Mine Health and Safety Council

MHSC

FINAL REPORT

PROPOSED ILLUMINATION GUIDELINES FOR EQUIPMENT OPERATING IN THE SOUTH AFRICAN MINING INDUSTRY (SAMI)

Project	|	SIM 160701 – Developing Minimum Illumination Standards for Mobile Equipment Operating in Open Pit and Underground Mines in the SAMI
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%	:	Percentage
Φ	:	Incident luminous flux
ρ	:	Diffuse reflectance
$\geq$	:	Larger than or equal to
$\leq$	:	Smaller than or equal to
$\Phi_{e,\lambda}(\lambda)$	:	Spectral Power Distribution
Φ_v	:	Total Luminous Flux
$\mathbf{f_1'}$	:	General V(λ) Mismatch Index
<	:	Smaller than
>	:	Larger than
A	:	Surface Area
cd	:	Candela
CIE	:	International Commission on Illumination
CM	:	Continuous Miner
DGMS	:	Directorate General of Mines Safety (India)
DMR	:	Department of Mineral Resources
DPM	:	Diesel Particulate Matter
E	:	Illuminance
E_v	:	Photopic Illuminance
FEL	:	Front End Loader
H	:	Horizontal
HR	:	Human Resources
I(θ)	:	Luminous Intensity Distribution
kph	:	Kilometres per hour
L_{ave}	:	Average Luminance
LDV	:	Light Duty Vehicle
LED	:	Light Emitting Diode
LHD	:	Load Haul Dumper
LOS	:	Line of Sight
m	:	Metre
m^2	:	Square Metre
MHSA	:	Mine Health and Safety Act
MHSC	:	Mine Health & Safety Council (South Arica)
MPV	:	Multi-Purpose Vehicle
nm	:	Nanometre
NSW	:	New South Wales (Australia)
NUM	:	National Union of Mineworkers
NUMSA	:	National Union of Metalworkers South Africa
O/C	:	Open Cast
OEM	:	Original Equipment Manufacturer
OH	:	Occupational Hygiene
OHSA	:	Occupational Health and Safety Act
PGM	:	Platinum Group Metals
PPE	:	Personal Protective Equipment
R(λ)	:	Relative Detector Responsivity
SABS	:	South African Bureau of Standards
SAMI	:	South African Mining Industry
SANS	:	South African National Standard
SD	:	Stopping Distance

4 LIST OF ABBREVIATIONS (continued)

Si	:	Silica
SIMRAC	:	Safety in Mines Research Advisory Committee
SPD	:	Spectral Power Distribution
TMM	:	Trackless Mobile Machinery
U/G	:	Underground
UASA	:	United Association of South Africa
V	:	Vertical
V(λ)	:	Spectral luminous efficiency function
VAT	:	Value Added Tax

5 OVERALL PROJECT SUMMARY

The overall project summary is shown in Table 1.

Table 1: Overall Project Summary

What was planned for the Milestone?	Was it achieved?	Any deviations?
Milestone 1 Project initiation	✓	*none*
Milestone 2 Literature Review of South African and international illumination requirements and practices for mining mobile and fixed equipment in underground and open pit mines	✓	*none*
Milestone 3 Define illumination levels that will meet the requirements for safe open pit and underground mining operations	✓	*Submitted +-3 weeks ahead of schedule*
Milestone 4 Develop an assessment tool for evaluating the effectiveness of illumination requirements and practices	✓	*Submitted >3 weeks ahead of schedule*
Milestone 5 Mine Visits	✓	*none*
Milestone 6 Identify and rank any shortcomings arising from the mine visit evaluations	✓	*Shortcomings not ranked*
Milestone 7 Develop minimum illumination standards	✓	*none*
Milestone 8 Highlight applicable aspects of illumination	✓	*Revised report based on workshop outcomes submitted*
Milestone 9 Conduct workshops in Gauteng, North West, Limpopo and Mpumalanga with subject matter experts and stakeholders to critique the draft minimum standards	✓	*none*
Milestone 10 Draft Final Report (submission)	✓	*none*
Milestone 11 Final Report (submission)	✓	*none*

6 EXECUTIVE SUMMARY

The main aim of this report is to provide a guideline on illumination standards, practices, principles and applicable aspects for equipment operating in underground and surface mining operations in the South African Mining Industry (SAMI). The contents of the guideline were developed throughout the project, through (amongst others) consulting and disseminating various information sources on the topic; conducting mine site visit evaluations and identifying key shortcomings; developing a first draft of the guideline; and engaging with key stakeholders through workshops for them to critique the draft guideline.

The guideline comprises of six main sections, and addresses mining illumination from the perspective of equipment, the surrounding environment and the people within this environment. The six main sections of the guideline are as follows:

- Illumination levels;
- Illumination Design Practices and Principles;
- Glare Control Practices and Principles;
- Colour Contrast Practices and Principles;
- Reflectance Practices and Principles; and
- Maintenance Practices and Principles.

In order to avoid repetition of information already presented in previous milestone reports, this report provides an overview of the project, summarising the preceding milestones/phases to provide sufficient context for interpretation of the guideline.

Supporting Documents:

Please note that this report should be considered in the context of (and in relation to) the work that preceded the work contained within this report. The previous milestone reports and project terms of reference are available for download below (ensure that an internet connection is active when clicking on the links):

- *Project Terms of Reference*
- *Milestone 1 Report*
- *Milestone 2 Report*
- *Milestone 3 Report*
- *Milestone 4 Report*
- *Milestone 5 Report*
- *Milestone 6 Report*
- *Milestone 7 Report*
- *Milestone 8 Report*
- *Milestone 9 Report*

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7 OVERALL PROJECT AIMS AND OBJECTIVES

The overall project aims and objectives can be seen in Table 2, as per the original project proposal.

Table 2: Overall Project Aims and Objectives

WHAT ARE THE EXPECTED RESEARCH OUTCOMES	▪ Literature review of South African and international illumination practices for mining mobile and fixed equipment in gold, platinum, diamond and coal. ▪ Definition of illumination levels for safe open pit and underground operation in gold, platinum, diamond and coal. ▪ Assessment tool for evaluating the effectiveness of illumination requirements and illumination practices for open pit and underground mining operations in gold, platinum, diamond and coal. ▪ Surface and underground mine visits ▪ Ranked list of shortcomings from mine visits ▪ Minimum illumination standards for mobile and fixed equipment operating in gold, platinum, diamond and coal open pit and underground mines. ▪ Most prominent aspects of illumination applicable to gold, platinum, diamond and coal open pit and underground mining operations. ▪ Workshops on findings
HOW WILL THE RESEARCH OUTCOMES IMPROVE HEALTH AND SAFETY IN SOUTH AFRICAN MINING INDUSTRY?	It is envisioned that the outcomes of this research could lead to improved illumination standards and practices in the SAMI. This, in turn, could lead to a reduction in machine-related incidents (where sub-standard illumination levels were a root cause of the incident) in the SAMI. The research outcomes could assist in achieving the MHSC's zero harm vision.
HOW SHOULD THE RESEARCH OUTCOMES BE IMPLEMENTED?	The research outcomes should be made available to all South African gold, platinum, diamond and coal mines to encourage them to assess their illumination levels and determine whether they are within standards. The outcomes should also be made available to other commodity mines to serve as a reference. Furthermore, outcomes should be made available to equipment manufacturers to provide them with valuable insights for enhancing their designs to specifically cater for the SAMI.
NAME THE CHAMPION MINE (S) THAT WILL BE USED IN THIS RESEARCH	Underground PGM Mine A; Underground Gold Mine B; Underground Coal Mine C; Underground Diamond Mine D; Surface Coal Mine E; Surface Hard-Rock Mine F. Confidentiality agreements prevent naming of the mines.

8 PROJECT SCHEDULE

Figure 1: Project Gantt Chart

	Milestone	May 2017	Jun 2017	Jul 2017	Aug 2017	Sep 2017	Oct 2017	Nov 2017	Dec 2017	Jan 2018	Feb 2018	Mar 2018	Apr 2018	May 2018	Jun 2018	Jul 2018	Aug 2018	Sep 2018	Oct 2018	Nov 2018	Dec 2018	Jan 2019	Feb 2019	Mar 2019	Apr 2019
1	Project initiation	■																							
2	Literature Review of South African and international illumination requirements and practices for mining mobile and fixed equipment in underground and open pit mines	■	■	■	■																				
3	Define illumination levels that will meet the requirements for safe open pit and underground mining operations					■	■																		
4	Develop an assessment tool for evaluating the effectiveness of illumination requirements and practices							■	■																
5	Mine Visits									■	■	■	■	■											
6	Identify and rank any shortcomings arising from the mine visit evaluations										■	■	■	■	■										
7	Develop minimum illumination standards											■	■	■	■	■	■	■	■						
8	Highlight applicable aspects of illumination												■	■	■	■	■	■	■	■					
9	Conduct workshops in Gauteng, North West, Limpopo and Mpumalanga with subject matter experts and stakeholders to critique the draft minimum standards																				■	■	■		
10	Draft final report (submission)																							■	
11	Final report (approval)																							■	■

9 PROJECT FINANCES

Table 3: Project Finances

No.	Milestone	Milestone Timelines Start	End	HR Costs	OPEX	Sub-contractor costs	Capital costs	Total (Rands) (excl. VAT)
1	Project initiation	*05/17*	*05/17*	147 198		-	-	147 198
2	Literature Review of South African and international illumination requirements and practices for mining mobile and fixed equipment in underground and open pit mines	*05/17*	*08/17*	187 200		-	-	187 200
3	Define illumination levels that will meet the requirements for safe open pit and underground mining operations	*09/17*	*10/17*	141 600		-	-	141 600
4	Develop an assessment tool for evaluating the effectiveness of illumination requirements and practices	*11/17*	*12/17*	129 600	**-**	**-**	**-**	129 600
5	Mine Visits	*01/18*	*05/18*	154 773	106 380	-	-	261 153
6	Identify and rank any shortcomings arising from the mine visit evaluations	*02/18*	*06/18*	81 000	-	-	-	81 000
7	Develop minimum illumination standards	*03/18*	*10/18*	61 800	-	-	-	61 800
8	Highlight applicable aspects of illumination	*04/18*	*11/18*	42 600	-	-	-	42 600
9	Conduct workshops in Gauteng, North West, Limpopo and Mpumalanga with subject matter experts and stakeholders to critique the draft minimum standards	*12/18*	*02/19*	199 050	-	-	-	199 050
10	Draft final report (submission)	*03/19*	*03/19*	73 599				73 599
11	Final report (approval)	*03/19*	*04/19*	147 198				147 198
Total				**1 365 600**	**106 380**	**-**	**-**	**1 471 980**

10 RESULTS

This report is presented across eight separate sections, as shown in Figure 2.

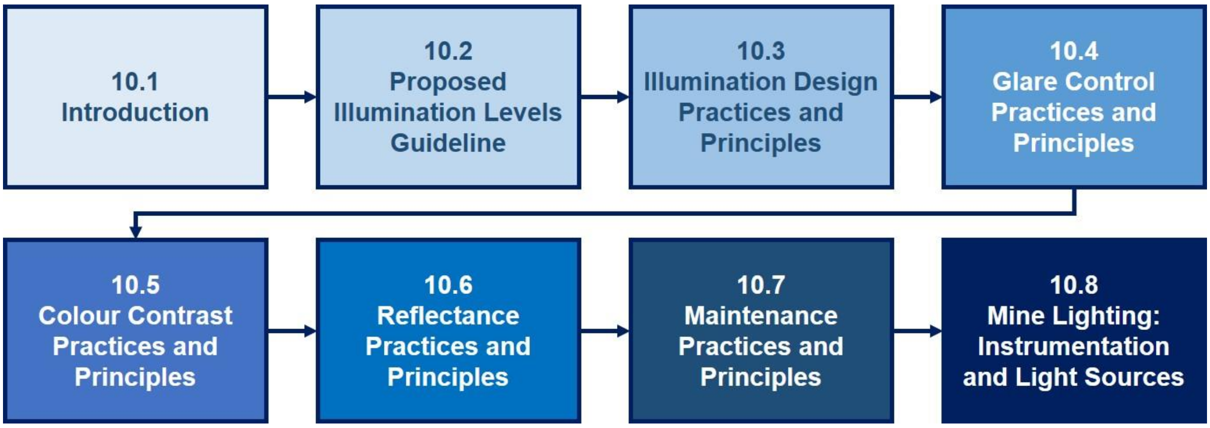

Figure 2: Results Overview

10.1 INTRODUCTION

The main aim of this report is to provide a guideline on illumination standards, practices, principles and applicable aspects for surface and underground mining operations in the SAMI. In order to avoid unnecessary repetition of information already presented in previous reports, this report provides an overview of the project, summarising the preceding milestones/phases. This provides sufficient context in order to interpret the guideline.

10.1.1 Project Overview

The project overview has been divided into seven separate sections, aligned to the expected outcomes/milestones of the project (as stated in the project terms of reference). Figure 3 provides an overview of the seven sections, where after each section will be discussed – focusing on providing summaries of what was achieved; conclusions made after each phase/milestone; and recommendations made after each phase/milestone. Furthermore, a link to an online soft copy of the applicable approved MHSC milestone report per section is provided, such that additional information can be perused through the detailed reports.

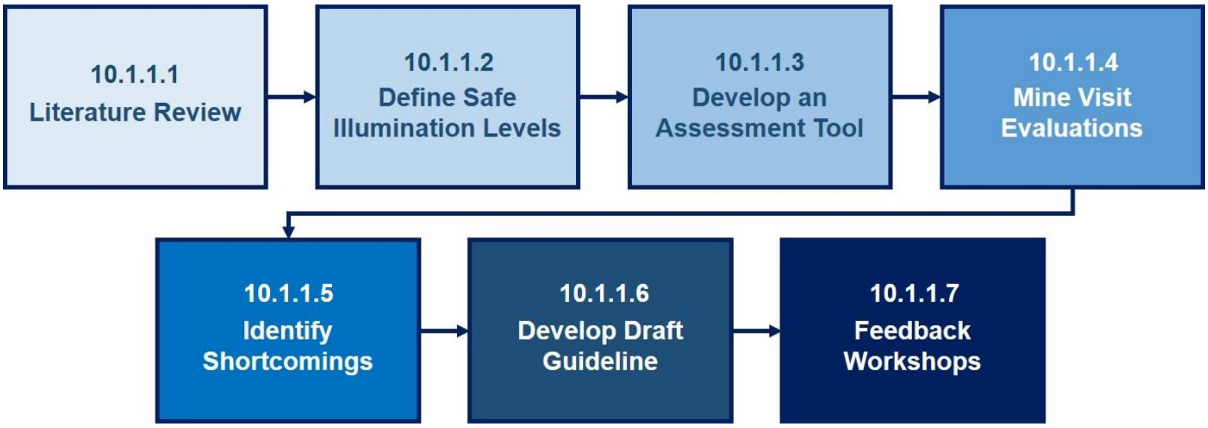

Figure 3: Project Overview Main Phases/Milestones

10.1.1.1 Literature Review

The aim was to conduct a literature review of South African and international illumination practices for mobile and fixed equipment used in mining and operating in underground and surface mines. The project team made the decision to widen the scope for this milestone, to also include extensive information with regards to illumination in general, and illumination in mining environments (not limited to equipment only). The reason for this was to ensure an enhanced understanding of the subject matter.

The literature review focused on the following main aspects:

- Basics of Luminance Vision
- The Visual Environment
- Impact of Lighting on Health and Safety
- Illumination requirements, standards & practices (South Africa)
- Illumination requirements, standards & practices (International)
- Other relevant guidelines
- Visibility standards
- SIMRAC project COL 451: Assessment of World-wide Illumination and Visibility Standards in Coal Mines
- SIMRAC project GAP 804: Role of illumination in reducing risk to health and safety in South African gold and platinum mines
- Technical Comments on COL 451 and GAP 804

In terms of illumination standards, practices and principles, information was obtained from the following mining countries: South Africa; USA; India; United Kingdom; Australia; Canada; Russia; Belgium; Czech Republic; Germany; Hungary; Poland; France; Italy; Sweden; Romania; European Coal & Steel Community. In addition, relevant global information was perused. The information presented and disseminated during the literature review was used, in large, to guide the project going forward. For further information, the detailed literature review can be consulted in the Milestone 2 Report.

The key conclusions from the literature review were as follows:

- Adequate or "good" illumination (as a whole – not limited to only equipment), in general, holds several benefits for the mining industry. Adequate illumination levels and practices could improve health, safety and productivity on mines. Arguably, these benefits could be achieved at the fraction of the cost of other interventions.
- Illumination systems on mines basically comprise of two main components – static lighting and dynamic lighting. Static lighting refers to permanent light installations (e.g. fixtures in haulages or lamp poles on haul roads) and dynamic lighting refers to worker cap lamps or lights on equipment.
- Although the scope of this project was limited to developing minimum illumination standards and practices for mobile and fixed equipment, it was found to be important to consider both static and dynamic lighting. The reason for this was simple – illumination standards and practices for equipment will be dependent on (and influenced by) the illumination levels and practices in the surrounding environment. The surrounding environment (in this context) refers to the area/s where the mobile and fixed equipment operates and performs activities in.
- The illumination "best practices" discussed in the literature review (both for South Africa and internationally) amplified the need for more informed and prescriptive illumination guidelines to be developed for mobile and fixed equipment in the SAMI. In general, it was found that there are common "trends" in the levels and practices, but large gaps still exist in terms of consensus and uniformity. This is especially true of mobile and fixed equipment – most of the information found through research focused only on static areas in mining.
- The extensive review of lighting basics; light in general and factors affecting a visual environment identified the necessary factors to consider in conducting the rest of the project. Factors such as glare, reflectance, refraction, absorption, transmission and line of sight (LOS) (amongst many others) will play a key role in not only developing a more informed approach to achieving the main objectives but also in distinguishing differences in requirements across different mining methods and commodities.
- A further realisation was made whilst research was conducted. The previous SIMRAC projects – COL451 and GAP804 – eluded to one of the key problem areas being LOS (in terms of equipment). The reality is that, irrespective of illumination levels, LOS will still pose a challenge (for the sake of getting the point across, consider blind-spots in normal road-going vehicles. Accidents due to blind-spots occur during broad daylight where illumination is essentially as good as it gets). Thus, LOS is a factor affecting the visual environment that will not be solved by increasing illumination levels - It is a machine design issue.
- Lastly, it was concluded that the literature research conducted would be of great value to the succeeding project milestones.

The key recommendations from the literature review were as follows:

- The information related to illumination levels, standards and practices should be analysed in depth in order to define preliminary "safe" levels that will meet the requirements for underground and surface mines. The technical light-related information contained in the literature review should be considered in defining these safe levels, as well as developing an assessment tool for the mine visits.

- The methodologies for assessment contained within the COL 451 and GAP 804 reports should be used as a basis in developing an assessment tool.

10.1.1.2 Define safe illumination levels for open pit and underground mining operations

The main objective was to define illumination levels, from the information gathered in the literature review, that would meet the requirements for safe surface and underground mining operations. Through the research work conducted during the literature review, it was noted that the objective was somewhat problematic in nature. Prescribed illumination levels (in lux) are essentially meaningless when considered in isolation. To provide meaning to these levels, they need to be combined with standards and best practices within an all-encompassing illumination system/framework. Thus, the approach taken in order to best achieve the main objective, was to develop an all-encompassing equipment illumination framework.

Taking this into account, the objective was addressed in full through the following four main areas:

- Surrounding environment recommended illumination levels for underground and surface mines.
- Mobile and fixed equipment recommended illumination levels for equipment operating in underground and surface mines.
- General equipment illumination "best practices".
- Safe equipment illumination framework.

In conclusion, a "safe" illumination level for mobile equipment (surface and underground) was produced, as well as additional prescribed levels for individual equipment (mobile and fixed). It was also concluded that the safe equipment illumination framework would serve as a sound foundation for the remainder of this project, and it was recommended that this framework be converted into a tool format, to be used for the mine visits and assessments. For further information, the detailed "safe" illumination levels and safe equipment illumination framework can be consulted in the Milestone 3 Report.

The key conclusions on defining "safe" illumination levels were presented in five main parts, namely:

- Surrounding Environment Illumination Levels;
- General Mobile Equipment Illumination Levels;
- Specific Mobile Equipment Illumination Levels;
- Specific Fixed Equipment Illumination Levels; and
- Equipment Illumination Safe Framework.

Surrounding Environment Illumination Levels

The surrounding environment illumination levels presented for surface mines and for underground mines served as a good starting point for the mine visits. They provided a sound foundation and understanding of what illumination levels should be like in the surrounding environment.

General Mobile Equipment Illumination Levels

In terms of the general lux recommendations for mobile equipment on surface mines, the illumination levels recommended by the IFC (2007), DMR (2015a) and the NSW Department of Primary Industries (1995) all incorporated equipment stopping distance within their lux level recommendations. This was found to be problematic – stopping distance is dependent on travelling speed, terrain and braking power/effectiveness. The recommended lux levels from the DMR (2015b) incorporate an actual distance, which is also subject to the same problem.

The NSW Department of Primary Industries (1995)'s recommended illumination levels make use of distance from the operator eyes. Additionally, they prescribe at which height the levels should be met.

The DGMS (India) (2016)'s recommended levels for working places of heavy machinery makes use of both horizontal and vertical prescribed lux levels. However, these recommended levels are not for light from equipment headlights, but rather for the surrounding environment.

In terms of the general lux recommendations for mobile equipment in underground mines, the above-mentioned points also apply. There are some slight differences in the recommended levels, but in essence, they are the same. This makes sense – in terms of recommended lux levels, it does not matter whether the mobile equipment is underground or on surface. Although different influencing factors exist in the different environments, equipment in an underground mine is essentially the same as equipment on a surface mine during night time.

Specific Mobile Equipment Illumination Levels

No specific recommended lux levels were found for mobile equipment operating on surface mines. For underground mines, several specific recommendations were found through research. Relevant recommended levels found were as follows:

- LHD (hard rock): 10 lux
- LHD (coal): 10 lux at 20m away from LHD
- Locomotive (hard rock): 20 – 60 lux at 1.5 times stopping distance
- Locomotive (hard rock): 10 lux at 20m away from Locomotive
- LDV (coal): 10 lux at 20m away from LDV
- Grader (coal): 10 lux at 20m away from Grader
- MPV (coal): 10 lux at 20m away from MPV
- Tractor (coal): 10 lux at 20m away from Tractor
- CM & Roadheader (coal): 20 lux at coalface, 10 lux at 5m away from CM
- Roofbolter: 10 lux at 20m away from Roofbolter
- Shuttlecar: 10 lux at 20m away from Shuttlecar

It must be noted that several of the above recommended levels included recommendations for when the equipment is reversing. These were not included, as the "best practice" is to apply the same levels to both ends of the equipment.

Specific Fixed Equipment Illumination Levels

The illumination levels prescribed for fixed equipment on surface mines essentially refer to the surrounding environment. Relevant recommended levels were found to be as follows:

- In pit crusher: 50 lux, measured horizontally
- In pit feeder breaker: 40 lux, measured horizontally
- Conveyor belt transfer points: 40 lux, measured horizontally
- Along conveyor belt: 20 lux, measured horizontally

The illumination levels prescribed for fixed equipment in underground mines also essentially refer to the surrounding environment. Relevant recommended levels were found to be as follows:

- Winches (hard rock): 20 – 27 lux
- Conveyor belt transfer points: 40 lux, measured horizontally
- Along conveyor belt: 20 lux, measured horizontally
- Chain Haulage System (coal): 15 lux across full heading profile
- Mono Ropes (hard rock): 50 lux

Equipment Illumination Safe Framework

It was concluded that the safe equipment illumination framework presented would serve as a sound starting point in reaching the ultimate objective of this research project. Although several gaps still exist, this framework would be refined and populated as the project progressed.

The key recommendations on defining “safe” illumination levels were that the work conducted should be used to develop the assessment tool, to be used for the mine visits. More specifically, the safe equipment illumination framework should be converted into a format where it forms the basis of the assessment tool.

10.1.1.3 Develop an assessment tool for evaluating the effectiveness of illumination requirements and practices

The main aim was to develop an assessment tool (based on the defined safe illumination levels) for evaluating the effectiveness of illumination requirements and illumination practices for open pit and underground mining mobile and fixed equipment across various commodities

Various illumination levels were developed by reference to the literature for mobile equipment, fixed equipment and the surrounding environment for underground and surface mines. Additionally, equipment illumination standards and best practices were suggested, where after a safe equipment illumination framework was developed. This framework, in turn, was used to develop the assessment tool/approach.

The assessment strategy comprised of several assessment templates that were developed, in order to observe, measure and document all relevant factors relating to the safe illumination of mobile and fixed equipment in underground and surface mining operations in the SAMI. For further information, the detailed assessment tool/approach can be consulted in the Milestone 4 Report.

The key conclusions on the assessment tool were as follows:

- It was found that the assessment "tool" is more of an assessment strategy/approach than a tool. This is due to the inherent complexity of "safe" equipment illumination on mines. A systems approach would be required in order to successfully conduct on-site assessments and the project team believed that the proposed "tool" or strategy presented would be suited to addressing this complexity by observing, measuring, documenting and assessing all factors relating to safe equipment illumination on mines.
- The proposed assessment strategy represented, from a theoretical perspective, the ideal approach/strategy. However, it must be noted that "theoretically ideal" does not always translate to "practically ideal". Thus, the strategy was to be modified as the real-life assessments commenced, in order to better address the eventual outcomes of the project and mitigate any practical issues that may have been encountered.
- Lastly, it was concluded that the assessments to be conducted at the various mine sites (using the proposed approach/strategy), would be approached by the team using an "ab initio" approach. From the preceding literature research and the assessment thereof, it was clear that the area of equipment illumination needed more comprehensive standards, practices and requirements. Thus, the team would not attempt to measure compliance to existing standards, practices and requirements, but rather aim to create new, more comprehensive and practical standards, practices and requirements.

The key recommendations on the assessment tool were as follows:

It was recommended that the assessment approach defined and discussed, along with the templates developed, should be used to conduct the assessments at the various planned mine visits. Furthermore, it was recommended that the first mine visit (and the results thereof) should be used to refine and optimise the general assessment approach and templates, in order to streamline the approach for the further visits. Lastly, it was recommended that the processing of the data obtained from the mine visits should start as soon as individual visits finished – in essence, following a batch approach.

10.1.1.4 Mine Visit Evaluations

The aim of the mine visit evaluations was to measure equipment-related illumination levels, and observe all standards, practices, principles and applicable aspects relating to the equipment visual environment. A total of six mine visits were conducted at the following types of mines:

- Underground conventional gold mine;
- Underground mechanised platinum group metals (PGM) mine;
- Underground bord-and-pillar mechanised coal mine;
- Underground block caving diamond mine;
- Surface open-cut coal mine; and
- Surface open pit hard-rock mine.

Cumulatively across all the visits a total of 36 classes of mobile/fixed equipment were observed and/or measured (using both a lux meter and an illuminance meter). Several mine sites had the same type of class of equipment, leading to (in some cases) more than one sample per class. Due to this, a total of 58 individual pieces of mobile/fixed equipment were subjected to observations and/or measurements. For further information, detailed results from the mine visits can be consulted in the Milestone 5 Report.

The key conclusions regarding the mine visits were as follows:

- The mine visits were conducted successfully, despite several challenges encountered in the arranging of the visits.
- Several “trends” were identified, and the team believed that there may be an opportunity for “quick-win” illumination recommendations, that would undoubtedly improve the visual environment at a fractional cost.

The key recommendations following the mine visits were as follows:

It was recommended that the data collected at the site visits should be used as inputs for succeeding milestones – and combined with literature from previous milestones – in order to achieve the goal of the project – zero harm due to a poor machine visual environment.

10.1.1.5 Identify and rank shortcomings arising from the mine visit evaluations

The aim of identifying and ranking the shortcomings from the site visit evaluations was to determine where potential gaps may be in the mining illumination “system”, as observed at the six mine sites that were visited. In order to achieve this main aim, the results from the mine visits were analysed in detail by the team, with the specific focus of improving the overall visual environment of equipment in mining operations.

The request as per the project terms of reference was to rank these shortcomings. This was found to be counterproductive in terms of the main aim of the project, as it was not possible to determine which shortcomings were more important than others (from a safety perspective). Each shortcoming could, in theory, result in either a non-fatal injury or fatal injury, so should be deemed equally important. Thus, the shortcomings presented were not ranked, but rather presented as a list for which mitigation measures were developed and included in the draft standards, practices, principles and applicable aspects.

Several practical and solvable shortcomings were identified. Pragmatic solutions and recommendations stemmed from the shortcomings identified, which would lead to the improvement of the equipment visual environment. For further information, the detailed shortcomings can be consulted in the Milestone 6 Report.

The key conclusions on the shortcomings were as follows:

- The results obtained from the mine visits were very useful in understanding the status quo on mine sites in terms of the visual environment. However, due to the relatively small sample size, the quantitative results could not be deemed as representative. This was unfortunate, but a reality. However, the qualitative results were not subject to the same fate.
- A number of issues relating to (directly or indirectly) the visual environment were identified during the mine visits, as well as in the analysis of the data. These issues would form the basis for the minimum illumination standards.

- A number of leading/good practices were also identified during the mine visits, as well as in the analysis of the data. As with the issues, these practices would form the basis for the minimum illumination standards.
- The shortcomings derived from the mine visit results were all factors that have a negative impact on the equipment visual environment and could lead to harm to employees. Thus, mitigation measures/root cause solutions would be developed to address these shortcomings in the illumination standards.
- Lastly, it was concluded that pragmatic solutions and recommendations would stem from the results discussed under the shortcomings and these would most definitely improve the equipment visual environment.

The key recommendations on the shortcomings were as follows:

It was recommended that the results from the mine visit evaluations be used to develop the minimum illumination standards, practices and principles.

10.1.1.6 Develop draft minimum illumination standards, practices and principles and highlight applicable aspects based on differences in commodity, mining method and surface/underground operations

The aim was to develop illumination standards, practices and principles for equipment operating in the South African mining industry. The standards, practices and principles that were developed were mostly generic, presented across six dimensions, each representing an aspect of the safe mining illumination framework:

- Proposed Equipment Illumination Levels;
- Illumination Design Practices and Principles;
- Glare Control Practices and Principles;
- Colour Contrast Practices and Principles;
- Reflectance Practices and Principles, and
- Maintenance Practices and Principles.

Furthermore, the aim was to highlight applicable aspects of mining illumination in the context of the standards, practices and principles proposed. These applicable aspects were highlighted by noting potential exceptions to the norm, based on differences between underground and surface operations; different commodities; mining methods; layouts; and other factors. The potential exceptions were categorised in table format according to the six main mining illumination dimensions. For further information, the detailed draft standards, practices and principles can be consulted in the Milestone 7 Report, and the applicable aspects can be consulted in the Milestone 8 Report.

The key conclusions on the illumination standards, practices, principles and applicable aspects were as follows

- It was concluded that the illumination standards, practices and principles proposed comprehensively represent the best practices, standards and principles of a “safe” equipment illumination environment. Furthermore, it was envisioned that the adoption thereof would lead to a safer operating environment at mine site.

- It was concluded that the proposed standards, practices and principles were in the first draft phase, and would be modified based on the stakeholder feedback at four different workshops.
- The applicable aspects/exceptions represented the main factors that may require potential deviations from the illumination standards, practices and principles proposed. At the time concluding the work on the applicable aspects, the work conducted throughout the project had reached a point where it was in need of being presented to a wider audience of relevant stakeholders in the SAMI, in order to obtain their inputs and feedback.

The key recommendations on the illumination standards, practices, principles and applicable aspects were as follows:

It was recommended that the standards, practices, principles and applicable aspects should be treated as a draft and should be updated based on the critique from the workshops. Thereafter, the standards, practices, principles and applicable aspects should be updated and modified based on the workshop outcomes, and then presented in the draft final report.

10.1.1.7 Conduct workshops to critique the draft minimum standards, practices, principles and applicable aspects

The aim of the workshops was to present the draft minimum standards, practices, principles and applicable aspects to relevant mining industry stakeholders, in order to obtain feedback and critique on the abovementioned project outcomes.

The workshops were successfully completed in the four provinces as prescribed in the project terms of reference, namely:

- 31 January 2019: Mpumalanga (Emalahleni)
- 01 February 2019: Limpopo (Polokwane)
- 18 February 2019: North West (Rustenburg)
- 19 February 2019: Gauteng (Randfontein)

The following companies/organisations attended the workshops:

- Afrimat
- Afrisam
- Andalusite Resources
- Anglo American Platinum
- Anglogold Ashanti
- ARM Platinum
- Assmang
- Association of Mineworkers and Construction Union
- Barnel
- Benhaus Mining
- Black Wattle Colliery
- Chromex Mining
- CRONIMET Mining
- De Beers
- Department of Mineral Resources
- Diesel Power
- ESH Training & Development Services
- Exxaro
- GCC Engineers
- Glencore
- Golo Mining
- HECS Occupational Hygiene
- Hernic Ferrochrome
- Impala Platinum

- Induna Risk Managament
- Ingwenya Mineral Processing
- Ivanplats
- Kangra Coal
- Kinross
- Kuyasa Mining
- Lanxess
- Londani Coal
- Lonmin Platinum
- Madini Mining
- Mamba Cement
- Mbuyelo Coal
- Msobo Coal
- National Union of Metalworkers South Africa (NUMSA)
- National Union of Mineworkers (NUM)
- Northam Platinum
- P2 Mining RAK
- PMC
- RDC Consult
- Royal Bafokeng Platinum
- Samancor
- Sedibelo Platinum Mines Limited
- Seriti
- Sibanye-Stillwater
- South 32
- Sudor Coal
- Trollope Mining Services
- UASA
- Umoya VOHE Solutions
- Vaalbult Mining Company
- Village Main Reef
- Vunene Mining
- Wesizwe Platinum

The workshops were generally well attended (in terms of number of participants) and relevant feedback and critique was obtained. The written and verbal feedback received from the four workshops was used to revise the draft minimum standards, practices, principles and applicable aspects, and present it as a uideline to the MHSC in this report. For further information, detailed results from the workshops can be consulted in the Milestone 9 Report.

The key conclusions on the workshops were as follows:

It was concluded that the deliverable of conducting four workshops in the four different provinces (Gauteng, North West, Limpopo and Mpumalanga) in order to allow industry experts and relevant stakeholders to critique the work done by the team to date was successfully executed. Furthermore, it was concluded that the critique, inputs and feedback obtained from the workshops would have a positive impact on the final outcomes of the project and ensure that the final work presented by the team would be practically implementable and would create value in terms of health and safety on the South African mines.

The key recommendations following the workshops were as follows:

The feedback received during the workshops should be used to revise the proposed standards, practices and principles presented, as well as the applicable aspects presented.

10.2 Proposed Illumination Levels Guideline

In the mining illumination context, a sound visual environment benefits far more from implementing good illumination practices and principles, than it does from proposing minimum illumination levels. Furthermore, measurement of illumination levels with illuminance meters is becoming increasingly complex due to the increased use of LED luminaires (and hence the array of light spectrum wavelength variations) into the mining industry. Thus, the minimum levels proposed in this document are based on current global best practices on mines – but should not be considered as the "be-all" of mine illumination. Furthermore, it should be presented to the SAMI as a guideline – this was the consensus at the industry engagement workshops. Some equipment might comply with the minimum levels, but the overall visual environment may be poor. Other equipment might not comply with the minimum levels, but the overall visual environment may in fact be a safer one.

A summary of the proposed illumination levels for fixed and mobile equipment is shown in Table 4.

Table 4: Summary of Mobile and Fixed Equipment Illumination Standards

	Measurement	Illuminance Level	Condition
Mobile Equipment	10 lux	Measured 1m off the ground, at three points 20m away from equipment Measured vertically towards equipment	All three points should be more than 10 lux.
Fixed Equipment	50 lux	Measured 1m off the ground, at points of potential interaction (man – machine) Measured horizontally and vertically	At least three of the five (H x 1 and V x 4) should be equal to or more than 50 lux.

10.2.1 Mobile Equipment

In terms of mobile equipment, the general best practice for the global mining industry was found to be in the same range. From this, the proposed *measurable* standard for mobile equipment is as follows:

10 lux at 20m in front of equipment, in the direction of travel

The illumination measurement should be taken at three different points (at a height of 1m above the floor, or in line with the operator's visual attention line of sight), and all points should either meet or exceed the 10 lux requirement. The three points are shown in Figure 4.

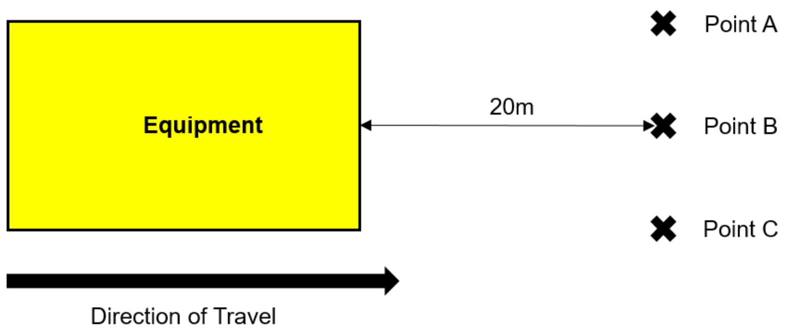

Figure 4: Plan View of Mobile Equipment Illumination Measurement Points

The measurements should be taken by making use of a standard illuminance meter in a vertical position, directly facing the equipment. When taking the measurements, the equipment lights should be the only source of light. There should be no interference from environment lights or caplamps.

10.2.2 Fixed Equipment

The proposed measurable standard for fixed equipment is as follows:

50 lux at points of interaction around the fixed equipment.

The illumination measurement should be taken at all points of potential interaction (e.g. A typical example of a point of interaction is around the grizzly by a rock-breaker) (personnel – machine; machine to machine). At each point, the measurement should be taken at 1m above floor level, in five different directions (as illustrated in Figure 5).

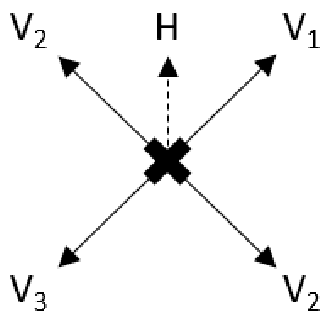

Figure 5: Vertical and Horizontal Measurement Directions

At least three of the five measurements shown in Figure 5 should be equal to or more than 50 lux.

10.2.3 Additional Considerations

- **Standard on light type vs. illumination levels**: A key consideration is that the standard should rather be placed on the type of light, and not the illumination levels. Thus, equipment can be equipped with lights with specific specifications and measured at the source and not in front of the equipment.
- **Taillights visibility**: Red tail lights should ideally be visible/distinguishable at 40m away from the equipment.
- **Frequency of Measurements**: Based on risk assessment, mines should determine the required frequency of illumination measurements.

10.2.4 Applicable Aspects

Table 5 displays the applicable aspects in terms of differences between underground and surface mines, and Table 6 displays the applicable aspects in terms of differences in commodity, orebody, mining method or other factors.

Table 5: Illumination Levels Applicable Aspects based on Differences between Underground and Surface mines

Dimension	Applicable Aspect
Mobile Equipment Section 10.2.1.1 *Fixed Equipment Section 10.2.1.2*	Potential exceptions proposed based on: **Weather conditions:** Foggy, misty and/or rainy conditions on surface, not encountered underground. **Natural lighting:** Natural lighting on surface during daytime, and cyclical nature of light levels (daytime/night time). **Daytime/Night-time transition periods:** Dawn and dusk periods on surface create a window of sub-optimal lighting where the contrast with the natural light renders artificial light ineffective. **Impact of different seasons on lux levels on surface**: Different seasons will play a role in the time that lux measurements are taken due to differences in ambient light levels.

Table 6: Illumination Levels Applicable Aspects based on Differences in Commodity, Orebody, Mining Method or Other Factors

Dimension	Applicable Aspects
Mobile Equipment Section 10.2.1.1 *Fixed Equipment Section 10.2.1.2*	Potential exceptions proposed based on: **Dust Levels:** Visibility will differ based on the dust and/or fog levels in or on the mine. In turn, dust levels are influenced by the rock type, rock properties, air velocity (or wind on surface mines), hydrogeology, humidity, location of dust sources (on surface mines) and dust mitigation systems (e.g. a diamond mine's inherent dust levels will be higher than a coal mine due to dry mining taking place. Although it must be noted that this can be adequately mitigated through using the correct dust mitigation measures). **Mining Method & Layout:** The dimensions of operational areas/working areas, mine layout, mining method and other method-specific aspects may require exceptions to lighting design. **Orebody Geometry:** Rolling or undulating ground conditions that cause uneven floors in turn impact light distribution and the effectiveness of operator sight in travelling equipment. **Risk Assessment:** Risk assessment should play a key role in the lighting design and the proposed minimum illumination levels, according to the type of equipment, activity and the environment in which it operates. **Indicator lights – LHDs:** No indicator lights should be used on LHDs as it is impractical. **Emergency lights**: Should not be applicable on all underground equipment as operators have caplamps to allow for safe egress during emergency. **Protective covers:** Impractical on trackbound equipment underground. **Number of taillights**: Certain surface haul trucks make use of one centre light (due to the equipment design). This is impractical to change to two. **LDVs roadworthiness**: LDVs need to also be roadworthy, thus adjusting their light design may impact roadworthiness. **Environmental operating height/width**: The nature of the mining operation (e.g. low profile, ultra-low profile) should determine the installation height of lights on equipment. **Bi-directional equipment**: Lux levels should be the same at the front and rear of equipment that is bi-directional. **Machine geometry**: Machines with different geometries will require different approaches to the physical measurement techniques used (e.g. roofbolter will require a different measurement approach as it mostly illuminates the hanging wall and not in front of the equipment). Size of equipment: The proposed measurement point of 1m above the floor will not necessarily work for large equipment (e.g. with a CAT 349 haul truck the operator cabin is as high as 4m from the floor). **Ergonomics**: Design of lighting should consider individual machine ergonomics.

10.3 Illumination Design Practices and Principles

10.3.1 Equipment Design Practices and Principles

10.3.1.1 Equipment Illumination Design Criteria (Mobile)

Headlights/Taillights

- At least two headlights/taillights on each end of mobile equipment should be present. The number of headlights/taillights can be increased if an adequate beam spread is not obtained with only two lights, or if increased illumination is required for production purposes. Based on risk assessment, consideration should be given to installing four headlights/taillights (where applicable), so that if one headlight/taillight stops working, there is still adequate lighting available temporarily. Where equipment design prevents this from being possible (e.g. large haul trucks on surface mines), secondary visibility measures should be considered.
- For mobile equipment, headlights/taillights should be integrated/interlinked to the direction of travel. As a result, the lights should automatically show bright white light in the direction of travel, and lower intensity red lights at the trailing end. The red lights should be visible from a distance of at least 40m away from the equipment. When the direction control is in neutral, red taillights should appear at both ends if the engine is running. OEMs should supply the mines with specifications for the correct luminaire to use for this purpose.
- Headlights/taillights should be positioned (where possible) on the edges/corners of mobile equipment, in order to indicate the width (or extremities) of the equipment, specifically at the front and rear of the equipment. If this type of positioning is not possible, reflective measures should serve the purpose of indicating the full width of the equipment (e.g. large haul trucks on surface).
- Headlights/taillights on mobile equipment should be installed such that sufficient and unobstructed illumination over the range of movement of the equipment (or components thereof) is provided. Light beams should be unobstructed by equipment components and/or the surrounding work environment.
- Headlights/taillights should be positioned and angled such that the beam spread covers the full visual target area of the equipment. This is especially relevant on surface mines and in large excavations underground. The beam spread of a luminaire should be increased if the equipment frequently operates in large excavations, or for equipment on surface.

Indicator Lights

Mobile equipment should be fitted with direction indicating lights, both at the front and rear of the equipment, in order to indicate when the operator is about to make a turn.

Brake Lights

Mobile equipment exceeding speeds of 8 kph should be fitted with appropriate brake lights, in order to indicate when the equipment is slowing down/stopping.

Ancillary Lights

In certain cases, adjustable light units may be required for mobile equipment in order to illuminate areas/activities critical to safe operation (e.g. a roofbolter with an ancillary lighting extension to illuminate the roof/hanging wall during operation). This could be facilitated by the provision of extendible/adjustable mounting arrangements. The mountings should be easily set to the required angle, and they should be secure enough that no movement or loosening occurs during normal operation.

Additional lights to indicate the safe side of the line of the sight to pedestrians (e.g. green lights indicating “safe to walk”; red lights indicating “unsafe to walk”). The need for this should be determined based on risk assessment.

Warning System

Mobile equipment should be fitted with a “dual signalling” pre-start audible and visual alarm system, and this system should also function (if required) while the equipment is travelling/tramming.

Emergency Lights

Mobile and fixed equipment should be fitted with emergency lighting, in the case that the normal power supply and/or primary lights fail. These emergency lights should mitigate any potential hazards/risks of injury, such that the operator can safely egress, and the equipment remains visible to mine personnel.

Protective Covers

Headlights/taillights on mobile equipment should be provided with protective covers or 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.

Information Displays/Dials

For mobile equipment, all information displays/dials (e.g. speedometers) should be self-illuminating, in order to enable operators to interpret them without using a caplamp. Information displays should be in the form of signage/pictures, as text or numbers only impacts on the concentration of an operator while reading them.

10.3.1.2 Equipment Illumination Design Criteria (Fixed)

Fixed equipment should make use of additional static luminaires incorporated into the working area, to ensure that all points of potential interaction meet the 50 lux standard proposed in Section 10.1.1.2. The area where fixed equipment is operating (as well as the area and walkways around it) should follow the same lighting design approach as illuminating an area of high activity.

10.3.2 Environment Design Practices and Principles

Note that this document’s focus is on the mining illumination system from an equipment context and will thus only provide high-level recommendations in terms of environment lighting design.

10.3.2.1 Static lighting

It is recommended that static environment lights should either be LED or fluorescent luminaires. These should be spaced such that light output is distributed uniformly, and "dark spots" are not created between luminaires. In areas of high activity, the luminaire density should be increased in order to increase the general illumination levels. 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.

10.3.2.2 Portable lighting

Consideration should be given to the provision of portable lighting units in production areas where the provision of permanent lighting is impractical. LED luminaires are recommended in the case of portable lighting. 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 mine personnel. In the case of surface mines, high-mast lights should be considered for use in working areas.

10.3.3 Additional Considerations

- **Maintenance**: Lights and light installations on equipment should be designed so that maintenance is an easy and quick activity (in terms of replacing lights).
- **Involvement of OEMs**: Consultation with the OEMs should be done on the type of lights to be used at any type of mine and the effects on the lights due to the conditions underground (e.g. water and dust).
- **LDV Roadworthiness**: Special consideration should be given in terms of design to equipment such as LDVs that need to be roadworthy as well. Designs for LDVs should be such that the LDVs remain roadworthy, whilst satisfying the lighting requirements on the mine.
- **Shaft Cages**: Illumination inside the shaft cages should be considered.
- **Standards Committee**: A standards committee should be established for lighting-related procurement issues. This includes engineers; occupational hygienists; operators and health and safety representatives to point out the issues of concern before procurement (essentially an issue-based risk assessment). This early on identification of issues will in turn influence illumination design factors (e.g. light type, areas where lights are installed, etc.).
- **Environmental Control**: Reducing air pollutants such as dust is critically important to consider in equipment illumination design criteria. There should be a balance between the illumination design and environmental control.

10.3.4 Applicable Aspects

Table 7 displays the applicable aspects in terms of differences between underground and surface mines, and Table 8 displays the applicable aspects in terms of differences in commodity, orebody, mining method or other factors.

Table 7: Illumination Design Practices and Principles Applicable Aspects based on Differences between Underground and Surface mines

Dimension	Applicable Aspects
Equipment Section 10.3.1	Potential exceptions proposed based on: **Beam spread:** Wider beam spread of illuminated area around mobile equipment required for surface operations. **Equipment size differences:** Differences in size of equipment will require differences in lighting design, and additional factors to consider (e.g. flags/poles on LDVs and small equipment). **Operating speed:** Differences in travelling speeds and stopping distances of equipment.
Environment Section 10.3.2	Potential exceptions proposed based on: **Nature of environment lighting:** Underground requires fixed lighting installations and portable lighting units, whilst surface requires mobile lighting plants. Differences in light types and/or lux output may be applicable. **Dust Levels:** Surface mines are more prone to high dust levels in the environment (e.g. around stockpiles) due to wind, and in need of the required mitigation measures and/or lighting design exceptions. **Ambient light design in non-operational areas:** Since underground environments are not exposed to natural sunlight, the waiting areas and refuge bays should be treated differently to production areas from a human psychology point of view (e.g. blue light emittance for mood and hormone balance). **Proximity to community/housing**: Proximity to communities/housing may have an impact on the ambient lighting design and levels on a surface mine.

Table 8: Illumination Design Practices and Principles Applicable Aspects based on Differences in Commodity, Orebody, Mining Method or Other Factors

Dimension	Applicable Aspects
Equipment Section 10.3.1	Potential exceptions proposed based on: **Dust Levels:** Visibility will differ based on the dust and/or fog levels in or on the mine. In turn, dust levels are influenced by the rock type, rock properties, air velocity (or wind on surface mines), hydrogeology, humidity, location of dust sources (on surface mines) and dust mitigation systems (e.g. a diamond mine's inherent dust levels will be higher than a coal mine due to dry mining taking place. Although it must be noted that this can be adequately mitigated through using the correct dust mitigation measures). **Mining Method & Layout:** The dimensions of operational areas/working areas, mine layout, mining method and other method-specific aspects may require exceptions to lighting design. **Orebody Geometry:** Rolling or undulating ground conditions that cause uneven floors in turn impact light distribution and the effectiveness of operator sight in travelling equipment. **Risk Assessment:** Risk assessment should play a key role in the lighting design and the proposed minimum illumination levels, according to the type of equipment, activity and the environment in which it operates. **Indicator lights – LHDs:** No indicator lights should be used on LHDs as it is impractical. **Emergency lights**: Should not be applicable on all underground equipment as operators have caplamps to allow for safe egress during emergency. **Protective covers:** Impractical on trackbound equipment underground.

Dimension	Applicable Aspects
	Number of taillights: Certain surface haul trucks make use of one centre light (due to the equipment design). This is impractical to change to two.
	LDVs roadworthiness: LDVs need to also be roadworthy, thus adjusting their light design may impact roadworthiness.
	Environmental operating height/width: The nature of the mining operation (e.g. low profile, ultra-low profile) should determine the installation height of lights on equipment.
Environment Section 10.3.2	**Bi-directional equipment**: Lux levels should be the same at the front and rear of equipment that is bi-directional.
	Machine geometry: Machines with different geometries will require different approaches to the physical measurement techniques used (e.g. roofbolter will require a different measurement approach as it mostly illuminates the hanging wall and not in front of the equipment).
	Size of equipment: The proposed measurement point of 1m above the floor will not necessarily work for large equipment (e.g. with a CAT 349 haul truck the operator cabin is as high as 4m from the floor).
	Ergonomics: Design of lighting should consider individual machine ergonomics.

10.4 Glare Control Practices and Principles

The proposed mining illumination glare control practices and principles are presented in three sub-sections, namely: equipment, environment and people.

10.4.1 Equipment

10.4.1.1 Luminaires

Headlights, taillights and/or ancillary lights on equipment could cause glare for workers. This should be mitigated as far as possible, by selecting the appropriate luminaire type; diffuser type; correctly positioning the light; and/or employing other glare-reducing measures on the equipment.

Positioning and Uniformity

Where possible, luminaires should be positioned above or below the visual line in order to reduce direct glare and allow the equipment operator to adequately see the travelling way and working area. Collective light output should be uniform, where no real visible difference in light output from lights in the same direction is present. Caution should be exercised when angling lights to reduce glare as this can have a potentially counter-productive effect.

Diffusers

Diffusive covers should be used on all equipment lights that may produce glare to operators or general workers. Diffusive covers should be such that they do not unduly restrict light output.

Adjustable Luminaires

Where required (based on risk assessment, application and environmental conditions), equipment should make use of adjustable luminaires with a “diffusive setting”. Equipment operators will then be able to reduce light output and the associated glare at will. The luminaires should have a high-intensity setting for when work is being done, and a low intensity setting for when the equipment travels in illuminated haulages and travelways.

Zero glare lights

The ideal solution for the issue of glare is to install zero-glare luminaires on equipment. Equipment with zero glare luminaires will not require any of the afore-mentioned mitigation measures. However, care should be taken to ensure that supplier claims of zero glare are completely accurate before abandoning other glare-reducing measures.

10.4.1.2 Windscreen

Equipment windscreens (if present) should be such that they improve the operators’ vision by reducing incoming glare, if glare to the operator is an issue. For windscreens without this ability, protective glare-reducing film products could be retrofitted.

10.4.1.3 Cabin Interior

To minimise the impact of incoming glare (from other equipment, workers or static lighting) within the equipment cabin, cabin interiors should be painted with a dark matt finish/colour (preferably grey) such that they reflect as little incoming light as possible.

10.4.2 Environment

Certain luminaires in the mining environment could cause glare for mine personnel and equipment operators. This should be mitigated as far as possible, by selecting the appropriate luminaire type; diffuser type; correctly positioning the lights and/or employing other glare-reducing measures on the equipment.

Positioning and Uniformity

Where possible, luminaires should be positioned above the visual line in order to reduce direct glare. Collective light output should be uniform, where no real visible difference in light output from lights in the same direction is present.

Diffusers

Diffusive covers should be used on luminaires in the mining environment that may produce glare to operators or general workers. Diffusive covers should be such that they do not unduly restrict light output.

Zero glare lights

The ideal solution for the issue of glare is to install zero-glare luminaires in the mining environment. Zero glare luminaires will not require any of the afore-mentioned mitigation measures. However, care should be taken to ensure that supplier claims of zero glare are completely accurate before abandoning other glare-reducing measures. Ideally, glare needs to be addressed at the source/root cause.

10.4.3 People

10.4.3.1 Suitable eye protection

Equipment operators should make use of suitable glare-reducing eyewear (in cases where glare cannot be reduced through other measures).

10.4.3.2 Responsible caplamp usage

All mine personnel should pay attention to not create unnecessary glare with their caplamps, especially in the case of interaction with equipment operators. The practice where people use lights to signal and communicate should be carefully considered as at times there is deliberate “blinding” to attract attention.

10.4.4 Additional Considerations

- **Road Maintenance**: Road maintenance is recommended to reduce the amount of unintentional glare from equipment headlights due to uneven surfaces.
- **Light Adaptation**: Gradually increase light intensity from lower lux levels to higher lux levels to ensure that employees’ eyes have time to adapt to changes in light levels in order to minimise glare due to light adaption.
- **Risk-based Approach**: A risk-based approach needs to be followed to identify the largest sources of glare and develop controls/mitigation measures for these sources.
- **Application-based Light Selection**: Mines should investigate different types of lights (type, colour, intensity, etc.) to determine which light produces the least amount of

glare within a given environment. The right type of light needs to be used for the right type of application.

10.4.5 Applicable Aspects

Table 9 displays the applicable aspects in terms of differences between underground and surface mines, and Table 10 displays the applicable aspects in terms of differences in commodity, orebody, mining method or other factors.

Table 9: Glare Control Practices and Principles Applicable Aspects based on Differences between Underground and Surface mines

Dimension	Applicable Aspect
Equipment Section 10.4.1	Potential exceptions proposed based on: **Height difference between equipment:** Greater differences between the heights of equipment in relation to one another and to people **Presence of dust/mist/fog/smoke:** Presence of high levels of fog, mist or dust on surface mines may lead to an increased risk of glare. **Presence of additional illumination on production equipment:** Presence of more floodlights/spotlights on or around surface equipment to provide increased visibility in high production areas.
Environment Section 10.4.2	Potential exceptions proposed based on: **Sun as a source of glare:** During daytime, the sun is an additional source of glare (by itself or reflecting off of surfaces such as rock or equipment). Adequate glare-reducing eye protection should be considered. **Reflectance of signboards/surface:** Some reflective material (particularly reflective signs) may at times become sources of glare in confined spaces underground. **Reflectance of substrate on surface:** Light substrates on surface mines could become sources of glare.
People Section 10.4.3	Potential exceptions proposed based on: **No caplamp on surface:** Issues relating to caplamp glare will not be present on surface mines. **Ineffectiveness of glare-reducing glasses underground**: Glare reducing glasses may not be effective underground and may pose additional risks.

Table 10: Glare Control Practices and Principles Applicable Aspects based on Differences in Commodity, Orebody, Mining Method or Other Factors

Dimension	Applicable Aspects
Equipment Section 10.4.1	Potential exceptions proposed based on: **Risk-based approach for adjustable luminaires:** Adjustable luminaires on equipment should be used if the level of risk justifies the investment. **Conventional mining**: No glare control measures are applicable to conventional mining equipment.
Environment Section 10.4.2	Potential exceptions proposed based on: **Water ponding**: Usually mine operations will have water accumulation, and this creates a lot of glare. This should be considered, particularly at night (on surface mines).
People Section 10.4.3	Potential exceptions proposed based on: **Individual's unique "risk profile"**: The impact of glare on individuals' medical conditions should be considered when declaring employees medically fit. Employees that require additional PPE in terms of their eyes should be furnished with them.

10.5 Colour Contrast Practices and Principles

The proposed mining illumination colour contrast practices and principles are presented in three sub-sections, namely: equipment, environment and people.

10.5.1 Equipment

Contrast can be defined as the degree of difference between the lightest and darkest parts of a certain visual observation. In the context of equipment within the mining visual environment, contrast refers to the degree of difference between the equipment and the surrounding environment – where the equipment should represent the lightest part.

The majority of the equipment currently operating in South African mines is either painted white, yellow, orange or red (or different combinations of these four colours). It is recommended that mobile and fixed equipment should be painted in bright colours (ideally white, yellow or orange), to create contrast to the surrounding environment (enabling the accurate recognition of the equipment by mineworkers).

10.5.2 Environment

10.5.2.1 Structures

Any structures within the mining environment should be made (as far as is reasonably practicable and based on risk assessment) visible by creating adequate colour contrast to the surrounding environment. It is recommended that structures should be painted in bright colours (ideally white or yellow), to create contrast to the surrounding environment (enabling the accurate recognition of the structures by mine personnel, in relation to the surrounding environment). In the cases where structures are in areas that have been whitewashed, a darker colour could be considered (e.g. orange, red).

10.5.2.2 Oddities/Extremities

Any oddities/extremities within the mining environment should be made visible by creating adequate colour contrast to the surrounding environment. It is recommended that oddities/extremities should be painted in bright colours (ideally white or yellow), to create contrast to the surrounding environment (enabling the accurate recognition of the oddities/extremities by mine personnel, in relation to the surrounding environment).

10.5.2.3 Signboards

Any signboards should ensure that there is adequate contrast between the background and the foreground colours of the signboard. Table 11 displays the SANS safety colours and Table 12 displays the SANS recommended colour combinations for signboards.

Table 11: General Meanings of Safety Colours (SABS, 2011a)

Safety Colour	Meaning or Objective	Example of use	Suitable SANS 1091 Colour
Red	Prohibition	Prohibition Signs Fire Prevention/Firefighting Equipment	Signal red (A11)
Blue	Mandatory Action	In a sign, to wear PPE	Ultramarine Blue (F09)
Yellow	Warning, risk of danger	In an indication of danger (fire, explosion, radiation, toxic hazard,	Golden yellow (B49)

Safety Colour	Meaning or Objective	Example of use	Suitable SANS 1091 Colour
		etc.). In a warning of steps, low passages, obstacles.	
Green	Information, safe condition	Escape routes Emergency exits Emergency showers First-aid and rescue stations	Emerald green (E14)

Table 12: Signboard Contrast Colours (SABS, 2011a)

Safety Colour/Foreground	Corresponding Contrast Colour/Background
Red	White
Blue	White
Yellow	Black
Green	White

In respect of the placement of signboards, the following is recommended (SABS, 2011a):

- A safety sign shall, wherever possible, be positioned in the most conspicuous position available.
- A safety sign shall be placed flat so that it does not create a hazard.
- A safety sign shall be placed for maximum effectiveness (e.g. where it can be seen readily and where it will provide optimum warning of the presence of a hazard or the presence of rescue and firefighting equipment.

Where possible, a safety sign shall be placed at 90 degrees to the passage or walkway which it is to serve.

10.5.3 People

PPE worn at the mine should be of such a colour that an adequate contrast to the surrounding environment is created. In terms of overalls and hardhats, it is recommended that bright colours be used (ideally white or yellow), to create contrast to the surrounding environment (enabling the accurate recognition of the mine personnel by the equipment operators).

10.5.4 Additional Considerations

- **Neon Colour for Hardhats:** Mine should consider the use of neon-coloured hardhats as these serve to provide adequate colour contrast and some form of reflectance.
- **White-walled Tyres:** In cases where the visibility of equipment tyres is an issue (based on risk assessment), mines could consider making use of white-walled tyres to increase visibility.

10.5.5 Applicable Aspects

Table 13 displays the applicable aspects in terms of differences between underground and surface mines, and Table 14 displays the applicable aspects in terms of differences in commodity, orebody, mining method or other factors.

Table 13: Colour Contrast Practices and Principles Applicable Aspects based on Differences between Underground and Surface mines

Dimension	Applicable Aspect
Equipment Section 10.5.1	Potential exceptions proposed based on: **Contractor vehicles**: Exception to be made for contractor vehicles operating in surface operations to avoid dictating to contractors what their vehicle colour scheme should be. **Light substrate on surface**: Application on very light substrate (e.g. salt pan) some dark colour could be required.
Environment Section 10.5.2	Potential exceptions proposed based on: **Differences in background:** Colour contrast to equipment, structures and people will differ based on the differences in the surrounding background in underground mines vs. surface mines.
People Section 10.5.3	Potential exceptions proposed based on: **Use of high-visibility vests:** Generally, high visibility vests are used more on surface than underground. **Use of hardhat colour for level control:** Different colours are used to control different levels in a mine, and thus the colour cannot be standardised. **Blue (with yellow accents) overalls on surface:** On surface, it is preferable to have blue and yellow overalls with reflective strips on both sides of the person. **Attraction of bees to bright colours**: Bees could be more attracted to bright (e.g. yellow) overalls, which could cause a potential safety issue at surface mines.

Table 14: Colour Contrast Practices and Principles Applicable Aspects based on Differences in Commodity, Orebody, Mining Method or Other Factors

Dimension	Applicable Aspects
Equipment Section 10.5.1	Potential exceptions proposed based on: **Level of DPM/Dust residue**: DPM/dust residue has an impact on the intensity of colours. **Distinction between equipment and vehicles:** Equipment should be yellow, vehicles should be white.
Environment Section 10.5.2	Potential exceptions proposed based on: **Colour of exposed rock**: Colour contrast to equipment, structures and people will differ based on rock colour (e.g. white equipment in a coal mine will have a different colour contrast ratio as compared to white equipment in a diamond mine). **Stonedusting in coal mines**: The effective rock colour is changed due to the required activity of stonedusting, which means that the colour contrast to equipment, structures and people will differ (albeit temporarily until the stonedusted area fades). **Size of structures**: The size of a structure should determine whether the structure should be painted in a colour that provides adequate colour contrast. **Risk assessment**: Risk assessment should determine which structures, oddities or extremities should have to conform to the colour contrast principle.
People Section 10.5.3	Potential exceptions proposed based on: **Caplamp light type used at different mines:** The caplamp type (e.g. LED colour spectrum) may affect the colour contrast based on perceived colour of equipment and surroundings in underground environments **Different colour overalls for different applications**: E.g. Flame-retardant; flash resistant; acid resistant– Dark blue/green **Overall colour coding part of MHSA compliance**: E.g. Safety representatives should be clearly distinguished from other worker colours. **Darker overall colours due to nature of work**: E.g. personnel working in maintenance have dark blue overalls due to grease/oil. **Colour of surrounding environment/rock**: PPE colour should be dictated by the colour of the surrounding rock/background. **Risk assessment**: Risk assessment should be done to determine what PPE should be worn by different disciplines

10.6 Reflectance Practices and Principles

The proposed reflectance practices and principles are presented in three sub-sections, namely: equipment, environment and people.

10.6.1 Equipment

10.6.1.1 Positioning of Reflective Strips

An integral aspect of a safe equipment visual environment is the application of reflective strips on equipment. Reflective strips should be positioned (as far as reasonably practicable) on equipment such that the full extent/width/height of the equipment can be derived based on the strips (from the perspective of a person with a light source), and the reflective strips should be placed such that they do not easily get damaged. Table 15 displays the recommended reflective strip colours for each equipment area.

Table 15: Reflective Strips Colour by Equipment Area

Equipment Area	Indicative	Additional
Rear	Red Strips Green Dot indicating operator side (if applicable)	Yellow Strips
Front	White Strips Green Dot indicating operator side (if applicable)	Yellow Strips
Sides	Yellow Strips	Yellow Strips

It is recommended that a reflective strip positioning and placement design should be done for each unique piece of equipment, and then replicated on the rest of the fleet.

10.6.1.2 Quality of Reflective Strips

Reflective strips should be of a high quality, with a minimum coefficient of retro-reflection as outlined in Table 16.

Table 16: Minimum coefficient for retro-reflective strips (SABS, 2011b)

Observation Angle (degrees)	Entrance Angle (degrees)	Minimum coefficient of retro-reflection for different colours of material when measured with standard illuminant A (cd/lux.m²)				
		White	Yellow	Red	Green	Blue
1/3	5	50	35	10	7	2
	30	24	16	4	3	1
	40	9	6	1.8	1.2	0.4
1.5	5	5	3	0.8	0.6	0,.2
	30	2.5	1.5	0.4	0.3	0.1
	40	1.5	1	0.3	0.2	0.06

Any suppliers supplying reflective strips to the mine should ensure that their reflective strips meet or exceed the minimum coefficient of retro-reflection values shown in Table 16.

10.6.2 Environment

10.6.2.1 Whitewashing

The use of whitewash and/or light-coloured shotcrete on sidewalls has the benefit of significantly improving the underground visual environment by increasing reflectance and hence, general levels of illumination. Whitewashing should be done, as far as reasonably practicable, in areas of high activity; areas where mobile equipment travels; areas where fixed equipment is operating; and/or where risk assessment determines the need for whitewashing.

10.6.2.2 Structures

Any structures within the mining environment should be made visible by making use of reflective strips to indicate the extent of the structures. This is especially relevant in terms of structures that are used regularly by mine personnel (e.g. a conveyor belt cross-over, stairway, etc.). These strips should follow the same placement logic as with equipment and should also adhere to the same SANS quality standards shown in Table 16 in Section 10.2.5.2.

10.6.2.3 Oddities/Extremities

As with structures, as far as reasonably practicable, any oddities/extremities (e.g. belt bridges, air crossings) that may present a risk of equipment collision or injury to mine personnel (if not visibly detected) in the mining environment should be made visible by making use of reflective strips to indicate the extent of the oddities/extremities. These strips should follow the same placement logic as with equipment and should also adhere to the same SANS quality standards shown in Table 16.

10.6.2.4 Signboards

Signboards in the underground mining environment should make use of reflective materials/strips to firstly attract attention, and secondly to adequately convey the intended message of the signboard. The colour of the reflective materials/strips should be as per the recommended signboard contrast colours (SABS, 2011a), and should also adhere to the same minimum coefficient for retro-reflective strips (SABS, 2011b).

10.6.3 People

PPE worn at the mine should incorporate reflective elements on overalls and hardhats. The placement of the reflective elements on overalls should be such that they indicate the width and length of the person (as far as reasonably practicable). The reflective elements should meet the minimum coefficient for retro-reflective strips (SABS, 2011b). The practice of adding reflective strips/stickers to the hard hats is discouraged as per the SANS standard of hard hats. The main reason for this is that reflective strips/stickers may conceal defects/cracks in the hardhat. Thus, the following options could be used to increase the reflectivity/visibility of hard hats:

- Hard hats that glow in the dark may be a potential option;
- Hardhat manufacturers should allocate a portion on the hardhat so that reflectors could be placed to increase visibility; and
- Make use of a reflective cover which only fits temporarily.

10.6.4 Additional Considerations

- **Reflective Paint**: For underground equipment where reflective strips are not practical, mines could consider using reflective paint instead of reflective strips.
- **OEM Involvement**: OEMs should include reflective strips into their design in order to protect/house the strips to last longer. Currently reflective strips are an aftermarket entity.

10.6.5 Applicable Aspects

Table 17 displays the applicable aspects in terms of differences between underground and surface mines, and Table 18 displays the applicable aspects in terms of differences in commodity, orebody, mining method or other factors.

Table 17: Reflectance Practices and Principles Applicable Aspects based on Differences between Underground and Surface mines

Dimension	Applicable Aspect
Equipment Section 10.6.1	No exceptions proposed.
Environment Section 10.6.2	Potential exceptions proposed based on: **Sun as a source of glare:** During daytime, the sun is an additional source of glare (by itself or reflecting off of surfaces such as rock or equipment). Adequate glare-reducing eye protection should be considered. **Reflectance of signboards/surface:** Some reflective material (particularly reflective signs) may at times become sources of glare in confined spaces underground. **Reflectance of substrate on surface:** Light substrates on surface mines could become sources of glare.
People Section 10.6.3	Potential exceptions proposed based on: **Potential reflective measures in gumboots/shoes:** If this is implemented, differences will occur between gumboots typically worn underground, and safety shoes typically worn on surface. **Reflective strips during daytime on surface**: Dark clothing with reflective strips are of no value in terms of being seen during daytime. For reflective strips to be effective you need darkness and light. There is a misconception that dark PPE with reflective strips is adequate for surface environments. It is not about the reflective strips, but rather about the colour contrast.

Table 18: Reflectance Practices and Principles Applicable Aspects based on Differences in Commodity, Orebody, Mining Method or Other Factors

Dimension	Applicable Aspect
Equipment Section 10.6.1	Potential exceptions proposed based on: **Type of and application of equipment**: Certain equipment (such as LHD's and FEL's) will not be able to accommodate reflective measures on their/buckets/scoops. These will wear out within a shift and are therefore impractical. **Equipment where the operator sits in the centre:** Exception to be made on equipment where the operator sits in the centre of the equipment – the red/green indicative strips will be immaterial. **Extremely muddy/dirty environments**: Strips will become ineffective shortly after operation starts.
Environment Section 10.6.2	Potential exceptions proposed based on: **Reflectance properties of exposed rock**: Ambient illumination levels in the environment will differ based on rock type (e.g. if the same luminaires are used, a quartzite environment will be lighter than a coal environment). **Use of reflective measures on brows**: Using reflective measures on brows (at mines with brows in the hanging wall) may be impractical. **Risk assessment approach to amount of reflective measures**: Higher risk areas should make use of more reflective measures on structures, oddities and extremities, as well as signboards. **Activity-based whitewashing:** Whitewashing should be done only where equipment operates consistently.
People Section 10.6.3	Potential exceptions proposed based on: **Potential reflective measures in gloves**: Different types of gloves are used for different applications, and reflective measures may only be plausible for certain types of gloves.

10.7 MAINTENANCE PRACTICES AND PRINCIPLES

In the mining illumination context, maintenance refers to all activities relating to sustaining a sound visual environment put in place on the mine. The maintenance activities generally revolve around either cleaning, repair or replacement of components or aspects within the broader mine illumination system (equipment, environment and people). The proposed maintenance practices and principles are given in table format in Table 19, in order to avoid unnecessary duplication of information. Thereafter some general practices and principles are discussed, based on the items provided in Table 19.

Table 19: Proposed Mine Illumination Maintenance Practices and Principles

Item	Description	Clean	Repair/Replace
Luminaires/ Covers/ Diffusers *(Equipment)*	All lights on mobile and fixed equipment	As required, based on visual inspection and risk assessment	Replace luminaires if: ▪ They are defective/non-functional or only functioning partially; ▪ Damaged and/or cracked (in case of no external cover being used); and ▪ Light output determined to be inadequate by OH/Safety department through measurements. Covers/diffusers should be replaced if they are damaged/cracked or restricting light output.
Luminaires/ Covers/ Diffusers *(Environment)*	All lights in the mining environment (e.g. haulage lights, shaft station lights)		
Reflective Strips *(Equipment)*	Reflective strips on mobile and fixed equipment	As required, based on visual inspection and risk assessment	Replace reflective strips if: ▪ Strips damaged/scratched off; ▪ Strips no longer reflect incoming light adequately Reflective strips should be maintained and regulated with regards to engineering inspections, maintenance and pre-use inspections.
Reflective Strips *(Environment)*	Reflective strips on structures, oddities and extremities in the mine environment		
Windscreens, Windscreen Wipers & Mirrors *(Equipment)*	None required	As required, based on visual inspection and risk assessment	▪ Equipment windscreens and mirrors should be replaced/repaired if they are cracked, shattered, badly scratched or impacting on the visibility of the equipment operator. ▪ Windscreen wiper systems should be replaced/repaired if they are no longer functioning, damaged or performing poorly. ▪ Windscreen wiper blades should be replaced if they are damaged, cracked or worn out.

Item	Description	Clean	Repair/Replace
Operator Displays *(Equipment)*	Display panels/dials in equipment cabin or on exterior of equipment (mobile and fixed)	As required, based on visual inspection and risk assessment	Operator display covers should be replaced if they are cracked, shattered, scratched or if the display becomes illegible for whatever reason.
Equipment Body *(Equipment)*	The exterior paint coat on the equipment body	Every planned maintenance interval, more regularly if required (based on visual inspection and risk assessment	The equipment exterior should be re-painted if: ▪ Paint has become visibly faded where the original colour is hard to discern; and ▪ Paint has been mostly scratched off/damaged.
Signboards *(Environment)*	None required	As required, based on visual inspection and risk assessment	Signboards in the mine environment should be replaced/repaired for any one of the following reasons: ▪ Signboard visibly deformed; ▪ Signage illegible/barely legible after cleaning; ▪ Damage to the signboards painted surface, and ▪ Damage to the reflective strips (if used on signboard). It must be noted that in the case of paint damage or reflective strip damage, it may be possible to repair the signboard by re-coating the surface and affixing new reflective strips.
Painted Structures *(Environment)*	None required	As required, based on visual inspection and risk assessment	Any painted structure should be repainted for any of the following reasons: ▪ Paint has become visibly faded where the original colour is hard to discern; and ▪ Paint has been scratched off to a large extent.
Whitewashing *(Environment)*	None required	Not applicable	Any whitewashed area should be whitewashed again for any of the following reasons: ▪ The original whitewash has become visibly faded where the original white colour is no longer discernible; and ▪ Whitewashing has been damaged/removed to a point where the whitewashing has become mostly ineffective.

Item	Description	Clean	Repair/Replace
Caplamp Cover/Luminaire *(People)*	None required	Per shift	Replace caplamp luminaire if: ▪ Luminaire no longer functioning; ▪ Luminaire only functioning partially; and ▪ Luminaire light output determined to be inadequate. Replace caplamp cover/diffuser if: ▪ Cover/diffuser cracked/shattered ▪ Cover/diffuser cloudy/discoloured ▪ Cover/diffuser scratched
Caplamp *(People)*	None required	Not applicable	The caplamp in its entirety (or components thereof) should be replaced or repaired by a competent person if any non-luminaire related reasons cause it to be faulty or non-functional.
Personal Protective Equipment *(People)*	Overalls, goggles, hardhat	Per shift (Hardhat, goggles) As per manufacturer recommendations (overalls)	Overalls should be replaced if: ▪ They are faded and do not have an adequate colour contrast to the environment, ▪ Reflective materials on them are worn out, scratched, damaged and no longer adequately reflecting incoming light. ▪ Risk assessment indicates the need for replacement. Reflective materials/strips on other PPE should be replaced for any of the following reasons: ▪ Material/strips damaged/scratched off ▪ Material/strips no longer reflect incoming light adequately Eye protection/goggles should be replaced for any of the following reasons: ▪ Eyewear cracked or scratched; ▪ Lenses foggy/discoloured; and ▪ Eyewear frame/body damaged.

10.7.1 Additional Notes

- **Cleaning Intervals**: In the case of cleaning, the length of the maintenance interval for the relevant illumination-related items is largely dependent on:
  - The general environmental conditions at the mine (e.g. a wet and muddy environment may require more regular cleaning as opposed to a dry and dusty environment for certain items).
  - Dust control/mitigation systems in place.
  - The operating environment of the equipment and the associated risks (e.g. a low-risk environment will require less regular intervals than a high-risk environment).
  - The infrastructure available and accessible to perform cleaning activities (e.g. amount and location of washing bays). In circumstances where washing bay accessibility and availability prevents cleaning from taking place, mines could consider making use of mobile washing units.

    Mines should determine reasonable intervals for planned cleaning based on the above factors. For unplanned cleaning, mines should determine whether items require cleaning through visual inspection – if the items are visibly dirty; dusty; muddy; or in any way obstructed by debris; they should be cleaned.
- **Repair/Replacement Intervals**: In the case of the repair or replacement of relevant illumination-related items, the intervals will not be consistent, and the repair/replacement should take place on an ad-hoc basis. If any item is deemed to require repairs or is due for replacement (through visual inspection and/or risk assessment), it should be done as soon as is reasonably practicable. If a specific item is found to require excessive recurring repair or replacement, the root cause should be identified and addressed.
- **Cleaning Best Practice**: Care should be taken during cleaning activities to not damage, scratch or in any way harm/adversely affect the items being cleaned. The appropriate cleaning chemicals and materials should thus be used for each item (e.g. an abrasive material should not be used to clean clear plastic luminaire covers, as it may scratch the surface and impede the light transmission through the cover). For unplanned cleaning, operators/maintenance crew members should be provided with a means to clean lights, reflective strips, windscreens, etc. to allow them to regularly clean and maintain these items.
- **Training of Operators and Maintenance Crew Members**: Operators/maintenance crew members should receive adequate training on how to perform cleaning activities. Furthermore, adequate training should be provided to operators/maintenance crew members on how to identify the need for any of the maintenance activities.
- **Involvement of OEMs**: Mines should also consider recommendations from OEMs on equipment maintenance practices and incorporate those of relevance into their illumination-related maintenance practices. The same applies to manufacturers of luminaires, PPE, reflective measures and paint.

- **Use of Checklists for Implementation of Measures**: Pre-use checklists should be used to perform the required daily planned illumination-related maintenance tasks, and to identify the need for any additional unplanned cleaning, repair or replacement that needs to take place.

10.7.2 Applicable Aspects

Table 20 displays the applicable aspects in terms of differences between underground and surface mines, and Table 21 displays the applicable aspects in terms of differences in commodity, orebody, mining method or other factors.

Table 20: Maintenance Practices and Principles Applicable Aspects based on Differences between Underground and Surface mines

Dimension	Applicable Aspect
Equipment Section 10.7	Potential exceptions proposed based on: **Sun damage – Paint:** Sun can bleach equipment/structures and reduce the time between repaints. **Sun damage – Reflective Strips:** Sun exposure could lead to faster deterioration of reflective strips, reducing the time between replacements. **Dust levels:** Potential differences in dust levels may require differences in the duration between maintenance intervals. **Weather:** Rain/Fog/Mist on surface may require differences in the duration between maintenance intervals. **Size of surface equipment**: Impractical to clean lights/windows/windscreens every shift due to size of equipment used at surface mines – will require a safety harness and lifting equipment for this task. **Painting/Washing restrictions underground**: Painting and washing of such machines underground is a challenge, considering: Environmental legislation; Flame proofing of tools; and Mobility of the equipment (restricted to section). **Impracticality of Repainting due to equipment size on surface**: Impractical to repaint a TMM that weighs 150tons or more. You cannot build a large enough paint bay, nor can you move it to an established paint bay.
Environment Section 10.7	
People Section 10.7	Potential exception proposed based on: **Small number of caplamps used on surface:** Maintenance relating to caplamps will be significantly less as compared to underground mines. **Other handheld lighting devices on surface:** Other handheld devices used on surface (e.g. torches used by security personnel) need to be maintained.

Table 21: Maintenance Practices and Principles Applicable Aspects based on Differences in Commodity, Orebody, Mining Method or Other Factors

Dimension	Applicable Aspect
Equipment Section 10.7	Potential exceptions proposed based on: **Coal dust and stonedusting:** Generally dirtier underground due to coal dust and stonedust. Requires more regular cleaning intervals. **Dry mining:** Any cleaning activities involving water need to be constrained to workshop areas (for kimberlite orebodies). **Water Presence**: Difference in hydrogeological factors and water presence may impact on the duration between maintenance intervals. **Dust levels:** Potential differences in dust levels may require differences in the duration between maintenance intervals. **Mine layout:** Some underground mining methods and layouts cause more scraping damage to the paint and reflective strips on equipment than others. **Exposure to other fluids:** The amount of exposure that equipment may have to grease, oil, hydraulic fluids, etc., in combination with dust exposure, will have a material impact on the required cleaning intervals.
Environment Section 10.7	

Dimension	Applicable Aspect
	Lack of washing bays on mines: Not all mines have washing bays for equipment, and thus cleaning of equipment is not always possible. Additionally, most TMMs remain underground, with no underground wash bay available. **Relative level of risk present in working area:** Maintenance/cleaning intervals should consider the relative level of risk present in the working area/for the piece of equipment. Higher risk – more regular intervals. Reasonable frequency period must be determined by the mines from a risk assessment conducted in terms of maintaining the reflective measures, lights, etc.
People Section 10.7	Potential exceptions proposed based on: **Availability of PPE based on geographical location of mine and available supplier base:** In many cases, **m**aking use of local suppliers, the service delivery is not up to standard. Employees are forced to wear defective PPE due to non-delivery.by the supplier. This could potentially be addressed by changing procurement policies. **More frequent overall replacement based on nature of work being conducted**: E.g. maintenance workers get grease and oil on their overalls, which leads to the decreased lifespan of their overalls.

10.8 MINE LIGHTING: INSTRUMENTATION AND LIGHT SOURCES

10.8.1 Introduction

Lighting measurements are generally done in two ways:

10.8.1.1 Illuminance (units Lux):

- Illuminance measurements to determine "how much" light is falling on the surface of the visual task and the background to the task.
- Once the Illuminance level has been established at a specific Lux level (as specified by local and international Occupational Health and Safety Act (OHSA), rules and regulations); then the visual reflectance of the task and the background will determine the "visibility" of the task.
- High visual reflectance will generally produce high luminance levels and low reflectance will produce low luminance levels. The ratio of task luminance divided by background luminance produces a luminance "brightness" contrast; which must be maximised and is what humans see.
- Illuminance meters (luxmeters) are very common, relatively cheap and robust; to be used in mine-lighting applications.
- Luxmeters used in mine-lighting have to comply with some minimum standards with regards to accuracy, sensitivity, resolution, $\mathbf{f}_1'$ factor, ease of operation, etc.

10.8.1.2 Illuminance Measurements

Illuminance measurements can be done in two ways:

- Traditional Luxmeters: Illuminance meters (luxmeters) measuring the luminance flux incident on the sensor surface; and divided by the sensor surface area – giving lumens per meter squared or lux.
- Modern Illuminance Spectrophotometers: Spectral illuminance measurements and instrument calculated illuminance values to be presented in lux, are growing in popularity.

10.8.2 Traditional Lux Meters

10.8.2.1 General

The definition of illuminance, E, is as follows: The incident luminous flux Φ in Lumen on a surface area A, divided by the area A of the flat surface in meter squared:

$$E = \frac{\Phi}{A} \quad \text{in Lumen/m}^2 \text{ or in Lux}$$

The radiation sensor in a traditional luxmeter usually uses a photodiode detector (mostly silicon) to measure the incident luminous flux ("visible power") and a fixed sensor area A, to measure E. Such luxmeters sensors combine the detector, with an optical filter to assure correct measurement of illuminance. Note that the sensor of a luxmeter, also includes a diffusor to assure all (or almost all), light incident on the sensor surface, is collected on the photodiode/filter combination – so-called cosine correction diffusor. The photodiode (detector) responsivity is wavelength sensitive R(λ) and typically of the shape as shown in Figure 6.

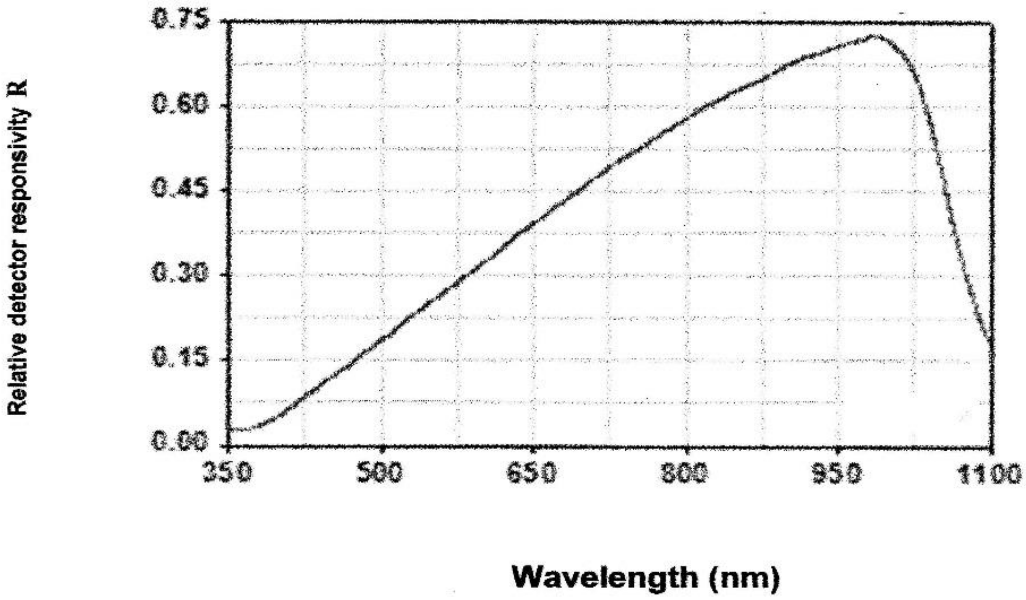

Figure 6: Typical relative Spectral Responsivity curve as a function of wavelength for a Silica (Si) photodiode

The combined photodiode and optical filter combination, must have a transfer function of the same shape as the spectral luminous efficiency function for photopic vision called V(λ) function in Figure 7 (also known as the *eye responsivity curve for daylight)*.

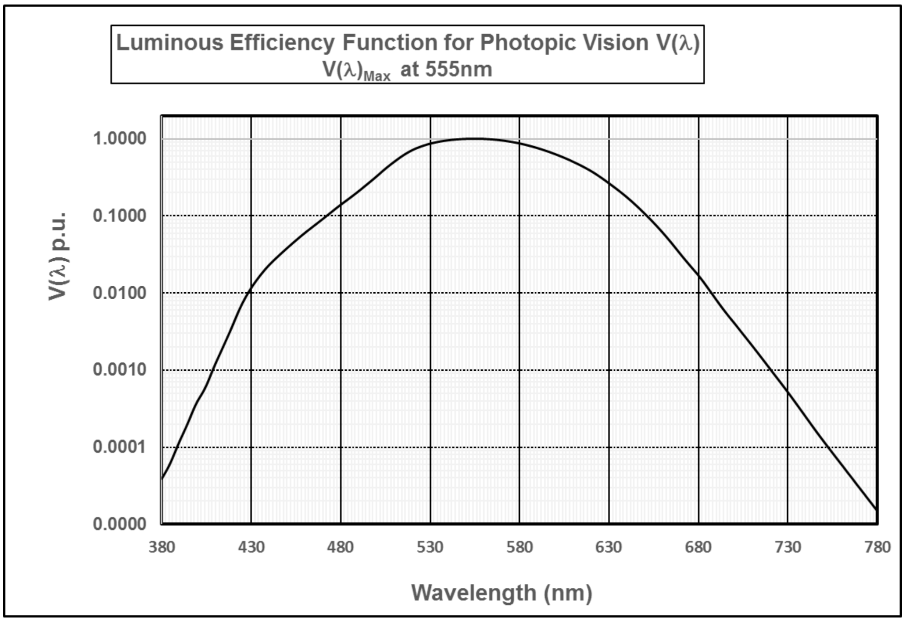

Figure 7: Luminous efficiency function for Photopic vision (CIE S010/E:2004)

10.8.2.2 Characteristics of the V(λ) Eye Responsivity Curve

Some important characteristics of the luminous efficiency function V(λ) (eye responsivity curve) include the following:

- The curve has been established from many vision tests of people over many years and an average curve V(λ) is now shown in Figure 7.
- The values of V(λ) as a function of the wavelength (in nanometres) are given in the CIE tables as very accurate 4 digit resolution values.
- The curve is not a smooth normal distribution and very difficult to establish with a detector/optical filter combination.
- The curve applies to Photopic Vision only i.e. $L_{Ave} > 10\ cd/m^2$
- For Scotopic Vision ("night vision") i.e. $L_{Ave} < 0.001\ cd/m^2$ a different eye responsivity curve has to be used V'(λ). During these conditions there is no colour perception & weak focus only on the edges ("peripheral vision") (see Figure 8).
- For Mesopic Vision i.e. $0.001 \leq L_{Ave} \leq 10 cd/m^2$**.** A mixture of the other two states of vision is encountered. These conditions may be encountered frequently in certain places in a mine.

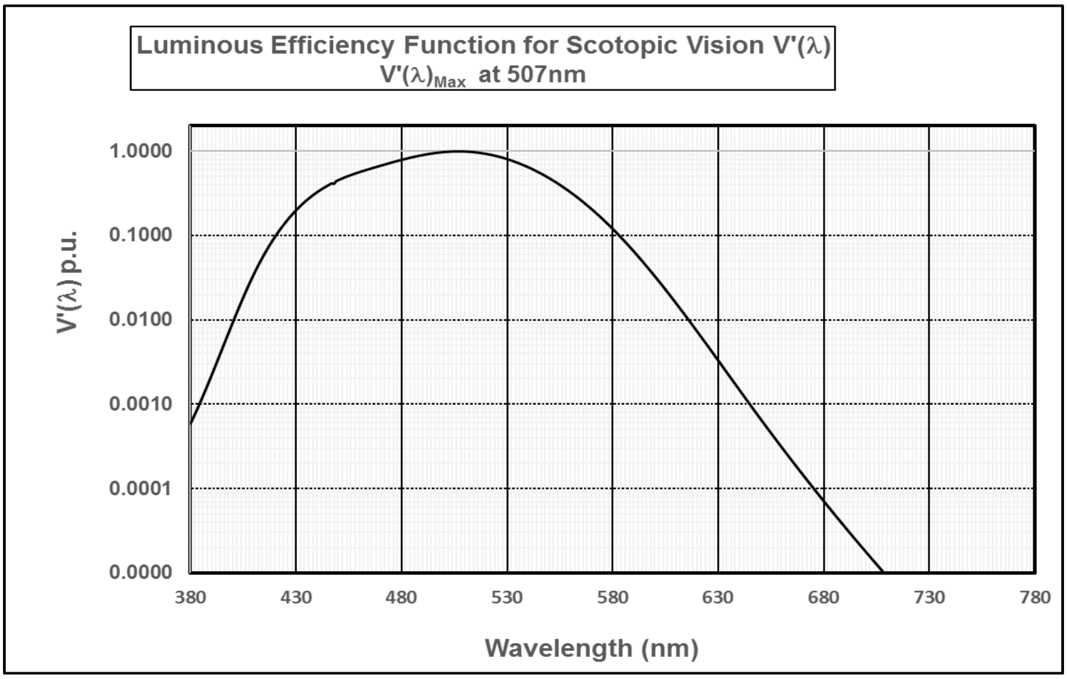

Figure 8: Luminous efficiency function for Scotopic vision (night vision)

Photopic Illuminance is given by $E_v = 683\int_{380nm}^{760nm} E_{v,\lambda}(\lambda)\cdot V_{\lambda}(\lambda)d\lambda$

Note that the unit of illuminance is lux or lumen/m^2 and $E_{v,\lambda}(\lambda)$ is the spectral illuminance from the source of light Two conditions can exist:

- The transfer function for the Luxmeter detector/optical filter combination *does* match the V(λ) curve (as presented in Figure 7) very accurately and can thus be used for measuring daylight Illuminance from *any* light source.
- The transfer function for the luxmeter photodiode/optical filter combination *does not* match the V(λ) curve very accurately (as presented in Figure 7) and *cannot* be used for measuring Illuminance from *all* light sources (many but not all).

10.8.3 Modern Lux Meters – Illuminance Spectrophotometers

10.8.3.1 General

With modern optical instruments and sensors, we can measure the fundamental spatial and spectral quantities of light, very accurately. From these two quantities all other quantities can be calculated. Examples include:

- From the spatial distribution of light (Luminous Intensity Distribution I(θ) in all directions); total luminous flux can be calculated accurately.
- From the spectral distribution of light (Spectral Power Distribution $\Phi_{e,\lambda}(\lambda)$ for all wavelengths); the total luminous flux Φ_v can be calculated.

The same applies for all other metrics, like illuminance, luminance, etc.

The radiation sensor in a modern illuminance spectrophotometer is usually a linear array of silicon photodiodes (usually more than 3 000 pixels), combined with sophisticated optics to allow for full spectral measurement of the incident spectral irradiance. The sensor is called a spectrometer and the responsivity of each photodiode detector is calibrated to produce an accurate spectral irradiance distribution.

From the spectral irradiance distribution, the following can be computed inside the meter and displayed in very advanced display configurations, such as:

- Spectral illuminance values (380nm to 780nm) for Photopic conditions, using the V(λ) function values to calculate the exact values of $E_{v,\lambda}(\lambda)$.
- Photopic illuminance in lux.
- Most colour appearance and colour rendering values (as required) can be calculated in the meter from the Spectral Illuminance values.
- By using the luminous efficiency function for scotopic vision V'(λ) values as shown in Figure 8, scotopic Illuminance measurements can also be done.

From the spectral illuminance readings $E_{v,\lambda}(\lambda)$, the total Illuminance can be computed accurately by the instrument as follows:

Illuminance is given by $E_v = 683\int_{380nm}^{760nm} E_{v,\lambda}(\lambda)\cdot V_{\lambda}(\lambda)\,d\lambda$ in Lux -

Note: As these instruments do not rely on accurate optical spectral detector/filter combinations as with traditional luxmeters; but rather use the accurate specified V(λ) values as shown in Figure 7; the measurement of Illuminance in Lux is not dependent on the spectral light distribution of the light source.

10.8.4 Inaccuracies that can occur with Traditional Luxmeters

Inaccurate illuminance measurements that *can* be the result of two factors in traditional Luxmeters:

- Photodetector/optical filter transfer function does not accurately match the spectral luminous efficiency function for photopic vision - called the V(λ) function;

combined with

- Light sources with narrow wavelength band spectral power distributions; e.g. colour LEDs such as Blue or Red (and linear fluorescent tubes)

  - $\mathbf{f_1'}$ Values

The quality of the optical detector responsivity curve, combined with the optical filter; may result in a mismatch with the standard CIE luminous efficiency function for photopic vision (as shown in Figure 7). This may cause deviations especially in the blue and red regions of light detection.

The General V(λ) Mismatch Index, $\mathbf{f_1'}$ was defined to be a general description of the photometric performance of photometers, such as luxmeters. This index is widely used in photometry, and it is relevant for selecting a luxmeter for low-uncertainty illuminance measurements. It quantifies the spectral mismatch between the relative spectral responsivity of a luxmeter and the luminous efficiency function for photopic vision, V(λ).

For good quality luxmeters the $\mathbf{f_1'}$ should be below 4%. These values can be measured for any Luxmeter. It is not possible to correct for an $\mathbf{f_1'}$ value of ≥ 4%, with a numerical “correction factor”.

  - Spectral Power Distribution of Light Sources

In the event of a Luxmeter suffering from a poor $\boldsymbol{f'_1}$ factor, that is larger than 4% and the light source has a narrow-band spectral radiation band e.g. red and blue sources then the luxmeter reading may be questionable for accuracy. Note that the readings under these conditions, cannot be corrected with a numerical correction factor.

Generally light sources may be divided into three main types of spectral power distributions (SPD):

1. Broad-band SPDs, such as incandescent and tungsten halogen lamps.
2. Narrow-band SPDs, such as coloured LEDs (especially red and blue).
3. Combinations of broad-band and narrow-band SPD light sources, such as white fluorescent lamps and white LED lamps (which is usually also a phosphor transformation light source).

11 CONCLUSIONS

From the results contained within this report and the knowledge obtained throughout the duration of the project, the following can be concluded:

The illumination levels proposed in Section 10.2 are a representation of the existing leading practices for mines, locally and internationally. The intent of the proposed levels is not to create a new standard, but to rather use it as a guideline. This point was exhaustively discussed at the four industry workshops, and the consensus clearly pointed towards a guideline instead of a standard. In further support of the guideline in lieu of a standard, several issues exist with measurement techniques, instruments and the relatively recent influx of LED luminaires into the mining industry. Lastly, a standard may be counter-productive in terms of the aim of the project. Compliance to a standard may in fact yield zero benefits in terms of health and safety, as the key issue in terms of illumination is not the actual lux levels, but rather shortcomings within the illumination system in its entirety. Addressing these shortcomings will yield far greater “health and safety” returns than complying to a lux level standard.

The illumination design practices and principles proposed in Section 10.3 aim to improve illumination and the visual environment from a design perspective. The practices and principles proposed are intended to be used as a guideline for mines when designing their illumination system (or components thereof). For equipment, the relevance of the generic design practices and principles needs to be determined by individual mines themselves, taking due consideration of the applicable aspects/exceptions provided.

The glare control practices and principles proposed in Section 10.4; colour contrast practices and principles proposed in Section 10.5; and reflectance practices and principles proposed in Section 10.6 all aim to address the shortcomings within the mine illumination system. The project team is of the strong belief that addressing shortcomings related to glare, reflectance and colour contrast will greatly improve the general visual environment on mines. This belief was affirmed in the feedback obtained at the workshops, where the majority of participants agreed that the practices and principles proposed would lead to a desired improvement. As with the illumination levels and design practices and principles, the glare control, reflectance and colour contrast practices and principles are intended for use as a guideline in the SAMI.

The maintenance practices and principles proposed in Section 10.7 serve to continuously maintain the practices and principles proposed in Sections 10.3 to 10.6 and ensure that it gets adequately maintained once mines implement any of the proposed design, glare, reflectance and colour contrast practices and principles. The maintenance practices and principles are intended to serve as guidelines for mines to include the relevant illumination-related aspects into their existing maintenance activities.

The information provided on measurement instrumentation and light sources in Section 10.8 was included due to several recurring questions at the workshops relating to measurements in general, and the accuracy of measuring LED lux levels with traditional luxmeters. The conclusions on this are as follows:

For general mine-lighting Illuminance measurements at Photopic luminance levels (and Mesopic light levels) with Luxmeters; will generally be accurate for *any light source*, provided:

- Good quality Luxmeters with an $\boldsymbol{f'_1}$ value ≤ 4% are used; or

- Good quality illuminance spectrophotometers are used.

As illuminance is measured and not luminance; some assumptions must be made to determine whether measurements are being made in photopic, mesopic or scotopic task and background illumination conditions:

- For photopic vision the luminance of the task must be above 10 cd/m^2. For a task with approximately Lambertian diffuse reflectance of around 30% (assumption), the illuminance E has to be above 100 Lux.
- For mesopic vision the luminance of the task is $0.001 \leq L_{Ave} \leq 10$cd/m^2 i.e. between 0.001 and 10cd/m^2. For a task with approximately Lambertian diffuse reflectance of 30% (assumption), the illuminance E has to be values of $0.01 \leq E_{Ave} \leq 100$ Lux, i.e. between 0.01 and 100 Lux. These levels will occur dominantly in mines.

For underground mine-lighting conditions, task Illuminance measurements will frequently be in the range from 0.1 to 10 lux and thus be mesopic (close to photopic). This implies a reduction in accuracy of measurement; even with good quality luxmeters and various light sources.

These errors will however be very small as the gradual movement of the Eye Responsivity curve from V(λ) for Photopic towards V'(λ) for Scotopic (but not Scotopic yet); is very small and for most white light sources can be ignored (i.e. LED and/or fluorescent lamps).

Note:

- For accurate Scotopic luminous flux measurements, the Spectral Power Distribution (SPD) of the light must be measured and by using the V'(λ) values (as supplied by the CIE), the Scotopic luminous flux can be determined.
- For very accurate mesopic luminous flux measurement the Spectral Power Distribution (SPD) of the light must be measured and by using the V(λ) and V'(λ) values (as supplied by the CIE), the Mesopic luminous flux can be calculated through interpolation.

12 RECOMMENDATIONS

It is recommended that the illumination levels and various illumination practices and principles contained in this report should be put forth to the SAMI as a guideline. The main intent of the guideline should be to improve the visual environment on mines in its totality. This point needs to be re-iterated, as a sound and safe visual environment is greatly dependant on addressing all of the components within the illumination system.

13 SUGGESTIONS FOR FURTHER RESEARCH

The following topics/areas are suggested for further research by the MHSC:

- Specialised LED lighting could potentially yield benefits in terms of employee well-being and fatigue management. Studies have shown that specialised "blue" LED lighting can improve general mood, well-being and productivity of those exposed to it. There may be scope to investigate the potential benefits of using these types of specialised LED lights in refuge chambers, waiting places and general areas in mines.
- Zero-glare LED equipment lights are a recent product offering that has been released by one of the biggest equipment lighting manufacturers in the world. The potential application of these lights in the mining industry could yield significant safety gains, as glare could be addressed at the source and effectively eliminated as a hazard. It is thus suggested that a potential study be conducted to test the zero-glare offerings, and to determine the financial viability of recommending these lights to the SAMI.
- The lack of area lighting in the vast majority of areas of underground mines is a pressing issue. Solving this issue would lead to safety gains. The working areas (proverbial known as "the coal-face") are arguably the most dangerous areas in a mine, and currently these areas are illuminated through caplamps and overly bright equipment lights. On this basis it is suggested that further research be conducted into cost-effective and mobile working area lighting for underground mines.

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