

Safety in Mines Research Advisory Committee

Final Project Report

The Role of Illumination in Reducing Risk to Health and Safety in South African Gold and Platinum Mines

GAP 804

Executive Summary

The aim of designing visual environments is not just to provide adequate lighting but also to improve the ability of workers to recognise what they see. Poor design of visual environments can induce:

- Errors caused by an inability to see properly
- Confusion, illusions and disorientation
- Visual discomfort and headaches

The current project builds on work done during COL 451 and, using the same proven research approach and methodology, expands the existing recommendations and guidance produced for the coal sector to embrace the needs of gold and platinum mines. COL 451 produced general guidance and recommendations for a wide range of underground coal mining locations and activities, to assist mine operators in improving standards for illumination and visibility and, hence, worker health and safety.

A review of current standards, research and developments relevant to illumination and visibility in gold and platinum mines was undertaken to update and supplement corresponding information elicited for coal mines by COL 451. The review provided an indication of the impact that poor standards of illumination and visibility have on safety and performance, and identified a range of factors that must be considered to ensure a safe visual working environment.

The **primary output** of this project is a self-contained set of recommendations for the gold and platinum mining sectors based on:

- Accepted 'best practice', both within South Africa and internationally; and
- Comprehensive underground observations of current visibility and lighting conditions

The recommendations are intended to assist in the identification of potential hazards that can result from poor visual environments across a comprehensive range of operational situations most frequently encountered in gold and platinum mines. Recommendations are made for improving the visual environment to reduce identified risks, and guidance is included on the selection, siting and maintenance of lighting equipment.

The recommendations were presented and discussed at a SIMRAC workshop to ensure their appropriateness, practicality and relevance to the industry. The recommendations focus on three main areas:

1. **Static Locations:** areas of the mine that are of a long-term or fixed nature, where it is feasible to install sufficient and suitable permanent lighting fixtures and other aids to improve the visual environment.
2. **Dynamic Locations:** changing areas of the mine, such as production and development areas, where installations would normally be temporary, semi-portable or mounted on machines.
3. **Mobile Machines:** typical mobile mining machinery, where consideration is given to the visual environment and requirements of both the operator and other workers.

Within the above areas, the underground observations identified the major tasks undertaken, their critical visual requirements, and the associated potential visual limitations and potential hazards. Recommendations are made with regard to:

- **Potential improvements to illumination/visibility**, for example, providing more effective arrangements of light fixtures, upgrading headlights/rear lights on mobile machines, improving the reflectance of walls, painting obstructions in highly contrasting colours, etc.
- **Potential improvements to sight lines**, for example, modifications to the profile of machines and operating compartments.
- **Additional considerations which could compensate for limitations in the visual environment**, for example the provision of high-visibility clothing, audible and visible warning devices, clear advance warnings of hazardous haulage conditions, etc.

This report provides a source of information that is designed to allow direct and effective action to be taken at both corporate and individual mine level to improve the visual working environment. This should, in turn, lead to improved safety and a reduction in the number of accidents that could arise from poor visual environments and standards of lighting. It is important to bear in mind that the recommendations are not prescriptive, and that each situation must be subjected to a specific risk assessment. The recommendations should be seen as guidance for best practice. As such, the information is presented in a form intended to serve as an aid to all members of the gold and platinum mining community when conducting such risk assessments for specific situations.

The recommendations have been designed to highlight the influence of the visual environment on safety and health at mines, by providing a comprehensive list of potential hazards that can arise from a poor visual environment. Consideration of this influence should be an integral part of health and safety risk assessments and the hazard identification process at all mines. Use of the recommendations as an initial reference source will encourage such practice. The recommendations should be used throughout the industry to help participants in risk assessment working groups to identify hazards and the likely limitations of current provisions, to assess risks, and identify those areas where the visual environment can be improved and hence, ensure health and safety within the bounds of what is 'reasonably practicable'.

The methodology adopted by the project can be followed at mine level to investigate specific locations and machine types that have not been examined. 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 for improving health and safety. The practical methodology for producing sight line plots will also enable mines to evaluate specific machines and hence, highlight any potential hazards arising from poor visibility.

When new machines are purchased, manufacturers and suppliers have a duty-of-care obligation under section 21 of The Mine Health and Safety Act (1996) to identify hazards and risks. Hence, they should also take cognisance of the recommendations made by the project, including the need to identify potential safety hazards that may arise as a result of unfavourable illumination and visibility. A case in point would be the provision of information on sight line restrictions to prospective purchasers.

It is potentially more beneficial to establish the basic requirements at each mine by applying risk assessment principals and bringing the majority of locations and operations up to a reasonable standard, rather than seeking ideal solutions for relatively specific and isolated problems. The current good practice and approaches to hazard reduction as identified by this project provide examples of how specific problems have already been tackled within the industry. These practical examples can be used by other mines to reduce risks and hence, the potential for accidents arising from unfavourable visual environments.

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1. Introduction

The provision of adequate illumination to ensure a safe visual working environment is a challenge faced by virtually all industries, but it is particularly difficult to meet in mining. The general objectives of providing lighting and illumination are to improve safety and increase productivity. Because people receive the bulk of their information visually, the quality and quantity of illumination is critical to safe and efficient performance. The provision of lighting is particularly important in the underground mining environment, where there is no natural light, and potentially hazardous tasks, often involving the use of large mobile machines, are conducted in severely confined conditions. It has been said that mining is the most difficult lighting environment in the world (IES 1993).

SIMRAC project COL 451 (Talbot et al. 1997) produced general guidance and recommendations for a wide range of underground coal mining locations and activities, to assist mine operators in improving standards of illumination and visibility and, hence, standards of health and safety. A review of relevant illumination standards and guidelines used in coal mining industries throughout the world and an assessment of their applicability to conditions in the South African coal mining industry was undertaken. The review also included an assessment of the available literature to identify those factors that must be considered to ensure a safe visual working environment. Studies on a wide range of underground machines and workplaces identified critical visual task requirements, and recommendations were formulated on standards for the improvement of both illumination and visibility under specific conditions. The project also made recommendations on improving the visual environment to reduce specifically identified hazards, and produced guidance for the selection, siting and maintenance of lighting equipment. The current project (GAP 804) builds on the work of COL 451 and, using the same proven approaches and methodology, expands the existing recommendations and guidance developed for the coal sector to embrace the needs of gold and platinum mines.

The accident reports held on the SAMRASS database rarely attribute 'Lack of illumination/visibility' as a primary cause of accidents on gold and platinum mines. The quality of the visual environment may, however, make a far more significant contribution to accidents than the records indicate. Although 'Lack of illumination/visibility' is rarely reported as the direct cause of an accident, it can often be a significant contributing factor.

A limited number of studies have been undertaken to support the generally held belief that an increased level of illumination has a positive effect on accidents in the mining industry.

Van Graan & Schutte (1977) and Austin (1989) refer to a study in the former USSR where, following the introduction of fluorescent lighting on a coal face, production increased by 3,5 per cent and the number of accidents diminished by 40 per cent. Both Trotter (1982) and Austin (1989) reference a Hungarian study demonstrating 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 per cent. Trotter (1982) also refers to an Indian study that concluded that 35 per cent of all minor accidents in coal mines could be attributed to poor lighting. More recent research in South Africa by Odendaal (1997), Franz, Ashworth & Mthombeni (1995) [GAP 203] and Ashworth & Phillips (1997) [SIMRISK 401] also supports the general theory that improved illumination reduces accident potential.

The purpose of this report is to provide a self-contained source of information and guidance specifically for the gold and platinum mining sector. To meet this objective it was deemed necessary to reproduce, with only minor editorial changes, extracts of applicable material from COL 451. This requirement applied particularly to various sections of the report that describe the research methodology, investigation procedures and the process used to develop the recommendations.

A review of recent changes in worldwide illumination and visibility standards, the scope of investigations undertaken by the present project and the conclusions reached are given in Sections 3, 4 and 5 respectively of this report.

A comprehensive set of recommendations for improving the visual environment to reduce the risks identified by the project is given in **Appendix A**. **Appendix A** also includes guidance on the selection, siting and maintenance of lighting equipment, and instructions for applying the methods used during mine investigations.

The results of the underground assessments carried out at collaborating mines are given in **Appendix B**.

1.1. Terms and Definitions

To ensure that the project findings and recommendations are of value to a broad spectrum of readers, the use of technical terms and definitions has been kept to a minimum. There are numerous books and references that provide detailed definitions of the terms used to describe and quantify visibility and illumination [for example, useful general references available on the Internet are NIOSH (2002) and Minesite (2002)]. Hence, these have not

been replicated. However, simple definitions and explanations are provided for those terms used most extensively in 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 radiated by a light source during each second.

Illuminance: Measured in lux, it indicates how much light (in Lumens) would strike a surface area of one square meter (incident light), hence, Lumens/m². It is a measure of illuminance that is 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 amount of light energy reflected from a surface relative to the amount of light striking it. Objects with greater reflectance appear brighter than lower reflectance objects viewed under the same lighting conditions.

Luminance: This is the luminous intensity emitted in the direction of the eye per unit of a source's apparent surface area. The eye can only see either a source of light or objects that reflect light originating 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/m²).

Contrast: The relative difference in luminance between two adjacent surfaces. In other words, how bright one surface looks compared to the other or to 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 that enters the eye and scatters within it, producing a veiling luminance over the retina with the effect of reducing the perceived contrast of objects being viewed. **Discomfort glare** causes fatigue and pain, as a result of non-uniform distributions of very bright light in the observer's field of view (Unger et al. 1990).

2. Factors Affecting a Visual Environment

Level of illumination is 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 dependent on the amount of light being shone at a target'. In mining, other factors that have been identified as affecting the overall quality of the visual environment include:

- Mounting height restrictions and task requirements often place luminaires in the worker's direct line of sight, causing glare
- Mounting positions restrict the size, location and light distribution of luminaires
- Luminaires must meet safety requirements for use in explosive atmospheres
- Inherent vision of the workforce population
- Low surface reflectance of rough, darkly coloured rock, which severely limits secondary reflections and indirect lighting
- Suspended dust and water vapour cause back scattering thereby reducing apparent illuminance and deposits of dust on brightly painted, potentially hazardous machinery, reduce their reflectance and, hence, their visibility
- Reduction of effective illuminance by protective eye wear

The range of factors that can influence the visual environment is summarised in Figure 2.1 (ECSC 1990):

To ensure the quality and reliability of visual performance and, hence, safety, all of these factors must be considered. Individual variables influencing visual perception (age, visual acuity, colour vision, etc.) although important, have not been directly addressed by the present project. The need for appropriate worker selection to ensure that individuals have sufficient visual abilities to undertake their work safely, is a well recognised requirement that should be addressed through programmes of initial screening and periodic testing. However, effort should be directed at tailoring the visual environment to meet the needs of workers and their tasks, rather than selecting individuals to cope with poor conditions.

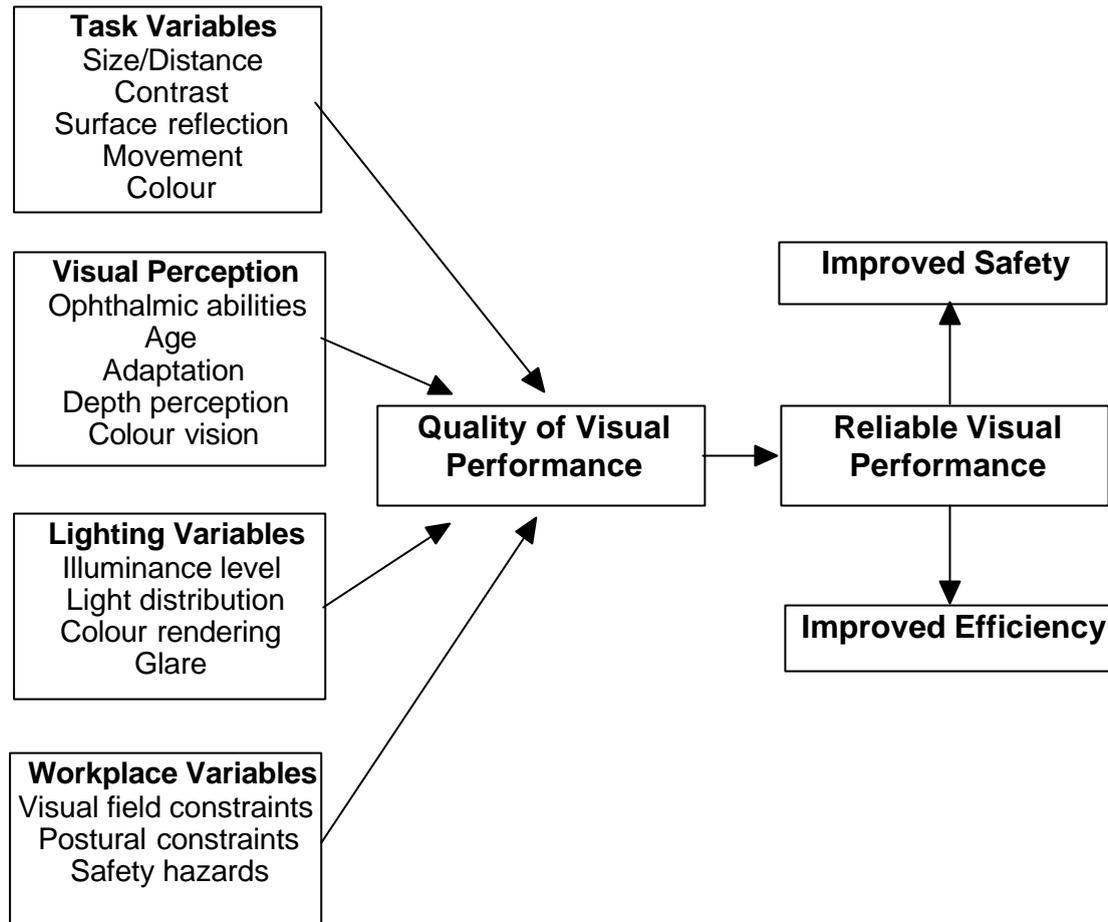


Figure 2.1: Major factors influencing the visual environment and visual performance (ECSC, 1990)

2.1. Glare

Glare is often a major problem in the mining industry. To reduce this, Baines (1972) suggests that it is better to have low-power lights with small distances between them, than high-power lights farther apart. For example, in an underground roadway the former provides even illumination, while the latter produces repetitive transitions between bright glaring light and darkness. Uniform lighting makes for better hazard perception, as dark patches and shadows act to camouflage obstacles and hazards. Trotter (1982) suggests 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

- Minimise luminance differences between visible sources and background
- Increase background or overall illuminance
- Ensure favourable luminaire positioning relative to work tasks
- Eliminate specular surfaces
- Provide light with the correct level, colour balance, and distribution

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

2.2. Reflectance

Crooks & Peay (1981) found that underground work environments differ significantly in their surface luminance and reflectance, output of luminaires, and the nature of visual impairment present. For a given level of illuminance, increasing surface reflectance can enhance the level and distribution of available light. Light-coloured surfaces generally 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 2.1.

Table 2.1 Reflectance of typical materials in mines

Material	Reflectance
Coal	3-15%
Quartz diorite	10-30%
Shale	22-45%
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 application of whitewash in certain locations is a legislated requirement in some countries.

2.3. Contrast

In terms of providing a visual environment conducive to safety and efficiency, illuminance 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 and fall hazards, etc.).

In such situations, it is frequently the contrast between the visual target and its background that is the most important determinant of reliable hazard detection. Bell (1982) states that the ratio of brightness between the task, the immediate background and the general background should be of the order of 10:3:1. Best et al. (1981) state that the ratio between maximum and minimum light levels in any given work area should not exceed 5:1. This is because objects with the same luminance as their surroundings are less likely to be detected, regardless of light level. 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 contrast. For example, the use of reflective strips on workers' clothing, tape or paint markings on vehicles or obstructions may provide a more effective solution than the provision of additional or higher-intensity luminaires.

2.4. Visibility

Zones that mine workers need to see 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 sight lines are common to a large range of mobile machinery used underground. A study in the United States (Department of Labour 1980) concluded that approximately 36 per cent of

the fatalities involving mobile equipment in underground coal mines between 1972 and 1979 were directly or indirectly caused by improperly designed operator compartments.

Studies of ergonomics and human errors in the UK coal industry; have shown that there is often little consideration given to ergonomics (in particular sight lines) in the design of mining equipment and machinery (Chan et al. 1985 and Simpson et al. 1993). In the UK, specific emphasis has been placed on load-haul-dump equipment [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 in judging the sides and corners of a vehicle when manoeuvring, and seeing people and obstacles close to the vehicle. A sight line plot taken from this report is reproduced in Figure 2.2. The grey areas indicate areas where objects less than 1 m high are not visible from various driver's seat positions in two different vehicles, even when they are not loaded. The report also states that between 1986 and 1991 50 per cent of all major and fatal accidents involving LHDs included cases of pedestrians being run over or struck by moving 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 per cent of major injuries caused by mobile machinery, the driver did not detect the presence of the victim.

Similar problems of poor visibility from LHDs in South Africa were identified by van Graan & Schutte (1977). More recent research in South Africa clearly identified similar ergonomic limitations (sight line provision and poor illumination levels) in the design of a range of transport machinery as a prominent latent failure that predisposed a considerable number of significant human errors and, therefore, increased accident potential (Simpson et al, 1996).

In order to ensure satisfactory visibility for operators of mining machinery, it is essential to know the areas that they will be required to see to enable safe operation. For mobile machines it is also important to have a means of assessing the operator's sight lines in relation to critical visual targets.

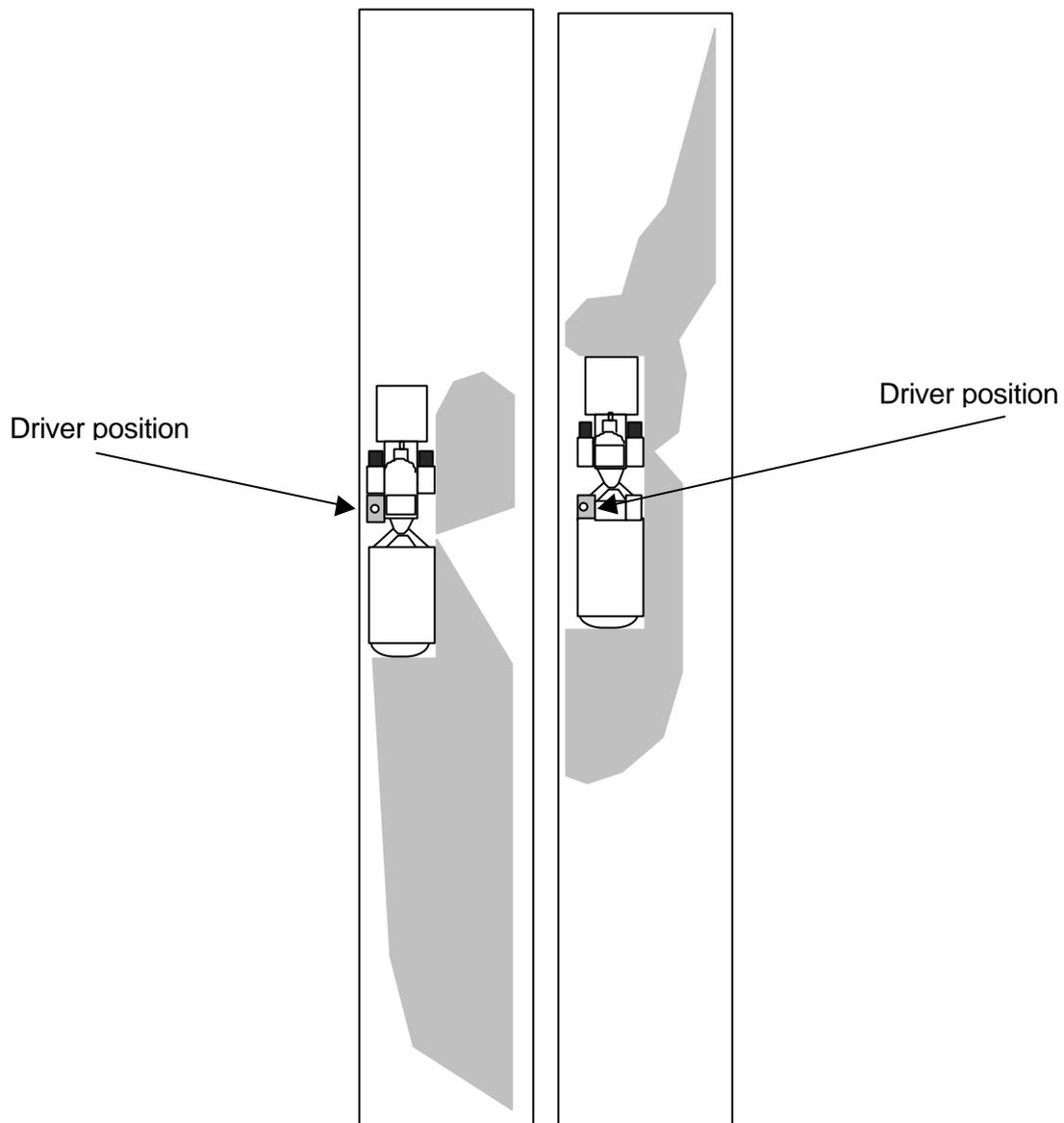


Figure 2.2: Sight line plot for LHD (HSE 1992)

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

- Shadow graph techniques, which utilise a suspended light at the driver's eye position to cast shadows onto gridded screens that represent the roadway sides. The shadows correspond with areas not visible to the driver in the position being considered, and are recorded photographically. This technique is recommended

in ISO 5006-1 (1991) for recording operator sight lines and fields of visibility from surface earth-moving machinery.

- Panoramic photographic techniques in which photos are taken around the machine on surface with the camera at the position of the driver's eye.
- Graphical techniques where sight lines are plotted using projections from general arrangement drawings of the machine.
- Line of sight techniques using a ranging pole around a machine and physically measuring what an operator can and cannot see. COL 451 developed this technique into a simple and practicable method for assessing machines in their normal working environment, where spatial constraints are likely to exist. The technique was applied during the present project to undertake similar assessments on machinery used in gold and platinum mines. Instructions for the use of this assessment procedure are provided in Appendix A5.

More recently, developments in the field of computer graphics have enabled the construction of a range of more sophisticated computer-based visibility assessment techniques as discussed in Section 3.

All of these techniques establish the limits of operator's sight lines, and with consideration to minimum requirements for visual attention areas to ensure safety and performance, operator training courses that address sight line restrictions could be developed. In addition, such techniques could aid in the formulation of other risk control measures, including operational procedures. They could also assist design engineers in identifying modifications to improve operator sight lines.

3. Review of Recent Developments in World-wide Illumination and Visibility Standards

A review of current standards, research and developments relevant to lighting in gold and platinum mines was undertaken to update and supplement corresponding information provided in respect of coal mines by COL 451.

Sources of information consulted included published journal articles and texts, academic studies, previous SIMRAC reports, Internet web sites for research and regulatory agencies and International technical organisations, as well as academic institutions and manufacturers of lighting equipment used underground.

As most of the information underground workers require to perform their tasks safely and productively is of a visual nature, visibility is a critical aspect of the workplace environment. The primary factors influencing visibility are:

- Line of sight, as influenced by the field of vision
- Illuminance level (incident light)
- Contrast ratio between the visual target and its surroundings (determined by the difference in their respective reflectances)
- The eye's state of adaptation to prevailing lighting conditions, including illuminance and glare
- Age and health of the eyes
- Virtual size of the visual target, relative to its surroundings and including distance, or more specifically: the size of the area on the retina that is stimulated
- Period of observation (time window)
- Relative movement of the visual target and the observer

Restricted fields of vision are a common deficiency of the visual environment in underground workplaces. In addition, these areas generally exhibit reduced illuminance levels and unfavourable contrast ratios between target and background, a problem sometimes exacerbated by the provision of supplementary lighting that causes glare. There are currently no standards governing glare in underground mines, leaving this aspect to the designers and installers of illumination systems.

Detailed standards specify illuminance levels for most industrial situations, e.g. AS/NZA 1680 (1990) and SABS 0114 (1996/1999), the Australian and South African standards for interior lighting, and ISO 8995 (1989), the lighting of indoor work systems. However no equivalent standards exist for underground mining operations. Statutory regulations generally deal with this aspect only in a very general sense, largely because of the difficulty in specifying requirements for the wide diversity of workplaces underground.

In view of the impact that illumination and visibility can have on workers' safety and productivity, the challenges of developing appropriate standards and the practical problems of implementing them must be weighed against the potential consequences of maintaining the *status quo*. The following review examines the relevant legislation in various countries, illumination standards and related current initiatives, previous research in the field, developments by lighting equipment manufacturers', and design issues.

3.1. Legislation in various countries

South African requirements for illumination and lighting in mines are stipulated in Chapter 15 of the Minerals Act (1991). The various regulations of the Act require persons in underground mines to carry a light (in practice a caplamp), the provision of "adequate" lighting at certain locations underground (e.g. stations and loading areas), that moving parts of certain machinery be 'clearly visible' and that mobile machines be fitted with lights that provide 10 lux of illuminance at a distance of 20 m.

The Coal and Other Mines Regulations for Safety Lamps and Lighting (HMSO 1995) state the requirements for lighting in United Kingdom mines. These specify the provision of 'suitable and sufficient lighting' at various regularly-used locations underground, including shaft and outlet entrances and sidings, the tops and bottoms of inclines, landings, junctions and places where vehicles are attached to a haulage rope or mechanically filled, as well as at motor or engine houses. The regulations additionally require that lighting be 'arranged for minimum eyestrain and glare', and that most of the areas where lighting is required are whitewashed.

Regulations for mine lighting in India and Australia are essentially similar to those in the UK, requiring 'suitable and sufficient' and 'adequate' lighting, respectively, at specified locations. The Australian regulations additionally stipulate that lighting be arranged to minimise glare and eyestrain, while in India certain areas must be whitewashed.

The preceding indicates that all four countries' regulations identify a number of critical areas for illumination, but only the South African regulation on mobile machinery provides any definitive or quantitative indication of what the level should be. The US regulations (Code of Federal Regulations, Mine Safety & Health Administration 1988) also provide some guidance in this regard, stating that surfaces in workplaces that are required to be lighted should have a luminous intensity of at least 0,2 cd/m², a level regarded as adequate for most mining tasks, particularly in conjunction with illumination provided by the miner's caplamp.

3.2. Illumination standards and related initiatives

Further to the legislated or regulatory requirements for underground lighting, which the preceding discussion showed to be stated mainly in general terms, standards have been formulated and applied in various countries to provide more specific guidance. Table 3.1 (after Bell, 1982, ECSC, 1990, MVS, 1992 and Piekorz, 1997) summarises minimum illuminance standards for various locations in mines worldwide, with the exception of Asia. In most cases countries' requirements are specified without regard to type of mine. Considerable variation exists in the minimum requirements, and even in the apparent importance ascribed to illumination in various locations. For ease of comparison, the range of specified minimum values for each type of location appears at the top of the relevant column, and the range of all values stipulated by each country appears at the left of the table under the country's name.

Ignoring the omission of a minimum requirement for certain types of mine areas by some countries, the highest illuminance levels are required for underground offices and workshops, followed by loading areas and shafts, and then machinery and haulages. In all countries specifying a requirement for the face, this area is assigned the lowest value, despite the propensity for accidents to occur in this part of a mine.

Table 3.1 Mine Illuminance standards in various countries

Location and minimum lighting recommendation in lux (with range)							
Location	Shafts	Machinery	Haulages	Loading	U/G offices	U/G workshops	Face
Range of values	(15-160)	(10-80)	(2,5-21)	(15-160)	(60-270)	(20-400)	(2-15)
Country							
Australia (20-100)	20	20	-	20	100	-	-
Belgium (20-50)	20-50	25	10	20	-	-	-
Canada (20-270)	21-50	50	21	20	270	270	-
Czech Republic (5-20)	15	20	5	20	-	-	5
Germany (15-80)	30-40	40-80	15	40	-	-	-
Hungary (2-100)	40-100	20-50	2-10	40-60	-	20-50	10
Poland (2-100)	30-50	10-50	2-10	15-30	-	30-100	2
United Kingdom (2,5-100)	70	30	2,5	30	60	50-100	-
European Coal & Steel Community (5-90)	40-90	-	5-15	15-80	-	-	-
United States (15)	-	-	-	-	-	-	15
South Africa (20-400)	20-160	10 (at 20m)	20	160	-	400	-

Note: - indicates no official recommendation.

While it may be argued that the need for precision in offices and workshops may be the basis for the relatively stringent requirements in these areas, it is suspected that the ease

with which an area can be lighted may also be a consideration, as evident in the universally low minimum requirements for face areas. Here the USA and Hungary specify more stringent requirements than the other countries considered and, interestingly, the face is the only area for which the US has specified a minimum illuminance level. South Africa has consistently stipulated the highest illuminance requirements, but does not specify a minimum value for face areas.

Standards of the International Commission on Illumination (CIE) provide the scientific basis and methodologies for specifying and evaluating lighting installations. The CIE report on Industrial Lighting and Safety at Work used information on national rules and recommendations in various countries to analyse the factors of lighting that influence workplace safety. Unfortunately the second phase of this initiative, an investigation of industrial lighting and the accidents caused by poor lighting, has remained incomplete due to a lack of information from participating countries.

The CIE Guide for the Measurement of Underground Mine Lighting, presently under revision, is intended to provide guidance in the measurement and reporting of illumination characteristics for mine lighting installations. This should enable uniform comparisons of performance among alternative lighting systems being considered during the design stage of mine planning, and standardisation in the quantitative evaluation of completed lighting installations.

Similar initiatives are presently underway at CIE to provide the means for evaluating discomfort glare from small light sources, and visual performance of workers under various types of lighting installations.

3.3. Review of previous research

Research of illumination and visibility within the context of impact on safety and productivity has been limited in recent years, particularly as relevant to underground mines. COL 451 previously reviewed work applicable to coal mines. Although many of the findings could benefit other types of underground mining, it is a general observation that collieries have progressed further than gold and platinum mines in addressing the needs of underground lighting, and that many of the advances made are attributable to coal-specific research. Experience has shown that many work situations benefit most from a task-specific lighting solution, and the same is true, but to a much greater extent, for all types of mining, indicating that if similar progress is to be made specifically for gold and platinum mines, it will

have to be based on the research of problems and the development of context specific solutions.

International studies

As cited in COL 451, a number of European studies have indicated that accident rates decreased by as much as 60 per cent when the overall level of illumination was increased. In a study referred to by Trotter (1982) and Austin (1989), the accident rate in one part of a Hungarian mine illuminated by special-purpose fixed lighting was shown to be 60 per cent lower than in other parts of the same mine where only caplamps were used. Austin also cited a study in the former USSR showing that the introduction of fluorescent lighting on one coalface led to a productivity increase of 3,5 per cent, accompanied by a 40 per cent decline in accident rate.

One Canadian reviewer (Tyson 1999) referred to the finding that lighting was identified as a contributing factor in only 2 per cent of accidents, but also found that in 13 separate underground fatalities between 1976 and 1985 coroners' juries made recommendations with respect to lighting, with some juries calling for further research into mine lighting and machinery design to improve visibility.

Also cited in COL 451 is Trotter's reference to a study concluding that, of all minor accidents in Indian coal mines, 35 per cent could be attributed to poor lighting. This level of prevalence may be indicative of the true underlying significance of illumination in the safety of underground mines, and bear relevance to the high incidence of slips and falls among fatal and reportable accidents in South African gold and platinum mines.

South African studies

Odendaal (1997) investigated a number of factors as possible contributors to accidents on four gold and four platinum mines in one mining group, including illumination, and provided a number of useful insights. Of a total of 61 occupations considered on these mines, approximately 74 per cent were solely dependent on caplamps for illumination during more than half of their shift, and accounted for between 88 and 95 per cent of reportable accidents during the three years considered. In addition, the 50 per cent of occupations solely dependent on caplamps for more than 75 per cent of the shift accounted for more than 80 per cent of the fatal accidents during the same period. No fatalities occurred on the platinum mines among occupations where caplamp dependence was 25 per cent of

the shift or less. Similar patterns are apparent when the data are considered in terms of accident frequency or rate, as opposed to numbers of occupations.

While caplamp dependence was clearly correlated with accident occurrence and rate, it cannot be said that lighting was necessarily the cause, as the counter-argument would be that the most dangerous workplaces, those at or near the face, have the greatest labour complement and just happen to be exclusively caplamp dependent. These two factors, relative danger and numbers of workers exposed, while somewhat deflating the case for a clear causal relationship between lighting and safety, also weigh heavily in favour of improving illumination where the need is greatest.

Odendaal also examined the relationship between work rate in combination with illumination on accident occurrence, and evaluated the prevalence of judgmental errors in such events. Failure to recognise the hazard was found to contribute to more than 55 per cent of reportable accidents on the four gold mines during the three-year period, and to 45 per cent of those on the four platinum mines. On both types of mine, failure to recognise a hazard and taking an unsafe position were most frequently cited where moderate to hard work was being performed and caplamp dependence was more than 75 per cent. These findings may indicate indirect or contributory impact of reduced illumination on vigilance that is exacerbated by the presence of additional stressors such as hard physical work, presumably under conditions of heat and humidity combined with the pressure of production demands.

Similar issues were investigated by GAP 203 (Franz, Ashworth and Mthombeni 1995), in which reduced illumination was the only environmental factor that could be convincingly correlated with accident occurrence. However, another finding of that work was that the accident reports studied nearly always focussed on the immediate cause and failed to identify root causes, which could have included unsatisfactory lighting in many instances.

SIMRISK 401 (Ashworth and Phillips 1997) examined SAMRASS data over a nine-year period ending in 1996 to quantify safety risks, and individual accident reports to identify the most significant sources of risk, including root causes. The identification of root causes was somewhat constrained by accident reports focussing on events and circumstances that immediately preceded the occurrence, and the administrative requirement to identify a single cause to the exclusion of all other possible contributors. The effect of such investigative methods creates a tendency to identify only the immediate or precipitating cause, leaving root causes and systems failures unidentified.

Use of the SAMRASS data to analyse accident types by cause indicated that lack of caution and alertness, together with failure to recognise a hazard, were major causes of both fatal and reportable accidents on gold and platinum mines over the period of review. It is entirely conceivable that unfavourable illumination could have contributed significantly to many of these judgmental failures, as well as to many of the slips and falls that occurred, another major cause of accidents and fatalities in gold and platinum mines.

Recent developments in the field of computer graphics as a design tool and training aid for addressing problems of visibility associated with mobile equipment are discussed in the final section of this review.

3.4. Developments by lighting equipment manufacturers

Other than improvements to the globe, involving the replacement of tungsten filaments with more efficient krypton, xenon and halogen sources, today's caplamp has remained essentially the same for more than a decade and, in some respects, for far longer. The local standard for caplamps, SABS 1438, consists of Parts 1 to 5. Part 1 (Incandescent lamps) was revised in 1999 and Part 5 (Light assemblies) was revised in 1996, but Part 4 (Helmet lights) was last revised in 1987. The relative lack of activity in revising the standard for what is arguably the most critical part of the caplamp may limit modifications by manufacturers to minor improvements unlikely to significantly enhance lamp performance or light distribution.

In this regard, manufacturers have developed refractive reflectors to optically concentrate the light produced, as well as wide-beam reflectors to distribute light over a wider area. However, despite the limited field of illumination that a narrow-beam reflector provides, thus limiting visibility to a relatively small area directly in front of the user, most users insist on it. Some perceive the more concentrated beam to be "stronger" and therefore better, while others find it more effective for signalling to fellow workers.

The variable focus reflectors offered by some caplamp manufacturers can deliver a narrow, concentrated beam, a wide, dispersed beam, or anything between these two extremes. However, the higher initial cost appears to be the principal factor in its limited acceptance among employers, along with its greater maintenance requirements. Similar reasons appear to account for the lack of interest in dual-globe lamps, which incorporate a small low-current globe off-centre to the reflector. In use, the smaller globe disperses its output over a wider area, although it does produce considerably less light than the main

globe. It also allows for greater battery life, which would benefit a trapped miner by providing continuous light for up to three days.

An innovation developed by one manufacturer is a small, low-voltage fluorescent lamp that can be connected to a caplamp battery by an extended lead, and appropriately positioned to provide area lighting additional to that from the caplamp. Final development and approval testing for underground use poses no insurmountable technical problems, but providing the requisite financial resources would be contingent on an indication of potential demand for the device. Another not so recent but largely unimplemented development is the compressed air lamp, incorporating a turbine to generate its own electricity. This type of device, available from more than one supplier in various sizes, is capable of producing between 1 500 and 3 800 cd/m² of luminous flux. This level of output is sufficient for area illumination, but it could be enhanced for specific situations by the incorporation of a reflector or diffuser, as appropriate, to direct and distribute the light produced while minimising glare. Manufacturers have indicated their willingness to pursue the development of improved lighting appliances and illumination systems, but their perception that mine operators are most concerned with limiting costs, constrains such initiatives.

3.5. Design issues

In pursuing the development of improved lighting systems, cognisance should be retained of the principal characteristics and fundamental limitations of the various types of light sources, as summarised in Table 3.2 (after Trotter 1982). The infrastructural requirements for various sources differ, as do their performance characteristics, and these should form the basis for selection criteria, with as much emphasis on illumination performance and visibility requirements as possible.

Table 3.2 Comparison of various types of light sources

Type of source	Approximate output (cd/m ² for clear bulb)	Average rated life (h)	Capital cost rank (1=costly)	Suitable for DC	Warm-up period (min)	Re-strike time (min)	Colour appearance and rendition
Tungsten Filament	10 ⁵ to 10 ⁷	750 to 1 000	7	Yes			Warm, white to yellow; Excellent rendition
Tungsten halogen	2 X 10 ⁷	5 ^a to 2 000	4	Yes			Warm, white, slight yellow; Excellent rendition
Fluorescent	5 X 10 ⁴ to 2 X 10 ⁵	500 ^b to 30 000	3	Yes			Warm, white; Excellent rendition
Mercury Vapour	10 ⁵ to 10 ⁶	16 000 to 24 000	6	Yes, with limitations	7-9	3-10	Cool, bluish; Average rendition
Metal Halide	5 X 10 ⁶	10 000 to 20 000	2	Yes, with limitations	2-5	10-20 ^c	Cool, blue-white; Good rendition
High-Pressure Sodium	10 ⁷	12 000 to 24 000	1	Not advised	3-4	0,5-1,0	Warm, golden colour; Fair rendition
Low-Pressure Sodium	10 ⁵	10 000 to 18 000	5	Not advised	7-9	1-2	Warm, amber; Poor rendition

^a Not a general service lamp.

^b 500-h lamp is not a general service source. The 30 000-h lamp is a cold cathode lamp and not suitable for mines.

^c Less, if special electrical circuits are used.

In addition to illumination performance, and in conjunction with visibility requirements, the potential problems associated with certain types of lighting must be anticipated during the design stage. Some of these, including glare and spectral/rendition deficiencies, are summarised in Table 3.3. The challenge facing designers is to balance the often-opposing requirements of task illumination that is conducive to safety and productivity with those of economics, the latter embracing initial capital expenditure, as well as operating and maintenance costs.

Table 3.3 Lighting problems, potential effects and possible solutions

Problems	Potential Effects	Possible Solution
Excessive glare	<ul style="list-style-type: none"> • Interference with vision, stress, irritability and decreased attention span • Increased accident rate • Decreased productivity 	<ul style="list-style-type: none"> • Limit light source brightness of 3 000 cd/m² and/or provide for directional control or diffusion of output, as appropriate • Position luminaries above visual line • Ensure uniformity of lighting
Limited spectrum of light source, as with mercury vapour, sodium vapour and high-sodium fluorescent lights	<ul style="list-style-type: none"> • Poor rendering of visual targets causing reduced visibility • Vitamin-D deficiency leading to poor absorption of calcium, reduced basal metabolism, hypotania, insomnia, irritability, increased accident rate • Decreased productivity 	<ul style="list-style-type: none"> • Provision of full-spectrum fluorescent lighting
Exclusion of full-spectrum or natural light by equipment, windscreens or eyeglasses/safety glasses	<ul style="list-style-type: none"> • Vitamin-D deficiency leading to poor absorption of calcium • Reduced basal metabolism, hypotania, insomnia, irritability • Increased accident rate • Decreased productivity 	<ul style="list-style-type: none"> • Provision of windscreens and eye wear of glass or plastic that allows UV transmission

Irrespective of the type of light source used, proactive maintenance of lighting systems is essential to prevent rapid deterioration in the effectiveness of even the best system, particularly under the harsh conditions that prevail in underground mines. Maintenance should include, in addition to the replacement of damaged and defective components, regular cleaning of luminaries and, where required, of electrical connections and switchgear.

Assistance in the design of improved visual environments and lighting systems may eventually be gained from the PC-based software package "Visibility Analysis Software" being developed by NIOSH (2001) to evaluate line-of-sight visibility for equipment operators and workplace illumination. The advantage of using computers for such analyses is that numerous design iterations can be tested quickly and efficiently to determine the effects of changes that are being considered. For the first application the user identifies specific points (called visual attention locations or VAL) that must be visible to the operator in the fore-aft, lateral, and vertical planes. The software then determines whether the relevant VALs will be visible to an operator in a given position. Output is in the form of a relative visibility rating, which can be compared with that for alternative machine designs or layouts. The software provides both graphic and tabular outputs to facilitate the identification and location of any visibility obstructions.

The illumination analysis function assists the lighting designer in configuring a system for minimal glare without compromising the required level of illumination. The software displays a three-dimensional representation of the mining machine, allows the user to specify a given lighting system, and then calculates the illumination level at critical locations around the machine.

A Windows 95/98/NT version is currently under development, and was originally scheduled for release sometime during 2001. This software is being developed for mobile equipment lighting systems, but if its approach proves useful, the same principles should be applied to other underground work situations.

A further development within the field of computer graphics is the application of virtual reality as a design tool and training aid for addressing problems of visibility associated with mobile mining equipment. Advances in the use of this technology have been considerable, particularly in the UK, where it has been applied to examine risks associated with the operation of a range of surface and underground mobile mining machines. Virtual reality is the technology that allows the creation of a computer-generated three-dimensional visualisation of the working environment, the movement of all items of equipment and people within it, and their relative behaviour. The computer allows the user to roam around the virtual environment in real-time, view it from any angle or position, and interact with any of the objects within. As an example of the use of virtual reality, a project was undertaken in British coal mines using the technique to examine how operator vision could be improved on LHDs. A virtual LHD was built with a control panel that allowed the user to drive the vehicle through a range of realistic roadway and lighting conditions, or walk

around the underground environment within which the LHD was driven. As the users moved their head or moved to a different location, the computer generated a new view of what could be seen from the new position. The model was used to undertake a detailed assessment of what different drivers were able to see directly and using visual aids such as mirrors and CCTV cameras when performing a typical work cycle. Allowing the workforce to drive the virtual LHD also provided an effective means of raising awareness of the risks associated with working in the presence of such vehicles. In addition, developers of the technique see computer graphics and virtual reality as having important applications in the development of real-time training simulators, accident reconstruction, safety awareness training, safety planning and design and risk analysis.

4. Development of Recommendations

The primary output of this project is general guidance and recommendations to assist mines in improving standards of illumination and visibility and, hence, enhancing health and safety. These recommendations address the potential hazards resulting from poor visual environments across a wide range of operational situations frequently encountered in gold and platinum mines and are based on what is 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 normally used, and, where standards are set, they vary significantly from country to country.

A previous SIMRAC project, COL 033A (Pardoe et al, 1994), conducted a review of 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 and 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 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 identifying ideal solutions for relatively specific and isolated problems. This was the approach adopted by COL 451 and by the present project, i.e. to produce general guidance and recommendations that would be applicable to a wide range of underground mining locations.

It was clear from the review of international standards and practices conducted by COL 451 and the review of recent developments undertaken during this project, 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 and water vapour levels, poor contrast due to the build up of dirt or dust, etc. Conversely, under more favourable conditions, these levels may be too high and result in the introduction of, for example, glare or adaptation problems. Following a prescriptive approach also conflicts

with the trend towards self-regulation and outcome-oriented goal-setting that underlies the risk assessment and management requirements defined in the Mine Health and Safety Act (1996).

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

4.1. Methodology

The investigation and analysis techniques developed and used during COL 451 proved to be highly successful in generating recommendations and guidance for the coal mining sector. Given this success, the same research approach and methodology was adopted for the current project.

The research methodology used is comprehensive and involves the process of task analysis and assessment using sight line plots. The process was used to investigate the visibility and lighting conditions at various locations in a sample of underground gold and platinum mines. The purpose of these investigations was to establish the nature and extent of current problems and identify the potential hazards arising from poor visual environments.

For each of the locations examined, the relevant key dimensions, sources of illumination and data on the background conditions were recorded. In those locations where tasks involved, for example, machine operation, the process of task analysis was used. This required development of a hierarchical task description, where the critical visual targets were established for each step identified. These visual targets are the essential features or points that operators must see to work safely. The visual targets were then grouped by spatial location, to derive more generalised visual attention areas to be considered against a list of illumination and visibility assessment factors. The quality of illumination required in each of these visual attention areas was then determined, largely by considering the most demanding visual task performed within the area.

For all the machines observed, sight line plots were produced using the technique developed during COL 451. These plots provided an effective way of establishing whether

key visual requirements established by the task analysis process were actually met. Thus, an effective method was provided for establishing what operators can actually see in comparison with what they need to see for safe and reliable operation.

As part of this process, the potential for hazards arising from poor visual environments was identified. The working practices observed were also compared with those prescribed in standard procedures and/or instructions for good practice, to help highlight areas where poor visual conditions can lead to problems of non-compliance or unsafe acts.

To facilitate further use of this assessment methodology, a more detailed elaboration of the investigation and analysis techniques used during the project is provided in Appendix A.

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. static and dynamic.

Static Locations

These locations include those areas of a mine where it is considered practical to provide permanent lighting installations, including:

- Haulages and junctions
- Inclined shafts and shaft stations
- Chairlift landings
- Underground workshops
- Refuelling bays
- Battery charging stations
- Orepass boxes
- Tips

- Services and equipment rooms including electrical sub-stations, pump rooms etc.

Dynamic locations

These are the locations where lighting installations would normally be temporary, semi-portable or mounted on machines. These locations are mainly in production or development areas, and those covered include:

- Stope faces
- Gullies and scraping installations
- Stope travelways
- Mono-rope haulages
- Raise-bore installations

4.2.2 Machines

The visibility and illumination provided for a sample of the following types of machine were also evaluated:

- Load haul dumpers (LHDs)
- Dump trucks
- Locomotives
- Face drilling machines

A **total** of 47 evaluation studies at five mines was undertaken by the project. These included 29 static locations, 10 dynamic locations and 8 mobile machines. The locations within which the mobile machines were evaluated were also included in the machine evaluations. For example, locomotive and LHD assessments included consideration of the respective haulage routes. In this way, an even larger sample of locations was considered.

Details of the locations and machines studied and the results derived from these studies are presented in Appendix B.

4.3. Recommendations

The assessment methodology and recommendations produced by the project are presented in Appendix A. They have been designed to act as a reference source that can be used by operators of gold and platinum mines to improve the prevailing standard of underground visibility and illumination. The recommendations are based on:

- Current scientific literature
- National and International legislation and recommendations
- Results of the mine studies conducted

The information in Appendix A is designed to assist mine management to:

- Identify potential hazards related to visibility and illumination
- Identify the factors to be considered when assessing such risks, and
- Develop strategies to reduce these risks

5. Conclusions

1. Although 'insufficient illumination/visibility' is rarely cited as the primary cause of an accident, a number of accidents, for example, slip/trip/fall incidents and machine collisions, may well have been prevented if sufficient lighting had been provided.
2. The diverse range of current worldwide 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 variations in the level of commitment to ensuring health and safety.
3. The recommendations produced by the project have been designed to highlight the influence of the visual environment on safety and health at mines, by providing a comprehensive list of potential hazards that can arise from a poor visual environment. Consideration of this influence should be an integral part of health and safety risk assessments and the hazard identification process at all mines. Use of the recommendations as an initial reference source will encourage such practice.
4. The recommendations should be used throughout the industry to help participants in risk assessment working groups to identify hazards and the likely limitations of current provisions, to assess risks, and identify those areas where the visual environment can be improved and hence, ensure health and safety within the bounds of what is 'reasonably practicable'.
5. It should be possible for the methodology adopted by the project to be followed at mine level, to investigate specific locations and machine types that have not been examined. 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 for improving health and safety.
6. The practical methodology for producing sight line plots will also enable mines to evaluate specific machines and hence, highlight any potential hazards arising from poor visibility.
7. When new machines are purchased, manufacturers and suppliers have a duty-of-care obligation under section 21 of The Mine Health and Safety Act (1996) to identify

hazards and risks. Hence, they should also take cognisance of the recommendations made by the project, including the need to identify potential safety hazards that may arise as a result of unfavourable illumination and visibility. A case in point would be the provision of information on sight line restrictions to prospective purchasers.

8. It is potentially more beneficial to establish the basic requirements at each mine by applying risk assessment principals and bringing the majority of locations and operations up to a reasonable standard, rather than seeking ideal solutions for relatively specific and isolated problems. The current good practice and approaches to hazard reduction as identified by this project provide examples of how specific problems have already been tackled within the industry. These practical examples can be used by other mines to reduce risks and hence, the potential for accidents arising from unfavourable visual environments.

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APPENDIX A: Recommendations for setting illumination and visibility standards in gold and platinum mines

A1.1. Introduction

These recommendations for setting illumination and visibility standards in gold and platinum mines have been derived from the results of the SIMRAC GAP804 'The role of illumination in reducing risk to health and safety in South African gold and platinum mines'. Similar recommendations were produced for coal mines under project COL451 'Assessment of world-wide illumination and visibility standards in coal mines'.

Accident records rarely indicate poor illumination or visibility as the primary cause of accidents. However, there is little doubt that visual conditions do have a significant impact on accident potential. For example, past European studies have shown accident rates decreasing by as much as 60% when the overall levels of illumination were increased.

Whilst it is easy to assume that visibility can be improved by simply increasing surrounding illumination levels, this is often not the case. Levels of illumination are only one of the many factors that determine the quality (and safety) of a visual working environment. Research has shown that to ensure a safe visual environment a wide range of factors must be considered. These include:

- **Lighting Variables**
 - * Illuminance level
 - * Light distribution
 - * Colour rendering
 - * Glare
- **Task Variables**
 - * Size & distance
 - * Contrast
 - * Surface reflectance
 - * Movement
 - * Colour
- **Workplace Variables**
 - * Visual field constraints
 - * Postural constraints
 - * Safety hazards
- **Visual Perception Variables**
 - * Ophthalmic abilities
 - * Age
 - * Adaptation
 - * Depth perception
 - * Colour vision

The wide range of interacting variables tabulated above has in the past led to a diverse range of illumination standards for underground mining in various countries throughout the world. Compliance with any prescribed lighting standard will not necessarily ensure a safe visual working environment given the wide range of variables that must be considered.

The objective of these recommendations is to assist in the identification of potential hazards that can result from poor visual environments across a comprehensive range of operational situations commonly encountered in South African gold and platinum mines, and to facilitate risk assessments that will lead to appropriate mine-specific standards for illumination. Hence, the primary objective of this document is to provide a source of information that will allow direct and effective action to be taken at both corporate and mine level, to improve the visual working environment. This should enhance safety and reduce the number of accidents arising from poor visual environments and standards of lighting.

It is important to bear in mind that the recommendations made in this document are not designed to be prescriptive, and that each situation should be subjected to a site-specific assessment of risks. The illumination levels included in these recommendations are provided as an indication of the minimum typically required to ensure that specific tasks can be undertaken reliably and safely. Hence, even though these recommendations are based on sound scientific research, they should not be used as mine standards. Mines must first confirm the relevance, applicability and practicability of recommended levels in terms of risk assessment outcomes, and then formulate mine standards accordingly. Risk assessments should be conducted on an ongoing basis, to ensure that the adopted standards are being met and that the intended outcomes are being achieved.

Since specified illumination levels are derived from minimum requirements for safe and reliable performance of specific tasks, complex measurement methods are not required. Where a minimum illumination level is recommended, the point of measurement is also given. For example, the recommended minimum level of "160 lux *at the winder*" provides both the level required and the measurement location.

As these recommendations are designed to provide guidance for good practice and favourable outcomes rather than prescriptive instructions, detailed specifications for electrical engineering requirements are not provided.

A1.2. Layout of the recommendations

The locations and sites examined were selected to include both good and bad visual environments, as identified by the collaborating mines, and visual assessments were carried out in the actual work situation. The recommendations are divided into three main sections:

1. **Static locations:** this section covers areas of the mine that are of a long-term or fixed nature, where it is feasible to install sufficient and suitable permanent lighting fixtures and other aids to improve the visual environment.
2. **Dynamic locations:** this section covers changing areas of a mine, primarily production and development areas that, by their very nature, move on an ongoing basis and, hence, it is less practical to provide fixed lighting.
3. **Mobile machines:** this section addresses a sample of typical mining machines and considers the visual environment of both the operators and the workers in areas where the machines normally operate.

The above sections are divided into sub-sections that follow the logical sequence of a typical risk assessment process. The sub-sections used and the objectives of each are as follows:

- **Tasks considered:** these provide an indication of the scope of recommendations made and hence, indicate the likely validity of a particular section for the risk assessment being conducted.
- **Critical visual requirements:** these identify the visual targets that must be seen for a visual environment that is conducive to safety and efficiency.
- **Potential visual limitations:** these provide an indication of the visual limitations most frequently encountered in typical mining environments that impact on critical visual requirements.
- **Potential hazards:** these are the significant hazards that are likely to result from visual limitations and hence, may require analysis to ensure a comprehensive risk assessment.
- **Recommendations:** these provide an indication of the range of control measures that should be considered to ensure that all reasonably practicable steps are taken to eliminate or mitigate risks arising from potential hazards.
- **Additional considerations:** in addition to the recommendations that relate directly to the quality of the visual environment, there may be additional measures that can be taken to further mitigate hazards. Where this is the case, typical examples are provided.

Because of the interactive nature of underground operations, some repetition was necessary in the presentation of these recommendations. Selectively repeating certain points enables each sub-section of the report to be considered on its own, thereby reducing the need to consult multiple sections of the report to identify all relevant recommendations regarding a particular issue. Two of the three main sections relating to static locations and mobile machines contain a summary of generic recommendations that apply to all relevant locations and equipment. For example, if the reader is considering illumination aspects related to locomotive operations, the relevant sections to be consulted are:

- (a) *General Recommendations* in the 'Mobile Machines' section;
- (b) *Locomotives* in the 'Mobile Machines' section;
- (c) *Tip and Orepass box* operations in the 'Static Locations' section; and
- (d) *Mono-Ropes* in the 'Dynamic Locations' section.

A2. Static locations

The dimensions, layout and equipment, as well as the tasks conducted in static locations will vary considerably from mine to mine, and even within a given mine. The locations studied during the project and addressed in this section should be used primarily as examples of the issues that should be considered when identifying hazards, assessing risks and setting mine standards.

A2.1. General recommendations

The recommendations that follow are applicable to a wide range of mine locations.

Lamp selection

The most common form of fixed lighting encountered in gold and platinum mines is strings of 60W incandescent lamps.

Table A1 shows a sample of typical roadway illumination levels taken at ground level where sidewalls were whitewashed to a height of 1.5 m, and lamps were relatively clean and not obstructed by pipes and other service ranges suspended from the hanging wall.

Table A1. Typical roadway illumination levels provided by 60 W incandescent lamps

Roadway		Spacing	Maximum	Minimum
Height (m)	Width (m)	between lamps (m)	illumination (lux)	illumination (lux)
3	2.5	4	13	6
3	3.5	9	11	3
3.2	3.3	7	13 (5)*	6 (1)*
5	5.5	9	10	8

*Figures in brackets are illuminance levels in the same roadway but with no whitewash on walls

In the case of high roadways, light distribution tends to be more even (i.e. smaller differences between maximum and minimum illuminance levels).

In comparison with the incandescent (tungsten) lamp, the fluorescent tube typically provides a 41 per cent energy saving (see Figure A1), lasts 20 times as long and provides 30 per cent more light. Table A2 also indicates that 'Deluxe cool white' fluorescent tubes do not suffer from any significant colour-rendering problems. Accordingly, it is

recommended that consideration be given to the use of fluorescent tubes for providing general area illumination.

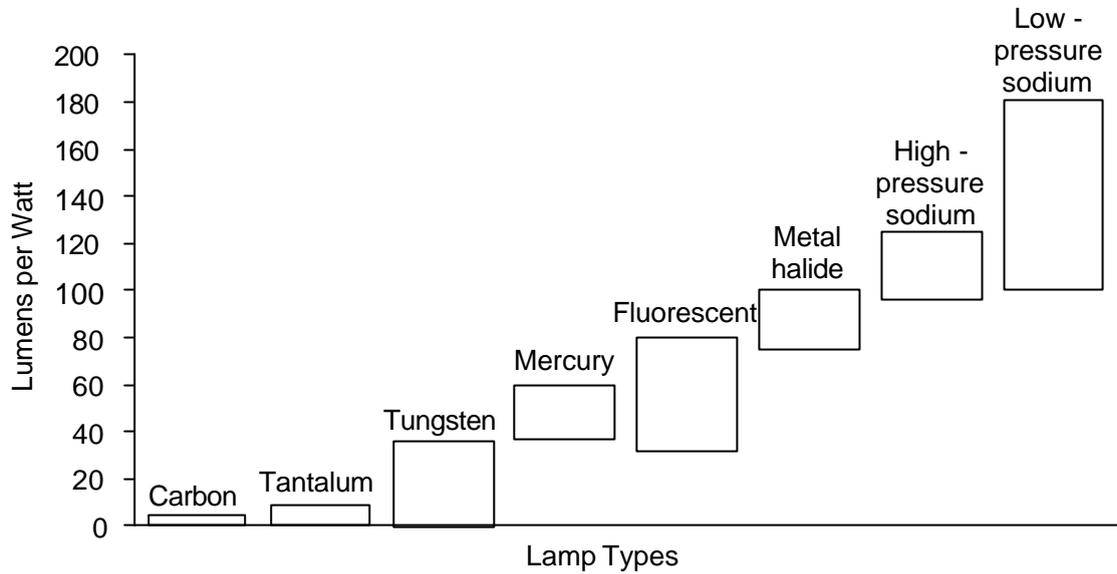


Figure A1. Lamp efficiency ranges for common light sources (after IES 1976)

Table A2. Colour-rendering characteristics of common lamp types

Type of Lamp	Colours Strengthened	Colours Greyed
Incandescent	Red, orange, yellow	Blue
Fluorescent:		
Cool white	Orange, yellow, blue	Red
Warm white	Orange, yellow	Red, blue, green
Deluxe cool white	All nearly equal	None very much
Deluxe warm white	Red, green, orange, yellow	Blue
Colour-improved mercury	Red, orange, yellow, blue	Green
Clear metal halide	Blue, green	Red
High pressure sodium	Yellow, orange, green	Red, blue

Orientation of tubular fluorescent lights

There are three basic arrangements commonly used for the positioning of fluorescent luminaires in mine haulages:

1. A single row of luminaires down the centre or to one side of the haulage, with each luminaire orientated longitudinally to the haulage.

This arrangement results in large variations in illumination along the haulage length.

2. A single row of luminaires down the centre of the haulage, with each luminaire orientated at right angles to the direction of the haulage.

This arrangement provides improved light distribution along the line of the haulage, but creates lower light levels on the sidewalls. It also tends to create glare that causes a distracting stroboscopic or flickering effect.

3. Two rows of luminaires, one on each side of the haulage, spaced such that the luminaires are on alternating sides and orientated in line with the haulage.

This arrangement provides the most uniform distribution of light, but care should be taken in conveyor roads to ensure that the conveyor structure does not create large areas of shadows on the walkway.

Arrangement 3 is the recommended option, even though it will initially require more in the way of materials and installation work.

Other issues

- High visibility clothing with reflective elements should be adopted as standard workwear for all underground employees.
- The use of whitewash and/or light-coloured shotcrete on haulage walls has the benefit of significantly improving the underground visual environment by increasing reflectance and hence, general levels of illumination.
- Visitors, particularly to sections where there is a risk of injury from moving equipment, should be required to wear clothing that makes them clearly distinguishable from mine employees.
- The adoption of good care and maintenance practices is essential for the benefits of good mine lighting systems to be fully realised. This implies:

- Prompt repair of damaged units and replacement of exhausted globes
- Regular, routine cleaning of luminaires and their protective covers
- Consideration should be given to the provision of portable lighting units in production areas where the provision of permanent lighting is impractical. Luminaires should provide an appropriate level of peripheral illumination to enable inspections and preparation work to be undertaken safely and reliably. Spotlights are not recommended for this purpose, and care should be taken to ensure that lights are not used in a way that is likely to impair the visual performance of other workmen.
- Whatever form of lighting is provided, measures should be taken to ensure that the distribution of light is not impaired by the location of equipment, ventilation ducting, pipe ranges and other mine services. Also, in situations where there is an increased risk of lights being damaged by mining or transport operations, the use of impact resistant covers should be considered.

A2.2. Underground haulages

The following potential hazards and relevant recommendations were derived from studies of various haulages, pedestrian walkways and junctions underground. They generally apply to haulages, primary locomotive routes, crosscuts and pedestrian walkways.

A2.2.1. Tasks considered

- Pedestrians walking in haulages

A2.2.2. Critical visual requirements

The critical visual requirements of pedestrians walking or working in haulages include:

- Floor conditions and obstructions
- Moving equipment (Locomotives, hoppers, material cars, mobile machines, etc.)

A2.2.3. Potential visual limitations

The following potential visual limitations were identified for pedestrians walking or working in haulages:

- Blind spots at junctions and around ventilation door installations
- Restricted illumination levels
- Abrupt changes in lighting levels
- Limited effectiveness of lights on locomotives
- Poor contrast between rolling stock and the general haulage background
- Defective or broken lights

A2.2.4. Potential hazards

1. Pedestrians slipping, tripping and falling in the haulage
2. Walking into, or being struck by, dolly wheels protruding from the sides of hoppers
3. Pedestrians struck by locomotives or rolling stock

A2.2.5. Recommendations

- Ensure efficient lighting layout and avoid masking of lights by mine services and pipe ranges
- Improve light maintenance
- Establish a minimum background illumination level of 5 lux (in addition to caplamp illumination) for designated pedestrian walkways. This recommended minimum level has been found to significantly enhance peripheral vision and hence, is likely to significantly reduce the risk of tripping, slipping and falling. Measurements should be made horizontally at ground level, and 5 lux should be the minimum level along the length of the walkway. Risk assessments should determine which haulages will require additional lighting.

Where pedestrian and vehicle routes cannot be segregated, consideration should be given the following actions:

- Improve contrast ratios between moving equipment and background conditions, i.e. provide clearly distinguishable bright markings at both ends of mobile equipment, e.g. chevrons, reflectors, etc.
- Paint mobile equipment in bright and contrasting colours
- Use audible and visible warnings or robots where locomotives pass through ventilation doors
- Provide more effective lighting on locomotives, trains and other moving equipment, directed in the direction of travel
- Provide clearly distinguishable means of identification at the tail ends of mobiles/trains/rolling stock, e.g. reflectors, chevrons, etc.

A2.2.6. Additional considerations

- Maintain high standards of housekeeping and walkway maintenance
- Cover gullies and drains that cross designated pedestrian walkways
- Consider the use of high-visibility clothing with reflective strips
- Prohibit locomotive movement during periods of high pedestrian traffic
- Provide refuge points at regular intervals along narrow haulages
- Install and maintain effective audible and visible warning devices on locomotives and loco trains

A2.3. Inclined shafts and shaft stations

The following hazards and potential recommendations were derived from observations at inclined shafts used for the conveyance of materials between different levels of the mine. The situations observed involved a pilot car attached to the end of the winding rope, to tension the rope and facilitate coiling when hoisting, and to guide the rope down the shaft when lowering. Material cars were attached to the pilot car by rope slings and safety slings were fitted over the cars, from the upper rope attachment to the lower coupling point of the bottom car. The slings acted as a backup attachment in the event of intermediate coupling failure. In addition to material transport activities, inclined shafts frequently incorporate pedestrian walkways, which should be given due consideration during risk assessments.

A2.3.1. Tasks considered

- Coupling and uncoupling operations
- Pedestrians travelling along the incline shaft
- Trimming of materials cars
- Winch operation

A2.3.2. Critical visual requirements

- Inspecting and checking of track, rope and couplings
- Movement and position of conveyances and rope
- Position of safety devices and switches
- Presence of pedestrians

A2.3.3. Potential visual limitations

- Defective or broken light units along the length of inclines and at shaft stations
- Lighting units covered in dust
- Poor reflectance of roof and walls
- Poor contrast ratios between pilot cars, conveyances, safety devices and background
- Defective lights on conveyances (bulbs expired, batteries discharged, mountings damaged, etc.)

A2.3.4. Potential hazards

- Runaways and derailments
- Pedestrians hit/trapped by conveyance or rope
- Slips, trips and falls
- Struck by conveyed objects intruding into walkways

A2.3.5. Recommendations

- For areas where conveyances are attached, given the safety-critical nature of these operations, a minimum light level of 30 lux around attachment points should be provided, but preferably a level of about 60 lux should be achieved.
- Illumination of conveyance: it may be beneficial for the conveyance to carry a light, to enable workers to recognise its approach. In any case, the end of the conveyance should be reliably detectable, e.g. chevrons/reflectors should be fitted, and be of clear and contrasting colours.
- Reliable inspection of track, rope and rollers will require a minimum of 30 lux. This could be provided by permanent lighting installations, or by using supplementary portable lights during inspections.
- To enable the reliable inspection of ropes by winder drivers, 160 lux of illumination should be provided where the rope coils onto the drum.
- Position indicators, ammeters and other gauges require a minimum of 160 lux.
- Consider the provision of additional lights above stairways. A minimum level of 5 lux is recommended for typical walking areas. Where steps must be negotiated this level should be increased to around 20 lux.
- Minimise glare potential for pedestrians approaching winder or station areas, where there may be a significant change in illumination levels.
- Increase the reflectance of walls and roof to assist in the uniform distribution of available light. Whitewashing and the use of white brattice type materials at critical points often provide a practical solution in these situations.

A2.3.6. Additional considerations

Good housekeeping standards should be maintained, including the removal of loose debris from steps, regular cleaning and maintenance of lights, removal of intrusive items from walkways, etc.

A2.4. Chairlift landings

Chairlifts are commonly employed in gold and platinum mines to facilitate access to different levels. Throughout the project several different chairlift landings were examined. Arrangements in terms of general layout and standard of illumination were very similar and of a high standard. Details of these layouts are provided in Appendix B.

A2.4.1. Tasks considered

- Boarding/alighting chairlift

A2.4.2. Critical visual requirements

- Moving chairlift, when boarding or alighting
- Designated boarding and alighting zones

A2.4.3. Potential visual limitations

No specific problems were identified in the installations examined, and the stations and landings were found to be well illuminated.

A2.4.4. Potential hazards

- Slipping, tripping and falling while alighting or boarding chairlift
- Struck by moving chairs

A2.4.5. Recommendations

- Good illumination is critical at boarding and alighting points. Provide light levels of 60 to 80 lux where the general illumination levels in the shaft are low (5 lux). Higher levels than this may be desirable but care should be taken to avoid glare.
- Glare or light adaptation may also be a significant problem around the surface entrance to the shaft. This can be alleviated by providing high lighting levels, say, 250 lux) at the top entrance, which should be gradually reduced as progress is made into the mine (e.g. allow 20 to 30 seconds to produce a comfortable transition between 250 lux and 5 lux).

- Increase the reflectance of walls and roofs to assist in the uniform distribution of available light. Whitewashing often provides a practical solution in these situations.
- Paint the edges of steps white, yellow, etc., to improve reflectance and contrast.
- Provide clearly designated areas to board and alight chairs.
- Paint chairs white, yellow, bright contrasting colour, etc. to improve contrast/reflectance.
- Ensure that approaches to chairlift boarding points provide for a gradual transition of illuminance level to that prevailing at the boarding point.

The two installations described in Appendix B were considered to be satisfactory in terms of lighting, and provide model solutions.

A2.4.6. Additional considerations

Good housekeeping standards should be maintained, e.g. regular cleaning and maintenance of lights and floor areas.

A2.5. Underground workshops

A number of potential hazards and recommendations were derived from studies of various underground workshops. Operations in these workshops include routine maintenance and breakdown repairs to locomotives and other mobile machinery, as well as machining and fabrication operations. The recommendations are generally applicable to all forms of workshops underground. Although surface workshops were not specifically examined, the following recommendations are equally applicable to these facilities as well.

A2.5.1. Tasks considered:-

- Routine maintenance and breakdown repairs to locomotive and underground mobile machinery
- Repair and maintenance of rock drills, etc.
- Machining and fabrication operations

- Arrival and departure of mobile machines

A2.5.2. Critical visual requirements

The following is a summary of the critical visual requirements of workmen in workshops.

- Floor conditions
- Tools and equipment
- Working/walking surfaces
- Steps and platforms
- Moving equipment
- Components and features of the machines and equipment being serviced

A2.5.3. Potential visual limitations

Some of the more general visual limitations in underground workshops are as follows:

- Illumination is provided by lights suspended from the roof. Since most maintenance tasks are carried out either underneath or inside vehicles, most of these tasks are undertaken in deep shadow.
- Light is obstructed by raised engine covers, vehicle chassis members, small access openings and the location of components within, and work positions adopted by maintenance personnel. As a result, workmen remove their caplamps and hard hats so they can use their lamps as portable light units while they place their heads inside machine enclosures.
- Most workshops were provided with ramps to facilitate maintenance of locomotives and other mobile machines. There is limited illumination for components beneath vehicles.
- Poor reflectance from walls.

A2.5.4. Potential hazards

Poor illumination contributes significantly to the following potential hazards in a workshop:

- Hand injuries through contact with sharp objects or entrapment while using machine tools.
- Components and substances falling on men working beneath vehicles
- Head injuries when working without a hard hat
- Caught by moving equipment/machines

Given workers' common practice of removing their self-rescuers and even their caplamps while working, there is the potential for workers to be caught without these items in the event of an emergency.

A2.5.5. Recommendations

SABS standards for surface workshops should also be met in underground workshops, a position strongly supported by participants in the workshop convened to consider the project's recommendations in draft form before their submission. Most underground workshops are permanent or long-term, working places where there are no practical constraints to the provision of good lighting and hence, no justification for applying standards underground that are inferior to those on surface or in general industry.

Where mining conditions limit the practicability of meeting higher standards, the following recommendations should be considered:

- Increase the reflectance of walls, particularly their lower sections, to improve light distribution beneath machines, by using whitewashing, etc.
- Increase illumination on platform steps and paint edges white or yellow to improve reflectance and contrast.
- Increase general lighting levels by means of wall-mounted light units in addition to those normally provided on the roof. Tests have indicated that florescent tubes mounted vertically on walls:
 - Provide more even distribution of light across workshops
 - Illuminate areas previously in dark shadow, and
 - Provide significantly better levels of illumination beneath vehicles

There is the potential for this solution to introduce glare, and care should be taken to minimise such effects.

A2.5.6. Additional considerations

- Provision of easily removable bonnets and hatches on vehicles
- Installation of lights under ramps and in pits used for working beneath vehicles
- More effective utilisation of portable lights
- Elimination of any possibility of stroboscopic effects around rotating machinery, by ensuring that such machinery is powered from a different electrical phase than the light source illuminating it

A2.6. Refuelling bays

The following potential hazards and recommendations were derived from studies of two diesel fuel storage and refuelling bays, one large purpose-built bay and the other a smaller "temporary" location. Details of their layouts are provided in Appendix B.

A2.6.1. Tasks considered

- Locomotive refuelling
- Trackless vehicle refuelling
- Filling of storage tanks
- Working in fuel bays and walking in adjoining haulages

A2.6.2. Critical visual requirements

- Workmen and obstacles in danger of being hit by moving vehicles
- The corners of turnings into fuel bays
- Floor conditions, both within the fuelling bays and in the haulages leading into these areas
- Fuel dispensers, levels and control valves

- Steps providing access to elevated working positions

A2.6.3. Potential visual limitations

The following major potential visual limitations were identified for pedestrians walking and working in the areas under consideration:

- Poor reflectance of walls
- Defective fixed and vehicle lights
- Absence or failure of audible tramming alarms on vehicles
- Large areas of dark shadow in places critical to safe operation
- Equipment not painted in colours that contrast with the background environment

A2.6.4. Potential hazards

- Slipping, tripping and falling as a result of fuel spillage
- Workmen in fuel bays falling from machines or elevated work positions

A2.6.5. Recommendations

- Ensure a minimum illuminance level of 50 lux in filling area to facilitate the control of fuel levels and the operation of fuel hose connection devices.
- Provide automatic cut-off valves on filler nozzles to eliminate the risk of overfilling and spillage, thus greatly reducing risks of slips, falls, and fires
- Increase the reflectance of walls to improve light distribution in refuelling areas
- Increase the contrast ratio between steps and background surfaces
- Provide good drainage and non-slip floors to reduce slip and fall potential

A2.6.6. Additional considerations

- Provide adequate steps and handholds on machines to facilitate safe and efficient refuelling operations
- Maintain a high standard of housekeeping and respond to fuel spillages promptly

- Maintain lighting systems to ensure effective illumination, e.g. prompt replacement of defective or expired lamps and regular cleaning of safety or diffuser covers

A2.7. Battery charging stations

The following potential hazards and recommendations were derived from studies of two battery-charging stations. Detailed layouts are provided in Appendix B.

A2.7.1. Tasks considered

- Removal and replacement of batteries from locomotives.

A2.7.2. Critical visual requirements

- Workmen and obstacles in danger of being hit or trapped by moving locomotives or by protruding battery covers
- Safe slinging of batteries
- Positioning of batteries and operation of hoists
- Checking battery's state of charge

A2.7.3. Potential visual limitations

No specific problems were identified in the installations examined. Both were well-illuminated with adequate workspace and walkways.

A2.7.4. Potential hazards

- Dropping of battery due to improper slinging or connection to hoist
- Short-circuit across battery terminals
- Use of an incorrectly or insufficiently charged battery leading to premature locomotive failure
- Hit or trapped by moving locomotives or protruding battery covers

A2.7.5. Recommendations

The two charging stations observed during the project were sufficiently well designed and illuminated to minimise any risks arising from a poor visual environment, to such an extent that they can be regarded as models for best practice. Again, details of their layouts are provided in Appendix B.

A2.7.6. Additional considerations

- Adhere to standards of housekeeping, and ensure that defective lights are replaced promptly
- Consider the use of tramming alarms on overhead cranes

A2.8. Orepass boxes

The potential hazards and recommendations that follow were derived from studies of two types of stope orepass box arrangements: one manually-operated installation and one remotely-operated installation.

A2.8.1. Tasks considered

- Climbing onto manual or remote control operating platforms
- Marshal locomotive
- Load hoppers from orepass box

A2.8.2. Critical visual requirements

- Position of hoppers relative to chute
- People in danger of being struck by moving hoppers
- Access ladders, platforms and walkways
- Water seeping from chute
- Spillage on track
- Hopper loading level
- Slipping and tripping hazards in walkways, on platforms and steps

- Obstructions in chute during loading operations, e.g. timber, large rocks, and actions to clear them

A2.8.3. Potential visual limitations

- The tracks and working areas were usually covered in spillage, mud or water. In addition, rocks, timber or equipment often obstructed working areas and walkways.
- Build-up of dust and slurry significantly reduces contrast ratios and hence, important visual targets rarely contrasted with background surfaces.
- Damaged and/or misaligned lights: where lighting installations were provided they usually took the form of a single 60 W incandescent globe that did not provide the sort of light distribution workmen require, and introduced a certain amount of glare. Bulbs were often positioned where they were vulnerable to damage and people working near them were subject to the risk of electrical shock from a broken globe.
- Safe means of access to working platforms were rarely provided, and in most cases workmen had to climb up onto hoppers to reach the platforms.
- Obscured lines of sight to hopper fill level from remote control stations.
- Hoppers restricted the distribution of light placing walkways in dark shadow.

A2.8.4. Potential hazards

- Mud rushes
- Derailments
- Slip/trip/fall injuries, including falls from height
- Other operational and non-visibility related factors are also likely to contribute to the risks associated with the hazards listed above. For example, the absence of rails round platforms, and obstructions interfering with the use of ladders are more likely to significantly contribute to the risk of falls.
- Injury while clearing obstructions from chute

A2.8.5. Recommendations

- Barring actions to clear blocked chutes put lights at risk of damage and hence, a large proportion of original fittings was inoperative. This problem should be addressed by installing impact-resistant light fitting in these areas rather than the usual exposed incandescent or florescent lights. Care should be taken to keep covers clean and replace those that have become opaque with age etc.
- Placement of lights is critical to avoid damage and provide sufficient illumination where required for safe work
- Remotely operated units must also be elevated to allow operators to see the load level in hoppers
- Provide a minimum illumination level of 20 lux, both on platforms (to detect obstructions in the chute) and at haulage level (to detect obstructions on and alongside rails)

Levels of about 60 lux should be provided at the lips of orepass boxes, to facilitate the clearing of blockages and enable reliable detection of water seepage.

A2.8.6. Additional considerations

Adherence to good housekeeping standards and ensuring that defective and expired lights are replaced promptly is of particular importance at orepass boxes.

A2.9. Tips

The potential hazards and recommendations that follow were derived from studies of three tip locations.

A2.9.1. Tasks considered

- Locomotive tipping operations, particularly the duties of guards. In many cases the driver's view is totally obscured while tipping and he is totally reliant on pea-whistle signals from the guard.

A2.9.2. Critical visual requirements

- Ramp position and control mechanisms
- Position of hopper relative to the tip
- Safety gates
- Debris on track and walkways
- Other workmen in the area
- Other locomotives operating in the area

A2.9.3. Potential visual limitations

- Driver's view often totally obscured
- Defective or expired fixed or vehicle lights

A2.9.4. Potential hazards

- Derailments caused by failure to recognise debris on track
- Pedestrians struck by locos
- Slips, trips and falls

A2.9.5. Recommendations

- A minimum of 30 lux at track level and 60 lux at control points is the likely requirement.

Levels well in excess of these can be readily achieved. For example, illuminance levels of 50 to 80 lux at track level and 100 to 120 lux at control points were often observed. In such situations, the risks arising from the visual environment can be considered to be as low as reasonably practical.

- Provide clearly audible as well as visible signalling devices at main tips. Dual signal devices are particularly important where illumination and noise conditions present a risk of distraction, interference or miscommunication. Such systems are presently being considered for inclusion in new guidelines for railbound transport equipment (DME 2001).

A2.9.6. Additional considerations

Situations were observed where many of the light fittings had been damaged during actions to clear large rocks on the grizzly, and in some cases these were blasted. Such a situation should clearly be avoided by:

- Installing luminaires with protective covers at tips
- Repairing or replacing damaged or defective lights promptly
- Shield or remove lights prior to blasting to protect them from damage

A2.10. Services and equipment rooms (Sub-stations, pump rooms, etc.)

Several types of locations were examined during the project that were mine- or situation-specific, including:

- Electrical substations
- Refrigeration rooms/plant
- Pump chambers
- Winder houses
- Offices, classrooms and meeting places

In all cases the levels of illumination achieved were adjudged to be satisfactory and the only possible deficiencies identified in these locations arose from failure to fully maintain the lights that had been provided.

As these locations are typically in stable areas and hence, largely unaffected by mining operations, there is no apparent reasons why the standards applied to surface installations (SABS, etc.) should not be applied here. Alternatively, standards from the MVS handbook (MVS 1992) for secondary workshops should be applied, i.e. 160 - 400 lux.

A3. Dynamic locations

A3.1. Stope faces

The potential hazards and recommendations outlined below were derived from studies of two stope faces at different mines. The tasks considered are outlined below.

A3.1.1. Tasks considered

- Pre-shift inspection
- Cleaning and sweeping operations
- General tasks, e.g. installing support pipes and face preparation
- Drilling

A3.1.2. Critical visual requirements

- Hanging wall conditions
- Misfires
- Drilling and charging
- Roof supports and barricade installation

A3.1.3. Potential visual limitations

The only sources of illumination typically available at the face are workers' caplamps.

A3.1.4. Potential hazards

- Falls of ground
- Failure to detect misfires
- Slip, trip fall
- Hit by scraper
- Hit by material or tools in use or being transported

A3.1.5. Recommendations

- Select caplamps on the basis of task and worker visual requirements
- Consider provision of additional portable light units at the face

A3.1.6. Additional considerations

Portable lighting systems are presently being evaluated at a number of gold and platinum mines. Encouraging reports of reduced injuries and improved productivity, as well as workers' acceptance of the additional measures required to protect these systems from blast damage, have been received.

A3.2. Gullies and Scraping Operations

The potential hazards and recommendations that follow were derived from studies of face strike and centre gully scraping operations.

A3.2.1. Tasks considered

- Pre-use winch inspection
- Scraping operations

A3.2.2. Critical visual requirements

- Winch unit ropes, snatch blocks, rigging chains and signalling device
- Scraper rope attachment points
- Workers travelling and material being transported in the gully
- Condition of ropes and coiling on drum
- Position markers on ropes
- Signal/warning light
- Clearances and interactions with adjoining scraper systems
- Rolling rocks
- Scraper and grizzly area

A3.2.3. Potential visual limitations

- Mining conditions and gully orientation almost invariably restrict the winch operator's line of sight to within a few meters of his position
- Signal lights often not in working order

A3.2.4. Potential hazards

- Workers hit by scraper
- Falls of ground and rolling rocks
- Struck by ropes/snatch blocks etc.
- Slip, trip and fall during rope inspections
- Hand injuries while inspecting/repairing ropes and snatch blocks
- Ropes or scraper scoops snagging
- Failure to stop scraping operations in event of an emergency, as a result of a defective or ineffective signalling system

A3.2.5. Recommendations

- Specific details of the winch driver's task are likely to vary from one location to the next
 - Where the driver needs to detect the scraper as it enters his line of sight (i.e. in close proximity to the winch), caplamp illumination may be all that is required.
 - Where the driver is expected to be aware of other potential hazards and/or monitor for rope coiling hazards, good peripheral vision to increase hazard awareness is likely to be required (minimum level of 20 lux)
- Avoid excessive illumination and glare, particularly in winch areas adjacent to general travelling ways, as well as problems with dark adaptation after passing the winch and entering darker areas.
- Whitewash winch areas to improve reflectance and light distribution, thus providing more uniform levels of illumination.
- Install and maintain proper, dedicated signalling arrangements that incorporate audible and visible devices at every winch installation

A3.2.6. Additional considerations

During the underground study a number of winch installations with defective signalling devices were observed, including:

- Bellwire not connected to signalling device
- Compressed air supply not attached to air whistle
- Bellwire not reaching the entire length of pull
- Bellwire not easily accessible from both sides of gully
- Bellwires snagged, fouled or obstructed
- Defective signalling device light
- Ineffective warning/lockout system

A3.3. Stope travelling ways

This section addresses the travelling routes between waiting places and workplaces. Hazards associated with travel to the waiting place are covered in the section on static locations.

A3.3.1. Tasks considered

Travelling from waiting places via:

- Gullies and scraper winch paths
- Material and mono-rope routes
- Dedicated access routes, including steep inclines, ladders and platforms

A3.3.2. Critical visual requirements

- Trip obstacles and other unfavourable ground conditions able to cause slips or falls
- Handhold points on ladders, platforms and sidewalls
- Material or equipment transported on the mono-rope system or stacked in travelling ways
- Mono-rope pulleys and ropes
- Rolling rocks and dislodged material stacks

- Centre gully and strike gully winch ropes, scoops and snatch blocks
- Clearances between roof, electrical cables, light fittings and service ranges

A3.3.3. Potential visual limitations

In most stope travelling ways the only illumination was from caplamps. In locations where other forms of lighting had been provided, such lighting installations were frequently broken or otherwise inoperative.

A3.3.4. Potential hazards

- Slips, trips, falls and falls from height
- Falls of ground
- Rolling rocks and materials dislodged by other people
- Contact with broken lamps creating a risk of cuts, contusions and/or electric shock
- Struck by equipment or materials being transported
- Injuries caused by contact with moving ropes
- Injuries from adjacent supports, obstructions, roof (in height restricted areas) and obstructions on floor

A3.3.5. Recommendations

- Consider the provision of fixed illumination systems in dedicated access routes and travelling ways/
- As for general walkways, provide a minimum background light level of 5 lux in addition to that provided by caplamps to improve workers' peripheral vision. This will serve to facilitate recognition of hazards and increase awareness of slip and fall risks.
- Reduce differences between well-illuminated and darker areas to avoid adaptation problems.
- Where lighting installations are subject to risk of damage, they should be protected by impact-resistant covers.

A3.3.6. Additional considerations

- Dedicated travelling ways should be of adequate height and width to allow free and unrestricted travel.
- Improve the condition and stability of ladders, barricades, platforms and handrails.
- Improve compliance with housekeeping standards relating to removal of loose rocks, debris and materials, especially in steeply-inclined areas where travelling risks are greater.
- Provide guards or barricades to prevent contact with moving ropes and materials.
- Provide and maintain effective signalling systems where a scraper gully is used as a travelling way.
- Discourage travelling in main scraper gullies during peak production periods.

A3.4. Mono-ropes

The potential hazards and recommendations that follow were derived from studies of several mono-rope installations. Winches are normally located in cross-cuts and operated by one or two people. Supplies are tied to the stationary rope with string and the winch pulls them to the stope, where they are automatically detached at the return wheel. Cross-cuts where winches are located are normally areas of high activity, as they usually also serve as:

- The main point of entry into stopes
- A waiting area for stope workers
- Materials transfer point where supplies are unloaded from locomotive materials cars and stacked prior to being winched into the stope

A3.4.1. Tasks considered

- Unloading and stacking supplies
- Mono-rope loading and winch operation

A3.4.2. Critical visual requirements

- Moving conveyances
- Pedestrians in walkway
- Rope condition, e.g. loose strands and kinks
- Trip obstacles and other ground conditions able to cause a slip or fall
- Winch controls and indicators

A3.4.3. Potential visual limitations

- Glare from spotlights and areas of deep shadow caused by the presence of materials cars or defective lights.
- Most of the mono-rope route is not visible from the operator's position

A3.4.4. Potential hazards

Struck by materials car

Struck by moving materials attached to the rope

Slips, trips, and falls (rail tracks and materials)

Hand injuries while attaching materials to rope

A3.4.5. Recommendations

- Provide a minimum level of 5 lux to enhance peripheral vision along the mono-rope
- Provide a minimum of 50 lux at the point where material is tied to the rope
- Ensure a uniform distribution of light across the working area and prevent glare by using floodlights in preference to spotlights.

A3.4.6. Additional considerations

- Provide effective signalling systems along the entire length of mono-rope routes.
- Where a mono-rope system operates within a section of a crosscut, ropes should be well clear of any workers travelling along the haulage or tracks to prevent materials from falling onto pedestrians or snagging other material on cars or locos
- Provide pre-start, stop and emergency warning signals
- Clear fallen supplies and debris from the mono-rope route at start of shift
- Design mono-rope layouts to reduce or eliminate the need to cross loco routes during routine materials handling or loading operations
- Improve tramming alarms on locomotives
- Provide barricades to segregate people from moving ropes and supplies

A4. Mobile machines

Most mobile machines used underground in gold and platinum mines are almost exclusively track-bound machines (i.e. locomotives). During the course of the project the only trackless machines observed were load haul dumpers and face-drilling machines. However, there were strong indications of an emerging future trend towards a more widespread use of trackless vehicles.

A wide range of trackless mobile machinery is employed in the coal sector and, accordingly, the guidance provided by COL 451 should be considered by mines considering the use of trackless machines not specifically covered by this project.

With the exception of those relating to locomotives, recommendations presented here are based on a very small sample of mobile machines, given their coverage in the aforementioned COL 451.

A4.1. General recommendations

The following recommendations are largely applicable to a wide range of mobile machines:

- Headlights should be mounted within recesses to minimise risk of damage.
- Headlight covers and recesses should not unduly restrict light output, and should allow sufficient access for the cleaning of lenses.
- Headlight covers should be provided with quick-release fasteners to minimise access difficulties and encourage regular cleaning and maintenance.
- Headlight casings should be easily dismantled to facilitate replacement of bulbs and prompt repairs. In particular, small fasteners that corrode or require special/improvised tools should be avoided.
- Mines should actively enforce their policies and procedures governing headlight maintenance. Pre-shift inspections should include the state of headlights and defective lights should be repaired, ideally, within one hour to prevent the operation of mobile equipment with defective lights.
- Artisans should be required to scrutinise and sign-off pre-shift checklists daily, ideally on their arrival in a section.

- Where necessary, adjustable light units should be provided to illuminate places critical to safe operations. These should be easily set at the required angle, and remain securely mounted during vehicle operation.
- To avoid confusion among drivers and reduce the risk of collisions, headlights and taillights should be automatically switched/linked to the direction of travel. More specifically, white lights should shine in the direction of travel, with red lights shining at the trailing end.
- Where feasible, headlights and taillights should be located at the corners of machines to provide an indication of their width for drivers of other machines.
- Chevron markings and suitable reflectors should be fitted to the front and rear of all mobile machines, in positions where they indicate the full width of the vehicle.
- All vehicles should be painted in a light colour to enable them to be clearly identified by other drivers and pedestrians in areas where general levels of illumination are low.
- To reduce glare from caplamps, headlights on other machines and overhead lighting installations, internal walls of cabs should be painted with a matt finish and, preferably, in a grey colour.
- Mines and machinery manufacturers should collaborate more actively with lighting manufacturers in the development of special-purpose machine lights that illuminate items and locations that are critical to safe operation.
- To minimise the risk of collisions resulting from a temporary loss of vision, drivers should be required to wear suitable eye protection.
- Engine-powered vehicles should be fitted with constant voltage alternators to ensure that the output of headlights and taillights remains constant regardless of engine speed. It is undesirable for light output to fall with engine speed, a characteristic of many vehicles currently in use.

A4.2. Locomotives

Battery- and diesel-powered units are widely used as the primary means of transporting men, materials and ore in gold and platinum mines. The potential hazards and recommendations that follow were derived from a study of four types of locomotive. These

were two 5-tonne and one 11-tonne battery-powered locomotives, and one 5-tonne diesel-powered unit.

A4.2.1. Tasks considered

- Loading and transporting ore from stope orepass boxes to tips
- General loco movement and shunting operations at stations and sidings

A4.2.2. Critical visual requirements

The critical visual targets of both drivers and guards are addressed, including visual requirements for:

1. Drivers travelling outbye with a train of loaded hoppers
2. Guard on foot leading a train inbye
3. Guards travelling inbye sitting inside a hopper on a train of empty hoppers

The common critical visual targets identified included:

- Workmen and obstacles sufficiently far ahead of a locomotive to be detected and the loco to be stopped to prevent a collision
- Workmen and obstacles directly in front of the loco to be detected before moving off
- Track and roof sufficiently far enough ahead for drivers to identify potentially hazardous conditions

A4.2.3. Potential visual limitations

- Driver's line of sight when travelling inbye is totally obstructed on some locomotives, requiring the driver to depend entirely on signals from the guard.
- Guard's view of track conditions and other potential obstructions is severely restricted when seated in the penultimate hopper while travelling inbye
- Small window apertures on some locomotives restrict drivers' forward view of both the track and roof.
- Poor lighting at rail stops, points, junctions etc. and other areas where clear driver vision is essential.

- Portable light units were not always used at the ends of trailing and leading hoppers. Often, when they were provided, some had expired bulbs, discharged batteries, damaged mountings or alignment problems. In addition, some units could not be switched between white and red.
- The following limitations were identified with regard to standards for locomotive headlights:
 - Lights were sometimes defective and in some cases had been defective for some weeks
 - Light output from some arrangements failed to comply with the current requirement of 10 lux at 20m
 - Lights at the ends of some locomotives could not be independently switched as appropriate for the direction of travel. There were also observed instances of locomotives operating with red and white lights shining at both ends simultaneously.
 - Some locomotives were provided with only white lights, even though standard instructions stipulated that red lights should be displayed on the trailing end.
 - Headlight output on some diesel locomotive diminishes significantly at low engine speeds
 - Levels of illumination provided by some headlights failed to meet standards.
 - Limited provision of effective visual warnings at the rear of trains.
 - People walking and working in locomotive haulage routes often wore dark-coloured, non-reflective overalls and hard hats.
 - Poor contrast ratios between locomotives, rolling stock, safety devices, etc. and background surfaces and objects, exacerbated by failure to keep such equipment clean.
 - Lack of effective visual warning signs to indicate potentially hazardous conditions, e.g. junctions and turns, working areas, poor track/ground conditions, etc.
 - View of track obscured by the presence of water.
 - Driver's view of guard frequently obstructed.
 - Glare from rear lights of locomotives parked or travelling in the same direction.

A4.2.4. Potential hazards

1. Derailment through failure to identify dangerous track conditions ahead
2. Collision with the back of stopped trains
3. Shunters trapped when coupling carriages and/or materials cars to loco
4. Collision with obstacles ahead
5. Drivers injured when leaning out of cab
6. Collision with other vehicles at junctions

A4.2.5. Recommendations

The level of illumination required from locomotive lights will largely depend on the visual tasks the driver and guard are expected to perform, and the likely maximum stopping distance of the locomotive. Site observations and discussions during the workshop convened to consider the project's findings and recommendations indicated that the visual task requirements vary considerably from mine to mine. To accommodate these variations, three alternative strategies are considered, and an indication of the illumination levels typically required to accommodate them is provided. Each of the three strategies considered requires that sufficient illumination be provided to:

- a) Enable drivers and guards to identify adverse track conditions and any obstructions that could cause derailments: 60 lux across the tracks at 1.5 times the stopping distance.
- b) Enable drivers and guards to detect the presence of people on the track or in restricted travelling ways, and stop in time to avoid collision: 20 lux across the tracks at 1.5 times the stopping distance.
- c) Enable pedestrians to identify approaching locomotives in sufficient time to move aside: 10 lux at 20 meters.

Strategies (a) and (b), both require tests and calculations for locomotive maximum stopping distance. This can vary considerably, as it depends on track conditions, total load, travelling speed and condition of the loco's braking system, as well as driver vigilance and responsiveness. Distances of approximately 60 metres (40 m stopping distance x 1.5) may need to be accommodated.

Where it is necessary to account for stopping distance exceeding 10 m, Strategy (a) is likely to be both impracticable and ineffective. Even if sufficient illumination can be provided, drivers and guards are unlikely to reliably detect track defects at the required distances. Furthermore, on many locomotives driver and guard sight line restrictions will preclude the use of this strategy.

It must be appreciated that when locomotives are pushing hoppers, the portable lights normally attached to the last hopper should provide similar levels of illumination to those required from locomotive headlights.

Other issues that may warrant consideration when setting locomotive illumination standards include:

- Provision of at least two headlights for each direction of travel
 - ◇ One headlight may be mounted and oriented downwards to illuminate the track and couplings
 - ◇ One headlight may be mounted and oriented upwards to illuminate the roof and shine over the top of hoppers or materials cars during shunting operations
- Headlight/taillight switching should be linked to the direction control, to shine white light in the direction of travel and red light at the trailing end
- All displays to be monitored while the loco is in motion should be self-illuminating, to enable drivers to easily read them without the use of caplamps, which can create glare on the fascia and display covers
- Provision of general lighting at a level of 5 lux in all tramming areas would greatly enhance visibility during tramming operations

Sight lines:

During the procurement of new locos, consideration should be given to the critical visual requirements outlined above.

- In order to meet the critical visual requirements of the driver to see pedestrians, obstacles and dangerous conditions ahead of the loco, window apertures should provide drivers with a clear and unobstructed view:
 - ◇ Across the roof and floor and up both sidewalls, from ground level to the roof of the haulage, at no less than 5 metres and beyond

- ◇ The head of a stooped miner directly in front of the loco (1,3 m above the floor)
- Care must also be taken to meet the critical visual requirements of the guard while travelling on the loco. This was often observed to be problematic when hoppers were being pushed by locomotives. Guards could not sit high enough to see from the last but one hopper without hitting their heads on the hanging wall or, more likely, pipe ranges, lights, roof bolts etc.

A4.2.6. Additional considerations:

- No speedometers fitted to many locomotives
- No speed restrictions or warning signs posted

Where design constraints prevent improvements to illumination and sight lines, alternative means of controlling the visual hazards should be identified, e.g. modifying work practices, enhancing pedestrian awareness of vehicles and machines, providing additional safety features such as emergency stops etc.

The recommendations that follow would not improve sight lines or standards of lighting, but could be considered as additional means of compensating for limitations in the visual environment.

- Provision of horns or hooters that are clearly audible over the stopping distance of the loco, but not so loud as to deter drivers from using them
- Provision of audible and visible pre-tramming alarms
- Radio links between drivers and guards
- Use of large reflective type signs
- Use of high visibility clothing fitted with reflective strips
- Provision of two-way mirrors at junctions and crossings
- Contrasting colours for locomotives and rolling stock to improve contrast ratio and facilitate recognition
- Improved standards of track maintenance and housekeeping to reduce reliance on visibility and driver/guard vigilance
- Control or prevent accumulations of ground water and provide effective warning signs in advance of potentially hazardous conditions

- Clearly mark fouling areas at all switches and junctions. Ideally these areas should be whitewashed and provided with additional luminaires to enable loco crews to easily identify the condition and position of points or obstructions within the fouling areas.
- Consider the installation and effective maintenance of robots at ventilation doors, junctions and other areas where the risk of collision is difficult to control

A4.3. Load Haul Dump machines (LHDs)

The potential hazards and recommendations that follow were derived from a study of LHDs with driver cabs located centrally on one side of the machine, and the driver seated in a sideways position.

A4.3.1. Tasks considered

- Transfer of ore from working faces to rail hoppers and tip area
- Transporting supplies from locomotive station to storage areas

Critical visual requirements

- Workmen and obstacles to the front, rear, in close proximity to the vehicle's pivot point and at each side of the bucket or load
- Clearance between the roof and the top of the bucket or load
- Clearance between underside of bucket and hoppers
- Clearances between the vehicle and haulage walls, bends and junctions
- Workmen and obstacles sufficiently far ahead of the vehicle to be detected and allowing the vehicle to be stopped before collision
- Warning signals, signs and other vehicles
- People or other machines positioned in or emerging from turning points ahead of the vehicle

A4.3.2. Potential visual limitations

- Obstructed lines of sight to the front, off-side and rear of the vehicle
- Lack or limited use of high-visibility clothing with reflective strips

- Output from headlights obstructed by bucket or load
- Defective headlights: bulbs expired, mountings damaged, lights misaligned, etc.
- Limited provision of effective visual warnings on moving or parked vehicles, e.g. chevrons/reflectors
- Line of sight and headlight restrictions combined with fixed side seating arrangements create the need for drivers to adopt adverse working postures, creating ergonomic impact on safe and efficient operation and worker health
- Glare from lights of other machines/vehicles

A4.3.3. Potential hazards

1. Collision with pedestrians and maintenance staff attending to the vehicle when moving off
2. Workmen caught or trapped in the pivot space
3. Collision with people, sidewalls and other objects or plant in the vehicle path
4. Drivers injured by working in unfavourable operating postures (immediate and long-term injury)
5. Collision with workmen, loads and plant when entering turns
6. Collision with corners of turns and junctions on the off-side

A4.3.4. Recommendations

Illumination:

- At least two headlights should be fitted to each end of LHDs.
- Headlights should be automatically switched to show a bright white light in the direction of travel and a lower intensity red light at the trailing end.
- Headlight illumination in the direction of travel should provide a minimum of 10 lux at 20 m
- Headlights should be positioned so their output is not obstructed by the bucket, load, or other aspects of the vehicle or work environment. This would be facilitated by the provision of extendible/adjustable mounting brackets (such arrangements have been successfully tested and applied in British coal mines).

Sight lines:

Lines of sight on LHDs are particularly poor, and are associated with high accident rates. When acquiring new machines, consideration should be given to the critical visual requirements given above. However, the recommendations that follow provide suggestions on how existing LHD sight lines can be improved:

- Provision of height-adjustable seats that can also be rotated through a range of 30°, so as to face forwards in either direction of travel.
- Modifications to the profile of vehicles, e.g. chamfering corners of engine covers, lowering mudguards, and removing or relocating items from the top of vehicles that obstruct drivers' view.

A4.3.5. Additional considerations:

Where design constraints prevent improvements to illumination and sight lines, alternative means of controlling limited visibility hazards should be identified, e.g. modifying work practices, enhancing pedestrian awareness of vehicles and machines, providing additional safety features on LHDs, such as emergency stops, etc.

The following recommendations would not improve sight lines or lighting standards but should be considered as additional means of compensating for limitations in the visual environment.

- Provision of visual tramming warnings
- Provision of emergency stops at each corner and articulation point on the vehicle
- Provision of mirrors at crossings

A4.4. Face-drilling machines

The potential hazards and recommendations that follow were derived from a study of face drilling operations in a trackless mining section. The recommendations offered are applicable to wheel-driven machines operated from side- or forward-facing operator positions on one side of the machine between the front and rear wheels. A feature of this type of machine is the long, fully articulated, drilling booms projecting forward of the front wheels by up to 5 m.

A4.4.1. Tasks considered

- Tramming forward along haulages within production sections and into blind headings
- Manoeuvring in headings to achieve the required drilling position
- Drilling the face, which involves articulating drilling booms to achieve correct drill position and alignment, drilling and then retracting the drills
- Reversing the machines out of headings and turning

A4.4.2. Critical visual requirements

- Drill boom assemblies and chalk markings on the face of heading during drilling operations
- Roof, footwall and face/sidewall conditions
- Clearances between the machine and the sides and corners of headings/haulages (particularly for the tyres and boom assembly)
- Workmen, materials, machinery and other obstacles to the front, rear and sides of the machine
- Machine controls

A4.4.3. Potential visual limitations

- When tramping forward much of the haulage ahead and to the off-side was obscured from the driver's view by the drilling booms.
- Headlights can dazzle workers standing in front of the machines.
- It was virtually impossible for drivers to see workmen stationed close to machines in the region extending from the centre-line of the rear axle to the end of the machine on the off side. Here there is a particular risk of people being struck during any rapid slewing movement by the tail end of the machine. Large obstacles can also be concealed within this region.
- It was also virtually impossible for drivers to see workmen stationed close to the rear end of machines, creating the risk of such people being struck or run over during reversing movements. Large obstacles can also be concealed within this area, since drivers are unable to see the ground within 14 m of the machine.

A4.4.4. Potential hazards

1. Collision with workmen, materials, machinery and other obstacles when tramping forward or in reverse.
2. Workmen trapped between the machine and sidewall on the off-side.
3. Collision with corners of headings.
4. Workmen dazzled by machine headlights and failing to detect the extent of the boom.
5. Workmen caught by the swinging drilling boom as the machine turns.

A4.4.5. Recommendations

Illumination

- Two or more forward-facing light sources should be installed to provide sufficient illumination over the range of drill boom movement, for positioning manoeuvres and clearance estimates.
- Floodlights are preferred to spotlights and they should be sufficiently separated to provide uniform distribution of light, thus minimising shadow and transient adaptation effects.

- Rear lights should be switched by the tramming control(s) to show red when the machine is stationary or moving forward and white when it is reversing.

Sight lines:

Design constraints on face-drilling machines limit the extent to which their sight lines can be improved. Therefore, alternative methods of controlling visual hazards may need to be identified, such as changing work practices or enhancing worker hazard awareness, e.g. the provision of audible and visual pre-start and tramming alarm devices.

Additional considerations

- High-visibility clothing with reflective strips should be worn
- Provision of audible and visual alarm devices for use when the machine is travelling

A5. Visual assessment methodology

The recommendations produced by the project are designed to act as an *aide memoir* and provide mines with the information required to assist them in achieving a good visual working environment. However, the guidance provided is only general and mines should undertake their own site-specific assessments of risks, to ensure that any visually related risks are adequately controlled. To facilitate this process, the visual assessment methodology employed during the project is detailed below. The investigation and analysis techniques described should enable mines to assess specific locations or types of machinery and determine appropriate standards of lighting and visibility within their risk assessment procedures.

The methodology incorporates a combination of task analysis and line-of-sight assessment techniques. Instructions for using these techniques, along with two sight line assessment examples, are given below. The data provided in Appendix B was collected using the techniques described and provides a further comprehensive set of examples that illustrate the typical outcomes that may be derived.

A5.1. Visual task analysis

1. For each location examined record:
 - 1.1 Key dimensions, e.g. haulage size, workspace/machine dimensions and layout, travelling distances, braking distances, etc.
 - 1.2 Sources of illumination, e.g. type, capacity/output, condition and placement of all sources of illumination
 - 1.3 Details of the visual environment, e.g. factors that influence background lighting including colour and surface conditions of walls, floor and roof
2. In locations where operations (including machine operations) are examined:
 - 2.1 Produce a hierarchical task description identifying each step or sub-task in the operation
 - 2.2 Determine the critical visual targets for each step, i.e. key features or points that must be seen to enable that part of the operation to be undertaken safely and efficiently

3. Group critical visual targets, according to their spatial location, into more generalised visual attention areas
4. For each visual attention area derived, record:
 - 4.1 Operational blind spots, i.e. all instances where there is no direct line of sight to a critical visual target. Blind spots can be recorded directly during an assessment or through the use of sight line plots. An appropriate method for producing sight line plots is described below.
 - 4.2 Major postural changes, i.e. all instances where normal working postures or positions must be changed to overcome line of sight restrictions. The need for major postural changes can influence reliable operation and, in the long-term, cause injury or physical disorders.
 - 4.3 Characteristics of the visual environment: measure these where possible, or subjectively estimate/describe:
 - 4.3.1 Visual angle: approximate size and distance of critical visual targets from the operator
 - 4.3.2 Illuminance: level on critical visual targets
 - 4.3.3 Reflectance: material, colour, texture and condition (wet, dry, dusty, muddy, clean etc.) of critical visual targets
 - 4.3.4 Contrast between visual targets and background surfaces/objects, described as High, Medium, Low, etc.
 - 4.3.5 Visual conditions: presence of glare, areas of deep shadow, dust, water sprays, high air velocities, etc.
5. Classify the most demanding visual tasks performed in each visual attention area, using the following key words and criteria:

‘Detection’	where it is only necessary to see the presence of an object or obstruction (e.g. to avoid a tripping or stumbling hazard, it may only be necessary to detect the presence of an obstacle in sufficient time to avoid it).
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- ‘Identification’ where, after detecting the presence of an object, it may be necessary to reliably identify what it is (e.g., a driver may need to detect an obstacle in the path of his machine and then identify it, to decide whether he should stop, steer round it or ignore it and carry on past it).
- ‘Coarse Tracking’ where it is necessary to establish 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 (e.g. positioning a hopper beneath an orepass box, driving in confined spaces or around tight corners, etc.)
- ‘Fine Tracking’ - where small targets must be tracked continuously during fine manipulative tasks, reading, etc.

6. Systematically consider the groups of critical visual targets against the visual environment conditions and identify any risks that may arise if critical visual targets cannot be seen or correctly identified.

A5.2. Development and use of sight line plots

Sight line plots provide a most effective means of examining operators’ lines of sight in relation to critical visual targets identified during the task analysis. In simple terms, they provide a means of establishing what operators of mobile machines can actually see, in comparison with what they need to see for safe and reliable operation. Several methods are available for measuring and recording sight lines, as outlined in COL 451. The ranging pole technique outlined below, also originally described in COL 451, provides a straightforward and informative way of examining mobile mining machinery operating in the confines of their normal underground working environment. The technique was used to examine all of the machines studied during the current project.

Instruction in the use of these techniques is given below.

1. Equipment required:

- 15-m tape measure
- 2-m tape measure

- 2-m graduated ranging pole
 - Notebook or notepad to record the measurements
2. Allocate two people to apply the technique. One person is required to act as an 'observer', by adopting the normal driving or operating position on the machine and sighting the ranging pole in various positions. The other person will place the pole in the various assessment positions and, for each position, record the regions of the pole that can and those that cannot be seen by the observer.
 3. Position the machine on a flat surface with at least 1 m clearance all around it.
 4. Mark a line on the ground extending all around the machine 1.0 m clear of the machine's sides.
 5. Adjust the driver's seat (if relevant) to the mid position.
 6. The observer should adopt the normal driving position and posture on the machine.

In cases where the downward field of view is likely to be obstructed by engine covers, buckets, window sills etc., the eye height position of a short (5th percentile) driver should be adopted.

In cases where the upward field of view is likely to be obstructed by an overhead canopy, top of a window apertures etc., the eye height of a tall (97.5th percentile) driver should be adopted.

Where necessary, assessments should be made for both positions.

The following eye heights should be adopted:

5th-ile seated = 674 mm from the upper surface of the compressed seat

5th-ile standing = 1486 mm from the floor of the driving compartment

97,5th-ile seated = 795 mm from the upper surface of the compressed seat

97,5th-ile standing = 1700 mm from the floor of the operator compartment

7. The ranging pole should be placed on the line circumscribed around the machine at 0.5-m increments. At each position the person holding the pole should record the areas on the pole that are visible to the 'observer' when adopting the relevant eye height(s). When sighting the ranging pole, the head and body movements of the observer should

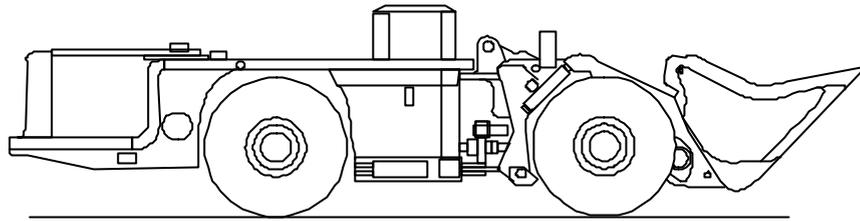
be restrained within comfortable postural limits and within the confines of the driving compartment. The 0.5-m increments can be increased or decreased, depending on the depth and purpose of the assessment being conducted.

8. If the assessment is being undertaken with the intention of subsequently modifying a machine to improve the operator's field of vision, features of the machine that obstruct the observer's view of the ranging pole should also be recorded.
9. Side plots should be produced using the following steps:
 - 9.1 Draw a scale plan elevation of the machine with the driver's eye position shown.
 - 9.2 Draw lines on the plan to represent the lines on the ground on which the ranging pole was positioned.
 - 9.3 Superimpose on each line the points at which each set of ranging pole measurements were taken.
 - 9.4 Plot the points recorded during the assessment for each position of the ranging pole.
 - 9.5 Shade the areas on the completed plots that represent regions on the ranging pole that the 'observer' was unable to see. These areas of shading depict 'blind spots', i.e. those areas close to the machine that drivers would be unable to see without, for example, leaving the seat, leaning out of the cab, adopting adverse working postures, etc.

The basic procedures outlined above can be extended or refined to accommodate more in-depth assessments.

Two examples of a sight line assessment using this method of analysis are given below.

Example 1. Sight line assessment of an LHD



Side plots for this machine are shown in Figure A5.1. Since it was the operator's downward field of vision that was most restricted, the assessment was undertaken from the 5th percentile eye height position. From such a plot it is possible to assess whether recommendations for the operator's critical visual requirement are met. For instance, one critical visual requirement identified for LHDs is:

“Workmen and obstacles to the front, to the rear and in close proximity to the pivot point of the vehicle, and at each side of the bucket or load”

To evaluate compliance with this requirement with regard to the presence of workmen, lines have been superimposed on the plots that represent the height of a South African mineworker of 5th percentile stature, adopting both stooped and erect postures. The plots clearly show the regions where small operators would experience difficulties in detecting the presence of such workers who adopt these postures.

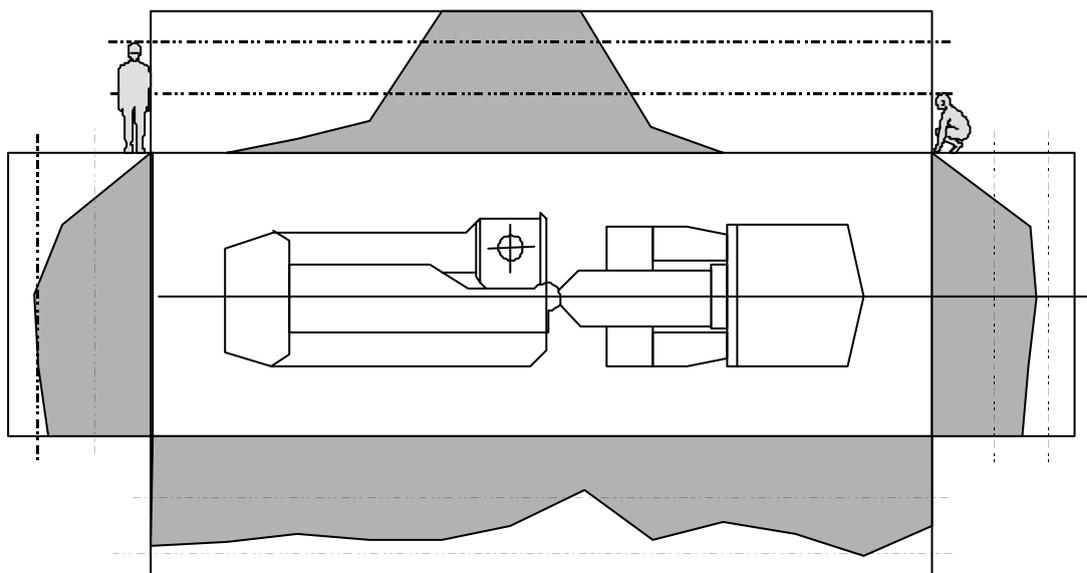
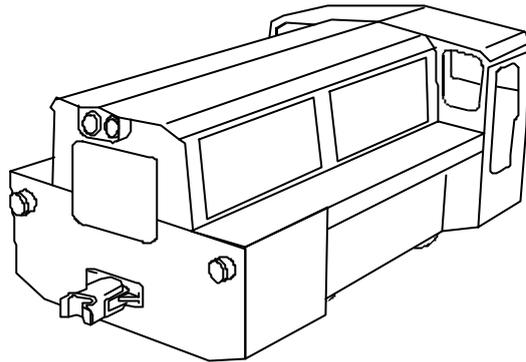


Figure A5.1. Sight line assessment of an LHD using side plots

Example 2. Sight line assessment of a locomotive



Side plots for this machine are shown in Figures A5.2 and A5.3. This type of loco has a single two-man cab at one end, with a swivelling seat to enable drivers to always face the direction of travel. It was therefore necessary to carry out two sight line assessments, one for each direction of travel. Figure A5.2 shows side plots for an assessment conducted with the engine trailing, and Figure A5.3 is the corresponding assessment undertaken with the engine leading. Again, lines representing the 5th percentile stooping and erect South African mineworker have been superimposed on the plots to provide a means of examining the machine in relation to the operator's critical visual requirements.

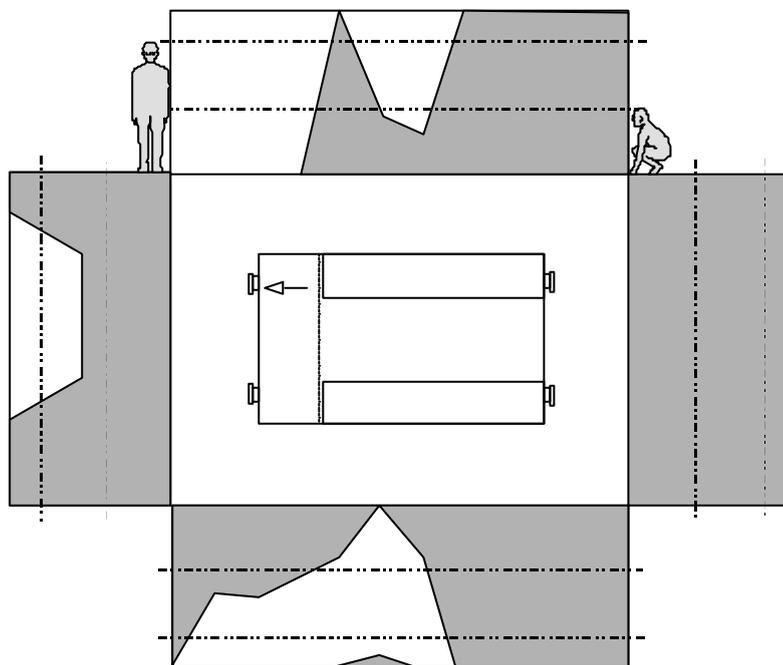


Figure A 5.2 Sight line assessment of locomotive (Engine trailing/pushing)

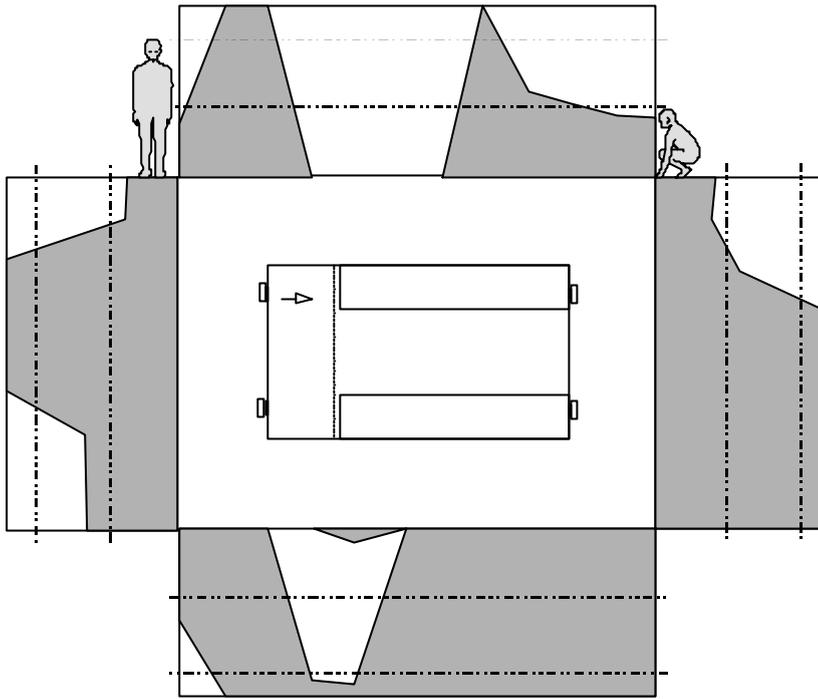


Figure A5.3 Sight line assessment of locomotive (Engine leading/pulling)