OUTCOMES OF THE TECHNOLOGY ADOPTION PROGRAMME FOR RISK BASED SUPPORT DESIGN IN BUSHVELD PLATINUM UNDERGROUND MINES

EJ Walls, C Maduray, D Govender, AP Boaduo, WC Joughin
SRK Consulting (Pty) Ltd
N Singh, K Naidoo
MHSC

Abstract

Research was completed in 2011 under funding from the Mine Health and Safety Council (MHSC, SIM120201 Track B) to develop a model for quantifying the rockfall risk associated with a support system in a given geotechnical environment (Joughin *et al*, 2012). To achieve a target of zero harm associated with rockfalls, it is necessary to understand the current risk associated with a support system and apply incremental improvements to reduce the risk level towards the target. This can be achieved by quantifying the rockfall risk in terms of injuries and economic losses using the model. Comparable risk profiles are then generated enabling the selection of a support system which will incrementally reduce the rockfall risk towards zero harm.

The adoption of relevant research within the industry to improve safety and profitability performance has recently become mandatory in terms of the Mining Charter (2010 amendment). Consequently, a technology transfer programme was required to ensure that operations are able to apply the risk model for on-mine support design. Under funding from the MHSC, SRK carried out a program together with the Chamber of Mines Rock Engineering Technical Committee (CoMRETC), Open House Management Solutions (OHMS) and champion operations from the Bushveld Platinum mines to train Rock Engineering practitioners in the model and review the resulting adoption outcomes. The program commenced in 2012 and was completed in June 2013.

On completion of the program, all of the stakeholder operations had successfully adopted components of the technology, however full application of the risk model to obtain comparative risk profiles had not been achieved at any of the operations. Several challenges to adoption of the technology were revealed during the program. Going forward, effective use of the risk model for support design in the industry will rest primarily on overcoming challenges to ensure that quality data and necessary tools and equipment are available..

1. Introduction

Falls of Ground (FoG) continue to present a risk to safety and productivity of mining operations. In the Bushveld Platinum underground mines of South Africa, the jointed nature of ground conditions gives rise to blocks or wedges, known as keyblocks, which must be supported to prevent failure. Failed keyblocks result in FoG's that can cause injuries (or worse) and impact on the performance of the operation. Support designs are required to provide solutions to the FoG risk in a manner that addresses both the safety risk while remaining economically viable.

Technology was developed and completed in 2011 as an outcome of the Mine Health and Safety Council (MHSC) research project "SIM060201 Track B - A Risk Based Approach to Enhancing Support Design in Bushveld Underground Mines" (Joughin, *et al*, 2012). The technology enables a FoG risk for an operation to be quantified in terms of losses due to rockfalls and costs associated with a particular support system in a given geotechnical environment.

A stipulation of the Mining Charter (Amendment, 2010) requires that the mining industry should adopt research outcomes which may improve cost effectiveness and safety performance. The

Chamber of Mines has embarked on a programme to manage the adoption process and meet these objectives. This technology transfer project was commissioned through the MHSC in 2012 to implement the risk based approach to support design within the Bushveld Platinum underground mines. Use of this technology is expected to improve the support design process and therefore provide sustainable solutions to the ongoing challenge of FoG risk mitigation in the industry.

This technology transfer programme is the first such endeavour to be carried out to meet the Mining Charter requirements and serves as a case study for future industry adoption projects. SRK facilitated the implementation process with the assistance of Open House Management Solutions (OHMS) who provided training and software support.

This paper presents the process followed to facilitate adoption of the technology in the industry, essential requirements to carry out a risk based support design, and findings from the review of resulting support designs at each of the operations using the technology.

2. Project Initiation, Stakeholder Engagement and Training

The project was launched in August 2012. To achieve a successful adoption of the technology in the industry, it was essential to secure stakeholder engagement at every stage of the process. Together with the Chamber of Mines Rock Engineering Technical Committee (CoMRETC), 45 Rock Engineering (RE) practitioners representing 20 stakeholder operations from champion mines in the industry were selected to receive training in the technology. A suitable training, implementation and review programme was planned together with the CoMRETC and OHMS.

Operations were selected from the following champion mines, ensuring broad participation throughout the industry:

- Anglo American Platinum (AAP) – 5 shafts
- XStrata Alloys (XStrata) – 2 shafts
- Lonmin Platinum Mines (Lonmin) – 4 shafts
- Impala Platinum Mines (Impala) – 5 shafts
- Northam Platinum Mines (Northam) – 1 shaft
- African Rainbow Minerals (ARM) – 1 shaft
- Aquarius Mines (Aquarius) – 1 shaft
- Royal Bafokeng Platinum Mines (RBPM) – 1 shaft

Each shaft was required to have the necessary tools and equipment, time and resources to carry out a support design using the risk based approach. A phase of procurements followed the launch of the project which was partially completed in time for the training courses.

Training was carried out together with OHMS at the operations during September and October 2012. The practitioners were then required to implement the technology on their respective operations.

Review of the resulting support designs at each operation was planned to commence on completion of the training in October 2012, however as a consequence of protracted labour action in the Platinum industry during 2012, implementation of the technology was severely inhibited. Reviews were initiated in February 2013 and completed in June.

3. Risk Evaluation Technology

FoG present a continual risk to achieving safety and production milestones in underground mining. To address this risk, the geotechnical and mining conditions giving rise to FoG's and the consequential losses must be defined and analysed. The risk evaluation process for enhanced support design in Bushveld Platinum mines was presented in the publications of Joughin et al, 2012, Part I and Part II. The main steps in the process are outlined briefly here.

3.1. Data Acquisition

To characterise the geotechnical and mining conditions associated with FoG's and the consequential losses, several sets of data are required for input into the risk evaluation model which includes, amongst others:

- Rock mass (joint) data to characterise the ground conditions in which blocks (keyblocks) can form and become FoG's. Underground scanline mapping must be carried out using specific mapping tools (e.g. compass, smartphone, scanline and/or clinorule). Several mapping shifts are typically required to collect sufficient rock mass data.
- Joint strength data (shear and tensile strength of joints or structures within the host rock) and rock mass density are required. Data may need to be sourced from laboratory testing or can be estimated from underground joint observations using published guidelines (Barton, 2002, Barton and Bandis, 1990).
- On-mine FoG distribution data must be available to check results from the rockfall hazard analysis. FoG data should quantify size, volume, location and associated injury of falls.
- Typical mining practice and support properties must be defined. Hazard zones represent areas of interest for rockfall statistics, injury distributions and remediation strategies. An example showing the relative distribution of keyblock failures (FoG's) within a working area that has been separated into hazard zones is presented in **Figure 1**.
- To quantify the economic risk associated with FoG's on the operation, several financial parameters are required, which include, amongst others support costs, revenue/ton, injury costs and a breakdown of production costs/ton (including blasting, tramming and processing).

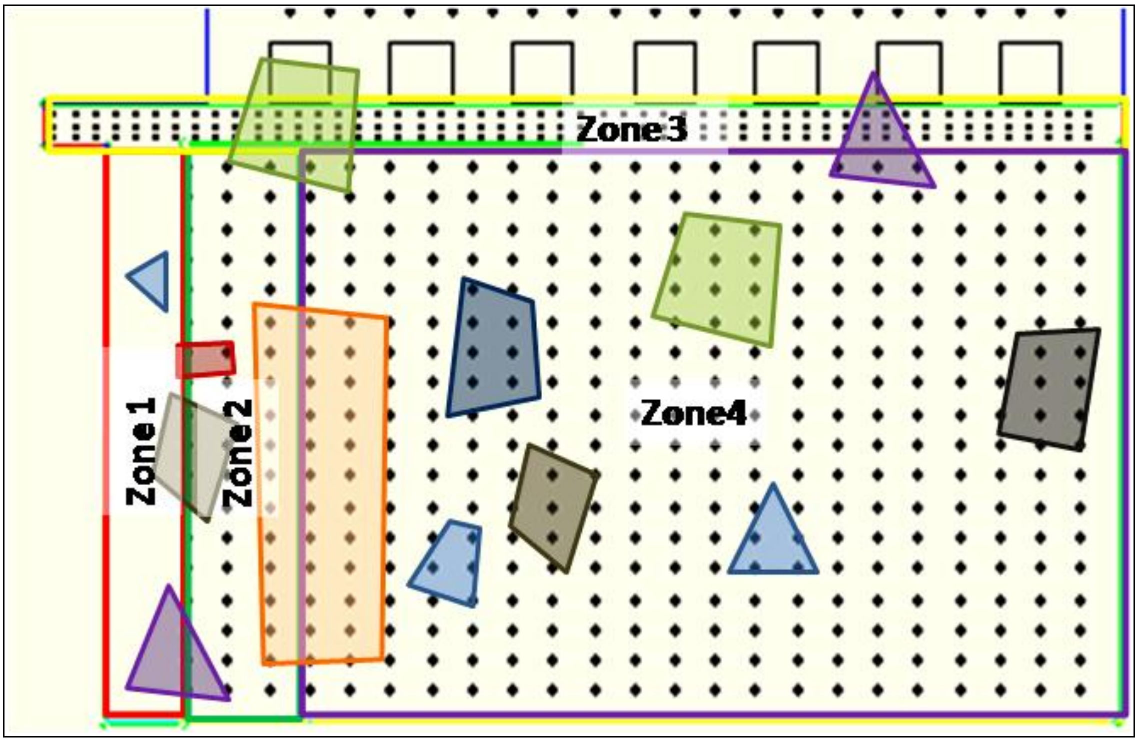

Figure 1: Example of FoG's within a mining layout showing zones of interest for hazard analysis

3.2. Data Processing

The rock mass (joint parameter) data acquired through scanline mapping must be processed to define joint sets and joint set properties. Joint sets are typically defined using a stereonet application such as DIPs (a RocScience application) which requires a software license. Joint set properties such as spacing, persistence, friction angle and cohesion are then calculated (Barton / Barton-Bandis) and variability data obtained where applicable.

3.3. Support Scenario Evaluation (keyblock analysis)

The JBlock application, which is a licensed analysis tool, is used to construct support scenarios and evaluate the associated FoG hazard within the geotechnical environment defined by the scanline mapping data. The application generates a statistical set of blocks (keyblocks) defined by the geotechnical conditions which then either fail or are stable in accordance with the support properties.

Outputs from are presented in the form of:

- A distribution of keyblocks in terms of size, location and failure mode;
- Proportional failure of support units;
- Proportional keyblock failure in relation to before or after blasting;
- Location and proportion of injuries in relation to the excavation and number of keyblock failures (FoG's).
- An example of a keyblock distribution obtained from a support scenario analysis is presented in **Figure 2**, showing stable blocks, blocks resulting in support failure and blocks failed between support units.

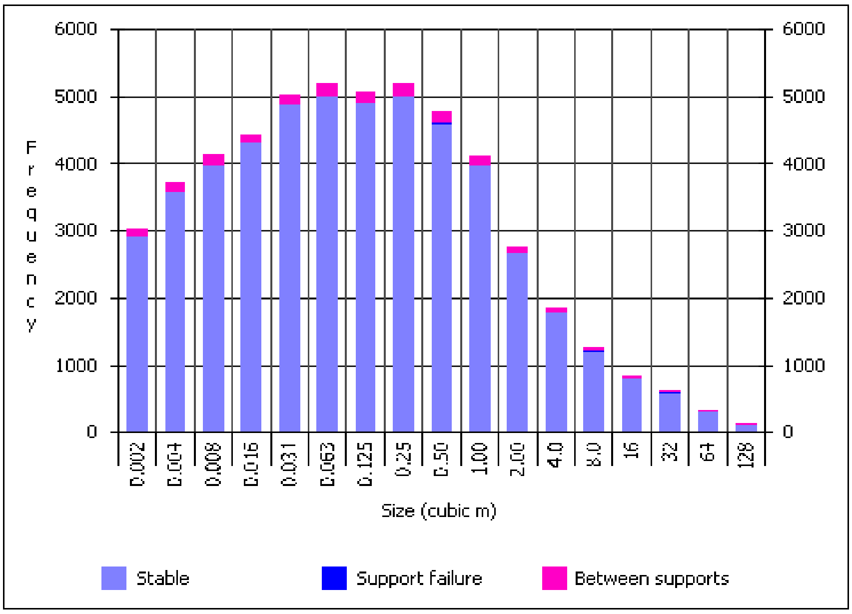

Figure 2: Example of possible keyblock distribution showing stable blocks, blocks resulting in support failure and blocks failed between support units.

A set of FoG hazard comparisons must be obtained for more than one comparable support scenario by changing certain parameters (such as support spacing or excavation geometry) and simulating the resulting FoG's.

At this stage, a support design can be selected based on the comparative FoG hazard results from variable scenarios within the same geotechnical environment. However, the limitation in this approach is that it is technically possible to infinitely increase the contribution of support and improve the support installation practices thereby commensurately reducing the FoG hazard to nil, i.e. eliminate all FoG's. However the reality implies a practical limit defined by current available technology to how much support can be installed, and a limit at which the cost of support exceeds the profitability of the operation. Furthermore, limitation of worker exposure is similarly a function of existing technology capabilities. The consequential impact of FoG's on losses to the operation must therefore be quantified to evaluate the economic feasibility against injury risk of a support system.

3.4. Risk Evaluation

The final stage is to obtain a risk profile of the hazard scenarios by quantifying the consequence of FoG's in terms of injuries (safety) and economic losses. The RiskEval application was developed for this purpose as an outcome of the research project and at present does not require a license to run. Mining parameters relating to rehabilitation strategies, revenue, production costs, risk mitigation strategies and injuries are input into the application together with the support scenario hazard results to obtain comparable risk profiles and select an optimum support design. An example of such a risk profile in terms of cost per m^2 and injuries per 100 000 m^2 associated with variable support installation practices within the same support system is presented in **Figure 3a** and **Figure 3b**.

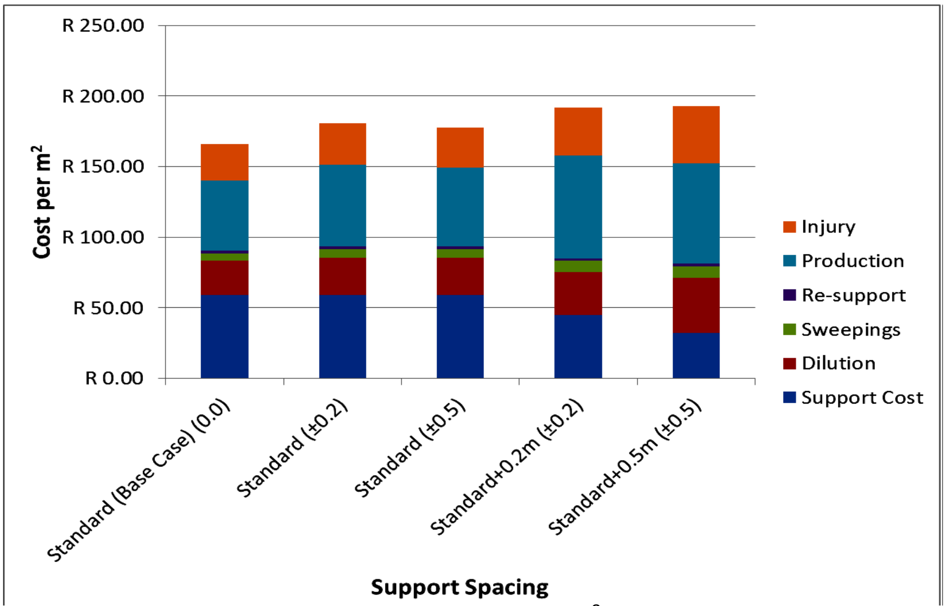

Figure 3a: Risk profile in terms of cost per m^2 for comparable support hazard scenarios.

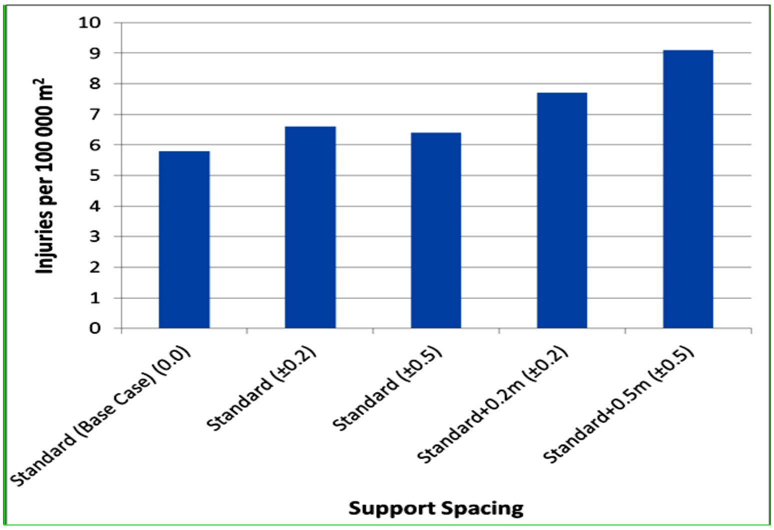

Figure 3b: Risk profile in terms of cost per injuries per 100 000 m^2 for comparable support hazard scenarios.

Evident from the results is that the design with the highest support unit costs (least deviation from support standard), is also associated with the lowest overall costs per m2 and lowest number of injuries, while increased deviation from the support standard leads to the highest overall costs and the highest number of injuries.

4. Adoption Outcomes

Several shafts succeeded in carrying out a FoG hazard analysis for single or multiple support scenarios, having obtained the required tools and equipment, input data and using the JBlock application. A single shaft succeeded in obtaining a support design for the operation based on comparative hazard analysis results. However, the risk evaluation process had not been carried out to completion using the RiskEval application on any of the operations.

4.1. Data Acquisition and Interpretation

Outcomes of the implementation review revealed that of the 20 shafts, 16 had carried out data acquisition. Three of the 16 shafts had employed the services of an external consultant to collect and interpret the data. As a result the skills to acquire data through scanline mapping were not well developed. The remaining 4 shafts had not been able to acquire data due to restricted underground use of their preferred method of data capture using iPhone technology.

On the 13 shafts that had carried out underground scanline mapping, varying levels of accuracy was achieved. During the reviews, underground observations of mapping skills were carried out and guidance was given where required to assist with compass use, scanline orientation recording and joint mapping. On completion of the reviews, skills were deemed to be suitably developed to continue with data acquisition going forward. Stereonet applications (DIPs) had been acquired at 11 shafts, enabling the RE practitioners to complete the data interpretation.

Shortcomings in the data acquisition and interpretation that were addressed included:

- Calculation of true joint spacing using the correct scanline orientation and calculation formulae. In several cases, the scanline orientation and structure position wrt scanline were not recorded, rendering the corrections impossible.
- Where joint sets could not be interpreted using a stereonet, this further precluded calculation of true joint spacing. Rudimentary spreadsheet-based joint set analysis was demonstrated and carried out where possible.
- Calculation of joint condition parameters.
- Improved use of the stereonet application.
- Incorporating significant structures such as partings and faults.

A spreadsheet was compiled to assist with the data interpretation calculations and distributed to the operations on completion of the first shaft review where it became evident that RE practitioners required continued guidance to acquire suitable geotechnical data.

4.2. Support Scenario Evaluation (keyblock analysis)

FoG hazard analysis was carried out for single or multiple support scenarios on 13 of the operations. Three operations succeeded in producing comparative FoG hazard profiles by varying selected excavation or support parameters. Of the 3 operations, only one operation successfully selected a support design based on the comparative FoG hazard results.

Ten shafts (50%) had obtained licensed, working copies of the JBlock application. Four shafts were in possession of demo versions which have limited functionality, however only 3 of the 4 shafts succeeded in using the demo versions. The remaining 6 operations encountered IT and/or procurements obstacles which prevented applications from either being installed or procured successfully and as a result did not carry out FoG hazard analysis. Additional training by SRK using an in-house JBlock version was given for operations without the required software to assist in developing proficiency. Local geotechnical data and input parameters were interpreted where available to produce results relevant for the operation.

Challenges were encountered in the use of the JBlock application. Where operations were in possession of a licensed software application, guidance was given using the results obtained to improve the excavation construction, define hazard zones, input support and geotechnical parameters and carry out a statistical analysis using the correct setup, number of runs and varibility parameters for comparative hazard results. Comparison of results against the on-mine FoG database was encouraged to check the fidelity of analysis results for the operation.

An example of an error encountered in support scenario construction is presented in **Figure 4**, showing an excavation that has been constructed too small (5 m wide face area only). In this case, the artificial abutments will support large blocks that could fall out in a real underground situation and the support system is therefore not being properly tested. The shortcoming is a result of insufficient understanding of the principles of keyblock analysis. The concept was addressed during review with a recommendation that continued experience is required to constructed support scenarios appropriately.

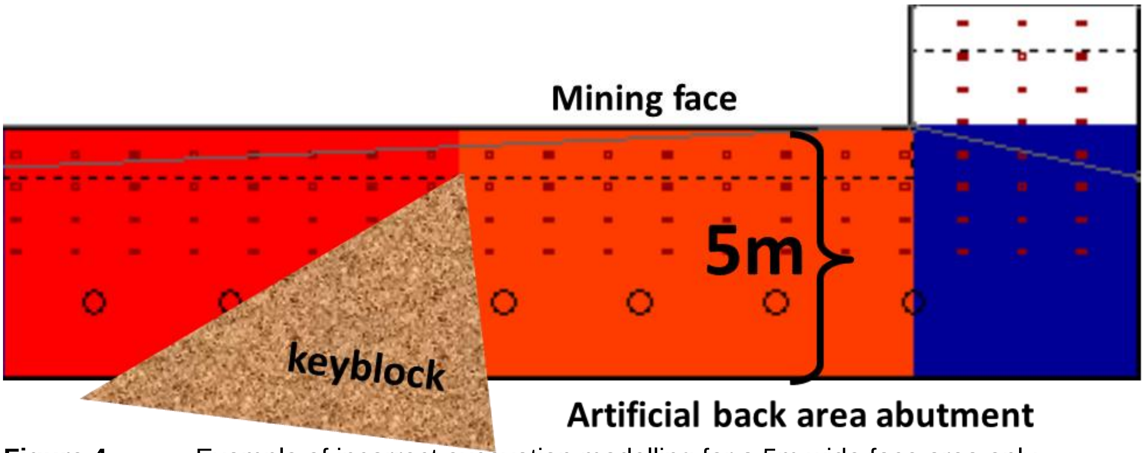

Figure 4: Example of incorrect excavation modelling for a 5m wide face area only

4.3. Risk Evaluation

Several obstacles were encountered on the operations using the RiskEval application with the result that none of the operations succeeded in completing a risk evaluation using the technology. Challenges included:

- Difficulty in acquiring on-mine input data relating to injury and production cost parameters. Several operations attempted to collect relevant input data with some success, however guidance was required to obtain a complete dataset.
- The RiskEval application is coded in a manner specifically suited to conventional breast panel mining layouts, with the result that some difficulty was encountered in applying the tool to Bord and Pillar mining. While it is possible to adjust parameters to suit Bord and Pillar strategies, this requires some careful interpretation of the RiskEval functions, particularly wrt rehabilitation strategies and guidance was required in this regard.
- The benefits of monitoring strategies such as FoGLights or closure Robots for risk mitigation through exposure reduction are not fully realised in the RiskEval application.
- On-mine IT obstacles in some cases restricted the use of JAVA (freeware required to run the application), and inhibited the use of RiskEval.

A guideline was compiled and distributed to assist users in the process of risk evaluation covering data acquisition, interpretation and software usage.

Figure 5 presents an example of on-mine worker exposure parameters selected by a particular operation for input into the RiskEval application, showing careful and thorough data acquisition for the analysis. Values are representative and not intended for actual reference.

	Exposure reduction due to rockfalls during the blast or barred out		No of persons per category	Time exposure of personnel (personnel present)			Time exposure analysis (proportion of time)			Time exposure analysis (proportion of time) adjusted for leave days		
Category (k)	*Blk*	*Bak*	*Nk*	*H1k*	*H2k*	*H3k*	*E1k*	*E2k*	*E3k*	*E1k*	*E2k*	*E3k*
Drill rig operator (panel)	0.65	0.9	2	4.0	4.0	4.0	0.5	0.5	0.5	0.5	0.5	0.5
Drill rig operator (ASD)	0.65	0.9	1	4.0	4.0	4.0	0.5	0.5	0.5	0.5	0.5	0.5
Stope Timber	0.65	0.9	3	4.0	2.5	2.5	0.5	0.3	0.3	0.5	0.3	0.3
Miner	0.65	0.4	1	6.0	2.5	2.5	0.8	0.3	0.3	0.7	0.3	0.3
Bolter	0.65	0.9	2	4.0	2.5	2.5	0.5	0.3	0.3	0.5	0.3	0.3
Sweepers	0.65	0.9	4	4.0	6.0	6.0	0.5	0.8	0.8	0.5	0.7	0.7

Figure 5: Example of representative on-mine worker exposure parameters for input into the RiskEval application

4.4. Challenges

Obstacles encountered by the operations that inhibited adoption of the technology included:

- Insufficient or inaccurate data.
    - Several dedicated underground scanline mapping shifts are required to capture sufficient data for characterising a geotechnical area, however time constraints were cited in most cases imposing a limit on RE availability. On-mine RE duties were observed to be largely dedicated to qualitative observations of daily production issues such as overall compliance to standards and local treatment of anomalous ground conditions, whereas quantitative data is required for input into the model.
    - Routine RE data capture and interpretation practices for technical solutions to ground control required some revival on the operations. A lack of familiarity with certain RE data principles was evident, which was addressed during the reviews.
    - To assess the impact of compliance to standards (behavioural impact on FoG risk), requires suitable variability data for input into the model, however data was frequently qualitative and required the application of subjective assumptions to obtain suitable values for the analysis.
    - Lack of tools and equipment prevented data capture and interpretation (compass, DIPs).

- Proficient use of the technology (JBlock and RiskEval applications) was hampered as a result of:
    - Insufficient practice using the software.
    - Unavailability of tools and equipment (license procurement and IT limitations)
    - Lack of economic understanding of the consequence of FoG's in terms of injuries and financial costs (RiskEval).

Other challenges that inhibited adoption of the risk evaluation technology included:

- Suitability of the applications to Bord and Pillar (or other) types of mining layouts;
- Poor transfer of knowledge from the course attendee to RE department practitioners;
- Inhibited procurements due to onerous on-mine administrational processes and budget restrictions, possibly as an outcome of lost production during protracted labour action;
- Restricted IT access to install software applications successfully;

- Restricted use of certain technology underground, in particular the use of iPhone mapping tools.

Overall, the most challenging obstacle on many (but not all) operations related to time constraints and unfamiliarity with essential principles of geotechnical data capture and interpretation.

5. Conclusions: Risk Evaluation Going Forward

The risk evaluation process for support design was introduced at 20 stakeholder operations on Bushveld underground mines. Variable success was achieved in carrying out a hazard analysis beginning with data capture, followed by data interpretation and keyblock failure analysis by evaluating support scenarios using the JBlock application. None of the operations succeeded in using the RiskEval application to evaluate the risk of FoG's in terms of losses due to injuries or costs.

Several challenges were encountered during the adoption process, however on completion of the reviews, 65% of the operations demonstrated sufficient proficiency with the technology to carry out a hazard analysis through to support scenario (keyblock failure) evaluation. Results at this stage of the process can be compared to select a support design based on proportional keyblock failure distributions within a working excavation, however the risk must still be quantified.

To realise the potential benefits of using the risk evaluation technology for selecting a support design to improve cost and safety performance on the operations, the following recommendations are put forward:

5.1. On-Mine Practices

- RE practitioners should be suitably equipped in terms of tools, equipment and time to carry out risk evaluation for support design using the technology.
- Routine practices of data capture to quantify geotechnical conditions and support practices should be encouraged to facilitate technical RE solutions to ground control.
- RE practitioners should be familiarised with the concepts of quantitative risk analysis particularly in terms of simple mining economics and injury consequences.
- Onerous procurements restrictions and IT limitations should be addressed to ensure that the required tools and equipment are made available.

5.2. Technology Development

Continued development of the technology is required to address certain shortcomings. Amongst others:

- The model needs to be adapted to cover a wider range of mining methods and support scenarios.
- The software requires ongoing development to meet the needs of the RE practitioners who use the technology.
- The software needs to be improved to address modes of failure other than keyblock failure.
- The benefits to risk reduction from monitoring must be incorporated into the model.

5.3. Technology Transfer Strategy

Several lessons from the technology transfer project may benefit future projects of a similar nature. Improved stakeholder engagement is recommended to:

- obtain buy-in from on-mine management to dedicate RE time towards technical projects;
- prioritise procurements of tools and equipment;

- prepare IT and administrational departments to facilitate the use of software and advanced technology such as iPhones in underground workings.

RE practitioners have demonstrated suitable proficiency in application of the technology on operations to carry out support design evaluations through to keyblock hazard analysis. The technology has been applied at 65% of the operations with varying success. The technology in its current form is suited to use on the Bushveld underground mines to improve safety and economic performance by evaluating the FoG risk and select a suitable support design. Further development of the technology to incorporate risk mitigating strategies such as monitoring and additional rock mass failure modes will enable broader use of the model going forward.

6. Acknowledgements

Thanks to:

- Mine Health and Safety Council (MHSC) for funding
- Chamber of Mines Rock Engineering Technical Committee for assisting to facilitate the adoption of the technology on operations
- Open House Management Solutions (OHMS) for providing training and software support for the project
- Champion operations from the Bushveld Platinum mines for applying the technology to carrying out risk based support designs.

7. References

Amendment of the Broad-Based Socio-Economic Empowerment Charter for the South Afrcian Mining and Mineral Insdustry. (2010, September). Republic of South Africa: Department: Mineral Resources.

Barton, N. (2002). Some new Q-value correlations to assist in site characterisation and tunnel design. *International Journal of Rock Mechanics & Mining Sciences*, Vol 39, 185 - 216.

Barton, N R, Bandis, S C. (1990). Review of predictive capabilities of JRC-JCS model in engineering practice. . *Rock joint, Proceedings of the International Symposium on Rock Joints* (pp. 603 - 610). Loen, Norway: Balkema.

Joughin, W C, Jager, A, Nezomba, E, Rwodzi, L. (2012). A risk evaluation model for support design in Bushveld Complex underground mines: Part I - Description of the model. *The Journal of the Southern African Institute of Minerals and Metallurgy*, Vol 112, 83 - 94.

Joughin, W C, Jager, A, Nezomba, E, Rwodzi, L. (2012). A risk evaluation model for support design in Bushveld Complex underground mines: Part II - Model validation and case studies. *The Journal of the South African Institute of Mining and Metallurgy*, Vol 112, 95 - 104.