Physical based visualisation of mine lighting systems

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It has been our experience that the impact of poor lighting on mine safety and productivity is disproportionate to its relatively low cost. In an effort to enable mining staff to make coherent and objective evaluations of the interaction among mining plant, environment, lighting equipment and the range of people interfacing with the this we developed specialised computational and presentation tools.
Our experience has shown that despite the obvious safety and productivity impacts it is not common for the visual requirements to perform a specific task to be thoroughly considered.
Our visualisation tools aims to reduce the complexity of such analysis significantly, and to provide the mine with a consistent method that can be applied to all tasks and plant types. The output of the process not only improves safety and productivity, it also provides solid input towards risk management, specifications for procurement and operation that can be applied across a fleet as well as the practical information required implement and maintain the selected solution.

Keywords: lighting; risk management, visual environment, physical based visualisation

1. Introduction

This paper focuses on how to analyse, optimise and then specify lighting systems that can consistently deliver visual work environments appropriate to any task in any mine. Optical system design, production and verification processes are not covered here but deserve equal levels of attention.

2. Status Quo

Based on our field research and feedback from our sales network lighting systems installed and operated on mines today are rarely the product of clear intent, and even less likely the result of performance based specifications. This is in sharp contrast to most of the other subsystems found in the productive plant on mine sites.
We found that lighting systems are the result of one or more of the following design & specification methods:

2.1 OEM solution

End users hope the OEM has invested sufficient resources into supplying the plant equipped with a lighting system suited to their specific needs.

2.2 Trial & Error

Operators, maintenance fitters, management and equipment suppliers use their experience and judgement in an attempt to design, improve or maintain the lighting equipment.

2.3 Reactive

An accident or safety audit highlights lighting as a subject that requires action. This tends to lead to a random proliferation of additional equipment, which becomes entrenched as a site-specific requirement.

2.4 Why

・OEM lighting equipment may not suit the specific application

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- No credible expert advice is available
- No End User specification
- Lighting equipment represents a small percentage of the asset value
- Beyond the basics lighting requirements become highly situation specific
- No “industry standard” exists, or few know which standard to apply.
- Something had to done to improve the situation
- Lighting is left to the discretion of the site electrician

2.5 Results

- Inappropriate equipment selection & location
- Poor visual environment – hazardous & poor productivity
- Complex & expensive maintenance
- Inconsistent performance
- Inconsistent equipment
- Personal preferences dominate
- Low degree of ownership
- High cost of ownership

3. Setting a new Objective

Based on the evidence there is scope to introduce a more rational process to the design and specification of lighting on mine sites, but it is also evident that the processes used in other industries do not translate well when applied to mining. To obtain the desired results requires some familiarity with the additional complexities and challenges in mining, and adjusting the process to accommodate these.

4. Challenges

4.1 Physical Environment

The combination of mechanical stress and corrosion faced by lighting equipment in mining is significantly more severe than that encountered in other industries[i]. Equipment that is not designed to operate in this environment fails prematurely and often unpredictably, or operates at a lower level of efficiency.

4.2 Duty cycles

The continuous operation of mining plant and in particular mobile equipment like excavators and haul trucks at their designed capacity rapidly consumes the design life of equipment that is not designed to operate in this environment.

4.3 Logistics

Most mines are located at the far end of complex supply chains, ensuring that the correct spare parts are available in sufficient volumes at the correct time to maintain the plant is a major challenge and cost to the organisation. Designs that do not factor this into the process rapidly become unsustainable economically and practically.

4.4 Staff

The nature of 24/7/365 operations require that multiple people are trained to perform each task, when combined with the typical high staff turnover in the industry it becomes clear that apart from being a perpetual task, training is also a significant cost to the enterprise. Systems and processes that do not minimize the training costs and consciously standardize their maintenance as far as possible are likely to deliver unsustainable outcomes.

4.5 Organisational

Mines are complex organisations and due their closely managed objective to produce their specific commodity as fast as possible at the lowest cost a high degree of internal competition exists. While this culture enables proven "best practice" methods to be adopted across the organisation, it also tends to reinforce risk-averse conservative decision-making.

5. Desirable features of a "Mine Lighting Design & Specification Process"

- Wide stakeholder ownership
- Clarity
- Risk reduction
- Sustainability
- Standardisation
- Measurable productivity improvements
- Safety improvements

6. Creating a new process

To deliver the results requires the creation of a new process that will actually deliver the desired results, and since the existing system does not deliver these, it made sense to try an alternative process that starts at the end-user side. This is the point where operational demands, supply chain logistics, and safety requirements all meet reality.

Our fundamental objective is to create a process that can do the following for the organisation:

- Extract the basic information required to analyse the core visual requirements and design a lighting system that meet those needs
- Provide information on the proposed solution in a format that enables the end-user to evaluate it and provide critical feedback to us on how it needs to be adapted to better suit their needs.
- Solicit input and feedback on the proposed lighting from maintenance staff, safety representatives and operators of other plant interfacing with the specific equipment under discussion.
- Package the resultant design & specification into a format that suits the needs of the plant operator, maintenance and procurement teams and also useable in risk management documentation.

7. The process employs the following steps:

- Collect Input data
- Create a 3D virtual model of the task & plant
- Create a lighting design in this virtual model
- Provide the images from the model to the client for comment
- Incorporate the feedback and deliver a complete specification.

8. Basic input into the new process

The most obvious input would be the customer requirements clearly stated in lighting engineering terms, but since the absence of exactly this information is one of the root causes of poor lighting on-site, our process cannot rely on this.

8.1 End user requirements

The base information is obtained from the end-user in terms familiar to them, using a simple Application Engineering Request document (fig 1) designed for email use:


Mining Application Engineering

HM-Application Number:
Date:
Project Name:
Hella Contact Person: BLANK
Customer Contact Details:
Description of Project

Please include type of machine if required. Make and model.
Suggested Products: BLANK BLANK BLANK BLANK BLANK

Additional Comments

Figure 1

- The type of mine
- Plant/Machine type/s
- Main problems that they have with the existing lighting

The other information required to create an initial design is inferred from similar projects we have done before, and whenever possible by finding an equivalent task in the most appropriate national or industry lighting guidelines.

8.2 Mining plant data

For most mobile plant we can find manufacturer brochures (fig 2) with sufficient information to create a 3D model suitable for the project[1].

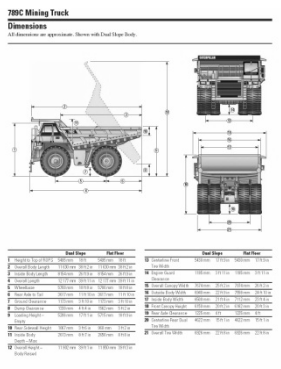
789C Mining Truck
Dimensions

Figure 2

Mine site data

The Application Engineering Request document itself provides most of the basic information we need:

- Operation type: surface / underground
- Ore type
- The nominated plant enables us to define bench dimensions
- Geographic location

When we need more information, a few site photos normally suffice to provide the additional information.

9. Virtual model creation

[1] Fixed plant like conveyor transfer stations, flotation tank farms and process plants are more complex and require some basic engineering drawings to create

This is where we integrate the information supplied by the client with our body of knowledge, and where we can choose from two fundamentally different routes to generate the images that will be sent back to the customer. The most common method to produce images from 3D models is subjective and delivers “artist impression” output based on the skills of a person trained in the art of digital image creation. The result can appear highly realistic but it can never be used as input for a performance specification. This method is well suited to generate visual content for use in simulators and entertainment.

The other route is completely objective or “physical based” and theoretically capable to be indistinguishable from reality. Output is the direct result of a process that applies testable physical behaviour laws to objects assigned physical characteristics. The objective is to produce an accurate reflection of reality useable in rational arguments.

The physical based output allows us to do at least the following that the subjective option cannot:

- Make traceable predictions
- Make measurable predictions
- Perform objective comparison and analysis
- Correlate predicted to measured performance
- Design data can be used for compliance assessment

10. Essential ingredients for a physical based model

10.1 Geometry

All objects in the model and their physical relationship to each other are contained in the geometry. Since most of the data is vector based[ii]; models are generated in actual dimensions.

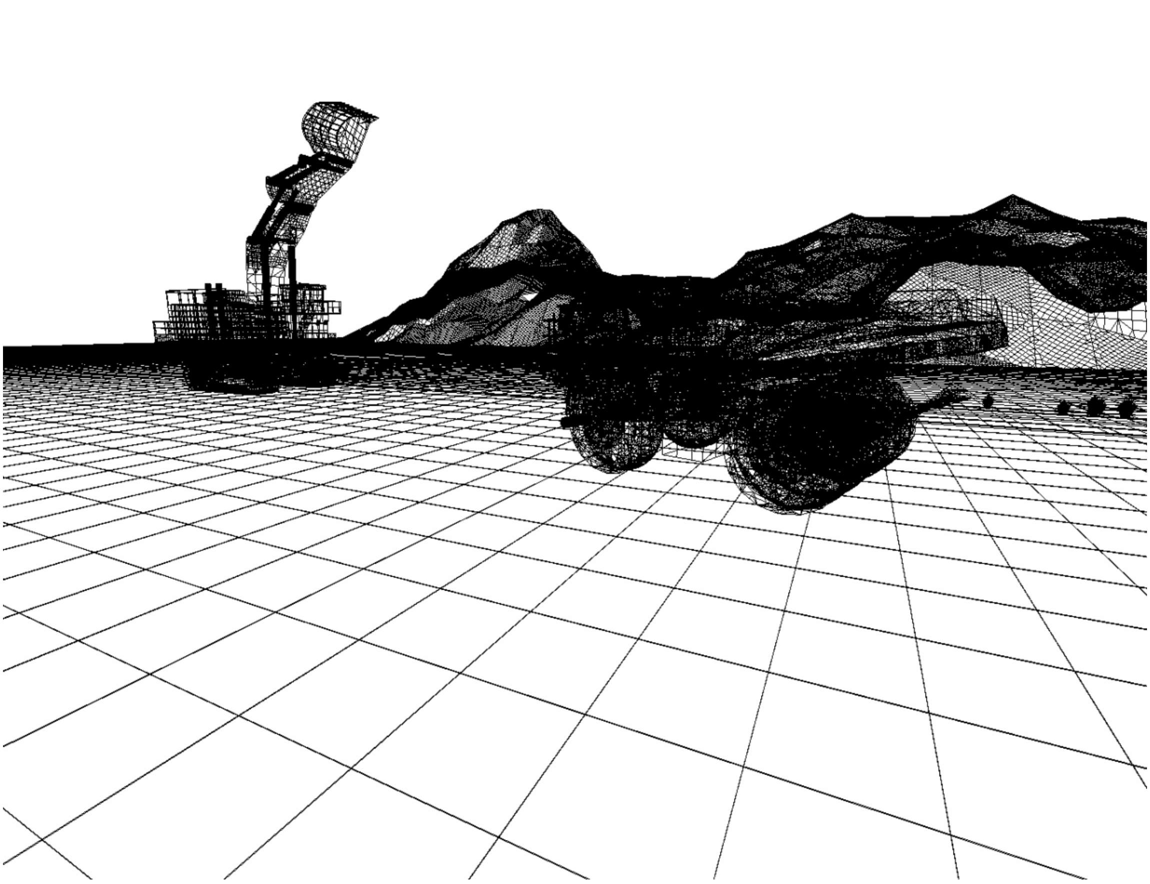

Figure 3

Model geometry of a typical lighting design

The geometric information in a model is normally a combination of library objects such as the light fittings we re-use often, and custom generated objects such as a particular haul truck type required for a specific project. Once we have created an object we can obviously recycle all or part of it.

Producing geometry tends to be single most labour intensive aspect of the process. While significant advances are being made in the tools to produce 3D geometry from 2D images[iii], at present the tools are still not sufficiently developed for this process.

In general terms each model contains three principal types of geometry:

10.1.1 Terrain

We can realistically create the work space of an open-cut operation, underground or the structure inside a process plant. The entrance of a decline shaft is an example where the model contains elements of surface operation, underground and a mix of daylight as well as artificial light.

The level of detail and scope of the model is only limited by that of the geometric content; the capacity of the processing systems to cope is no longer a practical

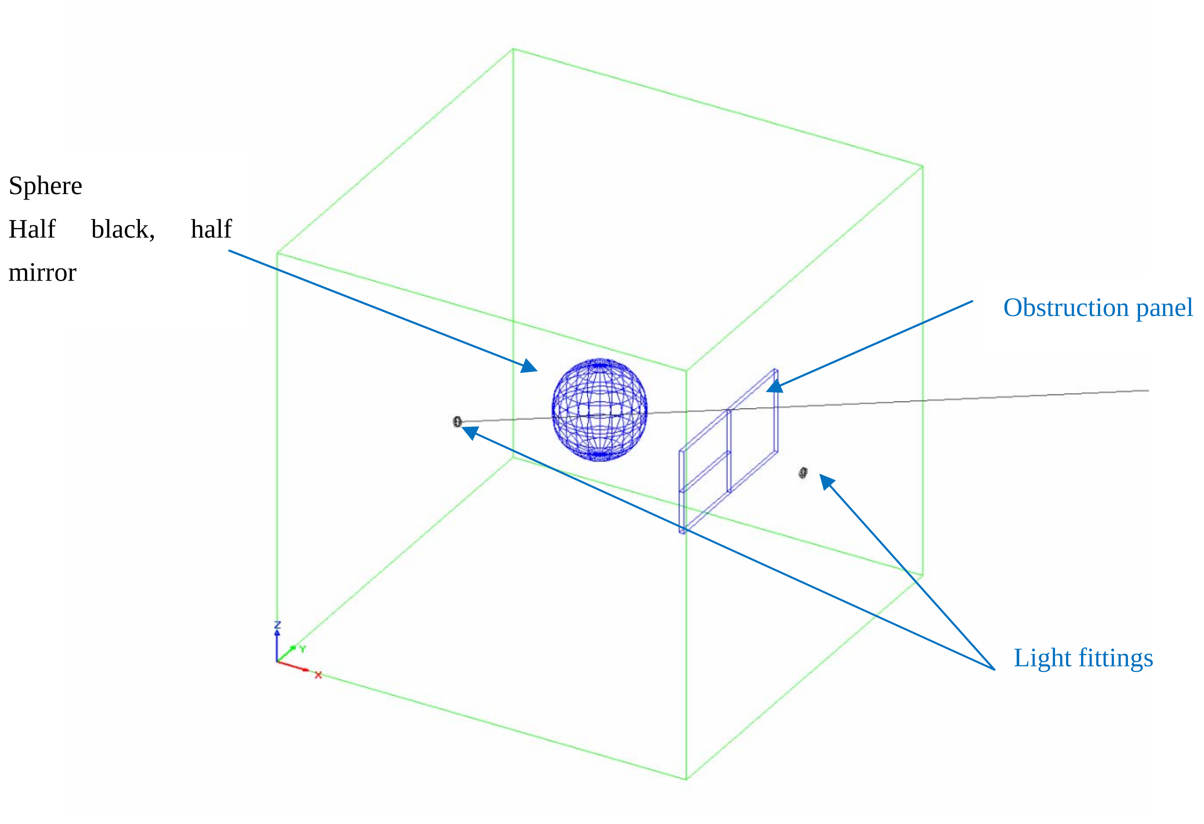

Figure 4

A simple model works well to explain the process, a simple cube containing a sphere and two lights, of which one is set behind and obstruction panel can illustrate how physical based lighting design works.

limit – so as usual cost becomes the constraint.

10.1.2 Plant

The process can mix different types of equipment – a maintenance workshop provides a good example where we create a piece of "fixed" plant and then add some "mobile" plant inside and outside the workshop.

Other examples would be the interaction between a shovel loading a haul truck, a haul truck dumping into the receiving bins of an in-pit crusher and the conveyor it feeds.

10.1.3 Lighting equipment

The lights themselves have some obvious shapes size and locations that must be captured in the model[iv], and we have practically no limit to the number and variety we can use in the model. We can also analyse the contribution or impact of daylight – which would be very important when we consider the previously mentioned shaft entrance example. When we do this the geo-spatial attributes as well as time-of-day information is added into the data to ensure the output we generate is relevant.

Up to this point there is no fundamental difference to the 3D representations in conventional CAD design and engineering systems. We would generally import customer-supplied data to speed up the job whenever it is supplied.

11 Lighting

In addition to the base geometric data described above the process now add specialised lighting data, and this is where some significant differences between the "artist impression" and "physical based" systems start to become apparent.

11.1 Location

Each individual light fitting has a unique location – it can be on top of a lighting mast, inside the cabin of a drill, hanging from the roof of a workshop or the sun itself at any date and time somewhere on this planet.

11.2 Aiming

In addition to the location of the light itself it is also aimed in a specific direction – sometimes without much consideration for example fluorescent lights in a store room, in other cases like high intensity pencil beam driving lamps high degrees of care and precision are required.

It is also worthwhile to consider that arrays of lights need to be located and aimed with care.

Some of the common problems encountered are:

- Lights obstructing each other
- Distracting reflections from mirrors, widows or other glossy surface
- Bright patches on surfaces close to the operator when the work area is more distant
- Glare to the operators of the plant the lights are mounted onto, or to others.

It should become obvious that the **process** of creating a realistic 3D virtual model requires the evaluation of issues that are often overlooked or left to an on-site electrician. If nothing else happens some significant benefits would already be gained from this evaluation process.

11.3 Type

Each light fitting in the model is assigned a type – typically selected from a catalogue of products (fig 5). As a manufacturer we have an obvious incentive to use our products – but we can use any light we have data available for. We often evaluate several types and may even offer different designs based of different types each with specific features. This enables clients to decide what delivers the best value for them based on a clear understanding of the merits of the available options.

Figure 5

11.4 Light source

The light source choice should be closely considered with the task, duty cycle, ease of service access and function of the light. It may be a life safety issue or convenience, colour accuracy requirement and many other parameters. The choice of light source and light fitting are equally important – and should never be evaluated in isolation.

Figure 6

There is a large range of light sources available each with its own advantages and limitations (fig 6). Apart from the obvious issue that different types of light sources require different light fittings, it is quite common for one type of light fitting to be capable of using different lamps.

Deriving the solution for any particular application is largely the result of finding the optimum selection and combination of location, aiming, type and light source. Adding additional manifold parameters like purchase cost, installation & maintenance cost, energy consumption as well as logistic related costs related to supply time, stock-holding costs etc., clearly places the problem into a class that career mathematicians consider challenging.

11.5 Photometry

Every type and model of light distributes light uniquely; this information can be measured precisely[2] (fig 7) and described as a vector array of light intensity versus measurement angle[v]. Spectral power distribution data of the light source describes the colour[vi] of the light emitted.

Each light fitting in the model is assigned its specific photometric data reference, and based on the aiming of the light in the model the photometric data is rotated to accurately replicate how the light will project it's light into the virtual space.

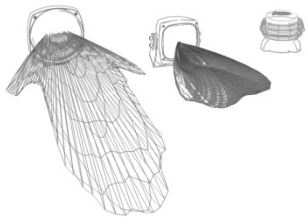

Figure 7

Photometric diagrams of typical light fittings

11.6 Depreciation

Nothing is perfect and eternal – and so it is in the virtual model. Allowance should be made for the impact of dirt on the light fittings and the changing performance of light sources as they age.

The convention among lighting engineers is to design a system that will meet the performance objectives when

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[2] The data for each light fitting is obtained by measurement in a photometric laboratory, essentially a temperature controlled, dark room equipped with photometer at one end, and a goniometer at the other. The light fitting is mounted onto the goniometer table and precisely rotated it in both azimuth and elevation relative to the photometer.

The measurement process, the measurement equipment and operation greatly affect the accuracy of the data. If the measured results are to have any credibility it is essential that the photometric laboratory be accredited by an internationally recognised organisation like TUV. With such accreditation the photometric data is fully traceable to international metrology standards and certificates of conformance with legal stature can be issued.

It is essential that photometric data of only this quality is used in physical based modelling – without it we are basically back to "artist impression" output that contains no objective lighting values.

the light sources are ready for replacement[3] – basically the same approach taken in any planned maintenance program.

Mining and its high mechanical stress, high duty cycle environment has an almost universally negative impact on lamp life, and thus requires more regular access to the lights for maintenance. Mining also exposes lights to more dirt and corrosive action that most other applications and thus generally reduce the efficiency of optical systems that by nature function best when clean.

Determining the extent of the impact on lamp life and light output of the light fittings requires more than a casual understanding of how each specific light source is constructed and operates. Nominally equivalent products respond very differently to the mining environment – and the impact on light source life can be an order of magnitude.

Once again the **process** requires conscious consideration and application of basic knowledge when selecting light sources and light fittings for mining applications this simple action tend to deliver significantly better outcomes.

12. Physical attributes

To compute the behaviour and distribution of light in the virtual model every geometric object in the model needs to be assigned some physical attributes to accurately represent the optical behaviour of that object[4]. The physical attributes assigned are determined by detailed measurement of material samples illuminated by traceable standard light sources in photometric laboratories.

12.1 Material

Every surface in the model (fig 8) is described in terms of its colour, reflectance characteristics from a perfect mirror to perfectly diffuse; it is also described in terms of its light transmission properties from perfectly opaque to completely transparent. Through this method we assign one part of a model the behaviour of glass, another that of yellow painted steel, a rubber tyre and so on ad infinitum.

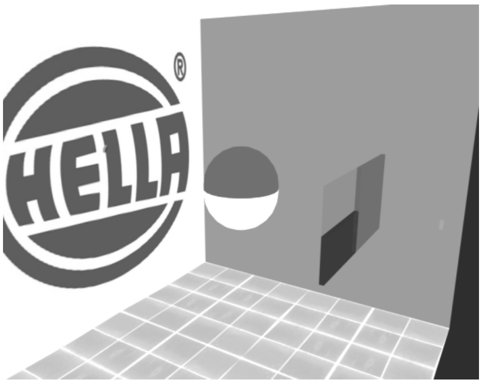

Figure 8

The walls of the cube and other items have been assigned material properties, it is displayed here artificially in an "unprocessed" state

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[3] To determine depreciation values for the light sources lighting engineers normally refer to the data regarding lamp life and end-of-life light output published by the manufacturer of the light source. It is important to understand that such figures are statistically derived values based on batch tests carried out under prescribed conditions. The objective of the standardised test is to provide reasonable data for use in general lighting applications like factories, offices and passenger motor vehicles.

[4] This step would be familiar to people engaged in Finite Element Analysis – and the general the process and computation is similar – in lighting simulations we are tend to focus on model *surfaces* whereas in FEA the focus is on *solids.*

12.2 Texture

Materials also exhibit fine surface details that tend to be geometrically consistent over the surface of the material – such as wood grain, sand, bricks or similar details that would be very time consuming to model directly. For such aspects of the model it is more efficient to describe it mathematically[vii]. A typical use of such a "displacement map" is to generate more realistic representations of water which would otherwise look like glass.

13. Computation systems

Optimising complex engineering systems by tracking the dissipation and effects of energy in the system over multiple generations of interaction by the application of brute force computation is now widely used, but it may be useful to pay due respect to the fact that the early hard fundamental work was paid for by the Manhattan Project and it's siblings – legitimate and otherwise.

In the present context of physical based lighting design the computational process essentially proceeds along the following route:

The virtual model containing the geometry, aiming data etc and all the required associated reference data like a photometric reports library; material library is loaded into a customised software package that will compute the "Radiosity Solution File" [5] the results are then used to generate images.

13.1 Phase 1: Energy estimate

As a first step in the process the total amount of energy in system is computed by adding all the light output of all the light fittings – this provides a starting point for the estimation of several computation processes.

13.2 Phase 2: Subdivision mesh creation

The next step along the path sub divides each modelled surface of the model into smaller surfaces (fig 9) so that a more accurate distribution of light can be derived. Subdivision mesh density varies throughout the model depending on the geometric relationships between the specific surface and light fittings and the overall system energy. Typically objects close to light fittings are assigned a finer surface mesh density than those far away.

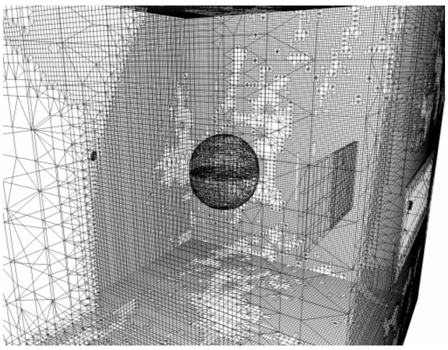

Figure 9 Initial subdivision mesh

Controlling the allowable gradient of change between adjacent cells of the mesh provides the lighting engineer an effective tool to balance computational efficiency against resolution[6] by focussing resources on areas where there are rapid changes in light intensity, and zones where the energy density is highest.

[5] Our "no charge to the customer" projects are created using dedicated but commercially available desktop equipment. Large specialised projects require customised 64 bit pipelines that can cope with unlimited models.

[6] It is important to note that the density of the sub division mesh does not affect the accuracy or fidelity of the computation only the resolution. Detailed discussions on this point falls outside the scope of this paper, but the author will gladly provide clarification if required.

13.3 Phase 3: Direct illumination calculation

The computation process itself normally occurs in two distinct stages: direct illumination and indirect illumination. In the both cases software considers each light fitting in series, generally in descending order of light-output.

Every surface cell in the model is analysed – if it has a direct line-of sight view to the specific light fitting under consideration the amount of light radiated into the cell is derived from the physically measured data (photometric file) and the cell's geometric relationship to the light fitting. This "direct illumination" is stored and eventually the contribution from every light fitting is summed for that cell[7].

After all the lights and all the cells have been computed, the Phase 2 process sub-division process is repeated and regions in the model are identified where the gradient of change in the refined mesh exceeds the requirements. These cell groups are reprocessed in another pass of Phase 3 and repeated until the set target gradient is met.

The Phase 3 computation concludes (fig 10) when every cell in the model "knows" the following:

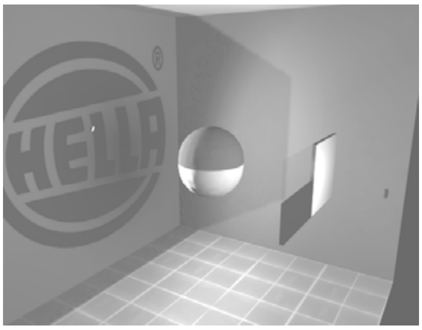

Figure 10

- How much light is radiated directly into it
- Where the light in it originated from
- The gradient of change between adjacent cells falls within the set limit.

We can use the Phase 3 results to determine the general illumination levels and major shadowing effects – and if we were modelling something like a parking lot the results would be sufficient for the majority of tasks.

13.4 Phase 4: Indirect illumination calculation

This stage of the process computes the "indirect illumination" due to the computational cost this information is often ignored – but the effects are important and make significant contributions to the visual environment. In most indoor situations about 30% of the useful light is reflected off something else, and outdoors the indirect contribution often approaches 100%.

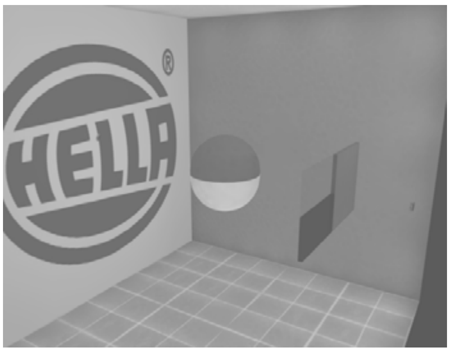

Figure 11 Indirect illumination only

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[7] This type of computation is often termed "point by point" for obvious reasons – it should be obvious that for all but the simplest models the task is not trivial, and that the algorithms applied should be rigorously tested and validated against physical measurements.

This phase of computation to obtain the Radiosity Solution File proceeds in a similar fashion of cell-by-cell evaluation, however it is vital to note the significant difference that every cell is now considered as both emitters and receivers of light. This is because the direct light output of the "real" light fittings was "captured" in the cells in the preceding computational phase turning each cell into a little light fitting.

In the current phase the physical material properties assigned to objects in the model are used to derive the physical optical behaviour of each cell. This is because the "captured" light energy is modified by the cell when radiated back into the model.

The major effects are:

・The amount of light radiated would be less than received[8] – according to the reflectivity of the object.

・The colour of the radiated light would be a subset of the colour received[9] the degree of change determined by the colour of the object.

・The radiation intensity changes according to direction depending on the "specularity" of the object – basically how much the object behaves like a mirror.

・The object may also transmit some of the light in a mix of diffuse and diffractive modes.

The indirect computation process is also repeated several for several passes complete with intermediate mesh subdivisions because a cycle computes the effect of only a single reflection – and reality is the result of multiple reflections.

It should also be reasonably clear that the "indirect" computational phase is significantly more complex than the "direct" phase. Some measure of control is required to optimise computational efficiency versus resolution, in this phase it is provided by setting energy thresholds.

・Only cells that contain more than a minimum quantum of light energy relative to the total energy content (computed right at the start) are considered as light sources.

・The indirect computation cycle is only repeated if the sum of energy, determined by the cell selection parameters exceeds a set percentage of the total energy content[10].

13.5 Store the solution

Once the whole four-phased calculation process has concluded every object in the model has been sub-divided into much smaller mesh cells, each of which contains the following data:

・Direct Illumination information derived from phase 1

・Indirect Illumination derived from phase 2

・Physical Attribute information

・Geometric information

・Origin relationships

This database[11] of information is commonly named the "Radiosity Solution File" and it is saved for use in the generation of visual output useful to humans.

14. Apply the solution to the model

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[8] There are no perfect reflectors – good quality pure white paint reflects about 85% of incident light.

[9] Objects do not create new colours – the process is always subtractive where some frequencies (colours) are absorbed and the remainder reflected off the surface or transmitted through the medium. The reflected colour and transmitted colour for translucent objects can be similar or complementary – and may also change according to angle.

[10] In practice the energy threshold definitions are more complex to ensure that large areas of small cells are not overlooked. When daylight is mixed with artificial light they are considered separately because the energy of the sun would swamp the artificial light.

[11] The design of the database itself is a critical factor in determining the efficiency of the Radiosity Solution File computation, and the subsequent applications of the Solution. It is not uncommon to require several Terabyte of storage, the speed and frequency at which data needs to be is accessed will cripple almost any network.

The Radiosity Solution File data itself does not provide the information we need but it is used to generate it.
To present the output in a meaningful way it is required to selected a “Point of View” it may be a standardised orthogonal drawing view like “Plan”, “Elevation” or “Isometric” that does not include perspective, or it may be a perspective view from anywhere in the virtual model. An unlimited number of viewpoints can be selected – a series of viewpoints can be placed along a path to create a “fly through”.
An image is “rendered” by applying the RSF data to the objects of the virtual model visible from the specified point of view.

14.1 The simplest answer is to plot the results numerically

In this format the model geometry is generally represented as a line drawing – commonly projected in one of the orthogonal views. The lighting data from the RSF is then plotted at specified grid intervals[12] for the visible surfaces.
Lighting data can be plotted in several metrics the most common being
- Illuminance (lux) - describing the amount of light that is incident on the surface
- Luminance (cd/m^2) - describing the intensity of light radiated, or the brightness of the surface

Numeric data is useful for lighting engineers to check details regarding compliance issues and for some statistical analysis.
It may be useful to recall that the key objective of the whole process is to improve the quality of lighting at a specific mine. Providing lighting information in numeric format is often no more useful than arguing the merits of a particular malt brew by chemical analysis.

14.2 It is often more useful to bring pictures

If we apply the RSF data in the model we can create images – and since we are all equipped with the tools to evaluate images we can now engage the target of our process: to directly consider the result.

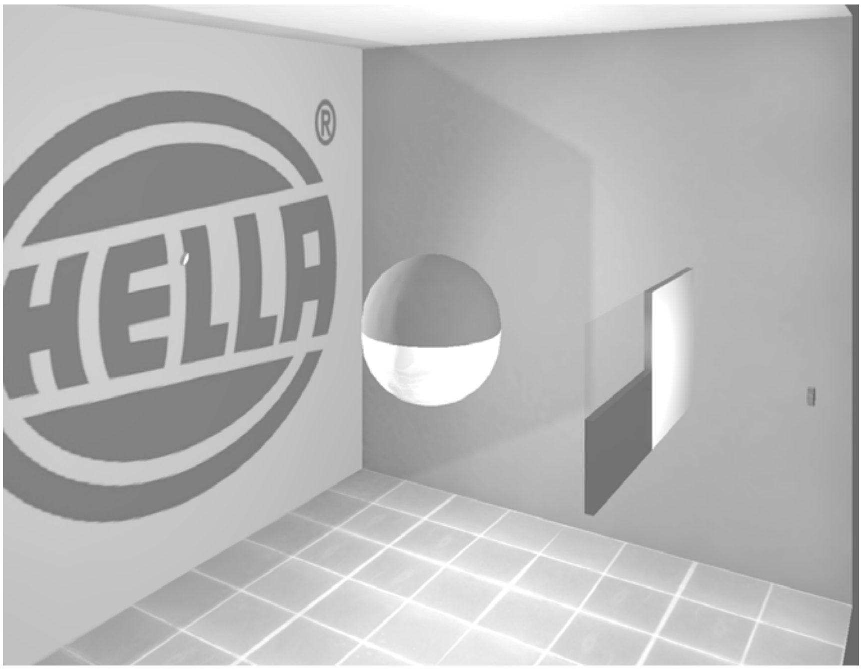


Figure 12

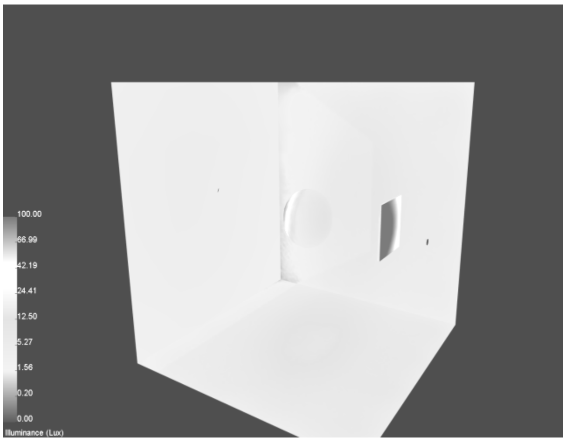
[12] The numeric grid can be computed directly – which we tend to do if we are not particularly interested in the indirect lighting. Indirect contributions can be done quickly by gross assumptions, which is how most lighting designs are still done.

Model shown with ray-traced direct and indirect illumination, note the natural reflections and shadowing effects are all faithfully reproduced

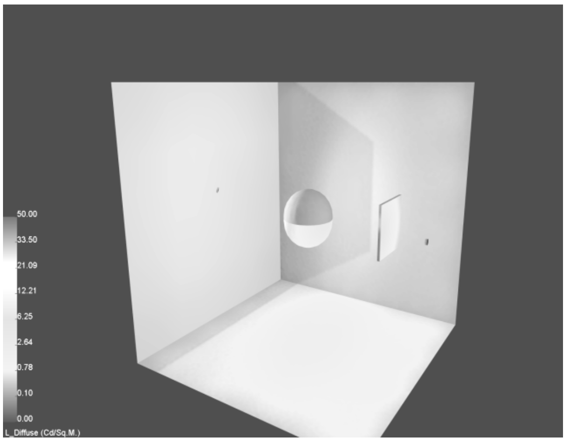
No one type of image is perfect but we can represent virtually all of the really important aspects in just three image types. (Remember that we can generate images from any point of view – so we can get as much detail as required.)

“Photo realistic” images (fig 12) are produced by using the RSF to generate luminance and colour values for every cell of the mesh visible from the selected point of view. To provide realism it is necessary to do a “ray trace” backward from the primary point of view to each visible cell and determine what that cell “sees” we can then add reflections and transparency of that view according to the material attributes. It is worthwhile to note that this process also compress the real life dynamic range of the RSF data into the commonly used “RGB” colour space so the images can be displayed on consumer visual displays and printed. While this compromise undoubtedly introduces a loss of fidelity[13] we all seem to accept it – as our love for television demonstrates.

Engineering data (fig 13 &14) can also be presented graphically – without compression. Illumination and Luminance values are simply transcribed to a spectrum of RGB colours scaled to suit the objective. These “false colour” images are familiar objects and eliminate virtually all need for direct numerical analysis.



Illuminance (Lux)
Figure 13



Luminance (cd/m^2)
Figure 14

15 Example Presentation

An example document is available for download at **www.hella.com/mining** under the “Applications Engineering” menu.

16 Results

16.1 Wide stakeholder ownership

The completion of the “Application Engineering Request” document starts the process that initiates a series of conscious decision-making events from the end-users. A wide range of stakeholders are drawn into the process through their input in defining the issues that require improvement, soliciting opinions on intermediate results or alternative options and even by providing photos or drawings of the plant.

16.2 Clarity

The performance of the lighting system is conveyed graphically – from multiple points of view. The graphic

[13] It is possible to display High Dynamic Range images on specialized equipment and some significant advances in this field will reach the general market soon.

nature of the output removes the mystery and most importantly the need for external specialists to evaluate and report on the results.

The same material can be evaluated and used at all levels of the organisation, and functions very well in multi language environments.

All pertinent information to install and maintain the system is included, and shown graphically:

- Detailed product schedule
- Installation locations
- Aiming angles
- Spare parts
- Compliance information is given and referenced.

16.3 Deliver clear Safety improvements

Safety and Lighting are closely related because lighting provides the means to see and to be seen. Safety is compromised significantly if either of these visual aspects are inadequate relative to the risks - hence the general absence of blind miners.

One of the less appreciated risk factors in our modern well ordered and sign-posted safe environment is the fact that risk escalates enormously if expected warnings are absent or fail – note how hard it is to drive behind a vehicle without stop signal lamps.

Based on the simple idea that we can prevent most hazards from causing harm if we have sufficient warning (and training) to avoid or mitigate the risk to acceptable levels it becomes quite clear that lighting is a major tool to alert us in good time.

Providing good illumination of the task area (workbench, desk, stairwell, haul road or blast hole) enables us to note anomalies, accurately estimate the speed and direction of other users & potential hazards in the space as well as the ability to obtain basic information of the surrounding environment.

Signals lights are not intended to deliver light to perform tasks but draw attention to changing conditions, alert and even identify hazards and to lead us towards safety.

In both cases the prime requirement is reliability commensurate with the risks – a failed globe among hundreds in the office has negligible impact but if that globe marked the entry to the safety chamber, the safety impact is quite different.

A very close second requirement is to deliver the visibility performance to fulfill its intended role when needed trough life, not only when first installed.

This process of designing a suitable lighting system and demonstrating the results graphically after obtaining manifold inputs has a much higher chance of ensuring that the safety requirements are carefully considered.

Finally the maintenance of lights can introduce safety risks related to the electrical system and access – the graphic output allows maintenance staff and safety specialists to evaluate these aspects and provide feedback to modify the design or create specific work procedures if required.

16.4 Risk reduction

“No Surprises” because everyone knows what they will see, what equipment is needed and where it needs to be installed

The process allows secondary users like service crews to include their requirements and where questions regarding visibility or other issue arise, additional viewpoint images can be provided rapidly. Should the results expose deficiencies; the design can be modified until all requirements are met – at a much reduced cost and risk than to develop the design using productive plant on-site.

Design results can be integrated into formalised risk assessment of plant and operational processes.

17 Ten measurable productivity improvements

- Good visual conditions enable operators to see hazards and reduce damage to plant

・Good colour rendering enables operators to accurately identify materials, at source and reduce contamination of ore by overburden etc.
・Reduced unplanned production plant downtime due to malfunctioning lights.
・Reductions in the repair time of lighting equipment.
・Installation and repair of lighting equipment becomes more efficient if clear information is available
・Repairing equipment designed for regular maintenance that includes sufficient light to see what you need to requires less time than otherwise
・Standardisation of lighting solutions and equipment reduces operator and maintenance team training time.
・Standardisation of equipment simplifies spare part inventory and reduce its associated logistical & procurement overheads
・Using the same lighting system on mobile plant enables the organisation to move the assets between operations
・Good lighting is an essential part of a good working environment, reducing fatigue and consequent absenteeism[viii].

18. Sustainability

18.1 The lighting system itself

The first hurdles in the long-term sustainability of the lighting solution are overcome through the process of widening the design ownership. The inclusive nature of the process provides opportunities for concerns regarding safe and effective maintenance access to the lights and product serviceability as well the procurement and stocking of spare parts to be integrated.

Including clear graphic information regarding the aiming for each light is essential to ensure the system can maintain its performance; it is not uncommon for lights to be moved during lamp replacement, repair or replacement.

18.2 Environmental impact

Because the lighting design delivers measurable productivity improvements – its own very small environmental footprint is reversed into gains.

The products specified in the design are designed to operate efficiently in mining applications, thus replacing multiple inferior units over life.

All serviceable products are supported with a full range of spares – and their modular design ensures that used lights can be 100% recycled into fully working lights.

19. Standardisation

Due to the comprehensive documentation supplied, a lighting solution for a task or piece of plant can be implemented across the site and organisation.

The organisation can include the lighting solutions into plant specifications when additional plant is procured.

The organisation can include the lighting design process in the procurement and evaluation of new types of plant, the process will highlight potential problems related visibility and ensure that the lighting of the new plant can be maintained and where possible use compatible or identical equipment.

20. Conclusions

・It is possible to design good quality appropriate lighting systems for mines using a simple process
・The design must reflect the realities of the mine to be valid and relevant, and must be able to withstand objective scrutiny and evaluation of its claims.
・An effective and economically viable method to deliver a valid design result is to use a rigorous process that accurately mimics reality in a virtual model.

• If the design results are delivered in a clear and accessible format that the end users can evaluate they will accept and implement it.
END

Authors' Biography.

Urbain du Plessis was born and educated in South Africa in computer science, business and physics, settling in Australia in 1997 to work on the Sydney 2000 Olympics after a career designing lighting systems for projects ranging from safari camps to nuclear power plants in many different countries. He joined Hella® in 2002 to create the Centre of Excellence – Mining™

Urbain and his team are responsible for the design, production, sales and marketing of application focused, engineering based lighting solutions to the global mining industry.

Urbain has received numerous lighting and design awards in South Africa, USA and Australia. The products designed by his team for the mining industry has been recognised with Australian Design Awards® in 2004, 2005, SAE®-A Engineering Excellence awards in 2004, 2005, 2006 & 2008

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• Fig 2 is a reproduction of a Caterpillar® product brochure

End Notes

The following material is not strictly bound into the paper but is highly useful in the context because the overall impact is taken into account in the physical based nature of the model:

Incandescent & halogen lamps: The resistance to flow of electric current in a material heats the material to incandescence. The glowing material – typically a coil of tungsten is suspended in glass globe containing a semi vacuum by two or more supports. Such a device is not only obviously mechanically fragile but becomes increasingly more fragile because some of the incandescent material boils away, and because the process is thermally driven it also contains an inherent positive feedback loop that creates "hot spots" on the filament. The evaporated metal is deposited on a cooler part of the lamp – such as the glass globe and reducing light output over time.

If we consider the effect of the mine environment on incandescent light sources the following qualitative conclusion may be drawn: The filament will most likely break sooner than it would when used in a "normal" application, and due to this shorter life there will be less impact on light output from deposits on the glass. This short lamp life process also create more regular opportunity to clean the light fitting – but based on what we have seen it appears to be more opportunities to entrap dirt inside the light.

Fluorescent lamps: An electrical discharge between two electrodes contained in a low pressure glass vessel excites a gas to generate Ultra Violet radiation which is converted into visible light by a fluorescent coating deposited on the walls of the glass vessel. Such a device is obviously less affected by vibration than an incandescent lamp – and hence they are expected to last about ten to twenty times longer. But it is important to know that all fluorescent lamps still contain two filament electrodes that are heated to glowing during the start cycle of the lamp, and it thus suffers from a similar evaporation driven end-of-life process. This leads to the familiar blackened ends seen on older lamps- this is the primary light-output reduction process but other process also cumulatively reduce light output. The fluorescent materials suffer practically no degradation over the life span of a lamp – but contamination affects them.

If we consider the effect of the mine environment on fluorescent lamps the qualitative conclusions may be that the lamps will last longer than predicted when they are used in places where they are never switched off and that means that the end-of-life light output of the lamp may be considerably lower than predicted.

High Intensity Discharge (HID) lamps: An electrical discharge between two electrodes contained in a high pressure translucent vessel excites a plasma cocktail to generate Ultra Violet and/or visible radiation. The discharge temperature of HID lamps is higher than the melting point of normal glass and some plasma (like sodium) is also highly corrosive, and the spectral power distribution of plasma radiation is highly pressure sensitive. This creates a different combination of factors that determine lamp life

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