Safety in Mines Research Advisory Committee

Final Project Report

Assessment of World-wide Illumination and Visibility Standards in Coal Mines

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1. Introduction

The provision of adequate illumination and the need to ensure a safe visual working environment is a challenge faced by almost all industries. The general objectives of providing lighting and illumination are to improve safety and increase production. Lighting provision is particularly important in the underground coal mining industry as there is no natural light, and large machines operate in a confined, dusty and a potentially explosive environment. It has been said (IES, 1993) that this is the most difficult lighting environment in the world

The overall objective of this project was to produce general guidance and recommendations for a wide range of underground coal mining locations and activities that will assist mine operators to improve illumination and visibility standards and hence, improve health and safety. The project conducted a review of the current illumination standards and guidelines use in the coal mining industries throughout the world to assess their applicability to conditions in the South African coal mining industry. A review of the literature was also undertaken to identify those factors that must be considered in order to ensure a safe visual working environment.

Inspection of the accident reports held on the SAMRASS database for the period 1994 to 1996 revealed that only three accidents where the cause was attributed to "Lack of illumination/visibility" had been recorded. The quality of the visual environment can make a much more significant contribution to accidents than this figure suggests. Although "Lack of illumination/visibility" is rarely reported as the direct cause of an accident, it can often be a significant contributory factor.

A few studies have been undertaken to try and support the general theory that an increased level of illumination has a positive effect on accidents in the mining industry. Van Graan & Schutte (1977) & Austin (1989) reference a study in the former USSR where, following the introduction of fluorescent lighting on a coal face, the production increased by 3,5% and the number of accidents decreased by 40%. Both Trotter (1982) & Austin (1989) reference a Hungarian study that showed that when one part of the mine was illuminated with 'special purpose' fixed lighting and another solely with caplamps, the accident rate in the lighted portion decreased by 60%. Trotter (1982) also references an Indian study that concluded that 35% of all minor accidents in coal mines could be attributed to poor lighting. Studies in other industries have also supported the general theory that improved illumination reduces accident potential (Sanders & Peay, 1988)

1.1. Terms and Definitions

To ensure that the project findings and recommendations are of value to the widest possible spectrum of readers, the use of technical terms and definitions has been kept to a minimum. The are numerous books and references that provide detailed definitions of visibility and illumination terms. Hence, these have not been replicated here. However, simple definitions and explanations are provided for the following terms as they are used extensively throughout this report:

Luminous Flux: This describes the quantity or amount of light emitted by a source during a given unit of time. Measured in Lumens, it indicates how much light is being given out by a light source each second.

Illuminance: Measured in lux, it indicates how much light (in Lumens) would strike a surface area of one square meter. It is measures of illuminance that are obtained from what are often commonly referred to as “light meters”.

Reflectance: This is the ratio of reflected luminous flux to incident luminous flux. In other words, the ratio of light energy reflected from a surface to the amount striking it. Objects with higher levels of reflectance will appear brighter than those of lower reflectance under the same lighting conditions.

Luminance: The luminance intensity emitted per unit of apparent surface area of a source in the direction of the eye. The eye can only see either the source of a light or objects reflecting light from some source. The luminance of any surface, as seen by the eye, is dependant on the amount of light striking the surface, the reflectance of the surface and the apparent size of the surface. The apparent size of the surface is a function of the actual size and the distance from the eye. Luminance is specified in candela/square meter [cd/m^2].

Contrast: The relative difference in luminance between two adjacent surfaces. In other words, how bright one surface looks compared to the other or the background against which it is being viewed.

Glare: Illumination engineers distinguish between two types of glare: disability glare and discomfort glare (Sanders & Peay, 1988). Disability glare is defined as glare resulting in decreased visual performance and visibility. The cause is stray light which enters the eye and scatters within. This produces a veiling luminance over the retina, which has the effect of reducing the perceived contrast of the objects being viewed. Discomfort glare causes fatigue and pain caused by high and non-uniform distributions of brightness in the observer's field of view (Unger et al, 1990).

2. Factors affecting a Visual Environment

Levels of illumination are only one of the factors that determine the quality, and hence safety, of a visual environment. Trotter (1982) states ‘seeing effectively is more complex than merely being dependant on the amount of light being shone at a target’. In coal mining, other factors that have been identified as affecting the overall quality of the visual environment (after Crooks & Peay, 1981; ECSC, 1990; IES, 1993) are:

- inherent vision of the mine population;
- low surface reflectance, usually less than 5%, which almost eliminates secondary reflections and indirect lighting;
- suspended dust and water vapour cause backscattering reducing apparent illuminance;
- reduction of apparent illuminance due to protective eye wear;
- mounting height restrictions and job tasks place the luminaires in the worker’s direct line of sight causing glare;
- mounting positions restrict the size, location and light distribution of the luminaires;
- Luminaires must meet the safety requirements for use in hazardous atmospheres.

The range of factors that can influence the visual environment are summarised in the following figure (ECSC, 1990):

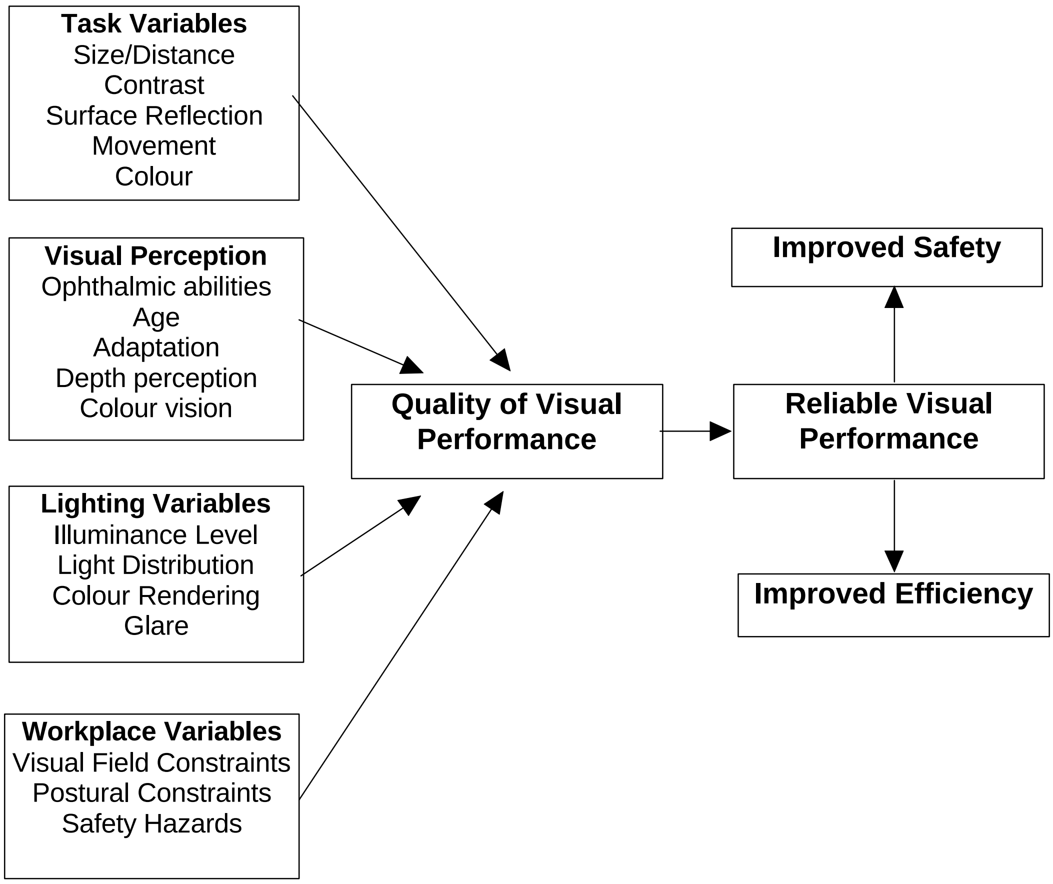

Figure 1.1.1: Major Factors influencing Visual Environment and Visual Performance (ECSC, 1990)

To ensure quality and reliability of visual performance and hence improve safety, all of these factors need to be considered. Visual perception variables (age, visual acuity, colour vision, etc.) although important, have not been addressed directly by the project. The need for selection to ensure that individuals have reasonable levels of the visual abilities required to safely undertake their job, is well recognised and should be accommodated by initial screening and periodic eyesight testing programs. Beyond this, effort should be concentrated on tailoring the visual environment to the needs of people rather than selecting individuals to cope with poor conditions.

2.1. Glare

Glare is often a major problem in the coal mining industry. To reduce this, Baines (1972) suggests that it is better to have lower powered lights with small distances between them, than to have high powered lights far apart. The former gives an evenly illuminated roadway, and the latter gives an alternate glaring light and then darkness. Good uniformity also makes for better hazard perception, as dark patches act as camouflage concealing obstacles and hazards. Trotter (1982) lists the following ways to reduce glare in the mining industry:

- Move illuminance sources out of the direct field of view;
- Shield sources from direct view;
- Use prismatic lenses, filters or cross polarizers;
- Keep differences in luminance between visible source and background small;
- Keep background and source illuminances high;
- Position work and lighting properly;
- Avoid specular surfaces;
- Use light of the correct quality.

It should also be remembered that glare is relative. For example, in an unilluminated area underground, the caplamp can give a blinding glare; but at a well-lit pit bottom it is less painful, and on the surface in daylight it may not even be noticed.

2.2. Reflectance

Crooks & Peay (1981) found that underground work environments differ significantly in surface luminance and reflectance, output of luminaires, and types of visual impairment that are present. For a given illuminance, light levels and distribution can be enhanced by improving the reflectance of surfaces. Generally light coloured surfaces reflect more light than dark coloured surfaces. Some typical percentages of reflectance in mines, as reported by a range of sources (Best et al, 1981; Baur & Wellbeloved, 1985; Sanders & Peay, 1988; Mine Ventilation Society of South Africa, 1992), are shown in Table 2.2.1:

Table 2.2.1: Reflectance of Typical Surfaces in Coal Mines

Surface	Reflectance
Coal	3-15%
Calcitic Stonedust	59%
Dolomitic Stonedust	34%
Rust	9%
Fresh Whitewash	65-95%
Faded Whitewash	20%-60%
Cement	10-30%

As can be seen from the above table, whitewashing a wall can increase its light reflecting ability considerably. Most underground mines make use of whitewash as a cost effective means of improving lighting performance, and the need to whitewash particular locations is required by legislation in some countries.

Similarly, stonedusting as well as being a safety measure for mitigating the effect of explosions, can also improve the reflectivity. South African legislation [Minerals Act 10.24.5 (d)] states that stonedust used must be "*light coloured*". The reflectivity of two types of stonedust in use in South Africa is given by Baur & Wellbeloved (1985). However, they also state that any benefit gained by the initial whiteness of stonedust on application is short-lived, as once contaminated by the addition of approximately 10% coal dust, both types of stonedust mixtures show similar reflectivity's.

2.3. Contrast

In terms of providing a safe and efficient visual working environment, lighting levels do not address the problem fully. Detecting the presence of a potential hazard is probably the most common and also the most critical visual task in terms of ensuring safety (for example, the need for drivers to see pedestrians or other obstructions, the need for pedestrians to see slip, trip, fall hazards, etc.).

In such situations, it is frequently the contrast between the visual target and the background that is most important in determining the reliability of hazard detection. Bell (1982) states that the ratio of the level of brightness between the task, the immediate background and the general background should be of the order of 10:3:1. Best et al (1982) state that the ratio between maximum and minimum light levels in a given area should be no more than 5:1. This is because objects with the same luminance as their surroundings are unlikely to be seen reliably, regardless of light levels. However, with more light the eye can see more detail, hence less contrast is required. In mines, as the light falling on the task and the immediate background are virtually the same, there is, in practical terms, a trade-off between providing higher light levels and good visual contrasts. For example, the use of reflective strips on workers' clothing, tapes or paint markings on vehicles or obstructions, may provide a more effective solution than the provision of additional or higher intensity lights.

2.4. Visibility

Determining what areas miners needs to see in order to perform their job efficiently and safely are generally referred to as *Visual Attention Areas*.

It is important to distinguish between what needs to be seen from what can be seen. Lewis (1986) states that 'every year people are killed, equipment is damaged, cables are cut and roof supports are knocked down because the operators of mobile equipment cannot see due to large blind areas created by the design of such equipment'. Poor sightlines are common to a large range of underground mobile machinery. A study in the United States (US Department of Labour, 1980) concluded that approximately 36% of the fatalities involving underground coal mine mobile equipment between 1972 and 1979 were directly or indirectly caused by improperly designed operator compartments.

Studies on both ergonomics and human error in the UK coal industry (Chan et al, 1985; Simpson et al, 1991); have shown that there is often little consideration given to ergonomics (in particular sightlines) in the design of mining equipment and machinery. In the UK, specific emphasis has been placed on LHD safety following the publication of a topic report by the Health and Safety Executive (HSE, 1992). This report concludes that the main area of concern identified with regard to ergonomic aspects of LHD design was poor driver vision. As a result, drivers often encounter problems when judging the sides and corners of a vehicle when manoeuvring, and seeing people and obstacles close to the vehicle. A sightline plot taken from this report is shown in Figure 2.4.1. This figure shows the areas in which objects less than 1m high are not visible for unloaded vehicles. The report also states that, between 1986 and 1991, fifty percent (50%) of all major and fatal accidents involving LHDs involved moving vehicles and resulted in pedestrians being run over or struck by vehicles, and drivers striking or becoming trapped against the sides of roadways. A similar conclusion had been reached in an earlier report by the UK mines Inspectorate (HSE, 1982) suggesting that in over 50% of major injuries caused by mobile machinery, the driver did not detect the presence of the victims.

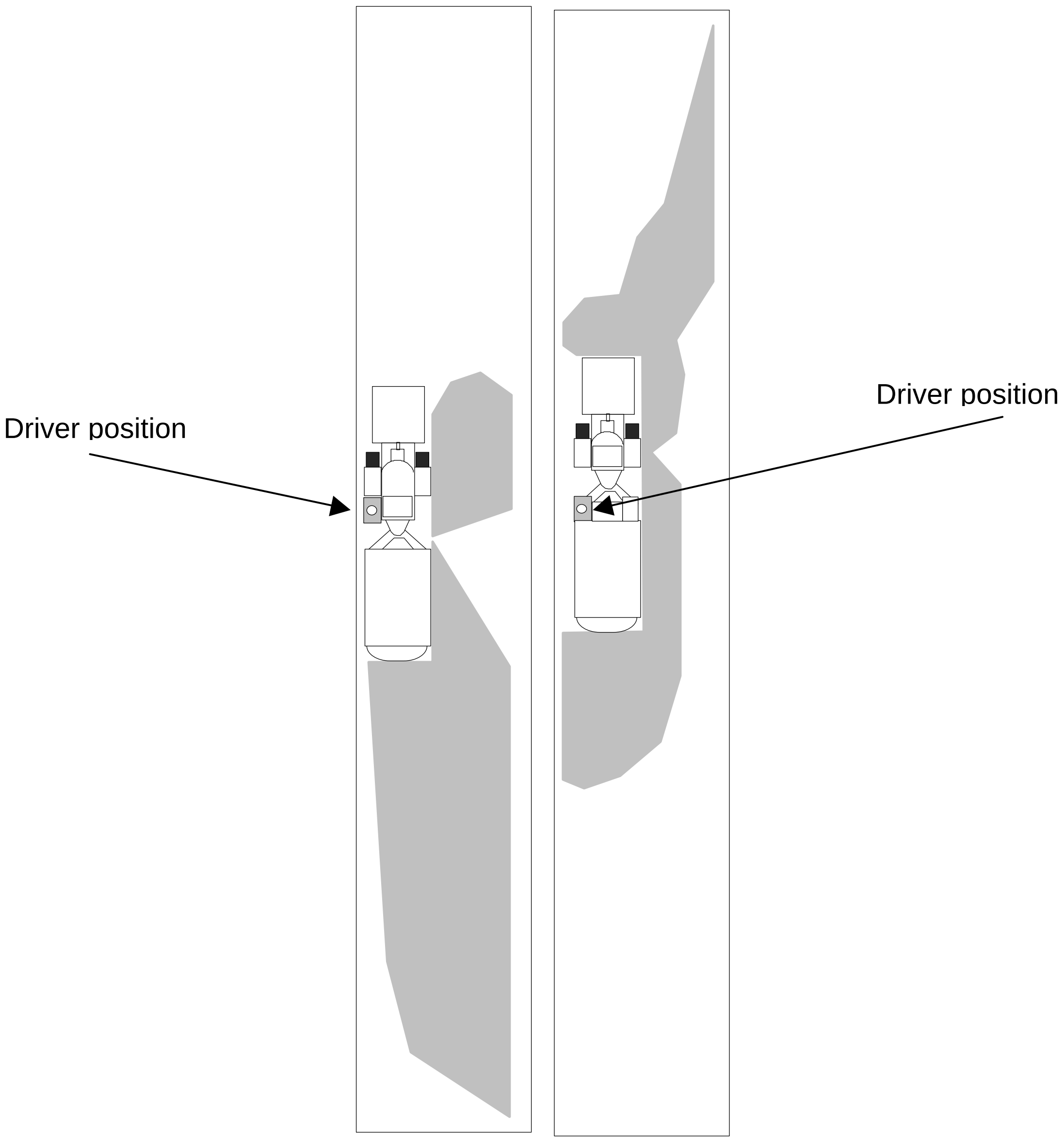

Figure 2.4.1: Sightline Plot of LHD (HSE, 1992)

Similar problems of poor visibility had been identified on LHDs in South Africa by van Graan & Schutte (1977). Recent research in South Africa (Simpson et al, 1996) clearly identified similar ergonomic limitations, (sightline provision as well as poor illumination levels), in the design of a range of transport machinery as a prominent latent failure which predisposed a number of considerable human errors - and therefore accident potential.

In order to provide mining machinery with satisfactory operator visibility, it is essential to know the areas that the operators will be required to see to enable them to work safely.

With mobile machines it is also important to have a means of assessing the sight lines provided by such machines against the visual targets.

There are a variety of techniques that can be used to evaluate sightlines and produce graphical representations of the results. Eleven such techniques were reviewed by Mason et al (1980) with a view for use in the mining industry. These can be grouped into the following categories:

- Shadow graph techniques, which utilise a suspended light at the drivers eye position, which cast shadows onto gridded screens representing the roadway sides. The shadows correspond to areas not visible to the driver in that position, and are recorded in photographs. This technique is recommended by ISO 5006-1 (1991) for recording the operators sightlines and field of visibility from surface earth-moving machinery.
- Panoramic photographic techniques in which panoramic photographs are taken around machines on the surface - with the camera at the position of the drivers eye.
- Graphical - techniques where sightlines are plotted using projections from general arrangement drawings of the machine.
- Line of sight techniques using a ranging pole around a machine and taking physical measurements of what an operator can and cannot see.

In the US, visibility analysis software known as “Crewstation Analysis Program” (CAP) (Unger et al, 1990; Unger, 1997) was developed at the former US Bureau of Mines. At present the CAP software has two models: the Line of Sight Model - that compares the visibility of specific machines to specific Visual Attention Locations, and the Illumination model - that assists in evaluating lighting arrangements to see if they conform to US Federal regulations whilst also reducing the potential for glare. These Visual Attention Locations were developed as part of earlier research (Sanders & Kelley, 1981) which investigated the visibility requirements for operators of shuttlecars, scoops and continuous miners. Visual Attention Locations (VAL) are areas where one or more important visual features are located.

Boocock et al (1994) describe a computer generated visibility technique know as SAMMIE (System for Aiding Man Machine Interface Evaluation) which produces visibility charts based on a 3D computer representation of the model through a computer aided design package.

More recently developments in computer graphics have allowed virtual reality techniques to be utilised in order to visually demonstrate operator sightlines from specific machines (Denby, 1996; Mason & Ballot 1997).

All these sightline techniques establish the operator's sightline limits which, if compared with the minimum visual attention areas necessary for safety and performance considerations, would enable operator training courses to be developed which incorporate any sightline restriction difficulties, as well as aid in the development of any other risk reducing control measures such as operational procedures. It would also enable design engineers to identify any engineering modifications necessary to achieve good operator sightlines.

3. Assessment of World-wide Visibility Standards

A review of current world-wide illumination standards and guidelines in coal mines was undertaken to assess their applicability to the conditions in the coal mining industry of South Africa. Where lighting levels are specified in either legislation or standards, the method of specifying actual levels of lighting varies from country to country. The majority specify levels in terms of illuminance.

3.1. International Mining Legislation

South Africa

In South African mines, the statutory requirement for illumination and lighting is given in Chapter 15 of the Minerals Act, 1991. Within this, Regulation 15.1 states that all persons working in non-illuminated areas shall carry a light; Regulation 15.2 states that 'adequate' lighting should be provided at various locations underground, such as shaft stations and loading areas; Regulation 15.3.1. states that the moving parts of certain types of machinery shall be 'clearly visible' and Regulation 15.3.2. specifies a minimum illumination requirement of 10 lux at a distance of 20m for all self-propelled mobile machines.

United Kingdom

The statutory regulation behind lighting in UK coal mines is still the Coal and Other Mines (Safety Lamps and Lighting) Regulations 1956 (HMSO 1979). Within this, Regulation 17.1 states that it is the duty of the Manager to: -

> *"secure the provision and maintenance of suitable and sufficient lighting at the following places below ground at all times: -*
>
> - *shaft or outlet entrances and sidings which are regularly used;*
> - *top and bottom of inclines that are regularly used;*
> - *sidings, landings, pass-byes, junctions off-takes, places where vehicles are regularly coupled or are attached to a haulage rope, and places where vehicles are regularly filled mechanically;*
> - *motor and engine houses",*

and that such arrangements must be "*arranged so as to minimise eyestrain and glare".*

Section 23 of the same regulations also states particularly areas underground where the roof and walls should be whitened. These include the shaft stations, top and bottom of every incline and every siding, junction and pass-bye.

Australia

The current New South Wales Regulations in Australia, [the Coal Mines (Safety Lamps and Lighting - Underground Mines) Regulations, 1984] are very similar to UK legislation. Here, Section 31 puts duties on the Manager to provide '*suitable and sufficient'* fixed lighting at specified places underground, and again states that such lighting shall be arranged to minimise glare and eye strain (Davis, 1997).

Canada

In Canada, each province regulates its own mining operations. Both the Manitoba and Alberta province call for the provision of '*suitable and adequate'* levels of lighting in their Mining Regulations.

The British Columbia Coal Mines Regulation Act states that "*All artificial illumination shall meet the standards of the latest code of the Canadian Standards Association in respect to industrial lighting, except where the electrical inspector does not consider these standards suitable*" (Greenwell, 1997).

India

The Indian statutory regulations regarding illumination and lighting are cited in the Coal Mines Regulations, 1957. These are similar to the UK and Australian Regulations in that 'adequate' lighting arrangements should be provided at fixed locations underground including '*every travelling roadway normally used by 50 or more persons during every shift'.* These regulations also require specific areas underground to be whitewashed. These areas include every shaft station, the top and bottom of inclines and every travelling roadway (Wells, 1997).

In all of the above legislation, there is no formal guidance on what constitutes a *'suitable and sufficient'* and/or *'adequate'* level of illumination. In most cases, this legislation originated well before the modern trend for self regulation via the use of risk assessment. In a risk assessment based legislative environment, a level of illumination that is 'suitable and sufficient' must be one 'where the associated risks are reduced to a level as low as is reasonably practicable'.

Based on these general regulatory requirements, some countries have drawn up specific recommendations as 'Guidelines' or 'Standards'. These are often produced either by the country's (or province's) Mines Inspectorate, or by mining companies themselves. These are discussed further in Section 3.2 of this report.

United States

The US regulations are probably the most prescriptive in terms of specifying illumination requirements. Provision 75.1719-1(d) of the Codes of Federal Regulations (Mine Safety & Health Administration, 1988) states that:

> *"The luminous intensity (surface brightness) of surfaces that are in a miner's normal field of vision of areas in working places that are required to be lighted shall not be less than 0.2 cd/m² [0,6 foot lamberts]..."*

This is an expression of luminance rather than illuminance. The term 'working place' is defined in the Act as "the area of a coal mine inbye the last open cross cut" (US Department of Labour, 1980).

These regulations apply to all mobile mining machinery in this area, and are expressed as machine vicinities to be illuminated to a minimum surface brightness of 0.2 cd/m². The reason for requiring illumination around these machines and in this area of the mine is that this is where worker activity is most concentrated, hazards are most serious and likely to develop (Whitehead & Bockosh, 1992). The specific vicinities have been selected according to visual requirements for task performance and hazard identification and are expanded on in US Department of Labour (1980).

According to Whitehead & Bockosh (1992) research has shown that the 0.2 cd/m² level is adequate for the performance of most mining tasks where fine perception of detail is not required. Most of the tasks where higher levels of illumination are necessary are carried out at close range and the miner's caplamp supplements this level of lighting. The term: "surfaces that are in a miner's normal field of vision" also implies that such lighting should accommodate peripheral vision.

These Regulations also specify additional requirements intended to provide increased visibility for miners in working places. These include the provision of a caplamp for all persons underground; helmets which should have a minimum of 6 square inches of reflecting tape on each side and back; and paint on exterior surfaces of mining machines shall have a minimum reflectance of 30%.

3.2. Illumination Standards

In order to expand or clarify legislative requirements, the Inspectorate and/or mining companies of some countries have provided guidance or recommended illumination levels of different areas and operations underground

Defining appropriate illumination levels for underground coal mines is a complex task (Lewis, 1986). Two studies were undertaken by the US in the early 1970's in order to determine the recommended levels of background luminance for underground coal mines. The outcomes of these studies, and subsequent refinements, resulted in the US lighting regulations highlighted in the previous section.

The Illumination Engineering Society handbook (IES, 1993) gives recommended illumination levels for a wide range of industries, but not mining. Crooks & Peay (1981) point out that '*economics will not allow the general level of lighting in a mine to approach the levels found in most surface industries'*.

Table 3.2.1 (ECSC, 1990; MVS, 1992; Piekorz, 1997) gives the recommended illuminance requirements (in lux) for several of the larger coal mining countries. Also included within this table are the recommended illumination levels South African gold mines as given by the Mine Ventilation Society of South Africa (MVS, 1992).

Table 3.2.1: Summary of International Illumination Levels (in lux)

	Shafts	Loading	Around Machines	Haulages	Headings	u/g workshop
Belgium	20-50	20	25	10		
Hungary	40-100	40-60	20-50	2-10		20-50
Canada (British Columbia)	21			21	53	
Poland	30	30	10	2-10	5-15	30
UK (British Coal)	70	30		2.5		50-150
European Coal & Steel Community	40-90	15-80		5-15	10-30	
West Germany	30-40	40	80	15		
Czechoslovakia	15	20	20	5		
South African Gold Mines	20-160	160		20		400

Table 3.2.1 demonstrates the level of variation across countries for each of the specified areas and operations. In considering health and well being, Odendaal (1997) states that the recommended minimum light level for general underground work is 54 lux, higher than many of the values in the table.

In the early 1980's the Commission Internationale de l'Ecairage (CIE) established a technical committee to review, collate mine lighting information and prepare guidelines for mine lighting standards. Trotter (1982) states that such guidelines (limited to underground coal mines) have been established by committee. However, it is unclear what has happened to these guidelines which recommended the following four levels of *luminance*.

Table 3.2.2: Luminance Levels as defined by the CIE (after Trotter, 1982)

Where traffic is light and mechanisation is minimal but general lighting is desired because of safety considerations.	0.05 $cd.m^{-2}$
Where mechanised equipment normally operates	0.2 $cd.m^{-2}$
Underground chambers where precision work is no performed	10 $cd.m^{-2}$
Underground chambers where precision work is being carried out	20 $cd.m^{-2}$

In terms of improving safety, setting standards that specify required levels of illumination without addressing all the other issues highlighted earlier, could in fact be counter productive. For example, a mine Manager may believe that he has taken 'suitable and sufficient' action to ensure a safe visual working environment. This may well not be the case. Sanders & Peay (1988) state that in reality, the setting of illumination requirements involves many trade-offs, including weighing the cost of increased illumination against the improvement in visual performance, and balancing increased levels of illumination against the increase in glare

3.3. Visibility Standards

While a considerable amount of research has been undertaken to address the standard of operator visibility on a range of mining machinery, little work has been applied to the development of visibility standards or the inclusion of line-of-sight criteria in mining regulations. The inclusion of recommendations arising from this research has however, to some extent, been addressed in Europe, Australia and the USA.

A considerable amount of ergonomic research was undertaken in the UK in the 1980's to examine various aspects of the design of underground mining machinery and transport systems including the limitations identified in Section 2.4. Notable outcomes of this work included a series of design handbooks known as Ergonomics Principles Reports for the various machine families examined (e.g. LHDs, continuos miners, roadheaders, shearers etc.). The aim of the handbooks was to provide designers with sufficient information to enable them to ensure that new or existing machines achieved minimum ergonomic standards before they were used underground. The operator's visual environment was one of he major issues covered by the handbooks. The sections covering visibility included:

- Descriptions of the limitations identified from research and the potential visually related hazards and performance implications associated with the limitations.
- Reviews of the general and specific available sight line criteria.
- Recommendations containing detailed context specific guidance and criteria.

Taking the roadheader handbook as an example, the section on sightlines contained recommendations on minimum sightline requirements to areas around a machine where the risks to men working near the machine were higher (e.g. at the corners of the machine). Design and evaluation procedures were also developed to identify the minimum operator eye-height or to identify the maximum machine profile in order to meet the minimum requirements.

Much of the UK research was funded by European Coal and Steel Community Health and Safety Programmes and the results of the research were disseminated and adopted by most of the participating member states. The recommendations produced were also adopted by a wider audience. For example, in Australia, the minimum sightline and lighting requirements for underground locomotives contained in their standard 'Design Guidelines for the Construction of Locomotives' (Department of Mineral Resources of NSW, 1991) were based on the UK ergonomics research on locomotives.

In another initiative in Australia, their ‘Draft Code for Free Steered Vehicle Driver Compartments in Underground Coal Mines (as outlined in Roberts, 1993) addresses the operator’s field of view through reference to ISO 5006.3, the visibility standard for surface earth moving machinery.

In the USA, the US Department of Labour produced a handbook (US Department of Labour, 1980) that describes in detail the mandatory regulations made in the Code of Federal Regulations (detailed in Section 3.1), as well as the enforcement policies and procedures regarding these regulations. This report details the specific areas around mobile machinery which are to be illuminated, and hence to be visible to the operator.

While the above research focused essentially on the design of new machines and equipment, Rushworth (1993 and 1995) undertook detailed investigations to reduce accident potential by improving the ergonomics and safety of existing locomotives and LHD driver cabs by retrofit. Central to both investigations was the development of a *Retrofit Index* which provided a working framework for the industry within which both ergonomic and engineering considerations were combined into a cost sensitive approach to the selection and assessment of retrofit changes. In the specific context of visibility standards, the work clearly demonstrated that significant improvement could often be made by low-cost and easily implemented retrofit changes. The recommendations produced by the work on LHDs provided the basis for the HSE Topic Report - Improving Visibility on Underground Free Steered Vehicles (HSE, 1996).

Whilst in the past few countries have undertaken major ergonomic studies on mining machinery, and in particular on visibility and sightline requirements, the need for such studies and an awareness of ergonomic principles will increase, particularly in South Africa. In South Africa, Section 21. (1)(c) of the Mine Health & Safety Act, 1996, specifically requires that ergonomic issues are considered by the manufacturer or supplier of mining equipment. Furthermore, the recently published Guidelines for drawing up a Code of Practice for trackless mobile machinery in South African mines (Department of Minerals & Energy, 1997) specifically require that the ‘*constraints to the operators vision from the driving position for different machines and conditions must be identified and noted on area plans to be included as ‘annexes’ to the code of practice*’. As a result, sightline assessments may have to be carried out within mines on all their existing machines.

4. Development of Recommendations

The primary output of this project was to be general guidance and recommendations that would assist mine management operators to improve illumination and visibility standards and hence, improve health and safety. These recommendations were to be based on what was currently accepted as 'best practice', both within South Africa and internationally.

Few countries stipulate 'fixed lighting' standards in their statutory regulations. The phrases 'suitable', 'sufficient' or 'adequate' lighting must be provided are used where standards are set they vary significantly from country to country.

A previous SIMRAC sponsored project COL 033A (Pardoe et al 1994) conducted a review of the illumination problems pertaining to South African collieries and proposed an empirical approach for further research to define lighting standards - and identify the lighting systems required to meet them. (This approach would involve the creation of a test environment where the illumination provisions required for particular machine/operational combinations could be determined. Such an approach would potentially identify optimum solutions, and produce recommendations for specific site and machine combinations).

There may be circumstances where optimal site and machine specific solutions are warranted. However, it is was considered potentially more beneficial to establish the fundamental requirements that would bring the majority of locations and operations up to a reasonable standard rather than to identify ideal solutions for relatively specific and localised problems. Hence, the overall approach of this project was to produce general guidance and recommendations that would be applicable to a wide range of underground coal mining locations.

It was clear from the review of current international standards and practices that recommending target illumination levels and visibility standards was neither practical nor advisable. Specified levels of illumination may still be insufficient to ensure safe and reliable visual performance due to site specific conditions such as high dust/water vapour levels, poor contrast due to the build up of dirt or dust, etc. Conversely, in more favourable conditions, these levels may be too high and result in the introduction of additional restricting sources e.g. glare. Such a prescriptive approach conflicts with the trend towards self-regulation and goal-setting that underlie the risk assessment and management requirements defined in the Mine Health and Safety Act, 1996.

If the hazards which can arise from a poor visual environment are to be minimised, it is necessary to identify the visual targets of the operators/drivers, and then, to ensure that they are clearly visible. Hence, the recommendations produced by the project have been designed to assist mines to integrate consideration of visual requirements into their risk assessment process.

4.1. Method

An investigation into the current visibility and lighting conditions that exist in underground coal mines was undertaken at various locations to determine the nature and extent of existing problems in the coal mining industry - and to identify the potential hazards arising from poor visual environments.

For each of the locations studied, the following information was gathered:

- **Key dimensions.** Relevant dimensions of operational location were taken. For example, roadway sizes, seam height, travelling distances, estimated braking distance, etc.
- **Sources of Illumination.** The type, condition and placement of all sources of illumination were recorded.
- **Visual Environment.** Factors that influence the background lighting in a location were recorded (i.e. the surface conditions of walls, floor and roof)

For all of the machines observed a hierarchical task description was produced. For each of the steps identified, the key visual targets (i.e. what the operator needed to see) were identified. For each of these visual targets, the following factors were then recorded:

- **Operational "blind spots":** The presence of any operational "blind spots" or the need for major postural changes to compensate for visual restrictions were recorded.

- **Characteristics of visual targets (VTs):** These included the following:

  Visual angle: approximate size and distance of the VT from operator.

  Illuminance: This was measured where practical circumstances allowed access otherwise a subjective estimate/description was used.

  Reflectance: Reflectance characteristics such as material, colour, conditions (wet/dry, dusty, muddy, clean, etc.)

  Contrast: The background against which the target is viewed. Subjective descriptions were used: High, medium or low

  Visual conditions: Notes of glare sources, deep shadows, dust, water sprays, high air velocity, etc.

  Classification of visual tasks: (e.g. Detection, Identification, Coarse or Fine Tracking). These aspects are discussed in more detail below:

The level of visual information required to reliably conduct a particular task step varies considerably. To accommodate this variability and provide an indication of the visual information required, visual tasks were classified using the following key words:

Detection: It is only necessary to see the presence of an object or obstruction. (For example, to avoid tripping or stumbling hazards, all that may be required is for a pedestrian to detect the presence of an obstacle in the roadway in sufficient time to avoid it).

Identification: It is necessary to detect the presence of an object and reliably determine what it is. (For example, a driver may need to detect an obstacle in the path of his machine and then determine what it is, to decide if he should stop, steer round it or ignore it and carry on past it).

Coarse tracking: Where it is necessary to check the position of an object in relation to some reference point or other object, and determine what corrective control action is required to keep within relatively coarse boundaries. (For example, control of machine cutting heads, driving in confined spaces or around tight corners, etc.)

Fine tracking: Used where small targets need to be tracked continually, and also for fine manipulative tasks, reading, etc.

All of the critical visual targets identified were grouped - based primarily on their spatial location - to derive more general visual attention areas. The quality of illumination required in each of these visual attention areas was then determined largely by considering the most demanding visual task that falls within the area.

During the study periods, the potential for hazards arising from poor visual environments were noted. The working practices observed were also compared to those prescribed (in standard procedures and/or good practice) to help highlight areas were poor visual conditions can lead to non-compliance with procedures or unsafe acts.

4.2. Study Results

4.2.1 Locations

Locations covered during the evaluation phase of the project have been sub-divided into two categories, viz. dynamic and static.

Dynamic locations

There are those locations where lighting installations would be temporary, semi-portable or mounted on machines. These are located mainly in production or development areas i.e.:

- Production Faces - Traditional, CM, Longwall Mining Operations,
- Development Faces,
- Miner's Boxes,
- Gate Ends, gate roads and conveyor roads,
- Electrical transformers and switchgear.

Static Locations

These locations include those areas of the mine where it is more practical to provide permanent lighting installations. The areas covered included:

- Inclined Shafts and Shaft Stations,
- Shaft Bottom Areas,
- Junctions,
- Transfer Points,
- Workshops,
- Haulage Routes and Travelways,
- Electrical Sub-Stations, and
- Fuel Stores.

4.2.2 Machines

The visibility and illumination provisions for a wide range of mobile machines were also evaluated. An extensive range of machines was studied. These included:

- Continuous miners and roadheaders,
- Chain haulage systems,
- Shuttle cars,
- Loading machines,
- Face drilling machines,
- Roofbolting machines,
- Load haul dumps (LHDs),
- Coal cutting machines, and
- Tractors.
- Shearers
- Light delivery vehicles (LDVs)
- Multi-purpose vehicles (MPVs)
- Locomotives (locos).

A total of 84 evaluation studies at nine mines were undertaken by the project. These included 34 static locations, 17 dynamic locations and 33 mobile machines. In addition, the locations within which the mobile machines were evaluated were also included in the machine evaluations. For example, LHD assessments included LHD routs and junctions; similarly, shuttlecar operations included roadway assessments. In this way an even larger sample of locations were considered.

Details of the locations and machines studied are given in Appendix A.

4.3. Recommendations

The recommendations document has been designed to act as a reference source that can be used in the South African coal mining industry to improve underground visibility and illumination standards.

They are based on:

- The current scientific literature
- National and International legislation and recommendations
- Results of the mine studies conducted
- Examples of current practices and effective approaches to risk reduction.

This information could assist mine management to:

- Identify potential hazards related to visibility and illumination.
- Factors to be considered when assessing risks associated with the above, and
- Indicate approaches towards reducing these risks.

5. Current Practice and Approaches to Hazard Reduction

In developing the recommendations on setting illumination and visibility standards, the applicability of existing world-wide standards to South African coal mining conditions were considered. In addition, during visits to the mines and suppliers of equipment to the mines, examples of 'good practice' and novel approaches to hazard reduction were also collected for inclusion in the final recommendations document. Some of the more significant developments observed are summarised below.

5.1. Improved selection and mounting of headlights on shuttlecars

Limitations in the headlight arrangements provided on the majority of the shuttlecars examined by the project resulted in a cone of dark shadow cast directly in front of the vehicles. This significantly increased the risk of collision with people and obstacles when travelling in both directions. The problem was created by the need to mount the lights at the corners of the vehicles, the use of light bulbs with narrow (9º-12º) beam angles, and from mounting the lights in deep narrow recesses which further restricted the beam angles.

An initiative taken at one of the mines comprised the use of similar output bulbs with wider (26º) beam angles mounted in recesses with chamfered sides which did not obstruct light output. The area of shadow was reduced significantly and, even with the wider angled beams, the regulatory light output of 10 lux at 20m should still be achievable given good care and maintenance practices are applied.

5.2. Reducing glare problems for the drivers of mobile machines

Driving compartment interiors on mobile machines tend to be painted white - which results in a highly reflective surface. Light from driver's caplamps, other machine headlights and overhead mine lighting installations reflects from these surfaces creating glare problems for the drivers and thereby increasing the risk of collision with people and obstacles.

An initiative taken at one of the mines involved painting the cab interiors with non-reflective mat-black or mat-red paint which significantly improved the drivers visual environment. European research supports this initiative, but recommends the use of mat-grey paint so that both black and white controls and displays will be visible against this background.

5.3. Effective warnings of roadway restrictions

A frequent cause of collision is the failure by the drivers of mobile machines to detect abrupt restrictions in the height and width of roadways far enough ahead to stop their vehicles safely. A number of mines have adopted the practice of clearly marking such areas with display signs comprising diagonal black and yellow chevrons. It was established that these signs are very effective in providing drivers with the required advance warning of such roadway restrictions and, since their introduction, the incidence of collision damage has fallen significantly. The benefit is further enhanced by the use of reflective signage/paint.

5.4. An effective tramming and parking light for mobile machines and equipment

A further cause of collision is the failure by drivers of mobile machines to detect other mobile equipment, especially vehicles and loads left parked in haulage routes. In most cases parked equipment is not provided with any form of visual warning and in some cases it is not painted in a colour that contrasts with the background environment.

A policy adopted at one of the mines involves fitting reflectors to the corners of all items of mobile plant. Furthermore, in a collaborative venture with a light manufacturer, each engine powered vehicle is being fitted with a revolving red tramming/parking light. When tramming, the light operates automatically and is powered directly by the vehicles electrical system. When the vehicle is parked, the light has to be switched on by the driver and operates from a battery. The battery has sufficient capacity to operate the light for seven to eight hours and is automatically recharged whenever the vehicle engine runs.

5.5. Improved visual access to electrical enclosures

It is often difficult to provide sufficient lighting to enable electricians carry out maintenance work effectively within electrical enclosures. To overcome these limitations electricians improvise by removing their hard hats and caplamps. The caplamp is placed inside the panels while they undertake the necessary inspections and adjustments.

To address these difficulties, one of the major suppliers of electrical flameproof enclosures has a flameproof enclosure under development which features a sealed glass inspection window and an internal light. Furthermore, the interior walls of the enclosure are painted with a light coloured reflective paint to enhance the all-round illumination levels within the enclosure. The enclosure is designed to enable routine visual inspections to be reliably undertaken without removing panels, and also to provide a more appropriate level of internal illumination to aid physical checks and adjustments.

5.6. Reducing visually related hazards at the entrance to production areas

When entering production areas, workmen often experience difficulties adapting to abrupt changes in light levels. Waiting areas are usually well lit, however, in production areas, in most cases the only sources of illumination are caplamps and the lights on vehicles. Given the instantaneous nature of the change in visual conditions, the risks of tripping and falling and/or stepping in front of moving vehicles can be significant.

The problem has been identified by a number of mines and the following initiatives have been taken to control the associated hazards:

1. Reflectance levels have been improved immediately inside the entrances to the sections through the use of white or brightly coloured/reflective brattice cloth and high reflective calcitic stonedust in preference to the more common less reflective dolomitic stone dust.
2. The suddenness of the change from a brightly lit to a dark environment has been reduced by extending the distances from the waiting places areas to the entrances to the sections, and gradually reducing lighting levels in the approaching roadways.
3. Entrances to the sections have been modified to prevent workmen stepping directly onto shuttlecar routes.

4. Portable light units have been provided directly inside the entrances to the sections to more effectively illuminate any tripping or other visually related hazards.

5.7. Improved caplamp design

A major manufacturer and supplier of caplamps in South Africa has recently introduced a modified version of their design which gives a significantly greater light output than previous models. A feature of the unit is a faceted design reflector. Light measurements taken 20m from the lamps indicated a 50% improvement over the original design of caplamp. Consideration could be given to the introduction of these units, particularly to those involved in the performance of visually critical tasks where the provision of other supplementary sources of illumination is impractical.

5.8. Optimising illumination levels in dynamic locations

Some mines experience difficulties in providing consistently satisfactory levels of illumination in dynamic locations i.e. in areas where equipment such as miners boxes, electrical switchgear and storage units, workbenches, feeder breakers, etc. are constantly being advanced. As a consequence, the tasks undertaken in these locations are not adequately illuminated and significant accident potential exists. To address these limitations, some mines are mounting the light sources directly onto the advancing equipment in preference to the roof or ribsides. By experimenting initially to provide a satisfactory visual environment from light sources mounted on the equipment, it follows that this visual environment can be reliably maintained in whichever location the equipment is moved - providing good care and maintenance practices are followed.

A particularly successful idea was developed at one mine to provide improved illumination levels for the various activities undertaken at a feeder breaker. The arrangement incorporates a swivelling adjustable arm on which is mounted a flameproof fluorescent light fitting. Two such units are mounted on the feeder breaker. The adjustments enable the lights to be set in different positions to provide optimum levels of illumination for the various operations undertaken e.g. discharging shuttle cars, clearing spillage and blockages, carrying out inspections and maintenance work, etc.

5.9. Alternators modified to improve output levels from lights on mobile machines

On the majority of the engine powered mobile machines examined, headlight output diminished at low engine speeds. Light output on some vehicles, when standing with the engine running at idling speed and when undertaking low speed manoeuvres, was virtually zero. In these situations the drivers had to rely on their caplamps to identify and avoid potential hazards. Similarly, the headlights provided little warning to people working in close proximity to the vehicle or to the drivers of other vehicles.

To address this problem one mine, working with a major supplier of electrical equipment for vehicles, is currently carrying out trials with a constant voltage alternator. Early trials with the unit have demonstrated that maximum light output from both headlights and taillights is maintained regardless of engine speed.

5.10. Ground treatment as an effective means of controlling dust in roadways

Where ground conditions are dry, dust created by the movement of mobile machines can significantly affect the visual environment for both the drivers of the vehicles and other roadway users. Some of the mines to apply chemical treatments to the ground to allay the dust. The chemicals, which are sprayed on the ground on a weekly basis, consolidate the dust and small fines and effectively reduce the amount of airborne dust created during tramming. The process was introduced initially as a means of controlling the respirable hazards associated with airborne dust, however, it is now also regarded as a very effective means of improving the visual environment and thereby reducing accident potential.

5.11. Visual aids for the operators of remotely controlled heading machines

One of the major advantages resulting from the application of remote control technology to mining machines, is that it has provided operators with the freedom to adopt a wide range of operating positions. This enables them to overcome the visual limitations associated with fixed on-board control arrangements. This facility, however, can result in operators adopting unsafe positions where, for example, they may be at risk from being trapped by the machine they are operating or struck by other machines. In the case of remotely controlled continuous miners and roadheaders, some operators have developed the tendency to work at the side their machines in order to enhance their view of the face and cutting head. In this position they are at risk from being crushed against the ribside and from exposure to noise, dust and roof falls.

To address these problems, the operators of one of the machines studied had been provided with a set of visual aids comprising an inclinometer - which displayed the angle of inclination of the cutting head; and a column of three lights - which indicated when the cutting drum was at the top and bottom. The top and bottom lights were coloured red and the central light was green. The lights were mounted on the rear of the machine where they could be ‘used’ by the operator from a relatively safe position. The operators found that it was possible to accurately control the machine using these lights.

5.12. Provision of visual aids to denote areas of unsupported ground

In production areas where roofbolts are used, the final rows of bolts are important visual targets since anyone working in advance of these bolts may be at risk from being struck by falling ground. Some of the mines visited had developed the practice of hanging brightly coloured reflective ribbons from the last rows of bolts to provide clear warnings to machine operators and other workmen at the point where they may be about to enter unsupported roof. The ribbons also provide a useful indication on the flow of air in the area.

5.13. Light unit developments for heading machines and shuttle cars

The project identified significant limitations in the visual environment directly behind most of the continuous miners and roadheaders examined. Existing lighting provision varied considerably, but generally failed to adequately illuminate the important visual targets and/or caused glare problems which impaired the view of both the machine operators and workmen behind the machines. The lights were also vulnerable to damage. As a result of these limitations, cable handlers and other workmen involved in activities in these areas may be exposed to a range of potential hazards which could include, for example, being struck or trapped by unexpected machine movements, being struck by approaching shuttlecars or other machines, being caught by or tripping over supply cables, etc.

An initiative taken at one of the mines involves mounting a new design of florescent light to the back of a continuous miner near the cable entry. The light unit is square shaped and flat and early indications are that it gives a much more effective level of lighting than most existing arrangements without causing any glare problems. In addition to effectively illuminating most of the important visual targets, the unit also provides an enhanced level of peripheral illumination. Being flat and square shaped, it is more amenable to being mounted in locations where it is less vulnerable to damage than the conventional straight light tubes which are often used.

The mine also intends to evaluate the potential of similar lights mounted at all four corners of their shuttlecars.

5.14. Reflective sleeves for caplamp cables

One of the more significant potential visual limitations identified by the project was a general failure by the mines to make pedestrians more visible to the drivers of mobile machines. While high visibility clothing with reflective strips, or wearing reflective braces/waistcoats was adopted as standard workwear at some mines, it was more common to see workmen in dark coloured overalls, often without any form of reflective markings. A novel idea developed by one of the mines involved fitting brightly coloured reflective sleeves over caplamp cables to make workmen on foot more conspicuous, particularly in unlit areas of the mine. This is an idea which has also been successfully implemented in a number of European mines.

The use of clothing fitted with reflective material by all persons entering a mine, should be consistently enforced.

5.15. Special purpose light units

A prominent supplier of light units for mining machinery reported that, in the past, a series of special purpose units had been successfully developed by a number of suppliers for specific mining operations. For example, reference was made to an integral triple cluster headlight produced for loading machines used in conventional drill and shot fire sections. The unit featured a hemispherical lens on which were mounted the following individual lights.

1. A spot light to illuminate the roadway ahead for tramming operations.

2. A flood light to provide peripheral illumination during both tramming and loading operations.
3. An orange spot light to penetrate dust and waterspray and illuminate the gathering arms of the loader.

By using a hemispherical lens it was possible to direct the lights in the different directions required.

The above unit does not appear to be in current use on the mines despite the indications of its initial success, nor were any other examples of special purpose units identified in use during the project. When applying the findings of the project, it may be beneficial for the mines to contact the lighting manufacturers with the view towards developing light units for specific applications.

5.16. Improvements in workshop lighting

The project established that lighting standards in vehicle workshops is generally poor. Characteristically, illumination is provided by florescent tubes suspended from the roof either longitudinally or laterally across the workshops. Most maintenance tasks are carried out either underneath or inside the vehicles and, with the above light arrangements, the majority of these tasks are undertaken in dark shadow. Light is cut off by raised engine covers, vehicle chassis members, limitations in the size of access openings and the location of components therein, and the positions adopted by the maintenance crew. Furthermore, the postures that fitters frequently have to adopt, prevents them from using their caplamps effectively. Since it is normal practice to paint the lower half of the walls a dark colour, the amount of available reflected light is also limited.

In a development at one of the mines florescent light tubes have been mounted vertically to the walls. A comparison between the two arrangements clearly indicated that vertical wall mounted arrangement was preferable in that:

1. It provided a more even distribution of light across the workshop.
2. It illuminated many of the areas that were previously in dark shadow.
3. It provided significantly better levels of illumination beneath vehicles of between 100 and 500 lux compared with the usual 10 lux to 50 lux.

6. Conclusions

The following main conclusions have been reached by the project:

1. Although 'insufficient illumination/visibility' is rarely given as the primary cause of an accident, a number of accidents, for example, slip/trip incidents and machine collisions, may well have been prevented if sufficient lighting had been available.
2. The diverse range of current world-wide illumination and visibility standards and recommendations arise principally as a result of the many variables that need to be considered if a safe and healthy visual environment is to be assured rather than from a variation in the level of commitment to ensuring health and safety.
3. The inclusion of a specific set of minimum illumination levels within regulations or guidance documents is contrary to the spirit of the Mine Health and Safety Act and is either unlikely to significantly improve health and safety if the prescribed levels are low, or conversely has the potential to impose a cost burden that outweighs the additional health and safety benefits derived if the levels are too high.
4. The recommendations document was designed raise the awareness of the need to consider the influence of the visual environment to ensure safety and health at mines by providing an comprehensive list of the potential hazards that can arise from a poor visual environment. Consideration of the influence of the visual working environment should be an integral part of health and safety risk assessment and the hazard identification process at all mines. Use of the recommendations document as an initial reference source will encourage this situation.
5. The recommendations produced by the project should be used throughout the industry to help participants in risk assessment working groups to identify hazards and the likely limitations of current provisions, assess risks, and identify those areas were more can be done to improve the visual environment and hence ensure health and safety within the bounds of what is 'reasonably practicable'.
6. It should be possible for the methodology adopted by the project to be followed at mine level to investigate specific location and machine types that have not been covered during the project. In this way, mines can determine acceptable lighting and visibility standards within a risk assessment framework and hence, determine

the relative priority that should be given to the allocation of equipment and resources within the resources available for improving health and safety.

7. The practical methodology provided in the recommendations document for producing sightline plots will also enable mines to evaluate specific machines and hence highlight any potential hazards due to poor visibility that may be present.

8. Where new machines are being purchased, manufactures and supplies have a duty-of-care under section 21 of The Mine Health and Safety Act, Act 29 of 1996 to identify hazards and risks. Hence, they should also take cognisance of the recommendations made by the project and the need to identify potential illumination and visibility hazards. For example, they should provide information on sightline restrictions.

9. It is potentially more beneficial to establish the basic requirements at each mine via the use of risk assessment principals to bring the majority of locations and operations up to a reasonably practicable standard rather than identifying ideal solutions for relatively specific and localised problems. The current good practice and approaches to hazard reduction identified by the project provide examples of how specific problems have already been tackled within the industry. These practical examples can be used by other mines to assist in reducing risk and hence, potential accidents.

10. It is expected that the approaches to hazard identification and risk reduction will be suitable and sufficient to address the vast majority of mining environments. However, there may be particularly complex and/or hazardous situations were more detailed investigation of the visual environment is desirable. In such situations the empirical approach suggested by COL 033a (Pardoe et al 1994) of setting up a test environment may be the only practical solution.

11. The progress made by mines in reducing risks and providing safe visual environments should be monitored and reviewed periodically (possibly over a one or two year period) to determine the value and applicability of the recommendations made and also to determine if further empirically based assistance and research is required.

12. While the project focused exclusively on underground coal mining, the literature review undertaken also clearly established that limitations exist in the standards of illumination and visibility applied to other types of underground mining and to surface mining operations. Consideration should therefore be given for additional projects to address these issues in future research programmes.

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