portable DG Tower at Intersection of Haul Roads in Quarry-2, 6 of Mine1

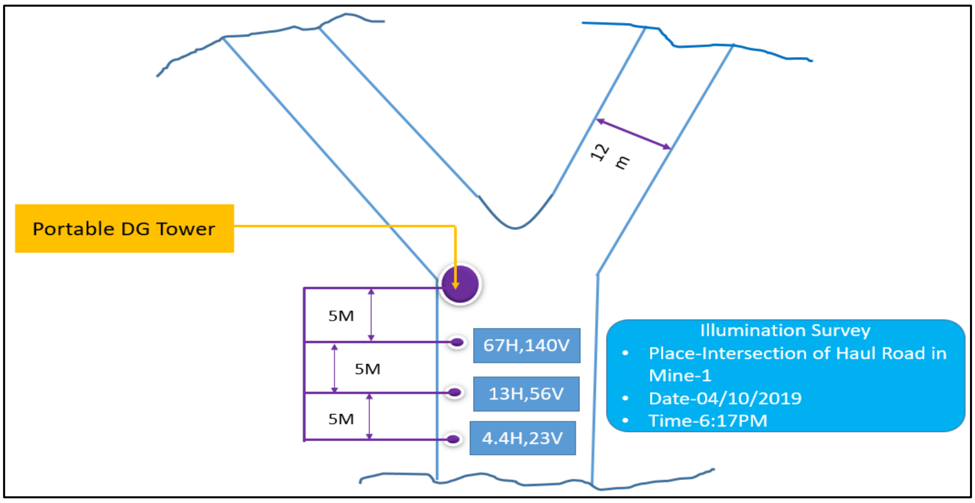


Fig. 3 Illumination Survey Profile at Intersection of Haul Roads in Quarry-2 & 6

***Field Conditions and Manner of Illuminance Survey***

During field observation, it was found that there was only one light source (yellow light) placed centrally inside the cabin on the top of the roof. The intent is to illuminate all control devices inside the cabin. The reading of horizontal illuminance was taken exactly on top of switches, gear lever, and speed meter. These points are strategically vital for better control of the dumper. The horizontal illuminance at switches, gear lever, and speed meter was 13.8 lux, 13.8 lux, and 14.3 lux respectively. Even though the steering lies in constant control of the operator, then also reading was taken because when the operator changes the gear or presses the switch in that case his one hand goes out of steering, and it is very much required that the operator must put the hand on the position after changing gear or pressing the switch. To do so, the illuminance in the cabin should be sufficient. After measurement of horizontal illuminance, it was found to be 15.6 lux.

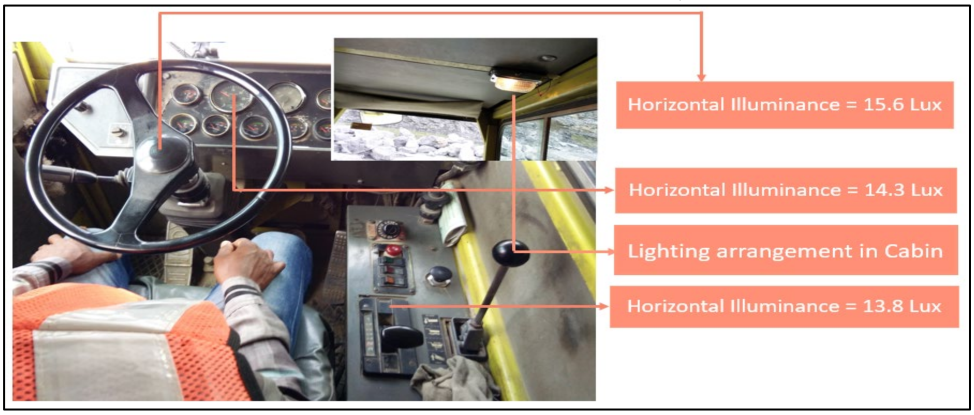


Fig. 4 Illuminance Level at Frequently used Features of Dumper's Cabin

**Illumination Survey at Hopper in Mine1**

The hopper points in a mine have special significance in the sense that it is a point where the unloading of minerals took place. At night-time, this area around the hopper must be illuminated properly to allow the dumpers to unload the dala material without collision with the last edge of the hopper. The visual field behind the dala determine the visibility of the area and thus the area must have sufficient lighting arrangement (Fig. 5). Furthermore, the rear vision camera installed in the operator's cabin can show the rear images only when the reflectance of the backside is sufficiently high otherwise blur, and the black image will appear in the camera (Fig. 6). Considering above field problems, it is important to assess the light availability at and around the hopper.


Fig. 5 Different Points at the Edge of Hopper at which Illuminance Level was Measured

Fig. 6 Rear Vision Camera Showing View of Hopper Chute

***Field Conditions and Manner of Illuminance Survey***

The limestone in Mine1 was being unloaded at the hopper from the opposite side in reverse gear (Fig. 6). The illumination survey was conducted to check the illuminance level at the hopper (Table 1). As per the statutory provision, it is required that both horizontal and vertical illuminance should be measured. Illuminance level was measured at point A, B, and C on one side and point A', B' and C' on another side of the hopper. During reading, no dumper was present even at about 20m from the hopper, and the area around the hopper was completely illuminated by lighting fixtures installed on the ceiling and high mast tower beside the crusher.

Table 1: Illuminance Level at the Edge of Hopper

| Points at edge of hopper | Horizontal Illuminance in Lux | Vertical Illuminance in Lux |
|---|---|---|
| A | 15.47 | 12.3 |
| B | 18.1 | 14.1 |
| C | 14.29 | 11.8 |
| A’ | 15.53 | 13.1 |
| B’ | 18.32 | 13.9 |
| C’ | 15.63 | 12.89 |

#### 3.3.1 Illumination Survey at the Last Edge of Dump Yard

There were many instances of accidents in opencast mines where dumper fall takes place in the dump yard. The reason is manifold but one potential reason is insufficient illumination at the edge of the dump yard. Unless or until the berm at the edge of the dump yard is clearly visible, the dumper operator cannot operate smoothly and there is a high likelihood that he may extend the dumper’s body beyond the berm edge. This is the reason behind the fall of dumpers in the dump yard. Thus, ensuring sufficient lighting arrangement at the dump yard to maintain good visibility is vital (Fig. 7).

***Field Conditions and Manner of Illuminance Survey***

To design a robust illumination system for the dump yard, it is very much important to assess the existing illumination level. For doing so, an illumination survey was conducted at the edge of the dump yard to check illuminance (Table 2). Both horizontal and vertical illuminance was measured using lux meter at points A, B, C, D, E, and F.

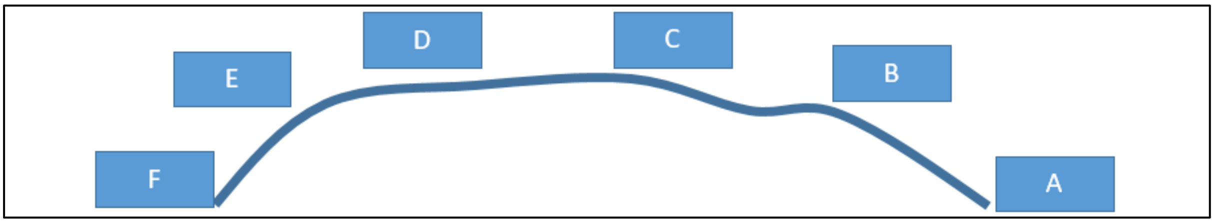


Fig. 7 Points at the Edge of Dump Yard on which Illuminance Level was Measured

Table 2: Illuminance Level at the Last Edge of Dump Yard

| Points at the edge of The Dump yard of Mine1 | Horizontal Illuminance (in Lux) | Vertical Illuminance (in Lux) |
|---|---|---|
| A | 1.6 | 2.4 |
| B | 1.8 | 2.3 |
| C | 2.1 | 5.4 |
| D | 1.9 | 4.3 |
| E | 0.3 | 1.7 |

| | | |
|---|---|---|
| F | 3.2 | 3.1 |

### 3.3.2 To Assess the Adequacy of Dumper's Own Light

The luminaire fixed in dumpers produces some light, which allows it to ply even in absence of external lighting arrangements. To check whether the luminaire setup is adequate for the safe movement of the dumper or not, the illumination survey was carried out by lux meter. No other luminaire was available in the vicinity of light produced by the dumper. Since 2.6m is the blind zone for the dumper thus first reading was taken from about 2.6m from the front edge of the dumper (Fig. 8).

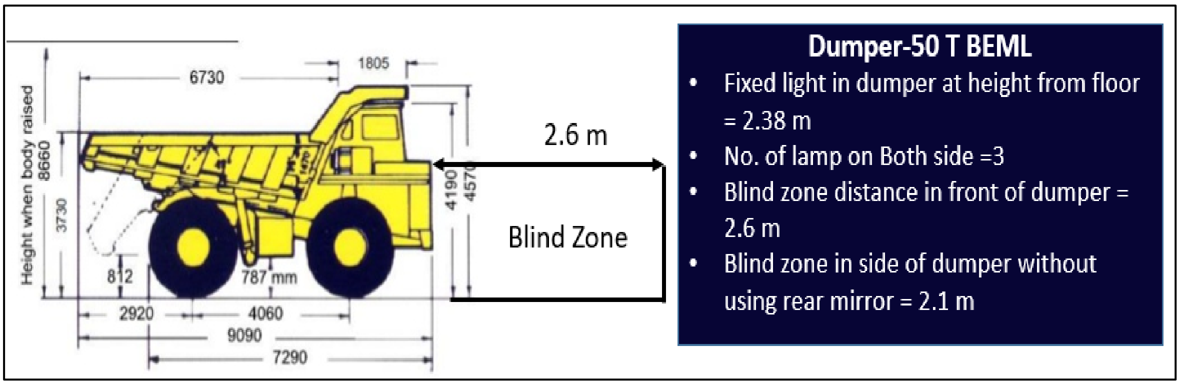


Fig. 8 Blind Zone in Front and Side of Dumper

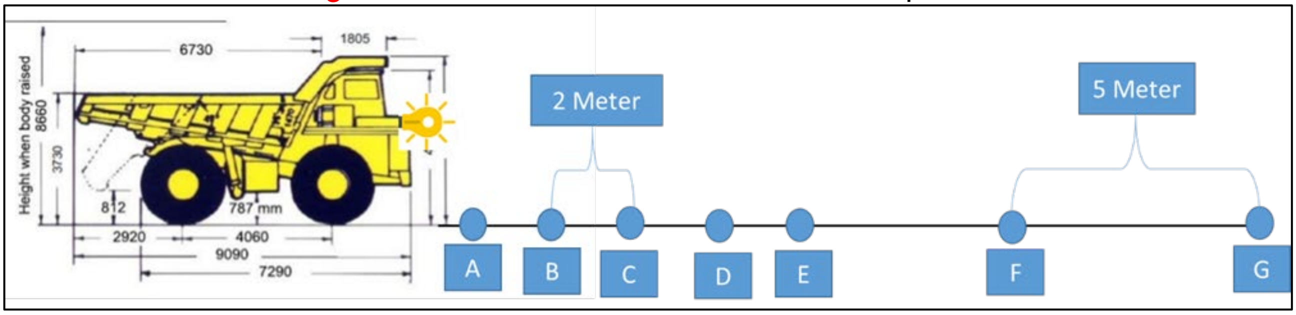


Fig. 9 Points in Front of BEML Dumper on which Illuminance Level was Measured without any other Luminaire

***Field Conditions and Manner of Illuminance Survey***

The first reading was taken at point A, which is about 2.6m from the front edge of the dumper. The next few readings were taken at an interval of 2m up to point E. Interval was increased to 5m up to point G (Fig. 10). When the horizontal illuminance value is reduced to such a level at which visibility of a nearby object is impossible at that point no readings were taken. At point G the horizontal illuminance was 1.48 lux (Table 3), this level of illuminance was not sufficient to recognize smaller objects, and even human identification was difficult.

Table 3: Illuminance Level of Different Points in Front of Dumper without any other Luminaire

| Points in Front of Dumper in Mine-1 | Horizontal Illuminance in Lux | Vertical Illuminance in Lux |
|---|---|---|
| A | 5.73 | 15.78 |
| B | 5.8 | 17.6 |
| C | 5.4 | 16.3 |

| | | |
|---|---|---|
| D | 5.1 | 15.2 |
| E | 4.79 | 13.9 |
| F | 3.29 | 6.7 |
| G | 1.48 | 3.11 |

### 3.3.3 To Assess the Adequacy of Dumper's Own Light with Fixture

To assess the level of illumination achieved when some other luminaire is available in the vicinity of the dumper's own light, again illumination survey was conducted. In this case, two LED light fixtures were available to illuminate the haul road (Figure 10).

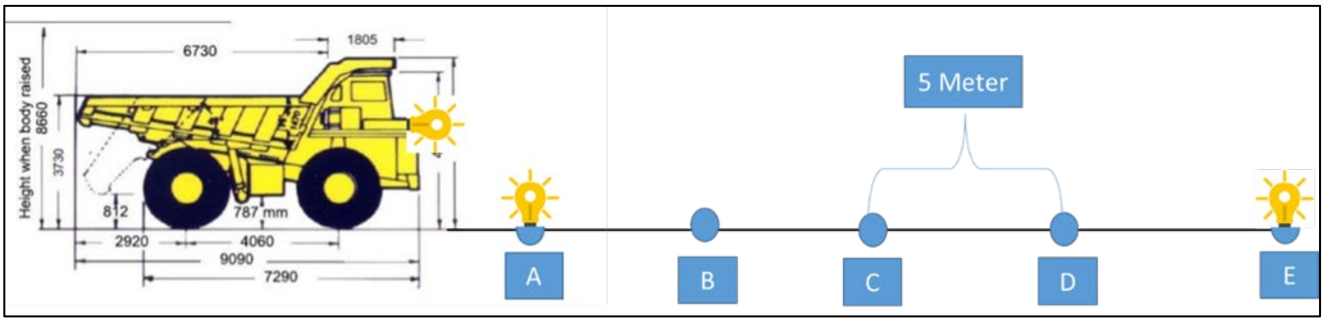


Fig. 10 Points in Front of BEML Dumper on which Illuminance Level was Measured with Two LED Luminaire Installed along Road Edge

***Field Conditions and Manner of Illuminance Survey***

The first reading was taken at point A as shown in Fig. 11, which was on the middle of the haul road and in line with the luminaire installed at the road edge. The distance of point A from the front edge of the dumper was 5m. In the same way, other readings at different points were taken at an interval of 5m up to point E. Both horizontal and vertical illuminance readings were taken at every point to cover the depth and height through which the machine operates (Table 4).

Table 4: Illuminance level of different points in front of dumper with 2 LED Luminaire

| Points in Front of Dumper in Mine-1 | Horizontal Illuminance in Lux | Vertical Illuminance in Lux |
|---|---|---|
| A | 25.43 | 40.28 |
| B | 18.54 | 26.8 |
| C | 13.36 | 17.79 |
| D | 20.67 | 9.68 |
| E | 12.67 | 15.21 |

### 3.3.4 Illumination Study at Loading Point

The production face of any mine is having the tendency to shift almost on daily basis, and it is not possible to install the permanent lighting arrangement in such a small period. Thus, the lighting at the face is either managed by the dumper-excavator's own light or to be managed by a portable DG tower. Dumper's own front and rear lights can illuminate the only front and back portion of the face, but it cannot be able to illuminate the area around it and at dala. Secondly, the excavator when kept in dig and drag position, at that time, the area between dumper alignment and shovel dig position is light deprived. At light deficient face, the excavator loads the material slowly to avoid any mishaps. This slow loading further increases the cycle time of the dumper and excavator and thus decreases the productivity of the dumper and excavator. Moreover, due to poor lighting, the material handling on the face is risky because of the limited illumination capacity of the excavator. It cannot illuminate beyond a particular height and any boulders beyond this height are difficult to handle and may fall suddenly and can cause heavy loss to mine authority. The need for a proper illumination survey and design cannot be neglected due to the reasons stated above.

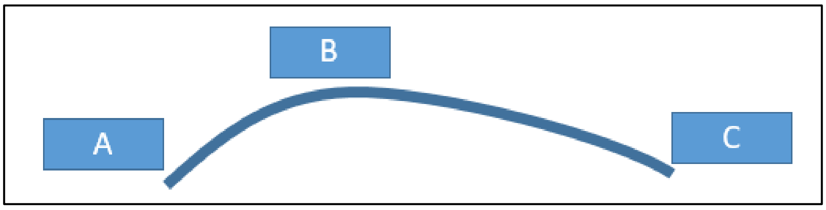


Fig. 11 Profile of Illumination Survey at Loading Face with Different Points within reach of Excavator Bucket

***Field Conditions and Manner of Illuminance Survey***

The approximate profile of the production face of Mine1 is shown above in Fig. 12. Since the bucket of the excavator had reached points A, B, and C thus both horizontal, as well as vertical illuminance readings, were taken at points A, B, and C (Table 5).

Table 5: Illuminance Level at Loading Face with Different Points within reach of Excavator Bucket

| Points at the edge of the face in Mine-1 | Horizontal Illuminance (in Lux) | Vertical Illuminance (in Lux) |
|---|---|---|
| A | 0.72 | 0.85 |
| B | 0.76 | 0.81 |
| C | 0.65 | 0.68 |

### 3.3.5 Reflectance at Different Locations

Reflectance was measured as explained in the Reflectance Measurements section of the methodology. Both dry and wet reflectance was measured at only that location where the dry and wet surface was present in close vicinity so that other surface characteristics would not vary much. The observation and calculation for reflectance measurement are summarized in Table 6.

Table 6: Result of Reflectance Analysis at Different Locations in Mine1

| Sl. No | Locations of point in mine 1 | Illuminance (E) | | Luminance (L) | | Dry Reflectance ($\frac{Ld}{Ed}$×100) in % | Wet Reflectance ($\frac{Lw}{Ew}$×100) in % |
|---|---|---|---|---|---|---|---|
| | | Dry ($E_d$) | Wet ($E_w$) | Dry ($L_d$) | Wet ($L_w$) | | |
| 1. | The intersection of haul road | 3.52 | 1.62 | 1.41 | 0.21 | 40.05 | 12.96 |
| | | 4.26 | 1.22 | 0.54 | 0.28 | 12.67 | 22.95 |
| 2. | Dump yard edge | 5.69 | 3.26 | 1.23 | 0.93 | 21.6 | 28.52 |
| | | 6.35 | 3.76 | 1.11 | 0.86 | 17.48 | 22.87 |

## 3.4 Illumination Survey and General Observations in Mine2

Mine2 is an opencast coal mine with a high degree of mechanization. The average stripping ratio in $m^3$/tons is 0.97 and the overburden was removed by blasting with an emulsion explosive. The existing grade of coal is G9 & G14 and the coal was being winned through surface miners. Loading is done by Payloader to Tipper. Transportation from working face to CHP was carried out by the same Tipper.

### 3.4.1 Illumination Survey at Strategic Locations

The illuminance readings taken in Mine2 are given in Table 7. The reading was taken by an oval shape lux meter which was calibrated three months before taking readings at various strategic locations.

Table 7: Illumination Survey at Different Location in Mine2

| Sl. No. | Location of points in Mine2 | Types of Luminaries, Wattage | Horizontal illuminance in lux | Vertical Illuminance in lux |
|---|---|---|---|---|
| 1. | Surface miner face | HPSV,250 W | a) 18.7<br>b) 10<br>c) 25.8 | a) 25<br>b) 6.7<br>c) 18.7 |
| 2. | Overburden face | HPSV,400 W | a) 21.3<br>b) 11.5 | a) 29.2<br>b) 9.6 |
| 3. | Excavator Operator's Cabin (Excavator) | --- | 24 | Not applicable |
| 4. | Haul road junction | HPSV,400 W | 17 | Not Applicable |
| 5. | External overburden dump (Topsoil) | HPSV,400 W | a) 22.6<br>b) 5.9<br>c) 3.5<br>d) 24.5 | a) 47.9<br>b) 7.5<br>c) 6.4<br>d) 38.5 |
| 6. | Substation (33/6.6 KV) | LED, 250 W | 93 | 132 |
| 7. | Control Room | LED, 250 W | 85 | Not Applicable |
| 8. | Excavation Workshop | LED, 250 W | a) 35.6<br>b) 36.9<br>c) 57.8<br>d) 57.5<br>e) 64.3 | ---<br>---<br>---<br>---<br>--- |

### 3.4.2 Observations after Illuminance Survey in Mine2

1) **Surface miner face:** There was observable variation in horizontal and vertical illuminance levels, on one hand, horizontal illuminance level was as high as 25.8 lux and as low as 10 lux, on the other hand, vertical illuminance level vary from 6.7 lux to 25 lux.
2) **Overburden face:** The horizontal illuminance level was above 10 lux, but the vertical illuminance level varied from 9.6 lux to 29.2 lux. The reading was taken without machinery's own light.
3) **Excavator operator's cabin:** The horizontal illuminance level was 24 lux at the steering level.

4) **Haul road junction:** The horizontal illuminance level at the middle of the intersection of haul roads was 17 lux. There were two HPSV lamps mounted on an 8m high pole facing toward the intersection of the haul roads.
5) **External overburden dump (Topsoil):** The horizontal illuminance level at the dump edge close to the HPSV pole was more than 20 lux but the level at the dump edge farthest from the pole was less than 6 lux. A similar level was observed in vertical illuminance also. There were four HPSV lamps mounted on an 8 m high pole.
6) **Substation (33/6.6 KV):** The horizontal and vertical illuminance reading was 93 lux and 132 lux respectively.
7) **Control Room:** The horizontal illuminance level was 85 lux at the control panel level in the electric substation.
8) **Excavation Workshop:** Only horizontal illuminance readings were taken, and the levels were more than 35 lux. The illuminance level was 35.6 inside the workshop where a 250 W LED light was fixed on the ceiling.

### 3.4.3 Illumination Survey on Haul Roads

The illumination survey profile for the haul roads of Mine2 is given in Fig. 12. The spacing between two poles of the height of 8m was 30m. LED type lamp of wattage 120W was in use to illuminate the haul road. The width of the haul road was 15m. Illuminance level readings were taken at 10m due to a paucity of time and resources. As shown in Fig. 12, the first reading was taken at about 1m from pole-1 at point A, the second one on A' lying at the middle of haul road, the last one was taken at A'' which was about 1m from other edges of the haul road. Similarly, all the readings were taken at points shown in Fig. 12. The horizontal illuminance level at different points is given in Table 8.

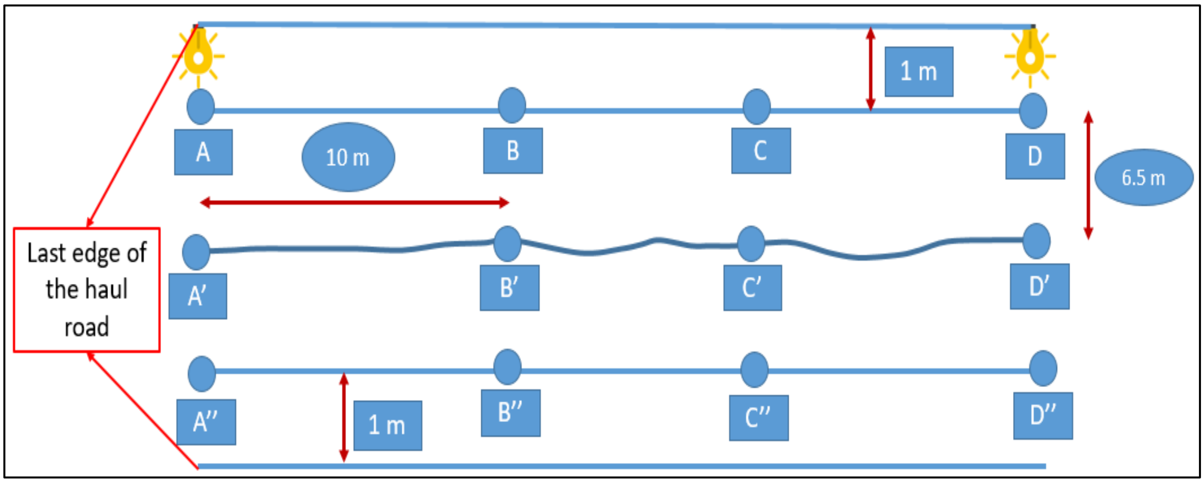

Figure 12: Illumination Survey Profile of Haul Road of Mine2

Table 8: Horizontal Illuminance Level at Different Points on Haul Road of Mine2

| Sl. No. | Different points on haul roads of Mine-2 | Horizontal Illuminance (In Lux) |
|---|---|---|
| 1. | A | 26.3 |
| 2. | B | 0.2 |
| 3. | C | 1.7 |

| | | |
|---|---|---|
| 4. | D | 46.4 |
| 5. | A’ | 24.5 |
| 6. | B’ | 1.3 |
| 7. | C’ | 2.4 |
| 8. | D’ | 30.6 |
| 9. | A” | 14.5 |
| 10. | B” | 1.5 |
| 11. | C” | 8.6 |
| 12. | D” | 18.7 |

### 3.4.4 Reflectance Measurement at Different Locations in Mine2

Reflectance was measured as explained in the Reflectance Measurements section of the methodology. Both dry and wet reflectance was measured at only that location where the dry and wet surface was present in the vicinity so that other surface characteristics would not very much. The observation and calculation for reflectance measurement are summarized in Table 9.

Table 9: Result of Reflectance Analysis at different Locations in Mine2

| Sl. No | Locations of points in Mine2 | Illuminance(E) | | Luminance(L) | | Dry Reflectance ($\frac{Ld}{Ed}$×100) | Wet Reflectance ($\frac{Lw}{Ew}$×100) |
|---|---|---|---|---|---|---|---|
| | | Dry ($E_d$) | Wet ($E_w$) | Dry ($L_d$) | Wet ($L_w$) | | |
| 1. | The intersection of haul road | 18.5 | 18.6 | 0.1 | 0.5 | 0.54 | 2.6 |
| 2. | External Overburden | a) 10.7<br>b) 12.8 | a)-<br>b)- | a) 0.9<br>b) 0.8 | a)-<br>b)- | a) 8.41<br>b) 6.25 | a)-<br>b)- |

### 3.4.5 Typical Issues that Affect Lighting Environment in Mine2

Spontaneous heating of coaly substance on the berm of haul road and water accumulation at overburden face were two most prominent problems of Mine2 which affects lighting condition in the mine.

#### 3.4.5.1 Spontaneous Heating of Coal in Berm and OB

The reject and some other carbonaceous waste materials were used to act as berm on the edge of the haul road. These carbonaceous materials on exposure to air catch fire due to the auto-oxidation tendency of coaly substance. Smoke and fumes that come out from the berm create visibility issues on the haul road as shown in Fig. 13. The problem became worse when the quantity of carbonaceous material is significantly high because, in this scenario, smoke cloud disperses across the haul road. Therefore, to avoid any accidents and to improve the machine’s productivity it is need of the hour to properly segregate coaly substance from the berm so that no spontaneous heating will take place.

Figure 13: Spontaneous Heating of Coal (Rejects) along Berm Causing Visibility Problem on Haul Road

#### 3.4.5.2 Water Accumulation and Associated Issues

The overburden face in Mine2 was having a water seepage problem due to which a considerable amount of water was used to accumulate at the face as shown in Fig. 14. Since surface reflectance of water accumulated area is different from the area having no water above that surface. This accumulation causes variation in the surface reflection of mine, which reflects into a non-uniform lighting environment on the face. Furthermore, a watery face forms a conducive environment for muck formation, which is highly detrimental to the productivity of machinery working in that condition.

### 3.5 Illumination Survey and General Observation in Mine3

Mine3 is a semi-mechanized open-cast coal mine. The average stripping ratio in tons of ore/tons of overburden was 1/3.5 and the overburden was being removed by blasting with site mixed slurry. Coal was extracted by blasting and then loaded by shovel to dumpers. Transportation from working face to CHP was carried out by the same dumper.

Figure 14: Mine Water Accumulation at Overburden Face with HPSV Lighting Arrangement

#### 3.5.1 Illumination Survey of Different Locations of Mine3

Illuminance was measured at only those places where the operation of the dumper was involved because these places affect the productivity of dumpers (Table 10). Any lacking in lighting conditions affects dumpers' performance. The illuminance survey was carried out by oval-shaped Lux Meter.

Table 10: Illuminance Level at Different Strategic Locations of Mine3

| Average illumination at | Horizontal illuminance in lux | Vertical illuminance in lux |
|---|---|---|
| Loading Point | 0.81 | 3.6 |
| Unloading point | 1.73 | 4.5 |
| Bends on the haul road | 3.71 | 5.6 |
| The intersection of haul road | 3.65 | 7.67 |
| Normal haul road | 12.37 | 13.07 |

#### 3.5.2 Observations after Illuminance Survey in Mine3

1) **Loading Point:** The average horizontal illuminance was 0.81 lux in front of the shovel and vertical illuminance was 3.6 lux at the same place.
2) **Unloading Point:** The average illuminance was 1.73 lux at the edge of the unloading point and vertical illuminance was 4.5 lux.
3) **Bends on Haul Road:** The average illuminance level in the middle of bends on haul road was 3.71 lux and 5.6 lux in the horizontal and vertical planes.
4) **Intersection of Haul Road:** The average horizontal and vertical illuminance level at the mid-point on the intersection of haul road was 3.65 lux and 7.67 lux respectively.
5) **Normal Haul Road:** The average illuminance level was 12.37 lux and 13.07 lux in the horizontal and vertical planes. However, this averaging makes overall illuminance higher than 10 lux but at some places, it was less than that value.

### 3.6 Cycle Time and Productivity Study in Mine1

The main objective of the cycle time study was to quantify the effects of poor lighting on the productivity of dumpers and excavators. Cycle time was noted down in specific time only so that parameters, as mentioned in the methodology section, can be made constant. Any change in cycle time between natural and artificial illumination is due to the lighting environment in the mine. In this way, the exposure of dumpers and excavators to poor illuminance levels is depicted using productivity and cycle time variation.

#### 3.6.1 Cycle Time and Productivity Analysis of Dumper-36 and Dumper-37

**Specifications of Dumper-36 and 37:**

- Make – TATA Hitachi EH 600
- Capacity – 35 Tonnes

The cycle time study was done on 04/10/2019, on that day artificial luminaires were switched on at 5: 45 PM. Readings of cycle time were taken both before 5: 45 PM and after 5: 45 PM. Cycle time noted before the time was in natural illumination whereas cycle time noted after the time was in artificial illumination. All other parameters were kept constant except the mode of illumination as mentioned in the methodology section.

The summary of cycle time calculation and productivity quantification of dumpers is given in Table 11.

Table 11: Cycle Time and Productivity of Dumpers in Natural and Artificial illumination

| Mode of Illumination | Cycle time of Dumpers in Minute | | Productivity of Dumper (TPH) | |
|---|---|---|---|---|
| | Dumper-36 | Dumper-37 | Dumper-36 | Dumper-37 |
| Natural | 29 | 30 | 72 | 70 |
| Artificial | 34 | 33 | 61.76 | 63.64 |

### 3.6.2 Cycle Time and Productivity Analysis of Excavator

The cycle time study of the excavator was done on 04/10/2019, on that day artificial luminaires were switched on at 5: 45 PM. Readings of cycle time were taken both before 5: 45 PM and after 5: 45 PM. Some readings of cycle time were noted before the time was in natural illumination whereas some cycle time was noted after the time was in artificial illumination. All other parameters were kept constant except the mode of illumination as mentioned in the methodology section. The summary of cycle time calculation and productivity quantification of the excavator is given in Table 12.

Table 12: Cycle Time and Productivity of Excavator in Natural and artificial illumination

| Mode of Illumination | Cycle time of Excavator (Second) | Productivity of Excavator (TPH) |
|---|---|---|
| Natural | 149 | 845 |
| Artificial | 168 | 750 |

### 3.6.3 Trip Wise Cycle Time and Productivity Analysis of Different Dumpers in Natural and Artificial Illumination

The observations were done on 13/03/2020. In this study of cycle time, the readings were taken on different trips. Some of the cycle time for dumper-1 and dumper-2 was taken between 4 PM-6 PM in natural illumination on the other hand some of the cycle time was taken between 6:30 PM-8:30 PM. The capacity of both the dumpers was 50 Tons and the make was BEML. Readings were taken after seating in both dumpers and care was given to exclude all waiting time because that time has nothing to do with the level of illumination. Cycle time was calculated by summing loaded travel time, empty travel time, loading time, and unloading time. The total lead (distance between loading point and unloading point) of both dumpers was 1700 m. The percentage of lead in which no permanent lighting was present is 46% and in this lead length, only some portable DG towers were commissioned. The effect of poor lighting across haul roads and at loading points on cycle time and productivity are summarized in Tables 13, 14, 15, and 16.

Table 13: Cycle Time of Dumper-1 and Dumper-2 in Natural Illumination

| Different Trips | Cycle Time in Second | |
|---|---|---|
| | Dumper-1 | Dumper-2 |
| Trip 1 | 968 | 946 |
| Trip 2 | 1087 | 905 |
| Trip 3 | 920 | 1013 |

Table 14: Productivity of Dumper-1 and Dumper-2 in Natural Illumination

| Different Trips | Productivity (TPH) | | Average Productivity (TPH) | |
|---|---|---|---|---|
| | Dumper-1 | Dumper-2 | Dumper-1 | Dumper-2 |
| Trip 1 | 185.95 | 190.27 | | |

| | | | | |
|---|---|---|---|---|
| Trip 2 | 165.59 | 198.89 | 182.39 | 188.95 |
| Trip 3 | 195.65 | 177.69 | | |

Table 15: Cycle Time of Dumper-1 and Dumper-2 in Artificial Illumination

| Different Trips | Cycle Time in Second | |
|---|---|---|
| | Dumper-1 | Dumper-2 |
| Trip 1 | 1033 | 1014 |
| Trip 2 | 944 | 1052 |
| Trip 3 | 1049 | 1019 |

Table 16: Productivity of Dumper-1 and Dumper-2 in Artificial Illumination

| Different Trips | Productivity (TPH) | | Average Productivity (TPH) | |
|---|---|---|---|---|
| | Dumper-1 | Dumper-2 | Dumper-1 | Dumper-2 |
| Trip 1 | 174.24 | 177.51 | 178.83 | 175.08 |
| Trip 2 | 190.67 | 171.10 | | |
| Trip 3 | 171.59 | 176.64 | | |

It is required to make clear that some trip's productivity in artificial illumination was even more than the productivity in natural illumination but the overall productivity of dumpers in natural illumination was more than productivity in artificial illumination.

### 3.7 Cycle Time and Productivity Analysis in Mine3

In Mine3 also, the procedure for taking cycle time readings was the same as in Mine1. Here, cycle time was noted in different trips in both natural as well as artificial modes of illumination. Summary of cycle time observation and productivity analysis are shown in Tables 17 and 18 respectively.

Table 17: Cycle Time of RD-2K01

| Different Trips | Cycle Time of RD-2K01 in Second | Mode of Illumination |
|---|---|---|
| Trip 1 | 977 | Natural |
| Trip 2 | 1017 | Natural |
| Trip 3 | 976 | Natural |
| Trip 4 | 1114 | Artificial |

Table 18: Result of Productivity Analysis of RD-2K01

| Different Trips | Productivity of RD-2K01 (TPH) | Average Productivity of RD-2K01 (TPH) | Mode of Illumination |
|---|---|---|---|
| Trip 1 | 184.23 | 181.88 | Natural |
| Trip 2 | 176.99 | | Natural |
| Trip 3 | 184.42 | | Natural |
| Trip 4 | 161.57 | 161.57 | Artificial |

## 4. CONCLUSIONS

Based on the analysis of observed data, the conclusion with respect to each mine is given in the following section.

### 4.1 Conclusion Drawn from Mine1

1. The illuminance level on the haul road was not complying with established standards.
2. It was found that the mine illumination is not only dependent on luminary wattage but also on operator preferences.
3. Portable DG tower at the intersection of haul roads causes excessive lighting, which affects the operator's productivity and safety.
4. The illuminance level in the operator's cabin was found inadequate as per the standard of illumination.
5. At the crushing point, the illuminance level was insufficient as inferred from the illuminance survey and image analysis of the rear vision camera.
6. Last edges of the dump yard were devoid of light and variable reflectance causes a variable visual environment.
7. The maximum horizontal illuminance level in front of the dumper was 5.73 lux. Thus, the dumper's own light was found inadequate for the dumper to safely ply on the haul road.
8. Horizontal illuminance achieved with the dumper's own light and two external luminaries was more than 10 lux.
9. Both horizontal and vertical illuminance level at loading points was not as per mine lighting standard of 15H, 15V.
10. Reflectance of haul road and dump yard was not uniform.
11. Average productivity of both dumper and excavator were reduced due to inadequate illumination levels.

### 4.2 Conclusion Drawn from Mine2

1. At the surface miner face, no need to add additional lighting arrangement but the periodic installation of a new lamp was required.
2. Horizontal illuminance was found adequate at the intersection of haul roads.
3. Illuminance at the farthest edge of the dump yard from the light source was insufficient.
4. Inadequate illuminance level inside the excavation workshop.
5. The haul road lighting was found inadequate, especially in the central portion between two luminaries.
6. Excavator's operator cabin was having less illuminance level as per standards of illumination.

### 4.3 Conclusion Drawn from Mine3

1. Horizontal illuminance at bends of haul road was found to be inadequate.
2. Average illuminance level at loading, and the unloading point was insufficient.
3. The productivity of RD-2K01 was reduced in artificial an illumination system.

### 4.4 Recommendations for Mine1:

1. Visual performance study can be done.
2. DG high mast should be positioned at both corners of the dump yard.
3. Frequent advancement of DG tower towards dump edge as dumping point advances forward.
4. DG high mast should be positioned at both corners of the dump yard.

5. Periodic cleaning of lamps is a must to improve the lighting condition of the dump yard.
6. A portable DG tower is needed to properly illuminate the working face.
7. Permanent or temporary lighting at the entry point of the face is a must.
8. Planning for permanent fixture installation should be done so that the installation would not lag face advancement.
9. Surface treatment can be done but it is a very costly affair.
10. Floodlight can be permanently installed at overhead conveyor point.
11. Water sprinkling over and around crusher point to stop dust to become airborne.

### 4.5 Recommendations for Mine2:

1. Illumination plan should go hand in hand with excavation Plan.
2. Dump progress plan should be made, and lighting installation must match the progress plan.
3. Study on the effect of spontaneous heating of coal on visual performance in mine should be done.
4. Replacement of operator's cabin luminaire for a better visual environment in cabin.
5. Portable high mast tower can be commissioned at the loading face to improve workplace illuminance.
6. Portable high mast tower is required at the external dump yard to ensure adequate illumination level.
7. Mix-up of LED and HPSV light must be avoided in maintenance workshop.
8. No additional HPSV lamp is required at OB face as illuminance level is adequate for better visual environment.

### 4.6 Recommendations for Mine3:

1. Central Illumination system for Sector-A
2. Requirement of daily advancement of DG light mast towards dump edge.
3. Detail illumination survey is required to ensure adequate illuminance.
4. Two-side lighting arrangement for wider dump yard.
5. High mast tower is needed for improvement in productivity and safety.
6. Special luminaire was required to illuminate at the bends of the haul road.

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