

# **Safety in Mines Research Advisory Committee**

Project Report

## **Review of past research areas – seismology and mine layout design**

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**Research Agency: Hands on Mining cc**

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## EXECUTIVE SUMMARY

The Safety in Mines Research Advisory Committee (SIMRAC) has managed research on behalf of the mining industry since 1993, and is now becoming concerned that the industry may not have implemented many of the results. SIMRAC selected six projects, valued at R52.89-million, to be evaluated under Project GAP 816b for their level of implementation in industry. The six projects with abbreviated titles are:

1. SIMRAC Project GAP 017: Seismology for Rockbursts: Control, Prevention and Prediction;
2. SIMRAC Project GAP 034: Deep Mine Layout Design Criteria;
3. SIMRAC Project GAP 223: Deep Mine Layout Design Criteria (continued);
4. SIMRAC Project GAP 303: Mine Layout, Geological Features and Geological Hazard;
5. SIMRAC Project GAP 336: Preconditioning;
6. SIMRAC Project GAP 409: Seismology for Rockburst Prediction.

The objectives of GAP 816b as defined by SIMRAC are:

1. To compile a succinct and clear summary of the research outputs of the six project reports listed above;
2. To list those research findings that can be implemented together with guidelines on how to implement them;
3. To analyse the research done in the six projects and identifying gaps in the research;
4. To provide general guidelines for future research.

The work is tackled by studying the six project reports, summarising them, noting their outputs, and evaluating them for their implementability in industry. Then gaps in the research are identified and future research guidelines are given. There is a danger that this work may have a bias, originating from the personal perceptions and prejudices of the project leader. In order to avoid such a possibility, a survey of the level of implementation of the research in industry was carried out, and an industry collaborator evaluated this report.

Like all research, this research is scattered with successes and failures. The seismic research of project GAP 017 (seismology for rockbursts) is a resounding success, being implemented in the Integrated Seismic Systems in mine-wide networks across the industry, and internationally. Controversy comes with this success, because it appears that seismologists are not in agreement with the approach adopted by ISSI, nor are they sure of the value of the parameters that ISSI has introduced to evaluate and quantify mining induced seismicity. The later seismic research, namely GAP 303 (geological hazard) and GAP 409 (prediction) are ahead of their time, and cannot be implemented until fundamentals such as accurate locations, accurate seismic quantification, and real-time seismic monitoring are in place.

GAP 034/223 (deep mine layouts) addresses all the issues that were extant in industry at the time of its conception. It is thus more a review of best practices, pillar design, analysis of seismic statistics, the viability of concrete pillars, caving, and numerical modelling parameters. Much of this work is incomplete, and will never be completed until there is a better understanding of rockmass behaviour in place. It therefore can never enjoy a high level of implementation, although parts of the reports will form springboards for future research. This work does contain the work on waveform similarity location techniques, which represents a breakthrough for seismic monitoring. The project leader cannot understand why it has never been widely implemented in industry.

GAP 336 (pre-conditioning) is the realisation of the SIMRAC vision: definition of problem, research to solve problem, and successful implementation of research outputs underground. This project is considered to be successful in its level of implementation in industry. Proper implementation of its outputs underground has been shown to bring benefits.

There are varying levels of implementation of the different project outputs in industry. GAP 017 and GAP 336 are perceived to enjoy relatively high levels of implementation, projects GAP 034/223 and GAP 303 moderate levels of implementation, while project GAP 409 is perceived as unimplementable. The industry survey suggests that the seismic research is relatively well known and widely implemented in the gold mining industry (80% overall) but remains totally unimplemented in the platinum mining industry (0% overall). In contrast to this result, there are four platinum mines with seismic systems already operational, being installed or being upgraded. Thus, implementation of the seismic research is set to grow in the platinum industry.

The mine layout research is relatively poorly implemented in the gold mines (50% overall) and virtually ignored in the platinum mines (10% overall). Nearly all of the research is aimed at deep level hard rock mines, and is thus seen by the platinum mines to be irrelevant. Overall, there is a higher level of implementation of the research than is perceived by the project leader.

The study has found that research into seismic monitoring will produce the most beneficial results for deep level mining. Fundamental aspects, such as event location accuracy, and more precise seismic source and seismicity quantification should be addressed. Automatic p- and s-wave picking in seismograms represents the last real bottleneck to real-time monitoring. This, and accurate seismic source quantification, are important steps towards improved seismic prediction.

There does not seem to be much reward in the mechanical approach, i.e. numerical modelling and rockmass property characterisation. In the opinion of the author, it is unlikely that there will be much reward in integrating seismicity

and modelling either, until seismic data is much better than it is now, and rockmass behaviour is understood and quantified properly. Future research strategy therefore seems clear: develop seismic monitoring techniques with particular emphasis on the accurate quantification of seismic parameters such as location and size. Then develop real-time seismic monitoring, concentrating on accurate automatic seismic event location technology. Once seismic monitoring techniques have been perfected, and rockmass behaviour understood, mine layout design will come naturally.

There are three overall conclusions that can be drawn from the study:

- The research outputs are being implemented where they are perceived to add value;
- The level of research implementation is higher than is perceived by the observer;
- Fundamental research and development must be completed before attention can be turned to higher order objectives such as prediction.

Overall there is a high level of awareness in the industry of SIMRAC research, although it is often associated with the contractor who did the work. The high level of awareness probably arises because of pressure to reduce accident levels, and by SIMRAC marketing of the results by workshops, papers, seminars and product launches.

## **ACKNOWLEDGEMENTS**

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<b>TABLE OF CONTENTS</b>		<b>Page</b>
	<b>EXECUTIVE SUMMARY</b>	<b>2</b>
	<b>ACKNOWLEDGEMENTS</b>	<b>5</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>7</b>
<b>2</b>	<b>IMPORTANT OUTPUTS FROM THE SIMRAC RESEARCH PROJECTS</b>	<b>8</b>
<b>2.1</b>	<b>Project GAP 017: Seismology for Rockbursts: Prevention, Control, and Prediction</b>	<b>9</b>
<b>2.2</b>	<b>Project GAP 303: Mine Layout, Geological Features, and Geological Hazard</b>	<b>10</b>
<b>2.3</b>	<b>Project GAP 409: Seismology for Rockburst Prediction</b>	<b>11</b>
<b>2.4</b>	<b>Projects GAP 034 and 223: Deep Mine Layout Design Criteria</b>	<b>12</b>
<b>2.5</b>	<b>Project GAP 336: Develop and Implement Preconditioning Techniques</b>	<b>14</b>
<b>3</b>	<b>LEVEL OF RESEARCH OUTPUT IMPLEMENTATION IN INDUSTRY</b>	<b>15</b>
<b>3.1</b>	<b>Project Leader’s Views of Output Implementability from Studying the Reports</b>	<b>15</b>
<b>3.2</b>	<b>Short Industry Survey</b>	<b>18</b>
<b>3.3</b>	<b>Combined Results on Implementability of Research</b>	<b>20</b>
<b>4</b>	<b>GUIDELINES FOR IMPLEMENTATION OF RESEARCH</b>	<b>20</b>
<b>5</b>	<b>GAPS IN THE RESEARCH AND FUTURE GUIDELINES</b>	<b>21</b>
<b>5.1</b>	<b>Gaps and Guidelines from Research Project GAP 017</b>	<b>21</b>
<b>5.2</b>	<b>Gaps and Guidelines from Research Project GAP 303</b>	<b>23</b>
<b>5.3</b>	<b>Gaps and Guidelines from Research Project GAP 409</b>	<b>23</b>
<b>5.4</b>	<b>Gaps and Guidelines from Research Project GAP 034/223</b>	<b>23</b>
<b>5.5</b>	<b>Gaps and Guidelines from Research Project GAP 336</b>	<b>24</b>
<b>5.6</b>	<b>Research Strategy for Deep Level Hard Rock Mining</b>	<b>24</b>
<b>6</b>	<b>CONCLUSIONS</b>	<b>25</b>
<b>7</b>	<b>BIBLIOGRAPHY</b>	<b>26</b>

## 1 INTRODUCTION

The Safety in Mines Research Advisory Committee (SIMRAC) has managed research on behalf of the mining industry since 1993, and is now becoming concerned that the industry may not have implemented many of the results. SIMRAC selected six projects, valued at R52.89-million, and listed in Table 1, to be evaluated under Project GAP 816b for their level of implementation in industry. The objectives of GAP 816b as defined by SIMRAC are:

1. To compile a succinct and clear summary of the research outputs of the six project reports listed in Table 1;
2. To list those research findings that can be implemented together with guidelines on how to implement them;
3. To analyse the research done in the six projects and identifying gaps in the research;
4. To provide general guidelines for future research.

Table 1: Research Projects Covered by this Project

<b>Project</b>	<b>Abbreviated Title</b>	<b>Pages</b>
GAP 017	Seismology for Rockbursts Prevention, Control and Prediction	310
GAP 034	Deep Mine Layout Design Criteria	45
GAP 223	Deep Mine Layout Design Criteria (continuation of GAP 034)	1314
GAP 303	Mine Layout, Geological Features and Geological Hazard	96
GAP 336	Preconditioning	168
GAP 409	Seismology for Rockburst Prediction	206
	<b>Total number of pages of typescript</b>	<b>2139</b>

In respect of the above-named objectives, this project has been carried out in the following way:

1. Study the six reports listed in Table 1;
2. Confirm meaning of outputs where they are not clear;
3. Summarise important outputs and compile them into a short report;
4. Evaluate implementability of outputs listed in the mining environment;
5. Provide examples of how outputs may be implemented;
6. Identify gaps in the research work;
7. Draw up guidelines for future research;
8. Obtain outside evaluation of and comment on the project.

The structure of this report will therefore follow the above listing of activities, starting with the study of the six project reports, and ending with independent evaluations of the work done, as well as the conclusions and recommendations. The overall approach to evaluating the project reports is thus to see them as a group addressing deep mining issues. As such, the reports are not completely evaluated on an individual basis. If the user wishes to study a full evaluation of each report, these are found in Appendix I.

## 2 IMPORTANT OUTPUTS FROM THE SIX RESEARCH PROJECTS

Throughout this section, it will be assumed that SIMRAC, by processes already in place, has ensured that all outputs required for each project had been delivered. Therefore, there will be no comment on whether the project had reached its set goals or not. Secondly, the project leader will identify the outputs from the reports rather than determine them from the original proposal accepted by SIMRAC (only GAP 223 has the proposal included in the report). This approach determines whether the outputs stand out sufficiently from the rest of the report to be recognised by the end user. For clarity throughout the rest of this report, the term *project leader* refers to MF Handley, while *author* or *authors* refer to the author or authors of the six research contract reports studied under GAP 816b. The *user* refers to the end-users of the research outputs in industry.

Evaluating the reports from the user's point of view may mean that some important outputs required by the project proposals may be omitted, either because they do not receive sufficient coverage and thus do not catch the project leader's attention, or because their benefits are not highlighted in the report. This approach helps to evaluate the implementability of the outputs, because an attempt has been made to evaluate the impact the report may have in industry.

The disadvantage of this approach is that the project leader's own perceptions of important outputs will influence the results of this report. In order to avoid this as much as possible, the project leader designed an output implementation survey, described in detail in Section 3, with three objectives in mind:

1. Determine the level of implementation of research outputs from the six reports, and from this deduce the perceived importance of the outputs in the industry;
2. Use the results as a collective opinion to override the project leader's perceptions and opinions if these differ from the collective results;
3. Determine, as far as possible, whether the end-user has identified the same outputs as the project leader.

Despite this, there may still be some bias because only those outputs seen by the project leader as directly implementable in the mining industry have been included in the survey. Independent evaluators of this work will therefore be asked to assess the validity of the project leader's opinions, and the results of the industry survey.

This section is broken up into five sub-sections, each covering a research project. Each project as a whole is described in broad brush strokes, followed by a listing and discussion of the outputs of the project. Research projects GAP 034 and GAP 223 are covered together because the former led into the latter in 1995, and the two are thus seen as one project. The seismology research is covered first, followed by the reports on mine layout design and pre-conditioning.



## **2.1 Project GAP 017: Seismology for Rockbursts Prevention, Control and Prediction**

This report sets the standard for the art of seismic monitoring in mines. The project leader is not sufficiently qualified to objectively evaluate the validity of variables used to quantify seismic events and mining induced seismicity, preferring to use an outside collaborator. Even if it is not perfect, the report will have a lasting value, and will be the springboard for future research in seismic monitoring on mines. It is necessarily incomplete because the technology as well as the theory is incomplete.

Chapters 1 to 5 cover hardware, configuration, and sensitivity of seismic networks, event location and velocity inversion, seismic ray tracing, and wave attenuation (site effects) respectively. The authors seldom refer to the origins and sources of the theory, therefore it is difficult to determine whether the work is exclusively that of ISSI and funded by SIMRAC, or whether it comes from other sources.

All of this work is implemented in the software available from ISSI; therefore it is automatically available on mines where the ISS has been installed. The client service offered by ISSI in their contracts with the mines ensures that it is properly implemented even if the people operating the seismic monitoring system on the mine have no knowledge or understanding of the theory.

Chapter 6, which covers seismic source parameters, is obscure, badly written, and difficult to understand. The audience is assumed to be composed of accomplished seismologists and the author (or authors) do not bother to reference some concepts, nor do they explain others. Nobody but gnostics at ISSI could implement this work in its current state. A seismologist on a mine would not be able to use this reference to try to understand or interpret the results of calculations made by the software. It appears that equation 6.23 is wrong, and equation 6.26 is supposed to represent a tensor, yet is here expressed in scalar form. Chapter 6 should therefore be rewritten for better implementation.

Chapters 7, 8, and 9 cover statistical analysis, predictability, and quantitative seismology respectively. They are well written, but all appear to have been completed in haste. The most startling conclusion to arise from this report is that an 8-dimensional phase space is necessary to describe seismic chaos (Chapter 8 page 18). Which are the eight independent variables that determine the chaotic behaviour?

Chapter 10 covers practical applications of the theory. Much of the impact of this chapter is lost through the very poor reproduction of all the figures. Despite this, the project leader is able to develop some appreciation of the implementation of the theory in practical mining situations, and recommends that the examples given are followed in mining situations elsewhere.

The outputs of the project usable by industry are as follows:

1. Implementation of a higher standard of data acquisition, processing, and visualisation based on digital methods.
2. New methodology for the continuous quantification for rock mass response to mining (still not real-time).
3. Limits of predictability of seismic events determined from chaos theory.

The first output is the Integrated Seismic System, which had already been developed and implemented before it received SIMRAC support. However, it did undergo significant improvement during the course of the research support. This work, together with Mendecki (1997), and Gibowicz and Kijko (1995) should still form the springboard for medium- to long-term mine seismic monitoring research.

## **2.2 Project GAP 303: Mine Layout, Geological Features and Geological Hazard**

This report attacks the problem of statistically quantifying the seismic hazard in gold mines in the Witwatersrand Basin. The underlying thesis of the report is that the relative mining system stiffness and stiffness changes are the most important drivers of the seismic hazard. The mining system consists of the rockmass, macroscopic structure within the rockmass such as faults and dykes, and mining excavations in the rockmass. Mining, i.e. the increase in excavation sizes drives system stiffness changes.

The authors claim Lyapunov exponents measure system stiffness and stiffness changes effectively. The Lyapunov exponent measure is derived from the seismic data obtained from mines, and a means of interpreting the data reliably and correctly will be important. The work has been carried out under five major headings:

- Stiffness and Hazard;
- Stiffness and Stability;
- Stiffness and Layout;
- Seismic safety exposure;
- Strong Ground Motion Hazard Monitoring.

The document quality is good, and professionally presented. The authors have written the report as if the audience in industry consists of highly skilled and qualified seismologists and modellers. Therefore, by far the greatest part of the report is far too technical to make its point to users in the industry, even if they bother to read more than the first few pages. Concepts are sometimes not explained; at others, a scanty introduction precedes the concept.

The unfortunate incompatibility of software used by the contractor and SIMPROSS compounds the communication problem because it has resulted in the unreliable reproduction of equations and symbols such as Greek characters in the text. This occurs throughout the document (including the glossary of

seismic terms in the beginning), with the instances being too numerous to mention. This must be rectified as soon as possible as the report cannot be used by anyone in this state.

There is a serious lapse in completeness in the final report. The user is referred to work described in the GAP 303 1996 Interim Report at the bottom of page 15, and then is again referred to the June 1998 interim report on page 53. This practice is unacceptable. All work undertaken in the entire project must be reported in totality in the final report, even if it is not central to the project. This includes background work and peripheral work, and work that produces interim results. All this work could appear in appendices for example, if including it in the main body is awkward. To save time and effort in repetition, it may be best to simply include all the interim reports in full in the appendices, if these documents are complete expositions of the work covered. Finally, there is no reference to the journal where the technical paper in the appendix may be published.

Outputs from this work consist of the following:

1. Application of the system stiffness concept to stability, hazard and layout.
2. Mine layout design methodology.
3. Case studies, which serve as future modelling and monitoring guidelines.

This work is not yet on a solid enough foundation for widespread implementation in industry.

### **2.3 Project GAP 409: Seismology for Rockburst Prediction**

The objective of this report is to predict rockmass instability based on the kinematics of failure and non-linear dynamics. Since the input data is variable, and pattern recognition is important, neural network techniques are indicated. The author adopted a two-pronged approach to the problem: firstly test to determine whether the data follows a power law, if not, then to use non-parametric statistics and a pattern recognition algorithm. The project results in two computer programs namely SOOTHSAY, and INDICATOR, which are an automated prediction algorithm and a pattern recognition algorithm respectively.

The literature survey manifestly does not meet its objectives in placing the work in context because the author summarises the content and important outcomes of groups of papers under selected headings, without highlighting the gap (or gaps) that the report aims to fill. The project leader is unable to ascertain from the literature survey whether the author has added anything new, or whether the report merely addresses the automation of prediction and pattern recognition work carried out by others in the algorithms SOOTHSAY and INDICATOR. It would appear that the major proportion of the effort went into the two algorithms, which, as best as the project leader can determine, appear to be partially successful, but still requiring considerable further testing and development. These two programs represent the two-pronged approach mentioned by the author on page 9 of the GAP 409 Report.

The main report appears to be a random collection of thoughts about seismic prediction. Figures are of questionable quality, often do not convey what the author intends, and are often not captioned. The overall style of the report renders it very difficult to understand, leaving the project leader unsure of its aims, content, and results. The project leader is not able to determine, in either the results or conclusions, which approach, or which algorithm, was the more successful. This work is far from implementable in the industry for two reasons: firstly, nobody will understand it, and secondly, it is an ambitious advance into uncharted territory.

The major question remains: are power law methods more effective than parametric statistics methods? There is no answer to that in the report, even though it is implied as a major objective on page 9. The project leader has the impression that the work is intrinsically good, and that it will form part of the road to seismic prediction, but is unable to evaluate it because of its fragmentary style. This is a brave and ambitious project undertaken before its time. As with the previous project, this research has incomplete foundations. Prediction cannot be possible under any circumstances without reaching the fundamental goals listed in the Section 3. These include a clear understanding of chaos in seismically active rock masses, accurate measurements of seismic instability indicators, and reliable real-time monitoring. The work is at the forefront of modern chaos theory, pattern recognition technology, and prediction technology, which contributes to its esoteric nature. This document will not be understood by industry.

The outputs from this research are:

1. SOOTHSAY
2. INDICATOR

Both programs need further development before they can be implemented for prediction purposes. The author has not annotated the listings, so it may be very difficult for another person to carry on with the development of these programs. This work is not yet ready for use because the basics for reliable prediction are not yet in place.

#### **2.4 Projects GAP 034 and GAP 223: Deep Mine Layout Design Criteria**

These two reports represent one large project that attempted to simultaneously address many points at issue in deep level mining during the early 1990's. This research project therefore sprawls across several research areas including pillars, backfill, and numerical design criteria, amongst others. The research done for GAP 034 precedes that in the GAP 223 report, since the former project led directly into the latter project in 1995. Collectively these two reports total 1359 pages of typescript, and only the latter project will be discussed because it completely supersedes the former. Because of its size at 1314 pages, GAP 223 is sensibly divided into seven separate volumes, as follows:

- Volume 1: Project Overview;
- Volume 2: Bracket pillars;
- Volume 3: Strike stabilising pillars;
- Volume 4: Concrete pillars;
- Volume 5: Back area subsidence/caving;
- Volume 6: Numerical design criteria;
- Volume 7: Appendices.

There was other research also undertaken as support work under the five main headings listed above, most importantly:

- Rock engineering and geological database;
- Seismic tomographic techniques;
- Waveform similarity and multiplet location techniques;
- Effectiveness of backfill as a regional support.

The interested practitioner may find more details of the contents of each volume in Appendix I in Section 4.

It is difficult to maintain objectives and direction in such a wide-ranging series of projects, therefore the project leader considers it amazing that anything at all was completed. Like all large research projects, this research contains spectacular successes and failures alike.

The multiplet location technique represents the spectacular success and the quantum leap necessary for improved seismic locations, albeit not all locations. The rationale behind the technique is that every seismic trace is unique, but that similar traces not only result from the same mechanism, but also come from the same place. If traces from several events are recognised as similar, then they can be used in conjunction with each other to improve the locations of all of the similar events, often with spectacular results. More details of the technique are given in Volume 3: Stabilising pillars, on pages 15-1 to 15-12.

The levelling surveys undertaken in follow-behind haulages near strike stabilising pillars represent the spectacular failure, because they measured inelastic movements in the fractured rockmass surrounding the stopes and the follow-behind haulages themselves, instead of the elastic response of the rockmass to pillar loads. This work appears in Volume 3: Stabilising pillars, on pages 11-1 to 11-53.

The report is professional in its layout and presentation. The language is good throughout, and it was evident that the authors took care to ensure that spelling and grammar were correct. The project leader found very few instances of poor or incorrect annotation in diagrams. The report loses some of its impact because of the generally poor reproduction of diagrams. Overall, it leaves a reasonable impression on the project leader. Some of the research is unnecessary (e.g. the effect of pillars on displacements in the footwall), and this detracts from its

credibility, while the quality of its language, structure, and diagrams enhances its credibility. It reflects a proper balance of effort divided between carrying out research and reporting the research. The reports on back area caving, bracket pillars, concrete pillars, and numerical modelling are relevant to the shallow and intermediate depth mines as well, although they have enjoyed little recognition so far.

The outputs from this project are as follows:

1. Preliminary design charts and bracket pillar design flowchart;
2. Minimum plan angle of approach between longwall and geological structure 35 degrees;
3. Geotechnical database;
4. Waveform similarity (multiplet) location technique;
5. Strike stabilising pillar instability cannot be “designed out” by varying width or span;
6. Passive tomography techniques more promising than active tomography techniques;
7. Concrete pillars are viable as regional support, although there is no indication whether the footwall foundation will be unstable or not if strike pillars are used;
8. The art of caving is described for tabular hard rock mines.

This project was too large for proper concentration on any one aspect. There are several other outputs (industry transferables) claimed by the authors which the project leader considers are not transferable to industry. See Appendix I of this report for further details. The project demonstrates the difficulty of achieving results based on observation and experimentation underground.

## **2.5 Project GAP 336: Develop and Implement Preconditioning Techniques**

This report represents the perfect self-contained research, reporting, and implementation as envisioned by SIMRAC. The report reflects that the team carrying out the research and development were capable and focused. The two underground preconditioning experiments demonstrate exactly what is necessary when preconditioning. The appendices contain two excellent sets of guidelines for face-parallel and face-perpendicular preconditioning, a clear guideline for mine standards when pre-conditioning, and a good description of the required education and training scheme. This report does not require any enhancements for implementation in industry.

This professional, good quality document clearly meets the objectives set for it. There are a few minor omissions in the report, for example positive and negative ride are not defined for Figures 1 to 21 in Appendix 1. There should be a decision table for face-parallel and face-perpendicular pre-conditioning. The project leader considers this work a success.

The outputs from this project are:

1. Two preconditioning methods and when to apply them;
2. Guidelines for preconditioning design, and mine support standards when preconditioning
3. Guidelines of required education and training for preconditioning;
4. Benefits of preconditioning.

This work is complete, and ready for implementation wherever it may be needed.

### **3 LEVEL OF RESEARCH OUTPUT IMPLEMENTATION IN INDUSTRY**

The gold and platinum mines are the intended recipients of the work. The degree to which the research has been implemented is tackled from two viewpoints. The first is the project leader's, obtained from the reports studied, and the second comes from a quick survey of users in the industry in order to avoid subjectivity. Each will be discussed separately, and combined at the end of this section.

#### **3.1 Project leader's Views of Output Implementability from Studying the Reports**

There are a number of possible reasons why research may not be implemented. The study of the six reports led to the collection listed below:

1. The research is irrelevant;
2. There are no outputs to implement;
3. The reports are difficult to consult and understand;
4. The useable results are lost in a sea of extraneous text and data, therefore they are not easily accessible to the user;
5. Outputs such as computer programs developed during the course of the research are either not made available to the user, are not sufficiently developed for general use, or are not compatible with systems in place on the mines;
6. The user does not understand the research and/or the research results;
7. Users have not taken the time to study, understand and implement the research;
8. The intellectual gap between the researchers and the users is so large that communication between the two groups is poor;
9. Users have been unable to spend time understanding the research and research results, hence have not implemented them;
10. Mining staff responsible for research implementation require considerable training before they understand the research and its implications;
11. There are no research implementation champions in industry;
12. The generally conservative outlook of mining people has prevented them from accepting and implementing the research;
13. Implementation of any work has to take place across many levels, from management down to the workforce, it is thus a process of selling, acceptance, training, preparation, testing, monitoring, and mine-wide

- application, each of which may have to take place several times at different levels before the entire process is complete;
14. Miners at the working face must implement the research results – this does not happen because of the difficulty of changing the attitudes and perceptions of a large and mostly illiterate workforce;
  15. The cost of training (both in time and money) needed to change mining practices and workforce perceptions may render the overall benefit of the research doubtful.

The above reasons are ideas the project leader has put forward in order to form a basis for assessing the implementability of research work, which follows below. The list of ideas is almost certainly incomplete. Any one of the above reasons alone could be enough to prevent the use of research results on a mine. An in-depth analysis of the reasons for non-implementation is beyond the scope of this report, but a simple analysis to evaluate the implementability of the work has been applied to the reports to assess them from a user point of view.

The analysis addresses three main areas, namely:

1. The report – quality of communication (5 questions);
2. Extra inputs necessary to get research implemented (2 questions);
3. The potential benefits of the work (3 questions).

Each report is evaluated as a whole, on the assumption that each project is self-contained – i.e. all the outputs produce one result that is implemented on the mine. The three areas of implementability above are addressed by 10 questions, which are listed in Table 2. There are five possible responses to each question, graded from a negative to a positive response. The most positive response earns 4 points while the most negative, zero. Table 3 includes the assessments for all the reports.

Table 2: Brief Listing of Questions and Answer Scores for Table 3

Question Number and Question		Remarks on Answer plus Score
<i>Category 1: Communication of the research</i>		
1	Clarity of report	Unclear – very clear, 0 – 4
2	Relevance of work	Irrelevant – relevant, 0 – 4
3	Intended audience	Non-mining – mining, 0 – 4
4	Report reproduction	Unacceptable – excellent, 0 – 4
5	Will work be understood	Not – possibly – yes, 0 – 4
<i>Category 2: Extra inputs needed for research implementation</i>		
6	Amount of training needed	Too much – none, 0 – 4
7	Interfere with mining process	Severely – not at all, 0 – 4
<i>Category 3: Benefits if research is implemented</i>		
8	Enhance safety	Not at all – strongly, 0 – 4
9	Increase productivity and morale	No – yes, 0 – 4
10	Improve bottom line	No – substantially, 0 – 4



The chances of implementation in industry are high if the project scores 31-40, moderate for scores of 21-30 and low for scores of 20 or less.

GAP 017 is implemented in the integrated seismic system software, which is widely used in the industry to evaluate and quantify seismic activity, whether or not the user understands the theory. ISSI does provide training, and there are reference textbooks such as those listed in the bibliography. Generally, highly trained and skilled individuals who manage seismic systems implement this work, and this helps to reduce the amount of training required for implementation.

All aspects of GAP017 are used to varying degrees in the mining industry. For instance, the location algorithms are implemented everywhere, seismic energy and moment parameters are widely used in seismic quantification, while the more esoteric variables such as the Deborah Number and Lyapunov Exponents are seldom if ever used. Generally, the project leader considers the outputs from this project relatively widely implemented and successful, not only in South Africa, but also worldwide. GAP 017 outputs are expected to be used more extensively both locally and internationally in the future.

Table 3: Assessment of Project Implementability

Category	Communication <sup>1</sup>					Extra Inputs		Benefits			Total
Report	1 <sup>2</sup>	2	3	4	5	6	7	8	9	10	
GAP 017	2	4	3	1	3	2	4	4	4	4	31
GAP 303	3	3	1	2	1	1	4	2	2	2	22
GAP 409	0	1	0	2	1	1	1	0	0	0	6
Seismic <sup>3</sup>	2	3	1	2	2	1	3	2	2	2	20
GAP 223	3	1	3	2	3	3	2	1	1	1	20
GAP 336	4	3	4	2	4	3	3	4	3	3	33
Layout <sup>4</sup>	4	2	3	2	3	3	3	2	2	2	26

Notes: <sup>1</sup>Question category – see categories 1 – 3 in Table 2;

<sup>2</sup>Question – see summary listing in Table 2 – Details appear in Appendix I;

<sup>3</sup>Average for seismic related studies – Projects GAP 017, GAP 303 and GAP 409;

<sup>4</sup>Average for mine layout studies – Projects GAP 034/GAP 223 and GAP 336.

The preconditioning techniques described in GAP 336 also enjoy considerable attention and implementation in the industry. Mining crews are generally not equipped to understand the principles of preconditioning, and therefore need training and then constant supervision before implementation is successful. The benefits of preconditioning outweigh the drawbacks, as has been demonstrated in several industry projects.

Parts of GAP 223 and GAP 303 have been used from time to time in industry, but neither has become the standard. There is not much chance that the outputs of either project will enjoy full implementation because they are still incomplete –

much research still needs to be done. Both contain much modelling work that is not implementable because industry either does not possess the software or the people trained to use the software and interpret the results. This will take many years to overcome. GAP 303 also contains prediction work (as does GAP 017) that cannot be used until seismic monitoring has undergone considerably more development, i.e. some of the outputs of these projects are ahead of their time.

The last project, GAP 409 is unimplementable because it is too far ahead of its time. Several other developments have to be complete before it is possible to consider prediction, namely:

- Accurate seismic locations, and therefore accurate seismic parameter determinations;
- Reliable real-time automatic seismic location software;
- Reliable real-time seismic source parameter quantification and visualisation.

Once these are all in place, researchers will be able to turn their attention to developing prediction techniques.

### **3.2 Short Industry Survey**

The perceptions above may not be accurate, hence a short survey was undertaken to check them. A total of ten respondents contributed to the survey. This might sound like a small number, but it still represents a significant part of industry, since each respondent replied on behalf of at least one mine, and in some cases, for several mines. Therefore the results can be taken as reasonably representative of industry.

Details of the survey and the data obtained from it appear in Appendix III. The main results are:

- Seismic systems are still not in use in the platinum mines, hence the three seismic reports, namely GAP 017, GAP 303 and GAP 409 have neither been read nor implemented (0% of respondents);
- GAP 017 is widely read on the deep level gold mines, primarily because of the ISSI seismic software in wide use in the industry (90% of respondents);
- Magnitude, moment, apparent stress, apparent volume, energy index, and moment tensor analysis, and seismic probability from the Gutenberg-Richter relation are universally used on the mines with seismic systems (100% of respondents);
- Seismic stress, seismic strain rate, seismic viscosity seismic diffusion, seismic Deborah number and seismic Schmidt number have been used, but not universally (70 to 80% of respondents);
- Real-time seismic hazard quantification has been tried by everybody (100% of respondents);
- Multiplet seismic location techniques as described in GAP 223 Volume 2 seem to be completely unknown in industry (0% of respondents);

- GAP 303: *Geological Hazard* has been widely read (80% of respondents), and implemented (50 to 80% of respondents) using the mine-wide seismic system;
- System stiffness has been used as a seismic hazard indicator (80% of respondents);
- Mine design methodology outlined in GAP303 has been used from time to time (50% of respondents);
- The SRP (Seismic Response to Production) is fairly widely used (70% of respondents);
- GAP 409: *Prediction* has been widely read on the gold mines (100% of respondents), and 50% of respondents agree that prediction will eventually be possible;
- Gold mining respondents were divided on the possibility of eventual reliable prediction (50%), while the platinum mine respondents were unanimous that prediction was possible;
- The rock mechanics research in GAP223 and GAP336 is considered irrelevant to the platinum mines (100% of respondents), the only possibly usable research being on bracket pillars, since they are sometimes left next to dykes in the platinum mines to avoid mining in bad ground;
- GAP 223: *Deep Mine Layout Design Criteria* has not been well received by the gold mines (40% of respondents overall), while GAP 336: *Preconditioning* has been well received (80% overall);
- GAP 223 Volume 1: *Project Overview* has been read by many (60%), Volume 2: *Bracket Pillars* (50%), Volume 3: *Stabilising Pillars* (30%), Volume 5: *Caving* (20%) and Volume 6: *Numerical Design Criteria* (40%);
- The 35-degree rule is implemented in the gold mines (80%), but generally not in the platinum mines (30%);
- The Rockburst Hazard Index (RHI) has not been widely implemented (50%), and the 250 MPa stress limit for ERR calculations remains essentially unapplied (20%);
- Programs such as WAVE and MINFFT remain unused by industry (0%);
- The geological and geotechnical database developed under GAP 223 Volume 2: *Bracket Pillars* not only remains unused by industry, it is completely unknown (0%).

The survey suggests that the seismic research is relatively well known and widely implemented in the gold mining industry (80% overall) but remains totally unimplemented in the platinum mining industry (0% overall). The mine layout research is relatively poorly implemented in the gold mines (50% overall) and virtually ignored in the platinum mines (10% overall). Nearly all of the research is aimed at deep level hard rock mines, and is thus seen by the platinum mines to be irrelevant. Overall, there is a higher level of implementation of the research than is perceived by the project leader.

### **3.3 Combined Results on Implementability of Research**

The research contained in the six reports is recognised by the industry, and is used where it is perceived to be beneficial, for example, the seismic research and preconditioning research. Like all new technology, it will take time to come into widespread use. The usefulness of research will be a combination of understanding the principles of the work, the cost of implementing it, and the benefits gained from it, as is discussed in Section 3.1.

Even work that is considered by the project leader to be completely inappropriate, e.g. the prediction in GAP409, is not completely ignored by the industry, because prediction (here “prediction” means in time, space, and magnitude i.e. an event will happen at a certain time in a certain place, and be of a certain size) is widely considered to be the “holy grail” for seismic research. So far, implementing seismic prediction is not considered by the project leader to be particularly successful because news of successful predictions has not yet been received in large number. However, the work in GAP 303: *Layout, Geological Features and Geological Hazard*, and GAP 409: *Seismology for Rockburst Prediction* has been used by industry, despite the project leader’s perception that both reports are obscure and difficult to understand.

It appears that much of the work has been put to the test, but not reported, creating the impression that the research is not being implemented. Success from implementing the work appears in general not to have been spectacular; hence unannounced implementation of results could easily have passed unnoticed. The results therefore appear as a slow improvement in safety over years rather than progress in leaps and bounds. Perhaps the injury trends in the industry are telling us exactly what is happening: there is a slow improvement because of better management, stricter imposition of the law, and increasing implementation of research results.

## **4 GUIDELINES FOR IMPLEMENTATION OF THE RESEARCH**

It appears that the research work is being implemented in industry. The constraints against implementation are the usefulness of the outputs, and the relevance of the work.

The work in all six projects is ahead of its time for the platinum industry, but will come into its own as mining progresses to deeper levels. The first mine-wide seismic system has been in operation at Northam for several years, a second at Amandelbult, a third is currently being upgraded at Impala, and a fourth has just been installed at Rustenburg Platinum Mines Frank 2 Shaft, with a fifth planned for Turffontein Shaft in 2002. Seismic research outputs are therefore being implemented in the platinum mines, and this will increase in the future.

The deep mine layout outputs lag those of the seismic research, although it is expected that this will increase as deeper areas are opened up. Both the seismic research and the deep level mine layout research enjoy considerably higher levels of implementation in the gold mines - approaching 100% in the deep level mines.

There does not seem to be any need to drive implementation further – it is happening as a result of pressure to improve rock related accident rates, and marketing of SIMRAC outputs through workshops, seminars, papers, and product launches. In the opinion of the project leader, there are a few omissions, listed below:

- Waveform similarity location technique;
- Geological database;
- Caving;
- Concrete pillars.

All four come from GAP 223. This is not to say that GAP 223 has been poorly publicised – it suggests instead that these outputs have not been made available to industry in the case of the first two, and favourable conditions for the use of the second two do not presently exist in the industry.

It is concluded that the industry is aware of the research outputs, accepts them, and implements them where benefits may be gained from them. There is therefore no need to do any more than is already being done to implement the work in industry.

## **5 GAPS IN THE RESEARCH AND FUTURE GUIDELINES**

There are many gaps in the work covered, some identifiable by the project leader, and others noted by the authors of the research reports. Each research project is treated separately, but it will become apparent that different projects sometimes point to the same gaps. A comprehensive list with short motivations for each is given below.

### **5.1 Gaps and Guidelines from Research Project GAP 017**

This is a far-reaching project that defines the directions for future research. The following list of gaps in research comes from the study of the report:

1. Automatic p-wave and s-wave picking techniques must be developed to the point that reliable locations are obtained 99.99% of the time, regardless of the proximity and size of the event. Manual seismic locations are the last big barrier to real-time seismic hazard monitoring in mines. There are promising neural network-based techniques currently being pioneered by J Niewiadomski to recognise seismic traces buried in noise – these techniques may be applicable to p- and s-wave picks.

2. The *quality index of location* is a useful parameter automatically provided by the integrated seismic system when carrying out automatic locations. It cannot be trusted because it has failed, spectacularly, on many occasions. The circumstances in which the algorithm fails must be defined. This may lead to improvements in the algorithm and therefore its reliability. This is considered an important component of automatic location algorithms because it provides the operator an index of reliability. Manual locations still provide a major bottleneck for real-time quantitative seismology, and a reliable location quality index will be a necessary component of automatic location technology.
3. Seismic location accuracy for mine-wide networks must be brought down from about 30 m error to about 1 m error. This requires a quantum leap in location techniques as well as their possible automation. It is necessary to undertake a full-scale study and comparison of seismic location techniques, including the wave similarity technique. Development of neural networks for this task promise success.
4. Seismic ray tracing methods should be developed further to improve location accuracy in seismically active mines.
5. Site effects must be reliably quantified, as input into point 6 below.
6. A new research project should aim to confirm seismic source quantification by remote sensing. This may be a literature study followed by tests using calibrated blasts. At present seismic networks automatically compute “apparent stress”, “apparent volume”, and the other seismic source variables without any indication of the associated error of computation. Without knowledge of the error of source quantification, quantitative seismology techniques are not practicable.
7. Identify the eight seismic variables that describe seismic chaos in 8-dimensional phase space, and determine their relative importance. Develop an understanding of the nature of the chaos, and what the attractors are.

All the above would make strong contributions to the eventual goal of seismic event prediction: if real-time seismic hazard determination is in place, and the results have surpassed an acceptable threshold, then prediction will be effectively in place. It is estimated that major advances in the above areas are possible in the next five years, and practical real-time seismic hazard quantification could be routine in ten years' time.

Although the reviewed work never suggested to the author that continuous monitoring might yield benefits, it is mentioned here because the industry collaborator regards it as important (see Appendix II). Continuous monitoring, instead of the “triggered monitoring” presently undertaken by seismic systems may help to produce answers on rockmass behaviour. It represents a fundamental change in the way in which seismic systems are operated, and may provide much data that is currently not being measured or recorded. Initial research in this area should answer the following two questions: is continuous

monitoring practical, and will it produce benefits presently not obtainable with “triggered monitoring”?

## **5.2 Gaps and Guidelines for Research Project GAP 303**

The work in this report is esoteric and based on an incomplete foundation. There seems to be no way to measure how poorly or well seismic parameters are being determined from seismic traces. For this reason, the project leader believes that research effort should address all the gaps listed in Section 4.1 before continuing with research in the area addressed by GAP 303. There are no suggestions for future research in this area until the fundamental issues in Section 4.1 are resolved.

## **5.3 Gaps and Guidelines for Research Project GAP 409**

As stated in Section 4.2, there are no suggestions for future research in this area until the fundamental issues in Section 4.1 are resolved. In the meantime, it is suggested that the report is re-cast into a more understandable format so that its intrinsic value can be realised in the future. The author should also add comments to the program listings provided in the appendix so that newcomers to the work would be able to develop the programs further.

## **5.4 Gaps and Guidelines for Research Projects GAP 034/223**

The failures in GAP 034/223 all originate in the inaccessible and therefore unknown rockmass. The following gaps have the highest potential of being resolved and for providing a tangible benefit to industry:

1. Concrete Pillar Placement (more a design than a research problem, since the research has established the efficacy of concrete pillars);
2. Find out why the results of the laboratory seismic tomography experiments were so poor. This will include investigating the quality of coupling between seismic sensor and solid, and between seismic source and solid. This work will help to reduce seismic parameter computation error in mine seismic systems, resulting in better quantitative seismology.
3. Research refined passive tomographic techniques for improved velocity inversion, which will help toward improved source locations.
4. Investigate the potential for neural networks to recognise waveform similarity, and incorporate the process in an automatic real-time seismic source location algorithm. The waveform similarity location technique must be developed to its maximum and then implemented as an integral part of the source location algorithm in existing seismic software. Along with this, there must be a clear definition (by testing) of its capabilities and limitations.
5. Expand the geological/rock engineering database, and add data on the burst-proneness (together with possible reasons) of the geological structures listed.
6. Determine the expected stable life of strike stabilising pillars.

7. Develop a pillar design criterion based on foundation rock strength.

All of these are relatively small projects in that they are either steps to a larger goal, or are revisits to work already done. It is likely that much of this work will be part of other projects already being researched, or that will be proposed in future.

### **5.5 Gaps and Guidelines for Project GAP 336**

There are no perceptible gaps in this work. If pre-conditioning is used in the industry, new techniques and ways of carrying it out will develop naturally.

### **5.6 Research Strategy for Deep Level Hard Rock Mining**

The research gaps listed above strongly suggest that research into seismic monitoring will produce the most beneficial results for deep level mining. The quality of data currently being collected is unknown, and therefore probably poor on average. This will lead to spurious results and erroneous conclusions. There is also considerable controversy in the seismic community about the validity of many of the seismic variables presented by ISSI. This controversy has existed since the publication of a review by McGarr (1998) on Mendecki's (1997) book. McGarr claims that many of the variables come from fluid mechanics, implying that they have not been tested in a seismological setting before. There appears to be no mention anywhere of the quality of data to be used in assessing the state of a rock mass seismologically. ISSI advocate larger and larger amounts of data to gain a better picture of processes at work – it now appears that this strategy may be incorrect because:

1. gathering larger masses of data is not practical with current automatic location algorithms;
2. there is no tested and reliable means of assessing the quality of the data measured;
3. larger amounts of data mean smaller and smaller events must be measured – this in turn means a less favourable signal to noise ratio and therefore a tendency to poorer quality data;
4. mine-wide seismic systems that record seismic events with local magnitude 0.0 and larger appear by experience to be manageable, and capable of positively affecting rock-related safety in a seismically active mine.

It thus appears to be beneficial to obtain *less* seismic data, but ensure that the data obtained is of the *highest possible quality*. Since there has been little work on the quality of seismic data the major thrust of seismic work should be to improve the data quality. This thrust should start with existing mine-wide seismic systems, confining itself to data with magnitudes greater than 0.0. First, a means to improve locations by an order of magnitude (thereby reducing location errors by a factor of 10) should be investigated and implemented. Secondly, research must aim for a means of reliably determining the quality of seismic data from the waveforms measured by the system transducers. This provides a reliable method to separate good data from poor quality data. A practical criterion (or



criteria) must be implemented to achieve this routinely. Thirdly, a reliable automatic location algorithm must be developed and implemented, in order to open the door to real-time seismology.

These three goals seem simplistic and basic, but without them future advances in mine seismology are unlikely. It is only then that the controversy around the value of the plethora of seismic parameters introduced by ISSI may be resolved, for it is only with good data that this will be possible. When reviewing the advances in seismology since the introduction of the ISS, it appears that there is no leap forward as a result of the introduction of any new variable or its use in seismic analysis. This begs the question: is it the quality of the data, the intrinsic variability of the phenomenon being monitored, or the variables being used to evaluate the phenomenon? None of this will be resolved without the return to basics proposed above.

Continuous monitoring, instead of the “triggered monitoring” presently undertaken by seismic systems, may help to produce answers on rockmass behaviour. It represents a fundamental change in the way in which seismic systems are operated, and promises to provide much data that is currently not being measured or recorded. Initial research in this area should answer the following two questions: is continuous monitoring practical, and will it produce benefits presently not obtainable with “triggered monitoring”? This approach is not recommended until the full potential of triggered monitoring has been realised.

The research gaps listed above (including continuous monitoring) strongly suggest that research into seismic monitoring will produce the most beneficial results for deep level mining. There does not seem to be much reward in the mechanical approach, i.e. modelling and rockmass property characterisation. Nor will there be much reward in integrating seismicity and modelling until rockmass behaviour is understood and quantified properly. Then, mine layout design will come naturally.

## **6 CONCLUSIONS**

There are three overall conclusions that can be drawn from the study:

- The research outputs are being implemented where they are perceived to add value;
- The level of research implementation is higher than is perceived by the observer because it is usually unannounced and seldom reported publically;
- Fundamental research and development must be completed before attention can be turned to higher order objectives such as prediction.

Overall there is a high level of awareness in the industry of SIMRAC research, although it is often associated with the contractor who did the work. The high

level of awareness probably arises because of pressure to reduce accident levels, and by SIMRAC marketing of the results by workshops, papers, seminars and product launches.

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