SIM 14 02 01
Training extension for the adoption of a risk-based approach to support design in Bushveld underground mines

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Project number: SIM 14 02 01 Training extension for the adoption of a risk-based approach to support design in Bushveld underground mines
Date: January 2016
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3 ABBREVIATIONS AND NOMENCLATURE

- Anglo: Anglo American Platinum
- Aquarius: Aquarius Platinum Limited
- ARM: ARM Platinum
- CoMCRM: Chamber of Mines Certificate in Rock Mechanics
- CoMCSC: Chamber of Mines Certificate in Strata Control
- CoMRETC: Chamber of Mines Rock Engineering Technical Committee
- CoP: Code of Practice
- DMR: Department of Mineral Resources
- Discontinuity: A planar break in the rock mass, also referred to as a “joint” or “structure”
- EMD: Electronic Measuring Device
- FoG: Fall of Ground
- GCD: Ground Control District
- Glencore: Glencore Xtrata
- GPR: Ground Penetrating Radar
- Hernic: Hernic Ferrochrome
- MHSC: Mine Health and Safety Council
- MN: Magnetic North
- Northam: Northam Platinum Limited
- NPV: Net Present Value
- OHMS: Open House Management Solutions (Pty) Ltd
- RE: Rock Engineer(ing)
- REO: Rock Engineering Officer
- REP: Rock Engineering Practitioner
- RM: Rock Mechanic
- SCO: Strata Control Officer
- SRK: SRK Consulting (Pty) Ltd
- TN: True North
4 ACKNOWLEDGEMENTS

The authors would like to acknowledge the following persons or institutions for their valuable contributions in completing the project:

- The MHSC for sponsoring the research;
- The participating mines for equipping and making available rock engineering practitioners (REP’s) to engage in the training process and apply the risk-based support methodology at their respective operations;
- The following mines for making their facilities and time available to host respective training courses:
  - Impala Platinum Mines, Rustenburg
  - Lonmin Platinum Mines, Rustenburg
  - Northam Platinum Mines, Booysendal
- The SRK project team for providing the required skills and project management to complete the project successfully. The project team comprised:
  - Project Leader - Jeanne Walls, Pr Sci Nat
  - Project Reviewer – William Joughin, Pr Eng
  - Presentation and review of geotechnical mapping, input parameters, collection of data and data processing – Ohveshlan Pillay, Pr Sci Nat, Siyamazi Ndlovu, Pr Sci Nat and Denisha Sewnun, Pr Sci Nat.
5 EXECUTIVE SUMMARY

The SIM140201 project was commissioned by the MHSC in 2014 as an extension to the SIM120201 project, “Technology Transfer for ‘A Risk Based Approach to Enhancing Support Design in Bushveld Underground Mines’”, which was completed in 2013. An opportunity was identified as an outcome of SIM120201 to continue and expand the skills development of rock engineering practitioners (REP’s) within the industry. The project commenced in August 2014.

The training programme intended to equip REP’s with the knowledge and skills to carry out risk-based support designs for fall of ground risk mitigation using the technology on their operations. The programme that was applied for the SIM120201 project was restructured for SIM140201 to promote improved understanding and execution of the method by the participating practitioners. Five training courses consisting of six training days spread over a period of five weeks for each course were carried out from January 2015 through to May 2015. Out of 100 REP’s provided for by the training programme, a total of 74 combined rock engineering (RE) and geology practitioners attended the courses.

To date, a total of 17 project reports have been received from a combination of 30 RE and geology practitioners. 42 course participants have not yet submitted a training report.

Overall results from this project, SIM140201, have shown a marked improvement from the outcomes achieved for the SIM120201 project. This was achieved in spite of the full complement of training report submissions not being received for this project (SIM140201).

A formal assessment of competency was not specifically incorporated into the outcomes for the project; however, each report submission was reviewed by the project manager with feedback provided to the author(s). The risk evaluation process comprising each stage of the analysis was successfully carried out by the overwhelming majority of REP’s, most of whom demonstrated sufficiently competent understanding of the principles, processing and interpretation to continue developing and applying the risk-based support design approach without direct assistance for the respective operations.
A small proportion of REP’s and geology participants will require further assistance to ensure a suitable level of independent, competent ability to apply the technology within the industry.

A number of software application and hardware challenges were identified for further research and development. Amongst these the most significant issues include developing the JBlock application to troubleshoot limitations pertaining to the interpretation of input parameters and developing the RiskEval application further to suitably address the evaluation of risk for bord and pillar operations. More general running issues include compatibility with Windows 8 and/or newer versions as well as the Apple platform.

5.1 Recommendations

Going forward, the industry has been provided with a number of REP’s with the necessary skills to apply risk-based support design. However, the application of technical solutions to operational challenges remains a challenging objective within the operational environment with the outcome that several REP’s still require further practice and guidance to correctly and successfully apply the technology. A strategic initiative is recommended to focus the application of technical solutions to operational challenges from within the operational environment, i.e. by on-mine REP’s. This may include independent as well as on-mine input. As such there remains an opportunity to continue development of the applied technical skills of on-mine REP’s.

Independently, further development of the technology is required in particular for JBlock and RiskEval to improve compatibility, relevance and usability of the interface. Research initiatives are recommended to address these two applications respectively.
6 PROJECT INTRODUCTION

The risk of death, injury and economic loss associated with falls of ground (FoG’s) remains a leading liability to successful underground mining. Rock engineering (RE) design is aimed at addressing this risk by using suitable tools and methods to provide quantified solutions for mitigating against rock mass related instability. A risk-based RE design approach is such a tool that was developed as part of the SIM060201 Track B project which was completed in 2011. The risk-based approach is a support design tool aimed at assisting mining operations to mitigate against and reduce the risk associated with FoG’s, with the view to eliminating the risk.

The SIM140201 technology transfer project was commissioned following the outcome of the preceding project SIM120201 completed in July 2013 to address a requirement for continued and extended training in risk-based support design for underground mines of the Bushveld platinum industry. Rock engineering practitioners (REP’s) and operations that had not received exposure to risk-based support design during the SIM120201 project, or required further guidance, were provided with an opportunity to attend a training programme with the outcome of completing a risk-based support design representing conditions at their respective operations.

6.1 Project Aims

The project was aimed at the transfer of research outcomes from the project SIM060201 Track B to the South African underground platinum mining industry by carrying out a training programme to this effect. In addition, it was intended to improve on outcomes of the SIM120201 technology transfer project completed in 2013. In particular, the understanding of, and completion of the risk-based support design process needed to be improved through to the final stage which comprises the risk evaluation using the RiskEval application.

The technology transfer programme was required to equip and train a widely representative resource of REP’s to carry out risk-based support design within the South African platinum industry. This was intended to result in the successful completion of risk-based support designs presented in the form of reports representing conditions at their respective operations. To this end, the submitted
design reports were reviewed with feedback to assess the ability of the REP’s to carry out risk-based support design.

Long-term outcomes of the technology transfer programme did not form part of the scope of the project. However, it is anticipated that REP’s will apply the technology to provide operationally-specific designs that effectively reduce, with the view to eliminating, the risk of death, injury and economic losses due to FoG’s in Bushveld underground mines. These outcomes can only be measured as an independent study after a protracted period of implementation.

6.2 Project Hypothesis

As a technology transfer project, a research hypothesis is not applicable. However, the successful outcome of the project relied on an underlying assumption that the necessary RE and operational skills and resources were available to enable the adoption of risk-based support design in the South African Bushveld underground mines. These requirements were presented to the industry as part of Milestone 1, outlined in Section 6.4.

6.3 Project Methodology

The project was carried out in three phases comprising eight Milestones:

- Phase 1: Project preparation. This phase comprised Milestone 1 of the project.
- Phase 2: Training courses. This phase comprised Milestones 2 – 8 of the project.
- Phase 3: Report. This phase comprised Milestones 7 and 8 of the project.

An extended account of each phase of the project is presented in Section 6.4 “Project Milestones”.

6.4 Project Milestones

6.4.1 Milestone 1 – Project preparation

Milestone 1 comprised the start-up of the project which addressed the project preparation. Outcomes of the milestone included:

- planning the training programme in conjunction with the Chamber of Mines Rock Engineering Technical Committee (CoMRETC),
- compilation of the necessary course material,
• preparation of a close-out report template to assist REP’s with completing a risk-based support design for their respective operations as an outcome of the training programme,
• identifying and selecting underground Bushveld platinum mines to participate in the project,
• setting up the training programme,
• planning the training schedule,
• advise participating operations on the course requirements and provide sufficient time (6 – 8 weeks) to acquire the necessary tools, equipment, software applications and plan availability of resources (REP’s),
• software installation assistance (OHMS),
• presentation to the MHSC,
• submission of milestone report.

Outcomes of Milestone 1 are presented in Section 7, “Milestone Deliverables”. The report is presented in Appendix A.

6.4.2 Milestones 2 - 6 – Training courses

Milestones 2 – 6 comprised the bulk of the project, consisting of a total of five training courses carried out over a period of five months together with Open House Management Solutions (Pty) Ltd (OHMS). Each course was structured to include six days of training, extended over five weeks, held at a suitable central operation. Up to twenty REP’s were facilitated by each course to achieve a final transfer of the technology to up to 100 REP’s in the Bushveld platinum industry.

The training programme addressed the following essential risk-based support design elements:
• Data capture, comprising theory and underground practical,
• Data processing and interpretation using the Rocscience “DIPs” application and MS Excel,
• Keyblock stability analysis using the JBlock application,
• Risk evaluation using the RiskEval application.

It was recommended that a holder of a Chamber of Mines Certificate in Rock Mechanics (CoMCRM) attends the course together with a holder of a Chamber of
Mines Certificate in Strata Control (CoMCSC) from the same operation to meet the required skills level for successful adoption of the technology. At the same time the REP’s attending the courses were required to be in possession of a minimum set of tools and equipment which were recommended as an outcome of Milestone 1.

On completion of each training course the attending REP’s were required to submit a report presenting a risk-based support design based on parameters representing their respective operations. The reports were reviewed with feedback. The submissions are presented in Appendix E.

A milestone report was submitted to the MHSC on completion of each training course, Appendix B through Appendix D.

A detailed account of the structure and outcomes of each training course is presented in Section 7, “Milestone Deliverables”.

6.4.3 Milestones 7 and 8 – Report

Milestones 7 and 8 comprise the following:

- a draft final report summarising the outcomes of the training programme,
- a close-out workshop held together with the CoMRETC,
- a final report including the outcomes of the close-out workshop,
- respective milestone reports and
- presentation to the MHSC.

Outcomes are presented in Section 7, “Milestone Deliverables”.

6.5 Champion Mines

REP’s from the following champion mining operations and consulting service providers completed the technology transfer programme:

- Anglo American Platinum
- Aquarius
- ARM-Impala Platinum Joint Venture
- Glencore
- Hernic Ferrochrome
- Impala Platinum Mines
- Lonmin plc
• Northam Platinum Mines
• Open House Management Solutions (OHMS)

Training facilities were made available by:

• Impala Platinum Mines, Rustenburg
• Lonmin Platinum Mines, Rustenburg
• Northam Platinum Mines, Booysendal
7 MILESTONE DELIVERABLES

7.1 MILESTONE 1 – Phase 1, Project preparation and start-up

The project was awarded during July 2014 after which preparation for the project commenced. The start-up presentation was delivered to the MHSC on 17 September 2014. Following the presentation, a workshop was held at Lonmin Platinum Mines in conjunction with RE representatives from the CoMRETC, participating mines and OHMS on 23 September 2014 to plan the training programme. Outcomes of the previous project, SIM120201, were discussed with the aim of improving the outcomes for SIM140201. The training schedule was planned, participating operations identified and the structure of each training course was revised during the workshop.

In parallel with the start-up workshop, SRK prepared the course material, distributed guidelines to each operation on the required tools and equipment and prepared a close-out report template for REP’s to present the results of a risk-based support design for their respective operations as an outcome of the training programme.

A minimum period of eight weeks was provided to the operations to acquire the necessary resources for successful completion of the training courses. During this time, OHMS was available to provide troubleshooting assistance with the installation and operation of software applications JBlock and DIPs (Rocscience).

A milestone report was submitted to the MHSC on completion of the project preparation (Appendix A).

7.1.1 Results Milestone 1

Course material

Course material was prepared to provide training for each of the constituent stages required to complete a risk-based support design. These stages comprise:

- Geotechnical data capture, presented by SRK;
- Geotechnical data processing, presented by SRK;
- Keyblock stability analysis based on geotechnical data, support characteristics and excavation design using JBlock, presented by OHMS;
- Risk evaluation based on outcomes of the JBlock analysis and operational risk input data, presented by SRK.
A comprehensive account of the risk-based support design process is contained in the deliverables for the SIM060201 Track B project with published references by Joughin et al (2012).

The following list of minimum resources required to carry out a risk-based support design was provided to each of the participating operations in advance of the training courses:

- Geotechnical measuring device comprising as a minimum a clinorule. In addition, a Breithaupt Cocla Clar compass was recommended. Other measuring devices such as a Silva compass and electronic Android or iPhone application were permitted but not recommended.
- Notebook computer
- Licensed, installed and operational copy of DIPs (Rocscience)
- Licensed, installed and operational copy of JBlock
- Installed and tested latest version of JAVA script

The total cost of the required tools and equipment in December 2014 was approximately R 55 000 – R 60 000. This includes the DIPs (Rocscience) and JBlock application as well as a Breithaupt Cocla Clar compass. Additional items such as RiskEval and the JAVA programming platform are currently accessible free of charge. Measuring devices such as clinorules and tape measures are small items that are usually available as a rule within Mines Technical Services requirements. Electronic measuring devices such as distomats and Android or iPhones may cost an additional R 5 000 each and a suitable electronic notebook approximately R 10 000.

The following on-mine data was required for availability during the courses, including, but not limited to:

- Support unit specifications in terms of performance capacity and purpose
- Support unit costs
- Support installation compliance data
- Excavation design (geometry)
- Mining sequence
- FoG record
- Rock mass properties such as intact rock density per lithological unit, intact rock strength and local field stress
On-mine FoG injury data
- Production performance
- Labour requirements
- Labour costs

The rock engineer (RE, holder of a CoMCRM) and strata control officer (SCO, holder of a CoMCSC) representing each participating operation were required to be in possession of the full set of resources between them when attending the courses.

Course format

The initial proposed format of each individual course was intended to comprise six working days over a period of four weeks as shown in Table 1. The proposed format was in itself an improvement over the course format carried out for the initial technology transfer project, SIM120201. However, during the start-up workshop a revised format was discussed to assist the REP’s with sufficient time between successive sessions to acquire and process the necessary data in preparation for the next component of the course. This was intended to further promote a more successful outcome of the course programme compared with SIM120201. The revised course format is presented in Table 2.

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Table 2  Planned course format as an outcome of the start-up workshop

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- **Training - data capture, data processing (spreadsheet, DIPs), Simple on-surface training in use of measuring instruments**

- **Week 1**
  - Training - underground practical (a.m.), review captured data (p.m.)

- **Week 2**
  - RE practitioners to capture and process data during Wk 1 and Wk 2 for review during Wk 2

- **Week 3**
  - Review results - data capture (logging), data processing (DIPs) - SRK team (a.m.). Train JBlock (OHMS) p.m.

- **Week 4**
  - Train JBlock (OHMS) a.m. Train RiskEval (SRK) p.m.

- **Week 5**
  - RE practitioners to design and analyse comparative support systems using JBlock

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- **Training - data capture, data processing (spreadsheet, DIPs), Simple on-surface training in use of measuring instruments**

- **Week 1**
  - Training - underground practical (a.m.), review captured data (p.m.)

- **Week 2**
  - RE practitioners to capture and process data during Wk 1 and Wk 2 for review during Wk 2

- **Week 3**
  - Review results - data capture (logging), data processing (DIPs) - SRK team (a.m.). Train JBlock (OHMS) p.m.

- **Week 4**
  - Train JBlock (OHMS) a.m. Train RiskEval (SRK) p.m.

- **Week 5**
  - RE practitioners to design and analyse comparative support systems using JBlock

<table>
<thead>
<tr>
<th>Week 1</th>
<th>Week 2</th>
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<th>Week 5</th>
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</thead>
<tbody>
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<td>Mon</td>
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</table>

- **Training - data capture, data processing (spreadsheet, DIPs), Simple on-surface training in use of measuring instruments**

- **Week 1**
  - Training - underground practical (a.m.), review captured data (p.m.)

- **Week 2**
  - RE practitioners to capture and process data during Wk 1 and Wk 2 for review during Wk 2

- **Week 3**
  - Review results - data capture (logging), data processing (DIPs) - SRK team (a.m.). Train JBlock (OHMS) p.m.

- **Week 4**
  - Train JBlock (OHMS) a.m. Train RiskEval (SRK) p.m.

- **Week 5**
  - RE practitioners to design and analyse comparative support systems using JBlock

<table>
<thead>
<tr>
<th>Week 1</th>
<th>Week 2</th>
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<table>
<thead>
<tr>
<th>10 RE + 10 SCO</th>
<th>10 RE + 10 SCO</th>
<th>2 weeks</th>
<th>10 RE + 10 SCO</th>
<th>10 RE (10 SCO Optional)</th>
<th>2 weeks</th>
<th>10 RE (10 SCO Optional)</th>
<th>10 RE (10 SCO Optional)</th>
<th>1 week</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRK</td>
<td>SRK</td>
<td>On-site</td>
<td>SRK, OHMS</td>
<td>OHMS, SRK</td>
<td>On-site</td>
<td>OHMS</td>
<td>SRK</td>
<td>On-site</td>
</tr>
</tbody>
</table>
Training schedule

Protracted strike action during the first half of 2014 compromised operational readiness for commencing with the training programme. Budget constraints and lost time to address operational duties had to be addressed. It was agreed during the workshop to defer commencement of the training courses to January 2015 to enable the purchase of necessary tools and equipment within the constrained financial environment and to allow sufficient time to address the backlog of work on the operations. As a result the proposed schedule (Table 3) was revised (Table 4) and submitted for approval to the MHSC on 23 January 2015. The request to revise the schedule was granted, extending the project completion to 31 August 2015.

Table 3  Proposed project schedule

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1 Milestone 1</td>
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<td>2 Milestone 2</td>
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<td>3 Milestone 3</td>
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<td>4 Milestone 4</td>
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<td>5 Milestone 5</td>
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<td>7 Milestone 7</td>
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<td>8 Milestone 8</td>
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</tr>
</tbody>
</table>
Table 4  Planned (revised) project schedule resulting from the start-up workshop

<table>
<thead>
<tr>
<th>Calendar</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
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<tbody>
<tr>
<td></td>
<td>19-23</td>
<td>26-27</td>
<td>28-29</td>
<td>2-6</td>
<td>9-10</td>
<td>11-12</td>
<td>16-20</td>
</tr>
<tr>
<td>Wk 0</td>
<td>Wk 1</td>
<td>Wk 2</td>
<td>Wk 3</td>
<td>Wk 4</td>
<td>Wk 5</td>
<td>Wk 6</td>
<td>Wk 7</td>
</tr>
<tr>
<td>Milestone 1</td>
<td>Software troubleshooting (OHMS)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Milestone 2</td>
<td>Training Course 1 (Implats)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Milestone 3</td>
<td>Training Course 2 (Implats)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Milestone 4</td>
<td>Training Course 3 (Mechanised)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Milestone 5</td>
<td>Training Course 4 (Lonmin)</td>
<td></td>
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</tr>
<tr>
<td>Milestone 6</td>
<td>Training Course 5 (Eastern Limb)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Milestone 7</td>
<td>Draft final report</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Milestone 8</td>
<td>Final report (close-out)</td>
<td></td>
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</tr>
</tbody>
</table>
Outcomes

Significant consequences of the revised course format were encountered during completion of the training courses (Phase 2, Milestones 2 – 6). The following knock-on effects occurred:

- Increase in the total duration from four weeks to five weeks for each training course. The increased duration was offset by running two courses at the same time which was possible due to the separation of approximately 10 days between successive sessions within each course. The concurrent running of two courses was further necessary to offset a nearly five month delay to the start of the training schedule (Phase 2 of the project) that was incurred due to the knock-on effect of protracted strike action in the platinum industry during the first half of 2014.

- An extension to the project was granted (presented under “Training schedule” in this section) following the presentation of the project on 23 January 2015. However, in spite of the extension, the schedule remained highly constrained which in turn led to an increased burden on the project management responsibilities and a cost overrun at the expense of the contractor (SRK) (Section 14, Financial Summary).

- The concurrent course schedule had a knock-on effect on availability of resources for REP’s attending from the same operation. This was due to operations usually being in possession of single software licenses and limited mapping devices such as a compass or electronic device (iPhone, Android or similar). As a result, REP’s were required to share resources between courses.

- The total number of REP’s to be facilitated by each course was increased from 10 (initially proposed) to 20 to promote a broader transfer of the technology within the industry. The requirement for the courses to be attended by a rock engineer (RE, i.e. holder of a CoMCRM), accompanied by a strata control officer (SCO, i.e. holder of a CoMCSC) from each participating operation remained unchanged. The course structure and planned schedule was unaffected by the increase in facilitated REP’s; however an associated increase in administrational duties of the contractor was not anticipated, leading to an unplanned increase in the project cost.

- The allocation of training components between SRK and OHMS remained unchanged; however, the sequence of training was revised, resulting in both
OHMS and SRK needing to be present on the same days during the second half of the course. The time for both SRK and OHMS to facilitate the respective course components was therefore affected negatively in that more time was required than initially planned. The potential effect of the revised sequence was not immediately evident during the workshop; however a significant effect was incurred in terms of professional time and course administration and hence overall project cost.

- It further became apparent during completion of the training courses that it was not possible to effectively review components of the risk-based support exercises independently. The constituent components of risk-based support design, viz data capturing, data processing, support scenario analysis and risk evaluation, are interdependent on the objectives and outcomes of each of the associated stages. As a result, SRK maintained a continuous presence throughout each of the courses, effectively increasing the planned time by 50%. However, the increased time allocated to each course was not accounted for in the planned project cost, leading to a cost overrun at the expense of the contractor (SRK).

7.1.2 Conclusions Milestone 1

The project preparation and initiation phase (Phase 1, Milestone 1) was completed as planned and on schedule. Phase 2 (Milestones 2 – 6) of the project commenced on completion of Milestone 1 as per the revised schedule submitted to the MHSC in January 2015. A copy of the milestone report is presented in Appendix A, Milestone 1 report.
### 7.2 MILESTONES 2 – 6 – Phase 2, Training courses 1 - 5

The five training courses comprising Milestone 2 through Milestone 6 respectively were completed on schedule as shown in Table 4. The first two courses were facilitated at Impala Platinum’s Rustenburg operations, the second two courses at Lonmin (Marikana) and the fifth at Northam Platinum’s Booysendal operation in the Eastern limb of the Bushveld complex.

![Course presentation at Booysendal](image)

**Figure 1** Course presentation at Booysendal

#### 7.2.1 Results – attending industry practitioners

A summary of the total numbers of industry practitioners per mining group that participated in the programme is presented in Table 5.
Eight mining groups were represented. With the exception of ARM, Aquarius and Northam, the proportion of certificated rock engineers (holders of a CoMCRM) represented 33% or fewer of the total attendees per group; i.e. for every certificated RE, approximately two additional practitioners (SCO, REO or Geologist) participated in the programme. Four uncertificated REO’s attended from Implats, while six geologists from Lonmin and one geologist from Hernic attended the programme. Inclusion of geologists in the programme was intended to develop additional resource skills to assist with the capture and interpretation of rock mass characterisation data for input into the next phase of the risk evaluation process, i.e. keyblock stability analysis using JBlock.

Attendance for the full duration of each course was achieved by 64% of the practitioners (i.e. 49 practitioners) while 26% (18 practitioners) attended 50% or more (i.e. a minimum of 4 or 5 days) of their respective courses. Seven (9%) of the practitioners attended less than 50% of the course duration or were registered but did not attend at all. Issues leading reduced attendance time included on-mine operational obligations, attending to a Section 54 and investigating a FoG.
A detailed account of practitioners that attended the technology transfer programme is contained in the milestone reports for Milestone 2 through Milestone 6, presented in Appendix B, Appendix C and Appendix D respectively.

It is the researcher’s opinion that the disproportionate attendance of RE’s, SCO’s and other uncertificated or non-practicing REO’s such as geologists and GPR analysts detracted from the effective understanding and adoption of the technology. The level of qualification associated with a SCO or uncertificated REO is not sufficient to gain the necessary understanding and responsibly apply the technology to provide a sound risk-based support design on an operation. This was evidenced by the errors and misunderstanding presented in the submitted reports (Section 7.1.3). Similarly, the 25% shortfall from the planned number of 100 REP’s to participate in the programme represents an under-utilisation by the industry of a skills development opportunity that was provided at no cost to the industry.

It is suggested that the initial, focused plan to facilitate a maximum of 50 REP’s strictly limited to comprise 25 RE’s and 25 SCO’s may be more effective than attempting to facilitate too broad a base of practitioners in one programme. An independent programme should be carried out to address the exposure and training of practitioners such as geologists and uncertificated REP’s to carry out rock mass characterisation data capture and interpretation.

7.2.2 Results – availability of resources

It was difficult to establish the exact suite of tools and licensed applications available to all of the attending practitioners due to sharing constraints. Most of the operations were able to obtain the necessary tools and licensed applications to complete a risk-based support design using the technology (Table 6); however each operation was usually equipped with a limited number of licensed applications and associated tools rather than a full set of resources per practitioner. This necessitated sharing amongst practitioners and/or sharing across operations within a group. As a result, despite most of the groups having obtained the necessary tools and application licenses, several practitioners in attendance at the courses were not suitably provisioned. The effective understanding and efficient completion of the course requirements was therefore inhibited to the effect that several practitioners did not successfully carry out a risk-based support design.
It is not considered feasible to equip each practitioner with a full set of resources to carry out a risk-based support design due to the scope of duties assigned to the on-mine REO’s. However, considering the essential importance of providing engineered solutions by the on-mine REO’s to address rock-mass stability challenges, it seems incongruous to limit the effective functioning of a RE department by necessitating the sharing of resources across operations and/or within a large department, given that the full set of tools and applications required to complete a risk-based support design is a relatively affordable (≈ R 70 000) once-off purchase.

It is therefore recommended as an outcome of this study that each operation at which there is a resident RE should be permanently in possession of a full set of tools and necessary software in order to effectively provide quantified, engineered solutions, in this case in the form of risk-based support design to mitigate against the risk associated with rock mass instability.

Table 6 presents a summary of the available tools and software applications as a percentage of attending practitioners per mining group. Note that the number of items identified as “available” is in reference to accessible resources to complete the risk-based support requirements. This also indicates “availability” in terms of sharing. However, the number of available resources does not necessarily indicate the total number of tools and/or application licenses per mining group as this information was not obtained.

A detailed account of available resources per attending practitioner is contained within the milestone reports, Appendix B through Appendix D.
<table>
<thead>
<tr>
<th>Mining group</th>
<th>No. of attending practitioners</th>
<th>Laptop</th>
<th>Compass or suitable measuring device for structural orientation</th>
<th>Mapping tools (clipboard, 30m tape, dissomat, underground plan, PPE)</th>
<th>DIPS (Licensed, installed and tested)</th>
<th>JBLOCK (Licensed, installed and tested)</th>
<th>JAVA (Installed and tested)</th>
<th>RISKEVAL (Installed and tested)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anglo</td>
<td>18</td>
<td>11</td>
<td>61</td>
<td>10 56</td>
<td>15 83</td>
<td>10 56 7 39 10 56</td>
<td>9 50</td>
<td>No. of attending practitioners</td>
<td>The eastern limb operation had no software licenses (DIPS, JBlock) for risk-based support design</td>
</tr>
<tr>
<td>Aquarius</td>
<td>2</td>
<td>2</td>
<td>100</td>
<td>1 50</td>
<td>1 50 1 50 1 50</td>
<td>1 50 1 50</td>
<td>1 50</td>
<td>No. of attending practitioners</td>
<td>No licensed applications</td>
</tr>
<tr>
<td>ARM</td>
<td>1</td>
<td>1</td>
<td>100</td>
<td>1 100</td>
<td>1 100</td>
<td>0 0 0 1 100</td>
<td>1 100</td>
<td>No. of attending practitioners</td>
<td>No licensed applications</td>
</tr>
<tr>
<td>Glencore</td>
<td>6</td>
<td>6</td>
<td>100</td>
<td>6 100</td>
<td>6 100</td>
<td>2 33 3 50 6</td>
<td>100</td>
<td>No. of attending practitioners</td>
<td>No licensed applications</td>
</tr>
<tr>
<td>Hernic</td>
<td>3</td>
<td>2</td>
<td>67</td>
<td>1 33</td>
<td>1 33 0</td>
<td>0 0 0 2 67</td>
<td>2 67</td>
<td>No. of attending practitioners</td>
<td>Implats was well co-ordinated. Although there was not a full complement of resources assigned to each individual practitioner, the availability of resources was well co-ordinated, ensuring effective availability and sharing, enabling all of the attending practitioners to carry out the necessary tasks for a risk-based support design based on the mining and rock mass characteristics for their own operation(s).</td>
</tr>
<tr>
<td>Implats</td>
<td>25</td>
<td>19</td>
<td>76</td>
<td>14 56</td>
<td>14 56 16</td>
<td>64 16 64 19</td>
<td>76 19</td>
<td>76</td>
<td>Implats was well co-ordinated. Although there was not a full complement of resources assigned to each individual practitioner, the availability of resources was well co-ordinated, ensuring effective availability and sharing, enabling all of the attending practitioners to carry out the necessary tasks for a risk-based support design based on the mining and rock mass characteristics for their own operation(s).</td>
</tr>
<tr>
<td>Lonmin</td>
<td>13</td>
<td>12</td>
<td>92</td>
<td>6 46</td>
<td>10 77</td>
<td>4 31 5 38 5 38</td>
<td>5 38</td>
<td>5 38</td>
<td>Lonmin experienced a shortage of licensed applications. This was in part due to REO's from the group simultaneously attending the courses and therefore unable to share a limited set of resources.</td>
</tr>
<tr>
<td>Northam</td>
<td>6</td>
<td>4</td>
<td>67</td>
<td>3 50</td>
<td>4 67 2</td>
<td>33 1 17 4</td>
<td>67 4</td>
<td>67</td>
<td>No licensed applications</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>74</strong></td>
<td><strong>57</strong></td>
<td><strong>77</strong></td>
<td><strong>42 57</strong></td>
<td><strong>52 70</strong></td>
<td><strong>35 47 33 45 48</strong></td>
<td><strong>65 47</strong></td>
<td><strong>64</strong></td>
<td>No licensed applications</td>
</tr>
</tbody>
</table>
The following key availability and proficiency indicators are noted:

- **Portable notebook (laptop)** – available to most practitioners; however occasional shortage. It is the researcher’s opinion that this is an essential tool that should not be problematic to acquire for all qualified SCO’s and RE’s. Shortage was possibly as a result of uncertificated REP’s participating in the programme and hence being unequipped.

- **Compass or suitable measuring device to capture orientated structural data** – availability varied from a full set of tools per represented operation, including a minimum of a clinorule and either a Breithaupt Cocla Clar compass or an electronic (Android or iPhone) measuring device (EMD), to having no measuring tools at all.

  It is the researcher’s opinion that every practicing REO, whether certificated or uncertificated, should be equipped at the very least with, and practiced in the use of, a clinorule. The shortage of equipment and lack of familiarity with the use of a basic tool such as the clinorule is evidence of the limited use of such a piece of equipment in everyday operational rock engineering practice. This is a serious technical deficiency that must be addressed for operational REP’s to provide a meaningful technical service to the industry.

  In addition, while a clinorule is practical and versatile, there are particular limitations that can only be overcome with the use of a reliable, practical and efficient measuring device such as the Breithaupt compass or EMD. The use of other devices such as the Silva or Brunton compasses is acceptable but practically problematic when used in an underground environment.

- **Mapping tools** – for the most part, basic tools such as measuring tapes, distomats, clipboards and an underground plan were available; however there was an occasional shortage. As with a tool such as a clinorule, it is impossible to carry out the basic tasks associated with providing technical rock engineering solutions without these fundamentally essential tools. It is the researcher’s opinion that every practicing REO must always have these basic, low cost tools at hand to effectively carry out a technical rock engineering function. These tools are usually readily available within the mine’s store catalogue.
Similarly to the evidenced lack of availability, and unfamiliarity with the use of, these tools, by several practitioners, it is reasonable to conclude that there is a similar dearth of applied technical data capture carried out in an everyday operational context.

The ability to complete the structural mapping process is dependent on the availability of tools which in turn affects the development of skills and effective capturing of the necessary structural data. A meaningful risk evaluation of keyblock instability is defined by the quality and availability of structural (geotechnical) rock mass data. Completion of the risk-based support design process is therefore contingent on capturing suitably representative structural data which can only be achieved given the provision of the necessary resources.

- **DIPs (Rocscience) application** – with the exception of Anglo and Implats, fewer than 50% of the participating REP’s had access to a licensed, working copy of the DIPs stereonet application. This presented a serious inhibition to the effective understanding of structural data characterisation, limited development of the necessary skills to interpret and group structural orientation data into joint sets and curtailed the ability to correctly proceed to the next component of the risk-based support design process.

- **JBlock statistical keyblock stability evaluator** – with the exception of Implats, fewer than 50% of the participating REP’s had access to a licensed, working copy of the JBlock application. It was therefore only possible for the participating REP’s with access to the application to achieve a complete risk-based support design.

- **RiskEval fall of ground risk quantification** – with the exception of two mining groups, more than 50% of the participating REP’s had access to working copies of RiskEval (and thereby also the JAVA script platform).

The risk evaluation component is the final phase for completion of a risk-based support design, dependent on outputs obtained from the structural data characterization which in turn feeds into the JBlock analysis. It was possible for the attending REP’s to test and run a risk-based support design during the training period using example output results from JBlock analyses that were carried out for the initial research (SIM060201 Track B). Therefore there was adequate development of the risk evaluation skills using the RiskEval application during the
training courses. However, completion of a risk-based support design based on representative site data could only be completed by those REP’s who had access to the preceding applications (DIPs and JBlock).

7.2.3 Results – completed project reports submitted for review

A total of 17 risk-based support design submissions were received, representing 30 practitioners that participated in the programme. Several of the reports were completed jointly by more than one practitioner; however, it is not clear what proportion of participation was included by the respective contributing authors. Two of the reports were submitted by geologists and addressed only the rock mass characterisation component as intended. The full complement of report submissions has not yet been received; however any submissions received prior to completing the final SIM140201 project report will be reviewed and outcomes incorporated into the final submission. Reports that have not yet been submitted are due to on-site responsibilities and unavailability of the necessary application resources.

With the exception of the geologists’ submissions and two REP reports, the risk-based support design process was diligently applied, accounting for each constituent component beginning with data capture through to presentation of risk evaluation results. This represents a profound improvement over outcomes from the initial technology transfer programme (SIM120201).

For each of the risk-based support design submissions, a detailed review was carried out by the project leader with feedback provided to the authors. A summarised overview of outcomes is presented in Sections 7.1.4 through 7.1.9. Note that the reviews did not include interrogation of the raw data or reprocessing of results as this would comprise a comprehensive process which the project scope did not allow. It was therefore not possible to check the results for fidelity with conditions at each of the respective operations. However, insofar as the programme required a demonstration of able completion of the risk evaluation process, this was carried out.
7.2.4 Rock mass characterisation - data capture

Mapping sheet

The mapping sheet provided, Appendix F, was successfully utilised by all of the REP’s to capture the required structural orientation and rock mass characterisation data.

Measuring tools and data capture

The measuring tools employed to capture structural orientation data varied through the use of clinorules, EMD’s (iPhone or Android) and various compasses. All of these tools are suitably valid. However, there are limitations with each:

- A clinorule is limited to measuring the strike of a discontinuity which must be corrected geometrically to dip direction. An example of the required correction is illustrated in Figure 2. However, the correction (± 90°, clockwise or anti-clockwise) is dependent on the relative offset of the strike direction from the scanline, whether measured to the “left” or to the “right” of the scanline as defined by the direction of the scanline. This can easily lead to confusing measurements and incorrect results.

It was therefore recommended during the course presentation to avoid confusion when mapping using a clinorule that every discontinuity measurement should be sketched in relation to the excavation and the excavation in turn must be orientated to true north (TN). The exact peg-referenced location of the scanline is therefore critical to obtain correctly orientated data.

It was not possible to check the accuracy of results for each of the respective submissions as the raw (sketched) data was not included in all of the course reports. However, during the course, data was captured as a practice exercise and reviewed. During the review, it was possible to check data captured using a clinorule against data from the same location captured by the other course participants; 90° rotated orientation errors were commonly evident.

In addition, the true strike of a structure can only be measured with reasonable accuracy when using the clinorule if the instrument is placed horizontally against a sub-horizontal contract service. A clinorule is not suited to measuring the strike
orientation against a surface that is significantly deviant from the horizontal. In these cases, the use of a suitable compass or EMD is recommended.

An advantage of mapping with a clinorule is that there is no need to correct for magnetic north (MN) as the data is captured geometrically, i.e. independent of MN.

To gain confidence in the accuracy of results captured using a clinorule, frequent quality assurance exercises must be carried out.

- EMD’s and compasses are sensitive to magnetically loaded items such as steel support and lithology. A further limitation of EMD’s is their dependence on an inclinometer, gyroscope and accelerometer which need to be frequently recalibrated during mapping for accuracy. It is therefore important to check the results from these devices against a known orientation from time to time.

No comments were made in any of the submissions relating to checks that may have been carried out validate the compass or EMD readings. It is therefore assumed that this practice has not yet become firmly established and must be reinforced to gain confidence in the data.

Data captured using a magnetic device (EMD or compass) must be corrected for magnetic north (MN). This correction was only referenced in one submission (Thembelani). Based on the given information it was not possible to check whether corrections for MN had been applied in the remaining submissions.
There are many logistical and practical difficulties with mapping in an underground environment. These may include inaccessibility to the measuring surface (excavation roof or stope back) due to the excavation height, interference from operational activities and other factors such as humidity and insufficient lighting.

Practical mapping exercises are illustrated in Figure 4 and Figure 5 illustrating the challenges of working overhead in a poorly lit, high stope height environment. The limitation of a Silva compass or any compass not equipped with a bottom-end levelling mirror (6, Figure 3) and a release lever (17, Figure 3) is immediately evident in practice when measuring hard-to-reach surfaces.
Figure 3 Breithaupt Cocla Clar compass

Figure 4 Measuring the relative strike of a structure using a clinorule
Figure 5  Measuring the relative structural orientation using a Breithaupt Cocla Clar compass

Data suite and orientation bias

The suite of data that was captured per submission ranged from fewer than 24 discontinuities from a single scanline up to more than 139 discontinuities (263, Northam) from 14 or more scanlines in 9 respective locations. The latter dataset represents a thorough representation of rock mass conditions for a particular ground control district (GCD).

Where data was captured along a single scanline only (on-reef development raise), this means that orientation bias errors were not accounted for. It is difficult to overcome scanline bias effects during the early establishment of the stope due to the confined excavation; however, as the mining front advances and exposes a greater rock face area, opposing scanline directions must be captured to offset the orientation bias.

In most cases, a maximum of two scanlines, usually in opposing directions, Figure 6, were captured for the purpose of the training exercise. This was sufficient to
demonstrate the level of skills development for the training programme. However, the quantity of data and spatial representation is not sufficient to provide a representative dataset for an operation.

Going forward, the quantity of data must be significantly expanded by continually carrying out mapping exercises throughout the operation.

Figure 6 Opposing scanlines to overcome bias error

Additional on-mine rock mass characterisation data

Complete characterisation of the rock mass to carry out a block stability analysis using JBlock requires that data such as the tensile strength, intact rock strength (UCS) and density of lithological units be captured. Values for these entries were sporadically declared; however no evidence of the source for this information was provided which
casts doubt as to the practitioners’ confidence in the authenticity and relevance of the data.

Similarly, an analysis of on-mine FoG data is highly advantageous to improve confidence in the rock mass characterisation data and resulting block stability analysis (Section 7.1.6). This was not an essential component required to demonstrate competency in carrying out a risk-based support design; however, was recommended during the training programme as a good rock engineering practice. Nonetheless, only a brief mention of fallout height was included in select submissions with no mention of the on-mine records in the remaining reports.

**General**

A good attempt at data capture was largely undertaken by all of the course participants. In select instances, a large quantity of data was captured representing several sites and addressing bias errors. In these cases, the initiation or continuance of an on-mine rock mass characterisation database is in place and can be continually developed going forward.

However, it is evident that several practitioners still require practice and guidance to overcome errors in understanding the mapping parameters, improve accuracy and improve the level of skill in using the respective instruments. Furthermore, in at least one instance, in-house skills must yet be developed to initiate a rock mass characterisation database on the operation.

Dedicated time, skills development and liaison with production personnel are required to facilitate the on-mine data capturing process. This must be actively managed and promoted both internally and externally to establish the practice as a norm, which it currently is not on most operations.

Safety issues are a concern. The mapping surface must be accessed directly to enable accurate mapping. There is no substitute for direct visual and sensory rock contact to gain a meaningful understanding of the rock mass condition. In particular joint surface condition in terms of roughness and infill quality. However, this requires exposure of the practitioner to the rock surface which is a safety hazard.
Alternative mapping techniques such as photogrammetry and core logging should be integrated into the mapping process wherever possible to limit the safety hazard due to exposure to the rock surface.

7.2.5 Rock mass characterisation - interpretation

Each of the datasets that was captured and submitted was processed and interpreted using the DIPs stereonet application (Rocscience) and the MS Excel spreadsheet method that was provided. An example of a characterised joint set is presented in the example, Table 7.

Table 7 Example of joint set characterisation results.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Count (no. of joints defining the set)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dip (deg)</td>
<td>21</td>
<td>55.0</td>
<td>90.0</td>
<td>74.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Dip direction (deg)</td>
<td>21</td>
<td>34.0</td>
<td>66.0</td>
<td>52.0</td>
<td>46.0</td>
</tr>
<tr>
<td>Persistence (m)</td>
<td>21</td>
<td>1.2</td>
<td>12.0</td>
<td>4.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Spacing (m)</td>
<td>15</td>
<td>0.2</td>
<td>19.1</td>
<td>3.9</td>
<td>6.0</td>
</tr>
<tr>
<td>Friction angle (deg)</td>
<td>21</td>
<td>10.6</td>
<td>36.9</td>
<td>27.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Joint roughness (Jr)</td>
<td>21</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Joint alteration (Ja)</td>
<td>21</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Stereonet interpretation using DIPs (Rocscience)

A selection of stereonet outputs from the report submissions are presented in Figure 7 through Figure 11 to illustrate various approaches applied to interpret the data. The first three plots represent respective geotechnical districts at the same mining group (Mining Group A). The fourth plot (Figure 11) represents a geotechnical district from a separate mining group (Mining Group B).

The following findings summarise some of the approaches applied, outcomes and challenges encountered:
• **Plotting / data presentation** (software and stereonet interpretation proficiency): the images presented in Figure 7 through Figure 11 have clearly different presentation approaches. In all of the plots, discontinuity orientations are plotted as poles representing the orientation of a plane. While all of the presentation approaches are in themselves acceptable, cognizance must be taken of the possible limitations to interpretation:

  - A polar plot (Figure 8) is limited in its suitability to wedge failure analysis which was not specifically required for the training exercise but may be required as a secondary function in more advanced interpretation exercises. Alternately, the remaining plots are projected onto an equatorial plot.
  - The absence of a stereonet overlay (Figure 7) limits the user’s ability to quickly inspect the data for accuracy.
  - Default contouring intervals (Figure 7) limits the user’s ability to select joint sets based on a fixed concentration envelope (recommended at greater than 4% - 6% pole vector concentration).
  - The absence of pole vectors superimposed over the contour intervals (Figure 9) limits the user’s ability to interrogate the integrity of a pole concentration in order to confidently define the boundaries of a joint set.
  - Background colour (Figure 9) and version (DIPs 5.0 - Figure 9 vs DIPs 6.0) are somewhat arbitrary; however the newer version is recommended to make use of relevant user-friendly upgrades and technical improvements to the application.

• **MN correction**: a correction for MN must either be applied to the input data while in the spreadsheet form or can be applied within the DIPs application. Only one submission made mention of a correction for MN; however none of the submissions stated at what stage the correction was applied.

• **Terzaghi bias correction**: several submissions incorporated a weighting correction (Terzaghi weighting) which is applied to assist in accounting for the joint identification bias as a function of linear mapping using a scanline. This weighting can only be applied using the DIPs application if the scanline orientations have been entered using the correct corresponding scanline identity.
for each joint orientation entry. The accuracy of these weighting corrections was not checked as part of the report reviews; however, by incorporating this element into the interpretation, this indicates an encouraging level of advanced assessment that was applied to the orientation data by several of the practitioners.

- **Steep-dipping joint set definition** (wrap-around effect): an important element of the keyblock stability analysis using JBlock was identified in that the boundaries of a steep-dipping joint set must be defined in such a way that conjugate orientations (180° difference in dip direction) must be distinctly separated. By illustration, in “normal” definitions of steep-dipping joint sets (Figure 11), the joint set is defined by a window that extends 180° across the boundary of the stereonet, incorporating all joints into a single joint set. Distribution of the joint orientations within this window is defined by a mean dip and dip direction and an angular distribution value, the Fischer “K” value.

In contrast, JBlock does not recognize a joint orientation distribution that crosses through 180° dip direction for steep-dipping joints. Hence, steep-dipping joint sets must be defined distinctly without a wrap-around effect as shown in Figure 7 (note that the freehand joint set window selection shown in the example is a user-defined preference only and has no bearing on the wrap-around selection of steep-dipping joints).

As can be seen from the figures, this was achieved correctly in some cases, while others did not apply this approach. As a result, the JBlock analysis will not correctly account for steep-dipping joints within the same set having a dip direction 180° from the mean (taking into account variability limits). Furthermore, to correctly evaluate the variability limits on discontinuity orientations using MS Excel, the 180° conjugate set must be accounted for by separating the discontinuities into two distinct groupings.

- **Low-angle joint set identification and corresponding confirmation with known on-mine joint set orientation data**: the dominant joint sets in the Bushveld platinum complex are known to be largely steep-dipping. It is not surprising, therefore that the overwhelming bulk of data is representative of steep-dipping joint sets. Also, the exposed underground rock surfaces are typically sub-parallel to the orebody horizon with the result that mapping bias will almost
inevitably result in failure to identify sub-horizontal discontinuities. The absence of sub-horizontal joint set data was evident throughout all of the submissions, with the exception of only two analyses.

Sub-horizontal or low-angle (dip <60°) features are distinctly problematic for rock mass stability in the Bushveld underground operations. Similarly, features such as curved ramp (thrust) faults and circular domes are difficult to detect but distinctly problematic for rock mass stability and must be included in the dataset. Additional approaches must therefore be applied to ensure that sub-horizontal data is incorporated into the analysis.

Suggested approaches were discussed during the training programme and include (but may not be limited to):

- Ground penetrating radar (GPR) scanning
- Borehole camera scanning
- Geological isopach data pertaining to known weak lithological horizons
- Sub-vertical borehole core logging
- Historic FoG database analysis

Isolated cases were presented (for example, Anglo - Union Mine) that incorporated low-angle discontinuity or weakness data. In this example, an excellent interpretive understanding of the rock mass characteristics is presented. However, an holistic approach to orientated structural analysis remains a challenge for many REP’s that must be addressed with continued skills development and improved understanding of rock mass characterization. In other words, the understanding of rock mass instability as defined by orientated structural data must extend beyond merely the collection and processing of data; to include an insightful and thought-through interpretation.

The continued development of skills is expected to be an on-mine function; however, external input from time to time will be necessary to maintain focus and provide objective guidance.

- **Data concentration (scatter)**: to confidently define the joint set boundaries, it was recommended during the training programme that each joint set should be represented by approximately 50 entries or more. However, in spite of a few large
datasets comprising more than 100 entries in total, the joint sets were ubiquitously
defined by fewer than 50 entries per set.

Given that collection of geotechnical data was probably only initiated at the
respective operations during the training programme, a limited rock mass
characterization database is understandable. For the purpose of the training
exercise, this was sufficient to demonstrate a certain skill level. However, going
forward, the databases must be substantially expanded to include multiple
scanlines throughout the operation so that the rock mass characteristics can be
confidently characterized for the respective operations.

- **Rotation (possible device error):** In Figure 10 results are shown for data that
  was captured using an iPhone. It is unusual that there is an apparent absence of
  steep-dipping joint sets. In addition, data points appear to be somewhat uniformly
distributed in a circular pattern which suggests a possible rotational effect.

The potential for error in data capture using an iPhone (or similar EMD) was noted
during the training course in that the EMD is sensitive to levelling and requires
continual recalibration. As a result, it is important that the data is continually
checked against a reliable reference such as a compass or clinorule during
capture.

However, the user remains responsible for continually and independently
orientating him/herself with respect to survey pegs and excavation orientation to
check results captured using any of the preferred methods. This was noted during
the training programme to be somewhat outside of many REP’s experience and
must be reinforced with continual practice during daily operational duties.
Figure 7  Weighted (Terzaghi) stereonet plot, Mining Group A – UG2 ............... 

Figure 8  Unweighted stereonet plot, Mining Group A - MR ..............................
Figure 9  Unweighted stereonet plot, Mining Group A – off-reef, no pole point overlay

Figure 10  Stereonet plot, Mining Group A – captured with an iPhone, possible rotational effect
Joint set characteristic interpretation using MS Excel

An MS Excel spreadsheet was provided during the training programme in which the calculations and joint set selection parameters were already presented. The REP’s could therefore enter the defined joint set selections from the DIPs analysis directly into the MS Excel spreadsheet to draw the resulting parameters. The calculation methods and characterisaton theory were presented during the training programme and can be referenced in the initial research project report for SIM060201 Track B. Outcomes from the joint set characterisation exercises are summarised herein.

The joint set presented in the example, Table 7, is reasonably well defined for the purpose of the training exercise; however, the following outcomes pertaining to the collective REP’s submissions are noted, based on the example in Table 7:

- **Dip and dip direction**: A mean dip and dip direction for each defined joint set are output directly from the DIPs application. However, variability limits are defined by DIPs in terms of an angular distribution, i.e. a Fischer “K” value. In contrast, JBlock is coded to interpret variability in terms of a standard deviation. As such,
the variability limits on dip and dip direction must be calculated independently using the spreadsheet functions.

A particular pitfall that must be avoided is the calculation of variability limits for dip direction. In the case where the dip direction can vary across 180°, as in a steep-dipping joint set, it is incorrect to bundle a conjugate joint set into one set and calculate a mean and standard deviation as this will result in a mean dip direction that can be 90° rotated from either predominant dip direction. If a steep-dipping joint set has not been defined as two distinct joint sets in DIPs, it is necessary to first separate the joint set into opposing directions and determine a mean and standard deviation for each grouping.

This was correctly carried out in certain instances (example, Table 7); however, the conceptual understanding of this requirement was not fully appreciated by all of the participants with the result that “wrap-around” joint sets were defined with an erroneous mean and standard deviation for the dip direction.

It was for this reason that a certificated rock engineer (holder of a CoMCRM) was recommended to complete the training programme as certain rock engineering concepts such as the interpretation of joint set orientation variability limits, which are a function of circular geometry, require a certain skill and training level.

In the example shown, the variability (standard deviation) is erroneously high; however, this may be a typing error as it is impossible that the standard deviation can be in excess of the difference between the maximum and minimum range value.

- **Persistence**: persistence is largely a function of the areal extent of the exposed rock mass against which data is captured and can therefore be problematic to characterise with any accuracy. Estimates must be made where the discontinuity is truncated within the exposed rock surface such as in confined raise lines and development ends.

Results were therefore largely variable. However, results can be improved by tracing discontinuities wherever possible against large surface areas such as in stoping panels. Instances of extensive trace lengths (persistence) in excess of 30 m were presented in select submissions (for example from Impala and
Glencore); however, several cases were presented with very short average trace lengths (2.0 m) which is clearly a function of the excavation size.

- **Spacing**: calculation of the joint spacing is a function of the relationship between the scanline orientation and the joint orientation. Hence, joint spacing can only be calculated for joints captured along the same scanline. To achieve this, the practitioner was required to carry out a rudimentary interrogation of the spreadsheet data to ensure that joint spacings were not calculated across discrete scanlines and eliminate errors.

Variable competency was demonstrated in executing this simple task, depending on the practitioner’s skill in processing spreadsheet data. As stated previously, it was for this reason that a skilled rock engineer (CoMCRM holder) was recommended to participate in the programme.

- **Friction angle ($\phi$) and joint surface condition ($Jr$ and $Ja$)**: reasonable results are dependent on the REP’s understanding of joint surface condition classification parameters ($Jr$ and $Ja$, Barton 2002). Furthermore, certain limitations apply when using the Barton (2002) approach for calculating $\phi$ which can result in unrealistically high values.

It was therefore necessary for the practitioner to apply a reasonable upper truncation limit to the outcome of calculations for $\phi$. The friction angle determined by Barton (1974) for filled discontinuities in a range of rock types does not exceed 42°; also, the base friction angle determined by Barton and Choubey (1977) for a range of rock types did not exceed 38°. Based on these literature references, an upper truncation limit of 42° was recommended during the training programme for all results exceeding this value.

The example (Table 7) represents results that appear reasonable; however instances were presented containing friction angles in excess of 70°; these are considered to be unrealistic and a poor application of the training material. To correct this, continued on-site training and skills development is required. Similarly to the preceding joint set characteristics, the minimum skills requirement to carry out interpretation of $\phi$ is the direct involvement of a holder of a CoMCRM.
General outcomes – interpretation of rock mass characterisation data

Notwithstanding the suite of data that was captured and presented to complete the training programme (i.e. the number of data points and scanline traverses), each of the submissions presented a complete interpretation process comprising the DIPs analysis and spreadsheet-based interpretation. In this regard, excellent participation was achieved which is a marked improvement over the outcomes from the initial project, SIM120201.

The quality of interpretation was variable, with submissions in which comprehensive, insightful and reliable results were presented. However, several submissions contained results that clearly demonstrated insufficient understanding of the interpretation requirements. This is attributed to, amongst others:

- The incorrect level of skilled rock engineering resources applied to the programme
- Insufficient ongoing on-mine application of basic skill functions such as MS Excel

Rock mass characterisation data is the fundamental departure point to complete a reliable and meaningful risk-based support design. Without accurately representative data, all other dependent outputs are nonsensical. It is strongly recommended that interpretation of the rock mass characterisation is directly overseen by a holder of a CoMCRM. In turn, this will feed into on-the-job guidance for the REP’s (recommended holders of a CoMCSC) who will carry out the data capture to ensure that the rock mass is correctly represented by the captured data.

7.2.6 Keyblock stability analysis including software proficiency, input data and interpretation

Based on the rock mass classification parameters obtained for the respective operations, a block failure stability analysis was carried out and presented in each of the submitted reports. To complete this, additional information was required, such as:

- Support installation compliance data to test the effects of variable support spacing as a result of actual practice;
- Support unit capacity;
• Mining method, accounting amongst others for mining layout, areas of interest defined by worker exposure (zones), face advance per blast, support spacing and support standard;
• FoG distribution to guide the selection of JBlock analysis parameters for block release distance with respect to the face and percentage fallout during each blast;
• FoG data (on-mine) to validate the aspect ratio (ratio of the height of each block to the square root of the face area of the block) for failed blocks and select an appropriate excavation-parallel clamping stress in the skin of the excavation;
• Mining environment which includes, amongst others, depth below surface to further assist in the selection of excavation-parallel clamping stress, and potential influence of seismicity (seismic acceleration normal to the excavation); and
• Rock properties such as rock density per lithological unit.

Outcomes – support scenario construction

Selected examples of support scenario constructions are presented in Figure 12 and Figure 13 for discussion.

There are many particular user-interface idiosyncrasies associated with the JBlock application, all of which will not be mentioned here. However, the definition of hazard zones is critical to correctly transfer the results from JBlock into RiskEval because RiskEval applies a hard-coded consequential outcome to each defined hazard zones to complete the risk-based design. This means that each hazard zone must be defined in the following order and at the same time taking cognisance of the associated impact on the risk analysis:

• **Zone 1**: face area
• **Zone 2**: sweepings area
• **Zone 3**: gully
• **Zone 4**: back area.

A dilemma was encountered in bord and pillar analyses in that “conventional” definitions of sweepings area, gully and back area are not applicable. Unique, creative solutions were therefore necessary, such as **Zone 2** and **Zone 4** defined over pillar areas in Figure 12.
The influence of defined hazard zones and their consequences for bord and pillar assessments has not been fully investigated and is therefore recommended as an outcome of the project for further development of the technology.

*Figure 12* Hazard zones for a bord and pillar stope showing Zone 2 and Zone 4 located on unmined ground

*Figure 13* Hazard zones for a conventional stope
Input parameters pertaining to support unit capacity (performance), hazard zone delineation, mining method, mining practice, block release distance and rock mass characteristics amongst others were variably presented. In some cases, input parameters were declared with good clarity, for example in Figure 14 through Figure 16; however, several submissions were received in which no explanation of the input parameters was presented. Source material was referenced only in isolated cases. This limited the reviewer’s ability to interrogate the results and gain confidence in the practitioner’s understanding of the method.

In no cases were features such as ramp domes or circular domes included, or if they were, this was not indicated. These features present a critical influence over block stability in the Bushveld underground mines. Additional work is therefore required by the practitioners to adequately represent actual on-mine conditions and complete a reliable risk-based support design for keyblock stability.

Data pertaining to variability in support installation quality was absent from all the analyses. It is unclear whether this data is captured on-mine or to what level of detail. However, availability of this data is recommended to improve the analyses, and may require a change in focus for on-mine data capturing practices.

Fallout height data was referenced in isolated cases; however, no further analysis of on-mine FoG records was presented to assist in validating the results and retrospectively guide the selection of appropriate input parameters. Admittedly, this is an advanced rock engineering task; however, such calibration initiatives are necessary to assist in improving confidence in the results.

<table>
<thead>
<tr>
<th>Parting (ICL)</th>
<th>Parting plane height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.9</td>
</tr>
<tr>
<td>Stdev</td>
<td>0.3</td>
</tr>
<tr>
<td>Tensile strength (kPa)</td>
<td>10</td>
</tr>
</tbody>
</table>

*Figure 14 Selected example of rock mass input parameters pertaining to a weak parting*
Outcomes – support scenario analysis results

Comparative support scenario evaluations were carried out and submitted for all of the reports. In several cases, results were interrogated further using the recommended methods that were presented during the training programme; however, anomalous results were obtained (selected examples, Figure 21, Figure 22) which were not well explained.

Selected examples of spatial keyblock failure distributions are presented from which the following outcomes are concluded:
• **Influence of abutments**: an understanding of the influence of abutments is required to avoid artificial results. There were no cases in which excavations had been constructed with incorrectly defined excavation boundaries; however, the effect of abutments in bord and pillar (Figure 17) and development (Figure 18) analyses must be given due cognisance when interpreting the results. For bord and pillar analysis it was recommended during the training programme to extend the excavation boundaries and replace pillars with very high strength “pack” or “rectangular” support (SRK example, Figure 20). This will create a more realistic evaluation in which blocks can form in the pillar holings. No cases were presented in which this had been considered.

• **Anomalous keyblock formations**: block formations limited to the face area (Figure 21), or strictly localised within an excavation (Figure 22) were presented. These results appear anomalous based on the project leader’s practical experience. It is therefore necessary to interrogate the input geotechnical parameters and analysis constraints that determine the formation, location and potential for failure of keyblocks. In addition, this reinforces the recommendation to check results against known on-mine data for validation.

• **Interrogation of results**: in most cases, results from the JBlock analyses were presented directly, without any further interrogation, for example Figure 23 and Figure 24. However, a selection of instances were presented in which the spreadsheet-based JBlock output data was processed further to produce independent histogram plots demonstrating additional output properties such as the normalised number of falls per 10 000 m² (Figure 25) and the mode of failure distribution (Figure 26). Interrogation of the input and output data requires a clear and insightful understanding of the mechanisms and parameters that govern keyblock formation and failure distributions. To accomplish this, a thorough review of the analysis by an experienced, certificated rock engineer (holder of a CoMCRM or accredited geotechnical engineering qualification) is recommended. An in-depth independent review of this nature by the project team did not form part of the scope of the project. It was for this reason that the participation by a CoMCRM was recommended for this programme.
An extensive range of potential interrogation options can be exploited using the spreadsheet-based outputs of JBlock. In view of the project being an initiation programme for adopting the technology, the efforts applied to investigate the data are encouraging. Going forward, continued improvement and detailed interrogation of the data can, and should be, explored based on the skills demonstrated thus far in the submissions.

Figure 17 Keyblock failure distribution plot, bord and pillar stope
Figure 18 Keyblock failure distribution plot, narrow on-reef raise development

Figure 19 Keyblock failure distribution plot, conventional stope
Final Report on SIM 14 02 01 “Adoption of risk-based support design in Bushveld underground mines”

Figure 20 SRK example excavation construction, bord and pillar

Figure 21 Limited keyblock failure distribution plot, conventional stope
Figure 22 Anomalous keyblock failure distribution plot, conventional stope

<table>
<thead>
<tr>
<th>Tendon successful</th>
<th>Tendon failed</th>
<th>Tendon steel break</th>
<th>Grout bond fail</th>
<th>Tendon too short</th>
</tr>
</thead>
<tbody>
<tr>
<td>979</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>39</td>
</tr>
</tbody>
</table>

Figure 23 Keyblock failure distribution histogram, JBlock
Figure 24 JBlock analysis output
Figure 25 Keyblock failure distribution histogram, JBlock

Figure 26 MS Excel mode of failure analysis – Morula
7.2.7 *Risk evaluation including application usage – proficiency and application challenges, data collection, interpretation of results*

Completion of the risk-based support design process comprises the interpretation of block failure hazard analysis results from JBlock into the RiskEval programme. The block failure hazard is thus related to consequential outcomes in terms of economic and safety considerations to determine a risk for the operation.

To achieve this, a suite of information is required from the operation. A detailed outline of the required information was presented within the SIM060201 Track B report and is not repeated here. In summary, the following important data (amongst others) must be captured within the RiskEval application:

- **Mining practice** (outlined in Section 7.1.6), including remedial strategies defined by the size and location of a FoG
- **Labour costs**
- **Injury distribution data**
- **Injury costs**
- **Production costs**

**Outcomes**

Out of the 15 REP submissions (i.e. excluding the attending geologists), nine cases (i.e. 60% of the submissions) contained a completed risk evaluation using the RiskEval application. This represents a very encouraging improvement over the outcomes that were achieved during SIM120201 in which only two attempts had been carried out.

The quality of results and interpretative insights were variable. For example, Figure 27, in which results appear to be sensibly aligned with an intuitive expectation for the effect of an increased bolt (Xpandabolt) length. However, in the same case, the distinction between costing results and number of injuries has not been understood by the practitioner(s) as these quantities have been presented in combination on the same chart. This mixture of data into a single chart was encountered in several submissions.
In several cases, a thorough effort had been made to obtain the full set of risk evaluation data requirements, going into great detail and presenting a broad suite of results (example, Figure 28). However, submissions were received in which the RiskEval component had not been attempted. Reasons that were put forward for not completing the RiskEval component included non-compatibility with development ends and bord and pillar operations, or alternately a lack of understanding.

It was known prior to commencing with the project that the RiskEval application is limited with regard to bord and pillar mining practices. Further development is therefore required; however, it was recommended during the training programme that an intuitive interpretation of bord and pillar parameters should be applied within the RiskEval application as a departure point to provide comparative results. This approach was attempted successfully in select instances (example, Figure 29).
Figure 28 Example of comparative risk analysis results for eight respective support scenarios
In spite of analyses that were carried through to completion using the technology, shortcomings in interpretation were identified, for example as shown in Figure 30. In this example, there is a distinct increase in the total costs from the second to the third scenario. This is counter-intuitive to an expected decrease in total cost (which includes consequential costs) that might be expected for a scenario in which the bolt spacings are closer (more support) than the preceding scenarios. A cursory inspection of the results will reveal that the support system cost has increased with an increase in number of support units. However, no comment to this effect was included in the submission nor was there any comment pertaining to the overall consequential costs, i.e. production losses and injury costs.

Similar deficiencies in interpretive insight were encountered during the training programme in that results were obtained and the application was successfully utilised; however, results were only superficially interpreted.
As a result, it is recommended that REP’s receive continued assistance with interrogating the risk evaluation process from a conceptual and causal perspective as well as to present the data correctly.

![Image of comparative injury results for eight respective support scenarios]

**Figure 30 Example of comparative injury results for eight respective support scenarios**

7.2.8 Software development – JBlock, RiskEval

The technology that was developed during the SIM060201 research project can be applied to conventional mining operations as is. However, several limitations were presented which are recommended for further development:

- Further development of JBlock to address a particular limitation in which the effect of a safety net (or membrane) appears to disproportionately reduce the FoG hazard (Figure 27).
- Further development of JBlock to address the “wrap-around” distribution of discontinuity orientations through 180° for steep-dipping joint sets.
- Further development of JBlock to address variability in clamping forces orientated sub-parallel to the excavation surface.
- Further development of JBlock and RiskEval to more suitably take into account the definition of hazard zones, most particularly for bord and pillar mining.
- Further development of RiskEval to more suitably apply to development (tunnelling) and bord and pillar operations, particularly in terms of remedial strategies.
- Further development of RiskEval to improve the accounting of cost elements such as SIMRAC levies and NPV.
- Minor software issues such as read-write errors between outputs from the updated version of JBlock and input requirements for RiskEval (i.e. header formats)
- Compatibility issues with AppleMAC platforms for both JBlock and RiskEval (and similarly with JAVA script) were revealed during the training programme. These issues might be investigated through further development of the applications.

7.3 **MILESTONES 7 and 8 – Project close-out**

Close-out of the project comprises Milestone 7 and Milestone 8, which are completion of a draft and final report respectively and a close-out workshop which was held on 7 December 2015. Minutes of the workshop are presented together with the close-out presentation in Appendix G. As an outcome of the workshop, it was agreed that the project findings should be presented at a meeting of the CoMRETC to assist in guiding a way forward for the technology. An account of the workshop is presented in more detail in the minutes (Appendix G).
7.4 **GENERAL CONCLUSIONS**

The level of success of the SIM140201 programme shows a substantial improvement over outcomes achieved from the initial technology transfer programme, SIM120201. This is attributed to an improved training programme (course structure) as well as increased familiarity and receptiveness within the industry to the technology.

Continued exposure and guidance within the industry is recommended to raise confidence levels in the outcomes, entrench practices and expand the number of practitioners within the industry with the capacity to produce a risk-based support design for their respective operations. However, an encouraging extent of exposure to the technology has been achieved and it is the researcher’s opinion that a strong platform has been established for continued improvement and use of the technology resulting in progressive, favourable constraint of safety and cost risk within the industry.

7.4.1 **Recommendations for further research**

Continued development of the applications JBlock and RiskEval are recommended as outlined to improve the applicability to various mining practices and address technology limitations.

Interest has been expressed for continued training opportunities, in particular the gold sector and northern limb of the Bushveld complex. Consequently, continued training programmes are recommended to transfer the technology further within the industry.

An on-mine review programme is further recommended for experienced and suitably certificated rock engineers (holder of a CoMCRM or similar geotechnical engineering accreditation) to assist in improving the understanding and interpretation of the risk evaluation process. This, in turn, will assist ongoing on-mine training in the use of the technology, thereby developing quality of outputs and competency of on-mine practitioners.

7.4.2 **Recommendations for implementation for the sector**

A major obstacle to successful implementation of the technology within the industry is a conflict in the perceived function of a rock engineering service with those of a compliance auditing and day-to-day production service. In order to achieve technical,
engineered solutions for rock mass stability problems, a rock engineering service must be empowered to carry out technical duties independently of day-to-day observations.
This is a larger challenge that requires an industry-wide intervention to restore a technical excellence function for on-mine rock engineering services.

7.4.3  Technology transfer options
The SIM150202 project was a technology transfer initiative that followed on from a similar project completed in 2013 (SIM120201) to transfer outcomes of the SIM060201 Track B research completed in 2011. The programme represents a successful technology transfer approach that may be applied in the same manner going forward to promote risk-based support design in Bushveld underground mines.
8 CONCLUSIONS

The SIM140201 project was commissioned by the MHSC in 2014 as an extension to the SIM120201 project, “Technology Transfer for ‘A Risk Based Approach to Enhancing Support Design in Bushveld Underground Mines’”, which was completed in 2013. The programme intended to equip REP’s with the knowledge and skills to carry out risk-based support designs for fall of ground risk mitigation using the technology on their operations.

Overall results from this project have shown a marked improvement from the outcomes achieved for the SIM120201 project. This was achieved in spite of the full complement of training report submissions not being received for this project (SIM140201). A small proportion of REP’s and geology participants will require further assistance to ensure a suitable level of independent, competent ability to apply the technology within the industry.

A number of software application and hardware challenges were identified for further research and development. Amongst these the most significant issues include developing the JBlock application to troubleshoot limitations pertaining to the interpretation of input parameters and developing the RiskEval application further to suitably address the evaluation of risk for bord and pillar operations.

Long-term outcomes of the technology transfer programme did not form part of the scope of the project. However, it is anticipated that REP’s will apply the technology to provide operationally-specific designs that effectively reduce, with the view to eliminating, the risk of death, injury and economic losses due to FoG’s in Bushveld underground mines. These outcomes can only be measured as an independent study after a protracted period of implementation.

Going forward, the industry has been provided with a number of REP’s with the necessary skills to apply risk-based support design. However, the application of technical solutions to operational challenges remains a challenging objective within the operational environment with the outcome that several REP’s still require further practice and guidance to correctly and successfully apply the technology. A strategic initiative is recommended to focus the application of technical solutions to operational
challenges from within the operational environment, i.e. by on-mine REP’s. This may include independent as well as on-mine input.

As such there remains an opportunity to continue development of the applied technical skills of on-mine REP’s in conjunction with further work to improve the technology in terms of compatibility, relevance and usability of the interface.

A selection of key observation points are noted for reference:

- **Data capture**: A good attempt at data capture was largely undertaken by all of the course participants. However, several practitioners still require practice and guidance to overcome errors in understanding the mapping parameters, improve accuracy and improve the level of skill in using the respective instruments.

- **Data interpretation (DIPs, MS Excel)**: Each of the submissions presented a complete interpretation process comprising the DIPs analysis and spreadsheet-based interpretation. The quality of interpretation was variable, with submissions in which comprehensive, insightful and reliable results were presented. However, several submissions contained results that clearly demonstrated insufficient understanding of the interpretation requirements. This is attributed to, amongst others:
  - The incorrect level of skilled resources applied to the programme
  - Insufficient ongoing on-mine application of basic skill functions such as MS Excel

- **Block failure (FoG) analysis (JBlock)**: Comparative support scenario evaluations were carried out and submitted for all of the reports. In several cases, results were interrogated further using the recommended methods presented during the training programme; however, anomalous results were obtained which were not well explained.

- **Risk Evaluation (RiskEval)**: Out of the 15 REP submissions, the majority contained a completed risk evaluation using the RiskEval application. This represents a very encouraging improvement over outcomes from SIM120201 in which only two attempts had been carried out. In several cases, a thorough effort had been made to obtain the full set of risk evaluation data requirements; however, the quality of results and interpretative insights were variable.
General

- Quantitative on-mine data availability remains variable. This data is essential to gain confidence in the quality of results.
- Availability of resources remains a challenge. This feeds directly into on-mine skills development.

8.1 RECOMMENDATIONS

The following pertinent recommendations are made:

- Continued development of the applied technical skills of on-mine REP’s is recommended to maintain the use of the technology, improve confidence in the results and address pitfalls.
- In addition, a focus on the availability of on-mine resources comprising skills, mandate, time and material requirements is recommended to assist in this regard.
- Further work is required to improve the technology in terms of compatibility, relevance and usability of the interface.

Signed:

J Walls, Pr Sci Nat
Project Leader

W Joughin, Pr Eng
Project Reviewer
9 REFERENCES


10 LIST OF APPENDICES

Appendix A: Milestone 1 report
Appendix B: Milestone 2 and Milestone 3 report
Appendix C: Milestone 4 and Milestone 5 report
Appendix D: Milestone 6 report
Appendix E: Risk-based support design submissions
Appendix F: Mapping sheet example
Appendix G: Close-out Workshop
11 FINANCIAL SUMMARY

A summary of the project finances is presented in Table 8. To date, planned budget amounts have been invoiced and received. However, a significant cost overrun for the project was incurred as a result of restructuring which was outlined in the report. The total cost overrun to date is approximately 11%, while the contractor (SRK) incurred a total cost overrun of 25%. The excess cost has not been invoiced to the client. However, the excess is noted for reference and due consideration.
### Financial Summary

#### Table 8 - Financial Summary

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### Notes

- Actual costs for the project reflected are up to date as of 12 November 2015.
- The role of Desiree Seupile and Carolin Madzvai was largely replaced by Omphile Pitay in correspondence with the NUM. Syne Ntuli was called in to assist for the first two courses.
- The travel and accommodation costs were applied to the project budget.
- The project budget does not account for an actual increase in the contractor's (or sub-contractor's) rates.
- Costs shown to date as at 12 November 2015.

### Financial Summary

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13 PROJECT CLOSURE

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<td>Project Aim</td>
<td>Facilitate continued exposure of the risk-based support design methodology to REP’s and operations that had not yet applied the technology or had identified a need to extend the adoption of the technology within their operation.</td>
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<td>Equip a widely representative resource of REP’s within the Bushveld platinum industry by means of a training programme such that at the close of the training programme the trained practitioners will have applied the technology on their operations.</td>
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<td>Outcome of Project</td>
<td>A total of 74 practitioners representing 8 mining groups received training in the technology. A total of 17 submissions were received collectively from 30 practitioners.</td>
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<td>Results from this project have shown a marked improvement from the outcomes achieved for the SIM120201 project.</td>
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<td>Continued development of the applied technical skills of on-mine REP’s is recommended to maintain the use of the technology, improve confidence in the results and address pitfalls. A focus on the availability of on-mine resources comprising skills, mandate, time and material requirements is recommended to assist in this regard.</td>
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<td>Further work is required to improve the technology in terms of compatibility, relevance and usability of the interface.</td>
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<td>Assessment of the long-term outcomes of programme did not form part of the scope of the project. However, it is anticipated that REP’s will apply the technology to provide operationally-specific designs that effectively reduce, with the view to eliminating, the risk of death, injury and economic losses due to FoG’s in Bushveld underground mines. These outcomes can only be measured as an independent study after a protracted period of implementation.</td>
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<td>Issues</td>
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<td>Administrative and Research issues encountered</td>
<td>Revised training programme and number of participants catered for by the project (Milestone 1) resulted in a significant cost overrun due to course structuring and increased administrative burden.</td>
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<td>Protracted strike action during 2014 delayed initiation of the project by three months due to operational readiness.</td>
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<td>Availability of resources remained variable. Where unavailable, this presented an obstacle</td>
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MHSC RESEARCH PROJECT CLOSE OUT

Recommendations for future projects
- Separate training objectives according to skills level to efficiently target and develop practitioners according to their experience and qualified ability.
- Set realistic numbers for course participants.
- Make sufficient provision for operational constraints such as labour action in the timeline.

Research assets

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MHSC RESEARCH PROJECT CLOSE OUT

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Advisory note to SIMRAC
- The project was completed successfully with important outcomes for the industry.

Recommendations to MHSC
- Continued development and implementation of the technology is recommended as presented.

Report on MHSC Website
- TBA.

Approval

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<th>Research Project Leader</th>
<th>J Walls</th>
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<td>MHSC Chief Research and Operations Officer</td>
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Notification

| MHSC Chief Executive Officer | date | signature |
| MHSC Chief Financial Officer | date | signature |
Appendix A: Milestone 1 report
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### Beneficial Data for Rock Mass Characterisation

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<th>Rock Type</th>
<th>Dip (deg)</th>
<th>Dip Direction (deg)</th>
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Appendix G: Close-out Workshop