Camdemia
Education

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 49-53
Available at http://ojs.library.dal.ca/ijge

Challenges and Opportunities of Higher Education for International Mining Engineers in China: Based on the Practice at Chongqing University

Li Liu[1, 2*], Yong Li[1, 2], Chunhong Ming[1, 2], Gun Huang[1, 2], Zhaolong Ge[1, 2]
[1] College of Resources and Environmental Science, Chongqing University, Chongqing, China
[2] National Experiment Teaching Center for Virtual Simulation on Mine Mining and Safety, Chongqing University, Chongqing, China

Abstract: Under the background of mineral industry transforms towards global and sustainable development as well as the establishment of innovative country in China, higher requirements for the mineral engineering education have been putting forward. Based on the research on the demands of mining engineers in the domestic and foreign, the mining engineering education objective, which includes the characteristics of international, innovative and interdisciplinary (referred as '3I'), was determined. To achieve the '3I' education objective, the international outlook, the economics and management knowledge, as well as the practical ability for knowledge using were enhanced in the new curriculum. Substantially, a new education system includes three sub-education models was generated. Practical outcomes show that the education system is effective on improving the overall quality of students, especially the innovative ability. In the end, the flaws in learning and teaching in the current education system were discussed, including students' concerns on the global level and understanding different cultures should be strengthened, as well as the teaching contents and teaching philosophy have to satisfy the changes and the demands of the industry development.

Keywords: mining engineering, international, innovative, interdisciplinary, education system

1 Introduction

A global transformation from an economic towards a sustainable development is promoted by current policies from the countries and unions all over the world (Stock and Kohl 2018). Taking China as an example, the Belt and Road Initiative (B&R) effort calls for the creation of six economic corridors or areas that would link up to 65 countries by land and sea. These nations represent 60 percent of the world's population and 30 percent of the world's total economic production. The first education summit connected to China's Belt and Road Initiative had taken place in Beijing in 2016. In 2009, Yanzhou Coal Group acquired all the 100% stake in Felix, Australia. In 2012, it completed the acquisition of Gloucester Coal Company. In 2017, it also acquired the Rio Tinto Coal Company in Australia. In 2011, Shenhua Group and Japan Mitsui products consortium gained 40% stake in Mongolia Taitorgai coal mine and became the largest shareholder of the project. At present, large mineral enterprises are multinational companies all over the world. There are 6 enterprises have already covered the whole world in the top ten mineral multinational companies. Consequently, young engineers must be trained to anticipate the sustainability challenges for contributing bottom-up to a global sustainable development, as well as be capable of performing in a more and more dynamic, transnational and intercultural global working environment (Li 2013, Yu et al 2013).

Besides the global development of mining industry, the mining technology has a great progress. In China, the number of intelligent unmanned coal mining workplace has reached to 47, and the TBM has been introduced for the construction of long distance inclined shaft in coal mine, as well as the 8.8 meters high support has been developed and came into use, in 2017. For UNESCO, education for sustainable development involves: integrating key sustainable development issues into teaching and learning. This may include, for example, instruction about climate change, disaster risk reduction, biodiversity, and poverty reduction and sustainable consumption. It also requires participatory teaching and learning methods that motivate an empower learners to change their behaviour and take action for sustainable development (UNESCO 2017, Marope et al 2015).

The interdisciplinary development of mining industry is the future of coal. The clear and efficient utilization of coal will receive more attention. According to the International Energy Agency (IEA), the survival and development of coal industry is strongly constrained by clean energy technology. The sub critical coal-fired power generation units with low efficiency will be eliminated immediately, so the development of Carbon Capture and Storage (CCS)

* Corresponding Author: Li Liu, Email: zhliuli@cqu.edu.cn, phone: +86 23 6511 1468

DOI: 10.15273/ijge.2018.03.008

technology will become an important protection strategy for coal industry (Oshokoya and Tetteh in Press).

Education must find ways of responding to such challenges, taking into account multiple worldviews and alternative knowledge systems, as well as new frontiers in science and technology such as the advances in neurosciences and the developments in digital technology. Rethinking the purpose of education and the organization of learning has never been more urgent (UNESCO 2015). Consequently, new perspectives for teaching and learning in higher engineering education are required, providing the competencies for coping with the sustainability challenges and for working within the dynamic global society (Wu et al 2014).

2 Current Situation

On the one hand, the modernization of coal mines needs a large number of high-quality employees urgently. On the other hand, the brain drain of coal enterprises is serious in recent years. As well as the enrollment of mining engineering in universities is difficult.

The research about coal resources, coal industry policy, laws and regulations, international trade policy of the countries along the B&R, as well as dialogue and communication with the IEA, World Coal Association (WCA) and the coal mining industry need to be strengthened.

According to the survey International Engineering Education of the Students in the College of Resources and Environmental Science in Chongqing University, part of the questionnaire and survey date were shown in Tables 1 and 2, some interesting results are obtained.

The number of valid questionnaire is 244, within 47.54% from mining engineering (includes International Accelerated Class), 33.61% from safety engineering and 17.62% from environmental science.

228 (93.44%) students think it is necessary to educate international engineer, while only 20 (8.2%) students pay attention to the discipline internationalization which 14 from mining engineering, 4 and 2 from safety engineering and environmental science, respectively.

99 (40%) students would like to study abroad after graduating, including 18 students from mining engineering international accelerated class and 33 from mining engineering, account for 47.37% and 42.31% of the number of participants of the two classes, and 31 students from safety engineering and 15 students from environmental science. The average ratio is 43.97% in mining engineering

Table 1 Part of international engineering education questionnaire

Questions	Options	Percentage
(1) What's your discipline?	International Mining Engineering	15.57%
	Mining Engineering	31.97%
	Safety Engineering	33.61%
	Environmental Science	17.62%
	Others	1.23%
(2) Is it necessary to international education?	Yes	93.44%
	No	6.56%
(3) Would you like study abroad after graduating?	Yes	40.57%
	No	59.43%
(4) How is it important of learning English?	Very Important	73.36%
	Fair Important	25%
	Not Important	0.41%
	Not Matter	1.23%
(5) The reason of English learning?	For Exam	70.9%
	Making foreign friends	29.51%
	Working in Foreign Company or Abroad	45.9%
	Improving the International Competitiveness	72.13%
	Being International Engineer	42.62%
	Personal Interesting	21.31%
	Traveling Abroad	33.2%
	Others________	3.69%
(6) What is your English level?	CET 4	81.15%
	CET 6	16.39%
	IELTS	2.05%
	TOEFL	0.41%
(7) How much do you know about discipline internationalization?	Very often	8.2%
	Once in a while	70.08%
	Never	21.72%

Table 2 Economics and management courses in the mining engineering

University	Course name	Credit	Classification
Missouri University of Science and Technology	Macro/Micro-economic principles	3	Compulsory
	Mining economy	3	Compulsory
	Mine management	2	Compulsory
The University of Queensland	Resource Estimation	2	Compulsory
	Professional Practice and the Business Environment	2	Compulsory
	Engineering Asset Management	2	Elective
University of Wollongong	Macro/Micro-economic	6	Elective
	Resources assessment	6	Compulsory
	Planning and development of mining area	6	Compulsory
Mcgill University	Engineering economy	3	Compulsory
	Mining economy	3	Compulsory
	Mining projects	3	Elective
Clausthal University of Technology	Enterprise management	3	Compulsory
	Cost accounting	3	Compulsory

and 36.8% in the safety engineering and environmental science. In opinion of the 99 students, the main reason hindering the students study abroad is the economic (90 students chose) and language barrier (41 students chose).

The English skills of the students need to be improved. Only 40 (16.39%) students passed the CET 6, and 5 and 1 student passed IELTS and TOEFL. For mining engineering, the ratio even lower, only 12 (10.34%) and 2 students passed CET 6 and IELTS, respectively.

The first two main reasons for English learning are improving international competitiveness (72.13%) and passing exams (70.9%). It shows that students want to improve their abilities, as well as face with heavy exam oriented learning. English learning is driven by both internal and external factors. There is significant correlation (0.150, 0.019) between questions 4 and 5.1. It interprets that the main reason why English learning is very important is exam-orientation.

The significant correlation (0.185, 0.004) between questions 2 and 3 indicates that the contradictory between the necessary of international engineer education and the desire of study abroad.

The comparison about the curriculum among Chongqing University, Missouri University of Science and Technology, The University of Queensland, Mcgill University, University of Wollongong and Clausthal University of Technology, as shown in Table 2. The most different is economics and management courses.

3 New Education Framework

3.1 Education objective

Based on the needs of mining industry global development, on the employees demands survey for more than ten international mining enterprises, such as Shenhua Group, Datong Coal Mine Group, Yanzhou Mining Group, Zijin Mining and so on, and the education objectives analysis of mining engineering of University of Queensland, Missouri science and Technology University, Clausthal University of Technology, McGill University and University of Wollongong, a new education objective of mining engineering is proposed after a number of discussions and argumentation of the Alumni Development Advisory Committee, namely International, Innovative and Interdisciplinary engineers, '3I' education objective for short.

3.2 Curriculum framework

Based on the outcome-based education (OBE) theory (William 1994), to achieve the '3I' education objective, the imperfections of the current curriculum are obviously. The international outlook, the economics and management knowledge, as well as the practical ability for knowledge using need to be enhanced in the new curriculum (Wang 2013, Felgueiras et al 2017), as shown in Figure 1.

3.3 Education system

For coping with the challenges related to global sustainable developments as well as for satisfying the employee demands of the mineral enterprises, new models for teaching and learning in mining engineering education are required.

According to the OBE theory, the education objective of mining engineering education follows the demands of mineral global development and the employee demands of the mineral enterprises (William 1994). For supporting the education objective, the international and interdisciplinary courses, intercultural management and law, as well as innovative practice efficiency throughout the undergraduate curriculum. As a result, a '3I' education system, including mining interdisciplinary innovative education model, teaching model of advanced educational technology integrated into lessons and an international mining education model, was developed, as shown in Figure 2.

3.4 Practical Outcomes

Based on the education model for ‘3I’ engineer education, an International Accelerated Class was established in grade 2013 and grade 2014 for the practice, respectively.

In grade 2013, there are 29 students in total. 2 students have the experience of abroad exchange study in the undergraduate period and 2 students continue their postgraduate study abroad. 12 (41.4%) students recommended for postgraduate without examination and 8 (27.6%) students passed the entrance exam for postgraduate. The further education ratio is 75.9%. 25 (86%) students and 11 (38%) students passed CET 4 and CET 6 respectively.

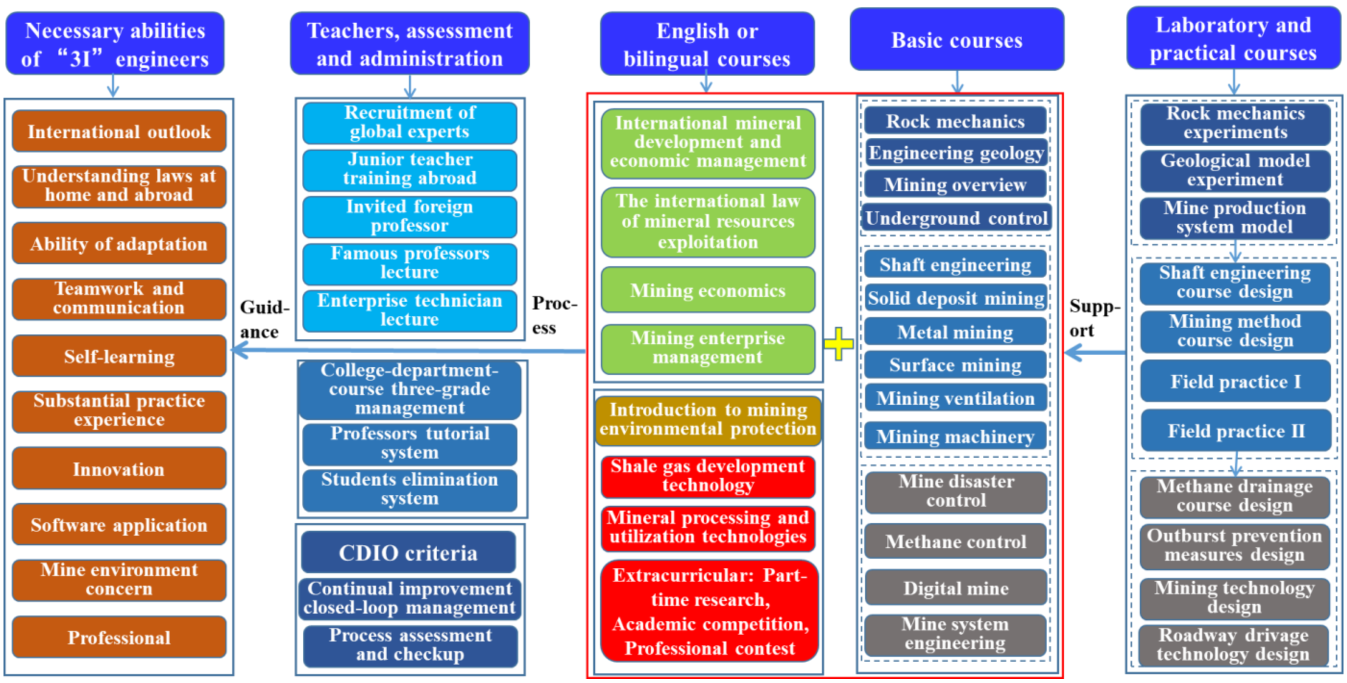


Figure 1 The new curriculum framework

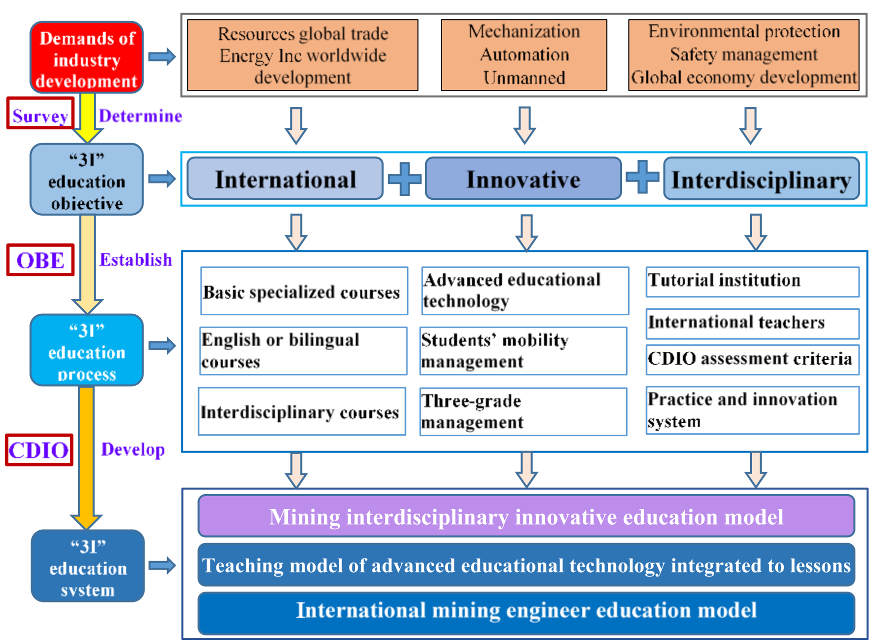


Figure 2 ‘3I’ education system

In grade 2014, there are 26 students in total. 1 student has the experience of abroad exchange study in the undergraduate period and 3 students will continue their postgraduate study abroad, 10 (38.5%) students recommended for postgraduate without examination and 4 (15.4%) students passed the entrance exam for postgraduate. The further education ratio is 65.4%. 24 (92.3%) students and 10 (38.5%) students passed CET 4 and CET 6 respectively.

According to the '3I' education model, the student' innovation ability have been improved. All the students in International Accelerated Class attended at least one innovation competition, such as The National College Student Innovation Competition (NCSIC), Student Research Training Program (SRTP) and National Higher Education of Mining Engineering Practical Work Contest and so on. Moreover, more than half of the students won the first prize in those competitions.

4 Summary and Discussion

The situation of mineral enterprises development and the current mining engineering education were analyzed according to the investigation and survey. A new education objective for mining engineering was proposed. Consequently, a curriculum framework of the transnational, interdisciplinary and innovative for '3I' education objective was established based on the OBE theory. Finally, a new education system includes three sub-education models was generated. The practical outcomes of the new education system were achieved the desire.

The more and more transnational and intercultural working environment coined by global economic trends set new requirements for teaching and learning in mining engineering education. However, there are some flaws in the current education system.

Firstly, the internationalisation of students need to be strengthened. The inadequacies include the language level which concerns to the international communication and understanding of different cultures, the concerns on the industry global development and the knowledge of management and international law.

Subsequently, students' interesting in the discipline is not enough due to mining engineering is an arduous specialty. Studying in the mining engineering is not the first choice of the most of students who are adjusted from another discipline.

In the last, the technology and equipment of mining industry have great progress in the recent years, as well as the teaching methodology and facilities. Consequently, the teaching contents and teaching philosophy have to satisfy the changes and the demands of the industry development. The '3I' education objective requires teachers to improve their teaching contents and methods.

Acknowledgement

This research was supported by the Key Research Projects of Higher Education Reform in Chongqing in 2014 (No. 142001) and Research Project on the Reform of Graduate Education and Teaching in Chongqing (No. yjg153007).

References

Felgueiras, M. C., J. S. Rocha and N. Caetano, 2017. Engineering education towards sustainability. Energy Procedia, 4th International Conference on Energy and Environment Research, **136**: 414 - 417.

Li, X.H., 2013. Reflections on the internationalization of Chinese Universities—Practice of international cooperation and exchange in Wuhan University. Journal of World Education, **2**: 5 - 10. (in Chinese)

Marope, P.T.M, B. Chakroun and K.P. Holmes, 2015. Unleashing the potential: Transforming technical and vocational education and Training. UNESCO, pp. 9, 23, 25-26.

Oshokoya, P.O. and M.N.M. Tetteh. Mine-of-the-future: How is Africa prepared from a mineral and mining engineering education perspective? Resources Policy, in press.

Stock, T. and H. Kohl, 2018. Perspectives for international engineering education: Sustainable-oriented and transnational teaching and learning. Procedia Manufacturing, **21**: 10 - 17.

UNESCO, 2015. Rethinking education: towards a global common good? pp. 9 - 10, 33.

UNESCO, 2017. Education for sustainable development. retrieved 17 Oct 2017.

Wang, J.H., 2013. The idea and strategy of internationalization education of Yale University. Journal of World Education, **3**: 37 - 40. (in Chinese)

William, S., 1994. Outcome-based education: Critical issues and answers. Arlington Virginia: American Association of School Administrators.

Wu, H.Y., H.S. Wu, I.S. Chen and H.C. Chen, 2014. Exploring the critical influential factors of creativity for college students: A multiple criteria decision-making approach. Thinking Skills and Creativity, **11**(**1**): 1 - 21.

Yu, L.M., C.T. Yin and H. Chen, 2013. Analysis of higher engineering education development trend and exploration into education internationalization. Research in Higher Education of Engineering, **2**: 41 - 52. (in Chinese)

Camdemia
Education

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 54-58
Available at http://ojs.library.dal.ca/ijge

Curriculum Review Process at the School of Mining Engineering at the University of the Witwatersrand

Rudrajit Mitra*, Cuthbert Musingwini, Paskalia Neingo, Zeenath Adam
School of Mining Engineering, University of the Witwatersrand, Johannesburg, South Africa

Abstract: The School of Mining Engineering (Wits Mining) at the University of the Witwatersrand (Wits) has a long history of Mining Engineering education, being the oldest and largest on the African continent. In 2016, the School celebrated 120 years in existence and according to the recent QS University Rankings, it is recognized as one of the world's top mining engineering schools, hosting an expansive program. It also has one of the highest growth rates of any of the engineering schools or departments, having seen a consistent increase in students to its program. (1) Need for re-curriculation: With mines in South Africa going deeper as shallow Mineral Resources are depleted, the challenges facing the industry today are substantial. However, best-practice innovations and technology offer the opportunity for the design and management of high-tech mines that are not only safer, but also more productive and environmentally and socially responsible, while still being economically successful. Feedback from industry experts and alumni continuously alluded to revising the existing BSc (Mining) curriculum in order to cater for the needs of an innovative and technology driven mining industry. The School hence decided to go through a comprehensive 2 day curriculum review workshop which hosted academic staff and industry experts from several engineering streams. (2) Finding: The future mining engineer should encompass skills and knowledge in 4 broad streams namely: Basics of Science and Mathematics, relevant core technical skills, operational management and a socio-economic understanding. (3) Aim: The School's new Strategic Plan and new technology driven curriculum will ensure~~s~~ that the Wits Mining Team can deliver Excellence in Teaching, Research and Service – in line with the Wits Vision 2022 of being "a leading research-intensive university firmly embedded in the Top 100 world universities by 2022". This paper reflects on the process that was undertaken for this review and comment on the final outcome that was attained.

Keywords: mining engineering, curriculum redesign, Industry 4.0, Wits

1 Introduction

The term "Industry 4.0" refers to the next development stage in the organisation of the entire value chain process in the manufacturing industry (Deloitte 2014). The first industrial revolution began in the late 18th century with the advent of steam power and the invention of the power loom. This led to mechanization and radically changed how goods were manufactured. The late 19th century gave rise to the second industrial revolution when electricity and assembly lines made mass production possible. The third industrial revolution was observed in the beginning of the 1970s, when advances in computing enabled the programming of machines and networks, powering automation (Deloitte 2018). Figure 1 provides an overview of the evolution of these industrial revolutions.

According to Marr (2016), Industry 4.0 introduces what has been called the "smart factory". In this system, the cyber-physical systems monitor the physical processes in the factory and make decentralized decisions. The physical systems become an Internet of Things (IoT), communicating and cooperating both with each other and with humans in real time via the wireless web.

Complex mining tasks are increasingly being handled by smart analytics software packages, while smartphones and other handheld devices have transformed the way that workers interact — not only with each other but with machines. Advances in robotics and sensor technology are also now making guided equipment much more affordable and effective. The use of tele-remote, assisted control and fully autonomous equipment is becoming increasingly widespread in the mining industry. These technologies will enable a fundamental shift in the way mining has been done in the past. There will be reduced variability in decision-making and more centralised automated operations that reduce variability in execution (Carter 2017). Further, according to Gorecky et al (2014), the development of Industry 4.0 will be accompanied by changing tasks and demands for the people in the factory.

From a mining perspective, the challenges facing the industry are increasing with environmental concerns becoming broadly understood, emergent technology changing the nature of work and society and resource nationalism fuelling the expectations of a better life. This is changing the roles and attributes of the mining engineer of

* Corresponding Author: Rudrajit Mitra, Email: rudrajit.mitra@wits.ac.za, phone: +27 63 213 2866

DOI: 10.15273/ijge.2018.03.009

the future, as it is being shaped with new and emergent technology and working practices, increased stakeholder expectations around competitive economic returns and rents, and community expectations for an inclusive and sociably acceptable industry (Smith 2017).

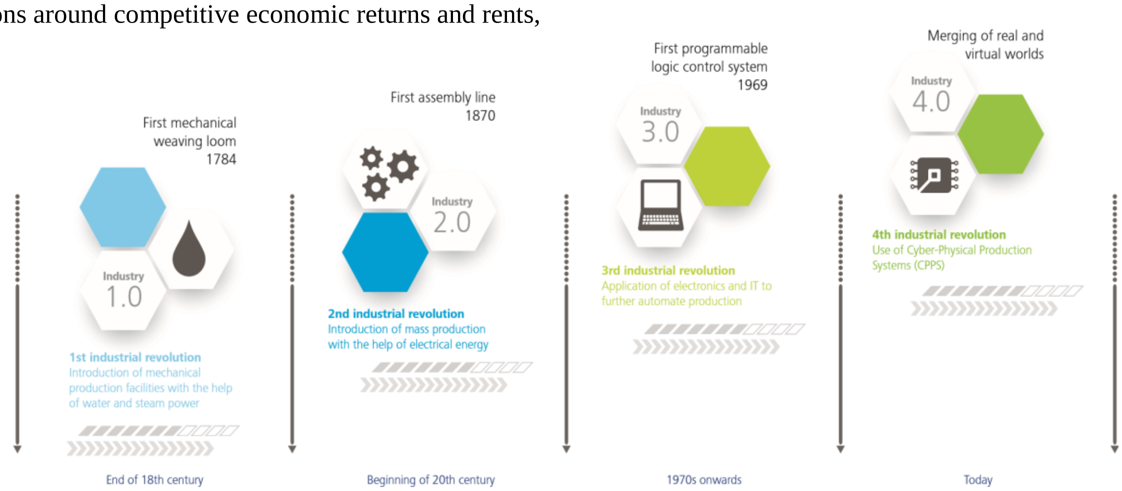


Figure 1 Evolution of Industry 4.0 (Deloitte 2014)

According to Weber-Youngman (2017), the following is how the mine of the future will look like:

(1) Remote control of most mining activities;

(2) Reduced man-machine interface risk through the use of advanced robotics and autonomous or near autonomous driverless vehicles;

(3) Virtual reality and augmented reality applications;

(4) Real time mine production monitoring and analysis through scanning and other monitoring initiatives and related real time response to the information obtained;

(5) Real time mine planning and design optimisation – the digital twin concept; and

(6) Mine design holography.

In order to prepare graduates for this new industrial revolution, Universities need to play a key role in training young minds to adapt to this new industry. As part of this need, the School of Mining Engineering at the University of the Witwatersrand (Wits) identified the requirement to redefine their curriculum to address these issues.

2 School of Mining Engineering at Wits

The School of Mining Engineering (Wits Mining) at the University of the Witwatersrand (Wits) has a long history of Mining Engineering education, being the oldest and largest on the African continent. In 2016, the School celebrated 120 years in existence and according to the recent QS University Rankings, it is recognized as one of the world's top mining engineering schools, hosting an expansive program. It also has one of the highest growth rates of any of the engineering schools or departments, having seen a consistent increase in students to its program. It currently offers both undergraduate and postgraduate degrees.

The undergraduate program is a 4 year degree designed to provide graduates with the engineering expertise they require as mining engineers. The School has, in conjunction with the South African mining industry, developed a range/suite of postgraduate courses designed to cater for the needs of graduates, which include technical subjects for specialist skills in mining, mineral resource management and evaluation, and rock engineering, as well as management skills in evaluation techniques and fundamental principles in mineral economics. On an average, the School has approximately 600 students across the four years in the undergraduate program.

Wits Mining graduates are ready for the industry's challenges and the School of Mining Engineering at Wits is known and respected internationally for the quality of its programs and graduates. The School's new Strategic Plan and new technology driven curriculum will ensure that the Wits Mining Team can deliver Excellence in Teaching, Research and Service – in line with the Wits Vision 2022 of being "a leading research-intensive university firmly embedded in the Top 100 world universities by 2022".

With mines in South Africa going deeper as shallow mineral resources are being depleted, the challenges facing the industry today are substantial. However, best-practice innovations and technology offer the opportunity for the design and management of high-tech mines that are not only safer, but also more productive and environmentally and socially responsible, while still being economically successful.

The School has a very active Industry Advisory Council, comprising of industry experts, and one of the objectives of the Council is to make sure that the School continues to deliver top class education to the students. The School also has regular meetings with other stalwarts from the Industry. During many of these meetings, there has been a consistent request from them to look into reviewing the curriculum for the BSc (Eng) degree in Mining Engineering. Sections 3 to 6 will discuss the program that is currently being undertaken along with the process that was followed to redefine the current curriculum.

3 Current Mining Program at Wits

The curriculum for the BSc (Eng) in Mining Engineering is a fixed 4-year curriculum without any variants and is typical of most international 4-year Bachelor degree curricula in mining engineering. Entrants into the program are mainly top academic school-leaving applicants both local and international, and from time to time there are few or no entrants that come from other routes. The Mining Engineering program recently underwent an accreditation process by the Engineering Council of South Africa (ECSA) and was granted full accreditation for another 5 years until 2022. The accreditation is carried out following the Washington Accord guidelines, to which South Africa is a signatory.

The primary purpose of the degree program is to prepare graduates who are eligible to register as Candidate Engineers (CE) upon graduation and eventually register as Professional Engineers (Pr. Eng.) once they have adequately completed the necessary training and experience requirements while being employed in the mining or related industries. Upon registration as a professional engineer, the graduates are able to practice individually as competent practicing engineers. The secondary purpose of the degree program is to enable graduates to proceed into postgraduate studies through one of the research Master degree programs that have or may not have a coursework component.

Mathematical and Natural science skills are developed through Mathematics and Science courses in the first and second year curricula and include courses such as Mathematics, Physics, Chemistry, Mechanics and Geology. Engineering Science skills are developed mainly in the second year curriculum through engineering courses such as Excavation Engineering and Electrical Engineering. Design skills are developed in courses that include Mining Graphics and Design in first year, Computerized Mine Design in third year and mining methods courses that involve a mini-design project in the final year. The final year Mine Design project which, is the capstone course for the degree, examines design and synthesis skills. Information Technology skills are developed throughout the degree program in a majority of the courses. Mining Engineering skills are developed in the third and fourth year curricula through such courses as Mining Methods, Technical Valuation, Mine Ventilation and Climate Control, and Rock Mechanics and Rock Engineering. Complementary Studies are introduced through courses such as Mine Management Principles, Mine Management Techniques, Financial Valuation and the Industrial and Research Seminar courses.

The structure allows for a coherent natural progression and development of the appropriate skills and competencies required in the ECSA accreditation's 11 Exit-Level Outcomes (ELOs), as described below:

ELO 1: Problem solving;
ELO 2: Application of scientific and engineering knowledge;
ELO 3: Engineering design;
ELO 4: Investigations, experiments and data analysis;
ELO 5: Engineering methods, skills and tools, including information technology;
ELO 6: Professional and technical communication;
ELO 7: Sustainability and impact of engineering activity;
ELO 8: Individual, team and multidisciplinary working;
ELO 9: Independent learning ability;
ELO 10: Engineering professionalism; and
ELO 11: Engineering management.

Table 1 provides a list of the courses that students have

Table 1 List of courses in current undergraduate Mining Engineering program

Year 1 courses	
MINN1001A	Engineering Skills (Mining)
MATH1014A	Mathematics I
PHYS1014A	Physics IE
PHYS1015A	Mechanics
CHEM1033A	Chemistry (Auxiliary)
MINN1000A	Mining Graphics & Design
MINN1997A	Practical Training (Mining)

Year 2 courses	
APPM2014A	Applied Mathematics IIA
ELEN2000A	Electrical Engineering
GEOL1001A	Geology 1A
GEOL1002A	Geology IB
MATH2012A	Mathematics II
APPM2014A	Applied Mathematics IIA
ELEN2000A	Electrical Engineering
GEOL1002A	Geology IB
MINN1996A	Practical Workshop Training (Mining)
MINN1998A	Vacation Work I (Mining)

Year 3 courses	
CHMT3018A	Ore Dressing & Extractive Metallurgy
GEOL3028A	Ore Body Modelling
MINN3000A	Industrial & Research Seminars I
MINN3001A	Mine Transportation
MINN3002A	Mining Engineering Laboratories
MINN3003A	Technical Valuation
MINN3004A	Computerised Mine Design
MINN3006A	Rock Mechanics
MINN3011A	Mine Ventilation & Climate Control
MINN3012A	Mine Surveying
MINN3013A	Mining A
MINN3014A	Health, Safety & the Mining Environment

Year 4 courses	
MINN4000A	Mine Management Principles
MINN4001A	Mine Management Techniques
MINN4002A	Industrial & Research Seminars II
MINN4003A	Mining B
MINN4004A	Mining C
MINN4005A	Financial Valuation
MINN4006A	Mine Design
MINN4007A	Project Report
MINN4008A	Mining D
MINN4009A	Mining E
MINN4010A	Rock Engineering

to currently undertake in the 4-year undergraduate mining engineering program.

4 Process followed to Re-define the Curriculum

As discussed in the earlier section, there has been a consistent request to redefine the current program at the School taking into account the various aspects of Industry 4.0. Specifically, the request has been to include more innovation and future technologies into the program. The School hence decided to go through a comprehensive 2 day curriculum review workshop with input from academic staff and industry experts. Invitations were sent to various experts in the mining industry across South Africa. On the day, there was a fair representation from the industry, both from coal and metalliferous mines and also from surface and underground operations. The Dean and Assistant Dean (Undergraduate) of the Faculty of Engineering and Built Environment at Wits were also invited. Further, staff from Mechanical & Industrial Engineering and Electrical Engineering were invited so that they can be involved in this curriculum redesign process as the future of Mining Engineering involves automation, robotics and artificial intelligence, amongst other fields. An external person from another University facilitated this process. His selection was based on his expertise and prior experience in curriculum design at other Universities.

The discussion was centered around a document that was commissioned by the School's Industry Advisory Council,–written by Smith (2017). According to Smith (2017), it is no longer appropriate to educate mining engineers in only how to design and operate mines safely and productively. The attributes and competencies of mining engineers needs to be redefined to accommodate the increasingly diverse and complex responsibilities across multiple disciplines and technologies. Furthermore, Smith (2017) indicated that there is a critical need to effectively incorporate the social license to operate, environmental and social impact assessment, regulatory and permitting constraints, risk assessment and management across the mine life cycle. A future undergraduate mining engineering curriculum requires to produce graduates with the ability to understand and operate within the holistic nature of mining engineering across the three dimensions:

(1) Core technological competencies that encompass the impact of Industry 4.0 on mining processes and people;

(2) A fundamental understanding of the skill sets, techniques and best practices across the environmental and social dimensions of the social license to operate;

(3) The capability to operate effectively in an increasingly interdisciplinary environment, especially relating to social intelligence, emotional intelligence and leadership skills.

A benchmarking exercise was done across mining engineering programs in the world and it was realised that none of the programs included the dimensions discussed above. Given that the Faculty of Engineering and Built Environment (FEBE) at Wits is underway in the process of introducing a common first year from 2019, this made sense for the School to reassess its entire program with respect to the implications of a common first year, content flow and development towards the eleven ELOs as discussed earlier.

The members present in the workshop were grouped together and each group was asked to design their own curriculum based on the discussion during the day. At the end of the day, these were collated and presented on the morning of the 2nd day. The combined curriculum from the groups were discussed and finally, the courses were grouped in the following four classes:

(1) Fundamentals;
(2) Relevant core technical skills;
(3) Fundamental operational management knowledge;
(4) Firm understanding of the socio-economic landscape.

5 Redefined Mining Curriculum at Wits

The main message from the workshop was that innovation, automation, personal skills, entrepreneurship, amongst others are necessary inclusions into the program.

In order to have flow of content through the years of study, some course were either moved to different semesters or merged in order to make place for new courses/content. Some of the new courses that have been introduced into the new program include: Digital Technologies and Mine Data Analytics; Engineering Services for Mining; Mine Transportation, Automation & Robotics; Water, Energy & the Environment; Mine Management Principles & Entrepreneurship; and Health, Safety & Mining Law. The content of the other courses will also be changed taking into account Industry 4.0. Table 2 provides a summary of all the courses that will be in the new redefined curriculum.

6 Way Forward

Currently, the School undergraduate management team is in discussion with the Faculty, University and other Schools in the University who deliver the service courses for the School to provide the necessary information for this new curriculum to be effective from 2019. The School has received full support from the Faculty for the changes and its curriculum model is currently being used as a template for other Schools in the Engineering Faculty.

The Engineering Faculty will roll out the Common First Year from 2019, and will be followed by the introduction of the new 2nd year curriculum in 2020, with the new curriculum being fully phased in by 2022.

7 Conclusions

The world is moving into the next development stage, termed as the 4th industrial revolution. The mining industry, just as any other industry, is also in the process of moving into this new stage. It has been realised that in order for the industry to successfully embrace Industry 4.0, the University needs to train graduates with certain skills and attributes so that they can be easily acceptable into the industry and will be able to make a huge impact in this new revolution.

As part of this new development, the School of Mining Engineering at Wits took a leading role, to redefine their undergraduate mining engineering curriculum after discussion with experts from the industry and academics from other streams. The new program will be rolled out from 2019, with 4th year curriculum being first taught in 2022.

Table 2 List of courses in the new redefined Mining Engineering program (includes common first year)

Year 1 courses (Common first year)	
Semester 1	**Semester 2**
Engineering Mathematics 1A	Engineering Mathematics 1B
Engineering Physics 1A	Engineering Physics 1B
Engineering Analysis & Design 1A	Engineering Analysis & Design 1B
Introduction to the Engineering Profession	Applied Mechanics for Engineering
English Literature in Context I (recommended elective)	Engineering Chemistry

Year 2 courses	
Semester 1	**Semester 2**
Geology IA	Geology IB
Mathematics II	Applied Mathematics IIA
Introduction to Underground & Surface Mining Methods	Engineering Services for Mining
Computer Applications in Mining	Computer Programming in Mining
Explosives Engineering	Mechanical Excavation of Rock
Engineering Survey	Digital Technologies and Mine Data Analytics
Practical Workshop Training (Mining)	Professional Development
Computer Programming Bootcamp (Mining)	

Year 3 courses	
Semester 1	**Semester 2**
Mine Ventilation & Climate Control	Ore Body Modelling
Underground Mining Systems	Surface Mining Systems
Mineral Resources Evaluation	Computerised Mine Design
Mine Transportation, Automation & Robotics	Rock Mechanics
Mine Surveying & Geospatial Techniques	Water, Energy & the Environment
	Ore Dressing & Extractive Metallurgy

Year 4 courses	
Semester 1	**Semester 2**
Mine Technical Visits	Mine Design
Project Report	Project Report
Rock Engineering	
Vacation Work (Mining)	
Mine Management Principles & Entrepreneurship	
Mining Optimization Techniques & Systems	
Health, Safety & Mining Law	
Financial Valuation	

References

Carter, S., 2017. "Industry 4.0 in the Mining Industry," March 13, 2017. https://www.processonline.com.au/content/industrial-networks-buses/article/industry-4-0-in-the-mining-sector-1259053519.

Deloitte, 2014. "Industry 4.0 - Is Africa Ready for Digital Transformation." https://www2.deloitte.com/za/en/pages/manufacturing/articles/africa-industry-4-0.html.

Deloitte, 2018. "The Fourth Industrial Revolution Is Here - Are You Ready?" https://www2.deloitte.com/insights/us/en/deloitte-review/issue-22/industry-4-0-technology-manufacturing-revolution.html.

Gorecky, D, M. Schmitt, M. Loskyll and D. Zühlke. 2014. "Human-Machine-Interaction in the Industry 4.0 Era." In *Proceedings of 12th IEEE International Conference on Industrial Informatics (INDIN)*, 289 - 294. Portp Alegre, Brazil: IEEE. DOI: 10.1109/INDIN.2014.6945523.

Marr, B., 2016. "What Everyone Must Know about Industry 4.0," June 20, 2016. https://www.forbes.com/sites/bernardmarr/2016/06/20/what-everyone-must-know-about-industry-4-0/#1dd331c5795f.

Smith, G., 2017. "Mining Engineering - 2020 and Beyond." Discussion document.

Weber-Youngman, R., 2017. "Skills Required to Thrive in the 4th Industrial Revolution." presented at the 28th Society of Mining Professors Annual Meeting & Conference, Torino, Italy, July 4.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 59-63
Available at http://ojs.library.dal.ca/ijge

Camdemia
Education

Earth Resource Management, a New Graduate Degree at the University of Utah

Michael G. Nelson[1*], Amy J. Richins[1], Francis J. McAllister[2], George Karpakis[2]
[1] Department of Mining Engineering, University of Utah, Salt Lake City, Utah, U.S.A.
[2] Department of Mining Engineering Advisory Board Member

Abstract: Earth's resources can be considered in three categories: captured or reusable—sun, wind, rain, tides, etc.; nurtured or renewable—ecosystems, including soils, plants, animals, etc.; and extracted—mineral deposits, including oil and gas. All three types of resources are used by humans for sustenance and for improvement of the quality of life. Increasing human population and the continuing extraction of depletable resources may lead to shortages of key commodities, unbalanced markets with wide price swings, and economic depression in areas where those resources are depleted. In addition, some resources may be used or extracted without adequate consideration of the influence of that use on other resources. Until recently, all of the earth's resources were treated as infinite, and the use of those resources proceeded accordingly. In particular, mineral resources were often "high graded" with little thought of the resultant influences on other resources. For true sustainability, an integrated, holistic approach to resource usage must be developed and implemented. That approach will necessarily incorporate the knowledge and methods of the sciences, engineering, business, law, and humanities, and will include five important components: people, resources, innovation, cooperation, and leadership. At the University of Utah, the College of Mines and Earth Sciences is preparing to offer a master's degree in Earth Resource Management. This course of study will be one of the options in the accredited Professional Management of Science and Technology program, administered by the University's Graduate School. It is designed to prepare professionals competent in all of the aspects of sustainable resource management.

Keywords: natural resources, management, human factors, culture

1 Introduction—Earth Resources

Human society in all its forms depends on the use of the earth's resources. These resources are materials and sources of energy that can be used to improve conditions for human beings. The survival and success of human society depends on the sustainable use of those resources.

Resources can be considered in three categories. *Captured* or *reusable resources* include those resources whose occurrence persists with little or no management by humans, such as sunlight, wind, and ocean tides. *Nurtured* or *renewable resources*—including soils, plants, and even ecosystems—are also persistent, but human management may be required to ensure or enhance their persistence and usefulness. *Extracted* or *depletable* resources are subject to exhaustion with continued use, and primarily comprise of mineral deposits, including fossil fuels.

There is of course overlap among these categories. For example, a renewable resource such as soil may be depleted by misuse or changes in climate conditions. Furthermore, use of one resource may have unexpected influences on others, as appears to be the case with the effects of fossil fuel utilization on climate and ecosystem.

The history of resource utilization is not encouraging. Large areas of Europe were deforested to provide lumber and fuel (Williams 2000). The American bison was almost exterminated so that native Americans, deprived of a critical resource, could be subjugated (Stoll 2017). Hydraulic mining in California caused severe erosion in the mining areas and uncontrolled flooding and siltation downstream. This resulted finally in the first environmental lawsuit in the U.S., Woodruff v. North Bloomfield Gravel Mining Company, adjudicated in 1884 (Holliday 1999). Of course, many other historic examples can be cited, and unfortunately similar misuses continue.

2 Earth Resources and Sustainability

Continued growth of the earths' human population is expected, in spite of a decrease in the growth rate, as shown in Figure 1.

Increasing population will result in increased demand for resources. This is shown clearly in projections of demand for steel (Figure 2), energy (Figure 3), and battery cobalt (Figure 4). If population and demand for resources increase as expected, the sustainable management of all earth's resources will be critical.

* Corresponding Author: Michael G. Nelson, Email: mike.nelson@utah.edu, phone: +1 801 585 3064

DOI: 10.15273/ijge.2018.03.010

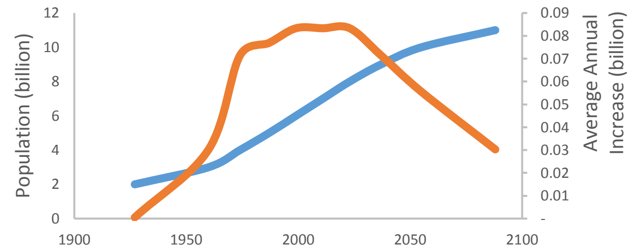


Figure 1 World population projected to 2100 (Source: United Nations 2017)

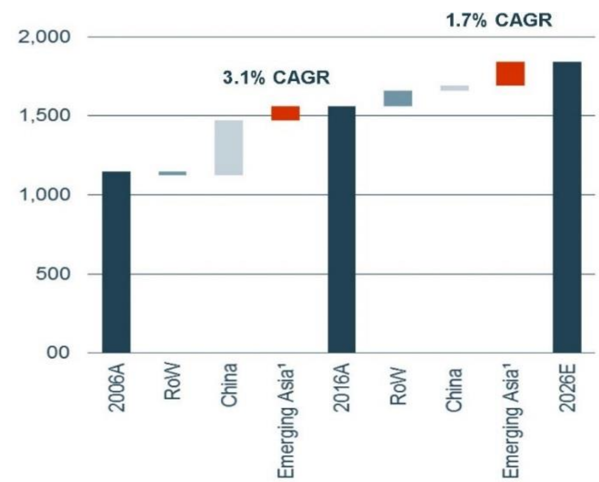


Figure 2 World finished steel demand projected to 2026. (Source: Basto 2018) [1]Emerging Asia includes India, ASEAN, and other South Asian countries, [2]New integrated steel projects commissioned or being built since 2017 (Sources: Platts, worldsteel; BHP analysis)

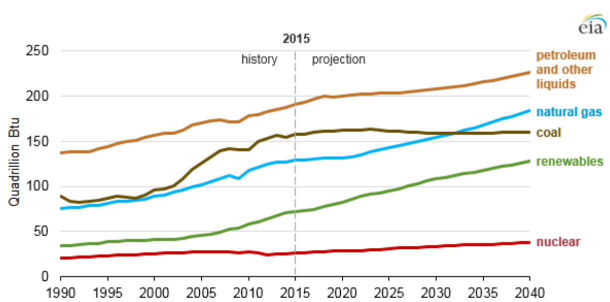


Figure 3 World energy consumption by energy source from 1990 projected to 2040. 1 quadrillion Btu ≈ 1.06E10^3 MJ (Source: U.S. Energy Information Agency 2018)

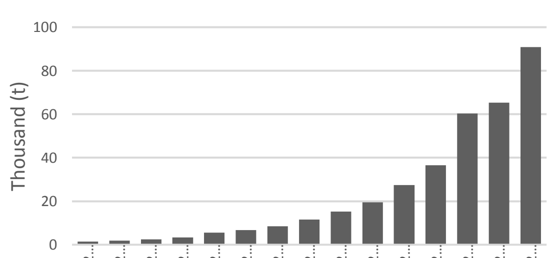


Figure 4 Battery cobalt demand projected to 2030. (After Burgess 2017)

3 A New Approach to Earth Resource Management

In 2015, considering changes in the mining industry, the Mining Engineering Department at the University of Utah undertook a revision of its strategic plan. Discussions with its Industry Advisory Committee (two of whom are co-authors of this paper), and other leading industry professionals clearly indicated the need for a new graduate degree for professionals working in or with the resource industries.

From these discussions it was concluded that executives and managers of resource production companies are often drawn from the companies' technical employees. The technology used in resource production is complex, and it is often thought that technically trained employees are best qualified to "run the company." The implicit assumption is that technically competent individuals can learn the additional skills (financial, social, political, and cultural) that are required in good management.

In some cases, resource production companies look for experienced engineers or scientists who also have advanced management training, often from a prestigious institution.

Both of these approaches rely on the individual to combine technical education and skills with business education, often with little guidance in how to do that successfully. In particular, the challenges unique to the resource production industries are often not fully addressed.

Two comments made during these discussions provide key insight. First, in a conversation regarding the public image of the mining industry, George Karpakis, retired CEO of BHP Specialty Metals, said, "I'm not sure what the mining industry will be like in 30 years. Mining will still be going on, but the industry will have to be completely different that it is now, or it won't be able to operate." Second, in a discussion of the skills needed by mining engineers, a Rio Tinto executive said, "I employ a lot of mining engineers. When I need to hire one, I can almost always find five or six good ones. On the other hand, if you could give me five mining engineers who can read a balance sheet, I'd hire all of them immediately."

The department concluded that there was a clear need for an advanced degree in earth resource management, and determined to propose such a degree as part of its strategic plan. In subsequent discussions with the Industry Advisory Committee, industry leaders, and University of Utah faculty from several colleges and departments, a draft curriculum was prepared.

4 Professional Master of Science and Technology

The University of Utah's Graduate School offers an accredited Master of Science and Technology (MST) degree for students who want to develop science, technical and business skills required for management careers in technology-based industries, government agencies or non-profit organizations. The degree has been reviewed and accredited by the National Professional Science Master's Association since 2001 (NPSMA 2018).

The degree was approved with five "tracks" or specializations, to be determined by the University. Four tracks are presently functioning: Biotechnology, Computational and Data Science, Environmental Science, and Science Instrumentation. The Mining Engineering Department has proposed the addition of a fifth track, Earth Resource Management, and approval of that proposal is expected in the summer of 2018.

The MST degree requires 36 credit hours in three categories: 15 in Graduate Science, six in Advanced Quantitative Skills, 12 in Transferable Skills, and 3 in a Professional Experience Project (internship).

(1) The Graduate Science category comprises courses chosen by the department or entity that administers the specialty track in which the student is studying. Each track requires certain core courses and provides a list of approved elective courses.

(2) The Advanced Quantitative Skills category focuses on modeling and statistical tools for solving real-life problems. Students complete a 3-credit course in advanced statistical techniques and electives based on their programs of study.

(3) The Transferable Skills category includes courses in Effective Communication, Accounting and Finance, Leadership and Management, Strategic Planning and Marketing, Production and Operations Management, Entrepreneurship and New Product Development, and Scientific Reasoning and Inquiry. Students also take three credits of graduate coursework from the School of Business or an approved elective.

(4) The Professional Experience Project is an essential component of the PMST degree, in which the student works with a local company, government agency or non-profit organization. These activities engage students in realistic work situations involving technical problems, teamwork, communication skills, and decision making.

5 Professional MST in Earth Resource Management

The Mining Engineering Department at the University of Utah has proposed the addition of a fifth track, Earth Resource Management, to the University's PMST program. This track will provide education specifically for management and leadership in the resource industries. It will be designed for individuals with undergraduate degrees in engineering and the physical sciences, but also open to those in business or communications who have strong technical backgrounds.

The program will provide instruction in the science and technology of resource utilization, as well as in finance, economics, management, leadership, law, and innovation. In addition, students will be able to include important courses in sustainability, social responsibility, and cultural sensitivity in their courses of study. Students will have flexibility to align their individual programs of study with their professional interests. The degree track will be intentionally and inherently interdisciplinary. The course offerings appear in Tables 1 to 7 below. Descriptions of all these courses are available in the University of Utah's online General Catalog (UTAH 2018).

Table 1 Earth resource management graduate science courses

Course*	Title	Credits
Required		
MG EN 6010	Mineral Extraction & Processing	3
MG EN 6340	Resource Economics & Valuation	3
Elective—Three Required		
MG EN 6015	Mine Visits	3
MG EN 6080	Mine Permitting and Reclamation	3
MG EN 6350	Safety & Health Management	3
MG EN 6370	Data Management in Engineering & Heavy Industry	3

*MG EN is Mining Engineering.

Table 2 Earth resource management non-science electives

Course**	Title	Credits
LAW 7240	Environmental Law & Policy	3
LAW 7200	Natural Resources	3
LAW 7220	Oil and Gas	3
LAW 7230	Water	3
LAW 7796	Mining Law	3
EHUM 6101	Foundations of Env Humanities	3
EHUM 6103	Ecology of Residency	3

**EHUM is Environmental Humanities

Table 3 MST courses

Course	Title	Credits
MST 6010	Effective Communication	1
MST 6012	Accounting and Finance	1
MST 6020	Leadership and Management	1
MST 6021	Strategic Planning and Marketing	1
MST 6022	Production and Operations Management	1
MST 6023	Entrepreneurship and New Product Development	1
MST 6500	Scientific Reasoning and Inquiry	3
MST 6600	Advanced Statistical Analysis	3
MST 6963	Special Topics	1-3
MST 6974	Professional Experience Project Planning	1
MST 6975	Internship and Work Experience	3

Table 4 Transferable skills electives

Course	Title	Credits
MST 6010	Effective Communication	1
MST 6012	Accounting and Finance	1
MST 6020	Leadership and Management	1
MST 6021	Strategic Planning and Marketing	1
MST 6022	Production and Operations Management	1
MST 6023	Entrepreneurship and New Product Development	1
MST 6500	Scientific Reasoning and Inquiry	3
MST 6600	Advanced Statistical Analysis	3
MST 6963	Special Topics	1–3
MST 6974	Professional Experience Project Planning	1
MST 6975	Internship and Work Experience	3

Table 5 Transferable Skills electives in Communication (COMM)

Course	Title	Credits
COMM 6365	Communicating Climate Change	3
COMM 6370	Environmental Communication, Special Topics	1–3
COMM 6580	Public Relations Cases and Campaigns	4
COMM 6640	Communication Technology and Culture	3
COMM 6710	Quantitative Communication Research	4
COMM 7200	Environmental Communication	3

Table 6 Transferable skills electives in entrepreneurship (ENTP), geography (GEOG), information systems (IS), management, and operations and information systems (OIS)

Course	Title	Credits
ENTP 6810	Venture Foundations	1.5
ENTP 6820	Venture Trends	1.5
GEOG 6162	Project Management	3
IS 6420	Database Theory and Design	3
MGT 6154	Competitive Advantage Through Human Resources	1.5
MGT 6500	Managerial Negotiation	1.5
MGT 6510	Problem Solving	1.5
MGT 6545	Leading Responsibly	3
MGT 6570	Power and Politics within Organizations	1.5
MGT 6590	Managing the Global Workforce	1.5
MGT 6790	International Management	1.5
OIS 6040	Data Analysis and Decision Making I	1.5
OIS 6420	Quality Management I	1.5
OIS 6425	Six Sigma for Managers	3

Table 7 Transferable skills electives in strategy (STRAT) and writing (WRTG)

Course	Title	Credits
STRAT 6071	Competitive Strategy	1.5
STRAT 6154	Competitive Advantage Through Human Resources	1.5
STRAT 6156	Advanced Leadership: Problem Solving in Business Organizations	1
STRAT 6171	Managing in the Global Economy	1.5
STRAT 6175	Leading Innovation	1
STRAT 6310	Business Law	3
STRAT 6350	Intellectual Property-Copyright, Patent, and Trademark	3
STRAT 6530	Competitive Advantage Through People	1.5
STRAT 6710	Strategy & Technology	1.5
STRAT 6720	Applications of Business Strategy	1.5
STRAT 6740	Strategic Leadership	3
STRAT 6750	Business Turnarounds	1.5
STRAT 6760	Profiles of Leadership	1
STRAT 6791	Global Strategic Management	1.5
WRTG 6000	Writing for Publication	3
WRTG 6080	Writing for Environmental and Sustainability Studies	3
WRTG 7060	Scientific Writing	3

6 MST Earth Resource Management Degree Delivery

All of the PMST degree tracks at the University of Utah are designed for both full- and part-time students. The full-time curriculum can be completed in two years—four semesters with nine credits per semester. The part-time curriculum requires three years—six semesters with six credits per semester. The program is designed to be convenient for working professionals, with courses offered in the late afternoon or evening.

It is expected that many of those interested in the Earth Resource Management—particularly those working at mining operations—will be located some distance from the University campus. The Mining Engineering Department plans to offer its core and elective courses for remote access, using live video and on-line technology. The Graduate School also plans to transition its MST courses for availability by remote access.

Acknowledgement

The authors gratefully acknowledge the assistance of Dr. Ray J. Hoobler, Director of the PMST degree program in the Graduate School at the University of Utah.

The authors also acknowledge the advice and input of the Advisory Committee of the Mining Engineering Department at the University of Utah—John Byars, Bowie Resources; Denee Hayes, Rio Tinto; Rick Hoggan, Millcreek Engineering; Bart Hyita, HyitaTech Consulting, John Kinneberg, Newmont Mining; Rex Plaizier, WesTech Engineering; Waldemar (Wallie) Rasmussen, retired (formerly EXXON Mobil); Richard Robison, retired (formerly Peabody Energy); and Matt Tobey, Rio Tinto Kennecott Utah Copper.

References

Basto, E., 2018. Global Iron and Steel Forecast, https://www.bhp.com/-/media /documents/media/reports-and-presentations/2018/180321_globalironoreandsteelforecast.pdf, accessed March 2018.

Burgess, L., 2017. Invest Ahead in the Scramble for Cobalt. https://www.energyandcapital.com/articles/invest-ahead-of-the-scramble-for-cobalt/6164, December 1, accessed March 2018.

Holliday, J.S., 1999. Rush for Riches: Gold Fever and the Making of California, University of California Press. p.274. ISBN 0-520-21402-1.

NPSMA, 2018. https://www.npsma.org/, accessed May 2018.

Stoll, S., 2017. Ramp Hollow, The Ordeal of Appalachia, Hill and Wang, a division of Farrar, Straus and Giroux, New York, p. 128. E-book ISBN: 978-1-4299-4697-1.

United Nations, 2017. World Population Prospects 2017, https://esa.un.org/unpd/wpp/DataQuery/, accessed March 2018.

U.S. Energy Information Agency, 2018. Annual Energy Outlook 2018, with Projections to 2050 (AEO2018). https://www.eia.gov/outlooks/aeo/, accessed March 2018.

UTAH, 2018. http://catalog.utah.edu/, accessed May 2018.

Williams, M., 2000. Dark ages and dark areas: global deforestation in the deep past, J. of Hist. Geography, **26(1)**: 28 - 46.

Camdemia Education

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 64-68

Available at http://ojs.library.dal.ca/ijge

Zijin Mode: Industry and Education Deep Integration in Mining Engineering

Wanzhong Yin, Weiran Zuo*, Lixian Zhang, Yan Fan
College of Zijin Mining, Fuzhou University, Fuzhou, Fujian, China

Abstract: This paper introduced the Industry and Education Deep Integration mode conducted by Fuzhou University in the process of Mining Engineering Education. The specific mode in Fuzhou University is named Zijin Mode, which can be briefed as "the enterprises support the construction of education, the enterprises participate in the education process, and the enterprises test the effectiveness of the education". There are six integrations in the Zijin Mode, i.e. the integration of organization, the integration of experimental platform and teaching resources, the integration of teachers' team, the integration of talent cultivation and use, the integration of teaching and the integration of science and technology innovation and transformation. The deep integration of industry and education in Zijin Mode provided guidance to Mining Engineering Education and worth popularizing.

Keywords: mining engineering, education, industry and education integration

1 Introduction

In December 2017, The General Office of the State Council of China issued some opinions on the deep integration of industry and education. The opinions pointed out that the promotion of human resources supply-side structural reform has been pressing for the deep integration of industry and education and the organic cohesion between the education chain, talent chain, industry chain and innovation chain. This is of great significance for improving education quality, expanding employment and entrepreneurship, promoting economic transformation and upgrading, cultivating new momentum for economic development across the board under new situations (General Office of the State Council 2017).

Mining Engineering discipline was established in Fuzhou University in March 2007. The idea of industry and education integration was generated at the founding of the discipline. Under the joint initiative of Professor Wu Minsheng, former president of Fuzhou University, and Mr. Chen Jinghe, board chairman of Zijin Mining Group, College of Zijin Mining was founded in Fuzhou University. The desire to found College of Zijin Mining is to improve the overall practical abilities of Mining Engineering graduates increasingly and to solve the bottle neck of talent cultivation quality, through the support from mining company in terms of the mine site practice platform and the participation of company's professionals into teaching process. Such industry-education integrated teaching mode is named Zijin Mode. The concept of Zijin Mode can be concluded as "the enterprises support the construction of education, the enterprises participate in the education process, and the enterprises test the effectiveness of the education" (Liu et al 2013), as illustrated in Figure 1. The exact mechanism of Zijin Mode will be introduced in section 2.

Up to now the Zijin Mode, as an example of the deep integration of industry and education, has been put into practice for ten years. The integrations in Zijin Mode were reflected in six aspects, i.e. the integration of organization, the integration of experimental platform and teaching resources, the integration of teachers' team, the integration of talent cultivation and use, the integration of teaching and the integration of science and technology innovation and transformation. Experience of these integrations is introduced in this paper to promote the development of Mining Engineering education.

2 Deep Integration of Industry and Education Mode

The principal and purpose of the integration of industry and education is to jointly cultivate talents by both university and industry. According to the requirement of industry and regional development, it is necessary to fasten the structure adjustment of talent cultivation, to innovate education organization form and to improve the joint development of education and industry. Based on above understanding, noticeable investigation had been conducted by College of Zijin Mining, Fuzhou University.

2.1 The integration of organization

The university and the enterprise set up college council together, to comprehensively guide the college construction and development plan. Fuzhou University appointed four members, and Zijin Mining Group appointed three members

* Corresponding Author: Weiran Zuo, Email: zuoweiran@163.com, phone: +86 13489988094

 DOI: 10.15273/ijge.2018.03.011

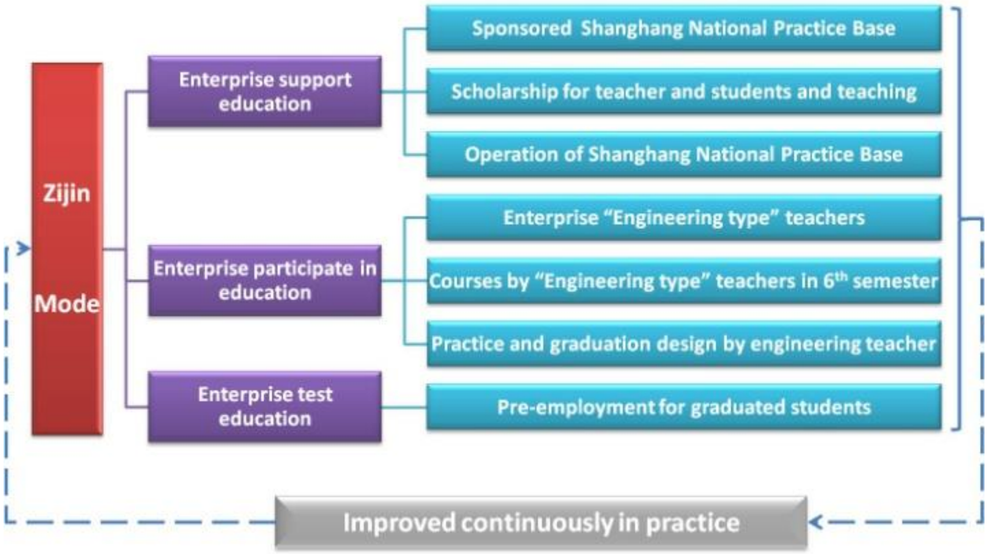


Figure 1 Schematic drawing of Zijin Mode

for the university-enterprise joint council. Board chairman of Zijin Mining Group, Mr. Chen Jinghe was appointed to be the chairman of college council. Generally, Zijin Mining Group appoint two key senior executives to be the council members, while Fuzhou University appoint a vice president, head of Academic Affairs Office and the leaders of the college to be the council members. Governing Council meeting was held twice a year for decision-making, advisory guidance and supervision and coordination for the college discipline construction and development, the discipline settings, the personnel cultivation, the interaction among industry, education and research, the schooling cost and other major issues.

College of Zijin Mining and Zijin Mining Group established a management committee in Shanghang Base to coordinate the construction and management of the teaching base. The management committee consists of Base Administration Office and a teaching steering group comprising members from both the enterprise and the university. The teaching base office established a relatively complete teaching management system, responsible for the day-to-day teaching operation management, logistics base, external communication and coordination, student management, laboratory management, and other transactions.

2.2 The integration of experimental platform and teaching resources

In the early period of the college, Zijin Mining Group donated 30 million Yuan to the college for teaching infrastructure construction and talent appointment. The company also provides scholarship to the college for a million Yuan per year. In 2010 Zijin mining group acquired 80 acres of land in Shanghang county, where the headquarter of Zijin Mining Group locates, and invested about 150 million Yuan to build the Shanghang Practice Teaching Base for College of Zijin Mining with complete hardware facilities prepared. The base has complex building, teaching lab building, museum, library, teacher and student apartments, canteens, and sports leisure facilities. After running for these years, rich experience of management and operation and fruitful teaching achievements had been obtained in Shanghang Base. In July 2012, the Shanghang base was approved as National Engineering Practice Education Center (Wang et al 2013).

Zijin Mining Group's subsidiaries, such as Geological Exploration Institute, Mining and Metallurgy Design and Research Institute, Analysis and Testing Company, Geological and Mineral Museum, Mining enterprises and other platforms, are open to college teachers and students. Teachers can use these platforms, resources, equipment to carry out teaching and research work, and students can follow the teachers and enterprise technical staff to carry out experimental activities and research training.

2.3 The integration of teachers' team

Talents introduced into College of Zijin Mining enjoy the Fujian Province and Fuzhou University talent introduction policy and enjoy the Zijin Mining Group's donated supporting funds. In recent years the college introduced more than 30 talents from universities, research institutes and industry. To guarantee the implementation of cultivation programme and to improve the students' engineering accomplishment simultaneously, Zijin Mining group select senior engineering professionals in enterprises to participate in teaching activities. The selected professionals will become the engineering-type teachers through pre-job training of the new teacher by Fuzhou University. A series of policies for the selection, employment and management of enterprises engineering-type teachers were formulated. A teaching operation management mechanism was also built. In the last 4 years, 97 engineering-type teachers were employed to take responsibility of courses teaching and enterprise practice guidance in Shanghang base, which laid a solid foundation for the implementation of the cultivation programme (Peng et al 2014a).

2.4 The integration of talent cultivation and use

In the talent cultivation process, deep industry-education cooperation was implemented. Zijin Mining Group participated in the design, implementation and management of every talent cultivation program. Students cultivation programme of all majors in the college were designed according to industry demand, based on the requirement of national mining industry standards and enterprise development, with the goal of cultivating severely needed applied talents for geology and mining industry; to improve the college's service capacity and contribution to geology and mining industry of China.

In Zijin Mode, a 3 + 1 talent cultivation system (3 years in Campus and 1 year in Shanghang Base) had been developed. The basic course learning is conducted in university for 3 years, and the study in the base enterprise is 1 year in total (Figure 2). This integrated talent cultivation had been implemented successfully in the last ten years. Benefited from the one year training in Shanghang Base, the graduates were cultivated to conform with the standard set up by the Plan for Educating and Training Outstanding Engineers (Peng et al 2014b).

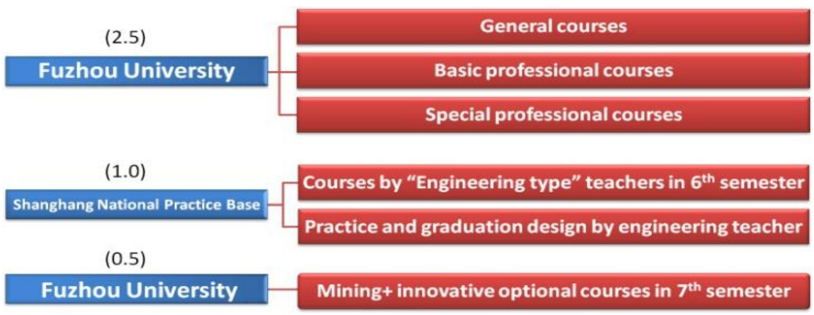


Figure 2 Courses system of Zijin Mode

College of Zijin Mining built a graduated talent database to track the career development of graduates and master the evaluation and suggestions of employers to students' quality in time. A teaching supervision group was established by the university and enterprise collaboratively, to monitor and guide the teaching operation of Shanghang Base and to ensure teaching quality. In addition, through operation and management symposium in Shanghang Base and symposium for enterprises engineering-type teachers, the feasibility and effect of the actual teaching operation of Zijin Mode were understood. Evaluation and recommendations were reported to the Council promptly, as the basis of adjustment of the training program, updating the teaching contents, and improving teaching methods.

2.5 The integration of teaching

The integrated cultivation programme of the 3 majors in College of Zijin Mining specified the procedure of enterprise engineering-type teachers' involvement in the process of education, which is mainly reflected in the sixth and the eighth semester of the study. Teaching activities for undergraduates in the sixth semester are conducted in Shanghang Base, including compulsory and optional courses, professional practice and course design, etc., taught by the engineering-type enterprise teachers. The professional courses teaching and practice in the base are sponsored by Zijin Mining group, with an average of 1.5 million Yuan per year.

From 2nd year for undergraduates, the college begin to organize students to sign contract with Zijin Mining Group, which is called Pre-employment Agreement. According to pre-employment status, students are sent to the pre-determined subordinate units of Zijin Mining Group to complete graduation design or thesis based on the practical project implemented in the subordinate units. This gives a chance for students to play the role in enterprise in advance and can shorten the future internship. Students can complete the graduation design or thesis under the supervision by both college teacher and engineering professionals from enterprise (Huang et al 2010).

When students are dispatched to the corresponding pre-employment enterprise, a college teacher will be determined as his/her supervisor. Each college supervisor is designated to a number of specific mine sites. The supervisor keeps in touch with these mine sites and is familiar with the basic geological background, the mineralization mechanism, the economic benefits and management and the mining and mineral processing features of these mine sites.

2.6 The integration of science and technology innovation and transformation

The college aims to take the full advantages of the college teachers in scientific research, actively provide technical services for enterprises, develop industrialization-oriented research results, improve the economic efficiency of enterprises, and achieve the purpose of energy saving and emission reduction. One example is the Fuzhou University-Zijin Mining Group joint project Study on the Epithermal – porphyry Copper and Gold Ore Deep Mineralization Mode and Exploration Technology Demonstration granted by Department of Science and Technology of China, with funding amounted to 60 million Yuan. The project outcome

Zijinshan Ore Field Mineralization Mode and Exploration Technology Research and Deep Prospecting Application had won the China Gold Association Special Award of Science and Technology in 2014 and the third prize of Science and Technology Progress of Fujian Province. College of Zijin Mining's engineering-type teachers can apply for National Natural Science Fund project through Fuzhou University's platform. This policy not only makes the best of the enterprise technical ability, but also encourages the college teachers to participate in enterprise-related research projects. This reflects the win-win advantage of the deep integration of industry and education.

3 Performance of Zijin Mode in Practice

3.1 Effect of Zijin Mode

The first-time employment rate of College of Zijin Mining in the past three years was as high as 98%, with postgraduate program enrollment rate being 20%. The tracking survey of the college graduates showed that their employers are of high satisfaction with them. For example, in the investigation of the quality of graduates in 2014, 31.3% of employers said they were very satisfied with the college's graduates, 68.7% of employers said that they were satisfied and there were no dissatisfaction reaction. The employers generally think that college graduates are with high quality, dedication, learning ability, practical ability and professional skills. The 2011 graduate, Zhang Junyang, majored in resources exploration, achieved percentage of positive drillhole as high as 80% in Xinjiang Ashele copper mine periphery exploration project, and won the 2014 Zijin Mining Group First Prize. 2012 graduate, Dai Shuiping, majored in mining engineering, had been promoted to department director of Wuping Zijin company within just 2 years, because of his excellent performance. He also won 2014 Zijin Mining Group third prize.

3.2 Innovations of Zijin Mode

First, Zijin Mode of deep integration of industry and education was created and operated successfully. The concept of Zijin Mode can be concluded as “the enterprises support the construction of education, the enterprises participate in the education process, and the enterprises test the effectiveness of the education”.

Secondly, the Shanghang practice teaching base is the first example for engineering universities in China as an independent, fully equipped practice teaching base invested and built by enterprise. This cast a model to prompt social, enterprise and personals to sponsor education work.

Thirdly, College of Zijin Mining created a system for the selection, appointment and management of enterprise engineering-type teachers and a management mechanism for teaching activities. This enables the enterprise engineering professionals to give full play to their advantages in the practice teaching for Mining Engineering students. As a result, the practice education level and capability of undergraduate students can be improved significantly.

Lastly, College of Zijin Mining created the management methods and operation mechanism for Shanghang National Engineering Practice Education Center, which provide a reference for mining schools and other engineering schools.

3.3 Exemplary role of Zijin Mode

After the ten years of running Zijin Mode, the college has achieved fruitful results in teaching reform. The development of Zijin Mode had benefited from Excellent Engineering Education and Training Plan launched by Education Department of China, the Pilot Project of Discipline Comprehensive Reform of China, the Pilot Project of Discipline Comprehensive Reform of Fujian Province and the Brand Discipline Construction Project for 211 High Level University sponsored by Fuzhou University. Zijin Mode had got great attention from the Education Department of China, the Education Department of Fujian Province, and the Department of land and resources of China. Zijin Mode had been presented many times in Excellent Engineer Education Seminar held by Education Department of China, seminars held by China Geological Society, Fujian province Higher Education Seminar and became a model for deep integration of industry and education.

College of Zijin Mining had been visited and consulted by the Committee of Higher Education of Shandong province, Minjiang University, Longyan University and other universities and colleges. In particular, with reference to Zijin Mode's operation and management mechanism and experience, Fuzhou University established Quangang Petrochemical College of Fuzhou University. Consequently, Fuzhou University established Jinjiang Science and education Park in cooperation with the Jinjiang City government, which had become one more highlight of the deep integrated of industry and education.

4 Conclusion

Zijin Mode of deep integration of industry and education in Mining Engineering had been created by College of Zijin Mining, Fuzhou University, and got significant achievements. Constructive reform experience had been obtained in terms of the development of National Engineering Practice Education Center and the establishment of enterprise engineering-type teachers team. Zijin Mode is highly coincided with the idea of deep integration of industry and education for present China higher education and is a meaningful investigation for the deepening education supply-side structural reform.

Acknowledgement

The design and operation of Zijin Mode is made possible through the across-the-board support from Zijin Mining Group.

References

General Office of the State Council, 2017. Accelerating the Integration of Industry and Education. China Economic Information, (**24**): 9p. (In Chinese)

Huang, P., Y. Liu and S. Wang and X. Zhong, 2010. Practice and thinking on the construction, operation and management of Shanghang teaching base under Zijin mode. Chinese Geological Education, **108**(**7**): 42 - 45. (In Chinese)

Liu, Y., P. Huang, X. Peng, S. Wang and Y. Fei, 2013. Implementation and experience of the teaching reform of “Zijin model”. Chinese Geological Education, (**2**): 27-30. (In Chinese)

Peng, X., Y. Liu and D. Li, 2014a. Resources Exploration Engineering enterprise practice and graduation design cooperation double supervisor training mode. Chinese Geological Education, (**3**): 66 - 68. (In Chinese)

Peng, X., Y. Liu, and D. Li, 2014b. Zijin Mode of Resource Exploration Engineering undergraduate enterprise cultivation program: Framework system and operational mechanism. Chinese Geological Education, (**4**): 41 - 44. (In Chinese)

Wang, S., Y. Liu, P. Huang, X. Lou and S. Liu, 2013. Relying on state-level project practice education center to construct enterprise double-type teachers team. Chinese Geological Education, (**2**): 64 - 67. (In Chinese)

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 69-73
Available at http://ojs.library.dal.ca/ijge

Camdemia Education

Using Virtual Reality to Enhance Mineral Processing Education

Seher Ata*, James Tibbett
School of Mining Engineering, UNSW Sydney, NSW, 2052, Australia

Abstract: Virtual Reality (VR) is playing an increasingly important role in education. It provides the opportunity to enhance the learning experience by representing complex systems in a 3D visualisation and freeing up cognitive capacity for learning. A 3D VR simulation of a base metal concentrator has recently been developed at the University of New South Wales (UNSW) Sydney, Australia. The module provides an interactive processing plant environment where the user can walk through and explore the entire processing flowsheet and simulations in the virtual world. This paper explores the potential benefits of VR for mineral processing teaching and learning by reporting results from a study comparing traditional and virtual reality mineral processing teaching environments. The main focus is on the understanding of the mineral processing system (equipment function, layout, flowsheet) by undergraduate and postgraduate students exposed to the two styles of education.

Keywords: virtual reality, mineral processing education, mineral processing plant

1 Introduction

Virtual Reality (VR) is the creation of an artificial environment that is experienced through sights and sounds provided by a computer (Squelch 2001). Users immersed within this environment are able to interact with 3D worlds and explore their surroundings (Bell and Fogler 1996). VR has been used across a wide range of industries and applications including manufacturing (Zimmermann 2008, Jiang 2011), military (Manojlovich et al 2003), entertainment (Hsu 2011), education (Bell and Fogler 1995, 1996, 1998, Shin 2002), process design visualisation (Schofield et al 2005, Squires et al 2015) and industrial training (Squelch 2001, Mitra and Saydam 2011).

The School of Mining Engineering at the University of New South Wales (UNSW) Sydney has a number of VR modules that offer a wide range of possibilities to present and simulate complicated mine environments including underground and surface mining to make specific subjects easier to understand (Laurence and Stothard 2010, Mitra and Saydam 2011, Saydam et al 2011). These modules are integrated into an ultra-high resolution, immersive visualisation environment, also referred to as the Advanced Visualisation and Interaction Environment (AVIE), which enhances the immersive feeling in VR-scenes. Example of VR modules include evaluating the feasibility of a mining project based on factors such as the characteristics of the mineral deposit, environmental concerns and economics; and health and safety focused modules that offer learning opportunities without exposing users to unacceptable risks.

A virtual processing plant has recently been developed at UNSW Sydney where the complex flowsheet and systems involved in the mineral processing of a copper ore were explained (Ata 2017). The virtual plant is based on the Northparkes copper concentrator, which is located in central New South Wales, Australia. The concentrator has two identical parallel modules, each consisting of grinding and conventional flotation circuits. The ore is crushed and ground in a Semi-Autogenous Grinding (SAG) mill, followed by two stages of ball milling, and a flash flotation unit where high-grade fast-floating particles are removed. The flash flotation tailings are processed in rougher, scavenger, cleaner, re-cleaner and cleaner scavenger banks to produce the final copper-gold concentrate. The ore has a grade of approximately 1.4% copper and 0.4 g/t gold. The final concentrate produced for each module assays 36% to 40% copper.

The virtual plant displays a 3D representation of the processing plant showing the interconnectivity and flow between items. Users are able to view the entire model and transition from one station to the next, as a piece of ore would. Elements within the environment are animated to showcase their function and in some cases section views are available to display the inner working of equipment to users. Panoramic photos and videos recorded in an actual plant site can also be viewed at various locations to show real-world applications of equipment in the processing plant, which helps students to identify individual unit processes forming the flowsheet and become familiar with their operation and the connection between the individual units. Relevant technical information on all the unit processes, such as dimensions, volumes and make, have also been provided along with information on the characteristics of the streams (particle size, pulp density and grade) to enhance understanding of the flowsheet's layout. Figures 1 and 2 are

* Corresponding Author: Seher Ata, Email: s.ata@unsw.edu.au, phone: +61 2 9385 7659

DOI: 10.15273/ijge.2018.03.012

screenshots of the module showing the grinding and flotation circuits, respectively.

The virtual concentrator is currently part of minerals processing courses taught at both undergraduate and postgraduate level at UNSW Sydney. Delivering mineral processing course material through a VR experience differs from the traditional approach of hand-out material on paper and a lecture presentation explaining the various elements in the processing flowsheet. In order to assess the potential of VR for minerals processing teaching and compare it to traditional teaching, we carried out a survey of both undergraduate and postgraduate students. This paper discusses the results of the survey.

Figure 1 Screenshot of the module showing grinding circuit

Figure 2 Screenshot of the module showing flotation circuit

2 Methodology

The aim of the survey was to compare two teaching delivery methods for describing a copper processing concentrator: traditional teaching and a virtual reality environment. In both modes, the students were initially provided with a basic description of a flowsheet and key information such as feed composition, particle size, reagents schemes, and flow rate of streams followed by detailed information on the individual unit processes in the flowsheet. The conventional teaching method was a lecture-based course and both delivery modes included approximately one- hour session.

Two surveys were carried out in 7 weeks apart: one with postgraduate mining engineering students and the other with first year undergraduate engineering students. The students who participated in the survey had little prior knowledge of mineral processing. In each survey, two groups of students were compared: one group was exposed to the traditional teaching method first and the other was exposed to the innovative VR experience delivery method first.

A series of questions were prepared to collect data on the effectiveness of the teaching methods. The survey had two parts. Part 1 was given to the groups of students immediately after they had been exposed to their group's initial teaching method. The groups were then swapped over to experience the other teaching method to make sure the students were educated to the same level. The students were then exposed to another survey (Part 2) to compare the two teaching methods. The questions consisted of a mix of yes/no, multiple choice, scale/rank and/or text-based responses. In Part 1 of the survey respondents were asked two multiple choice questions, three open-ended questions that allowed respondents to type their answers in their own words and five rank questions where respondents were asked to agree or disagree with a number of statements, to rate items on a scale, or to rank items in order of importance or preference. Two open-ended questions were added to Part 2 to obtain unstructured feedback. Respondents were asked the reasons for their preferred teaching method and why they found the other teaching experience less effective. The survey had Ethics approval from Human Research Ethics Committee.

3 Results and Discussion

Of the 52 students enrolled in the classes (38 UG and 14 PG) 31 students (17 UG and 14 PG) participated in the survey, giving a response rate of approximately 60%.

Students were asked which teaching method they preferred, and which one gave them more understanding of the plant operation after they exposed to both delivery methods. Table 1 shows that 12 out of 14 (86%) postgraduate and 12 out of 17 (70%) undergraduate students stated they preferred VR over the traditional teaching, while. 4 out of 17 (24%) undergraduates and 2 out of 14 (14%) postgraduates preferred in-class teaching. Interestingly, 1 out of 17 (6%) undergraduate student found the combination of both teaching modes is more effective than the in-class or VR delivery mode alone. It is also clear from the table that undergraduate students prefer the traditional lecture more than postgraduate students. The undergraduate group had a higher proportion of overseas students who may have found in-class teaching more effective, as evident from the comments presented in Table 2.

Table 1 Percentage of respondents preferring each teaching method

	Teaching method		
	VR	Traditional	Both
Undergraduate	12/17 (70%)	4/17 (24%)	1/17 (6%)
Postgraduate	12/14 (86%)	2/14 (14%)	0

Students were asked what they liked about the two modes of teaching after they were exposed to both delivery methods. Their answers are shown in Table 2. The respondents who preferred VR mentioned "visual – easy to understand", "able to see connection between the different steps" or "motivating" method, whereas respondents who preferred in-class listed "slides are better for a later recap", "more information, text visible, easier to memorise" and "prefer learning style as information is provided in words".

When students were asked to list what they disliked about their less preferred method of teaching delivery, respondents who preferred in-class mainly mentioned that "it was less effective to memorise the name of each process", and "the traditional method can get boring" while respondents who preferred VR mentioned that "it is harder to take note" and that "it [the module] is too crowded".

Students were asked to rate the teaching process on several specific dimensions (see Table 3 for the questions and the Appendix for the rating dimensions). Students' responses using the first (i.e., "extremely boring"; "extremely difficult") or last (i.e., "extremely enjoying", extremely easy) options on the seven-response choice rating scales were scored for all question items. Scores ranged from 1 to 7 for each task type where higher scores reflect a greater tendency to have a positive attitude toward the teaching methods. The results indicate that the postgraduate students were more satisfied in both VR and the traditional teaching methods than the undergraduate students. However, overall both the undergraduate and postgraduate respondents who preferred VR found the content more engaging and interesting. Both undergraduate and postgraduate students found that the material used to explain the copper processing plant was easier to understand in the VR mode than the traditional delivery method.

Table 2 Reasons given for preferring VR and traditional delivery mode

Student responses
Reasons for preferring VR
(a) It was very engaging and seeing it visually make it easier to understand. Absolutely love it.
(b) To grasp the entire process on site.
(c) VR was more interesting and motivating.
(d) Able to see the way it flows. Able to look at the different steps and how it works.
(e) Visual learner, easier to understand.
(f) Difficult to visualise without VR.
(g) Some of the equipment and stages are unknown but in VR I can identify what they are.
Reasons for preferring Traditional
(a) It is in writing form, easy for me to understand.
(b) Different slides for the specific apparatus. Slides are better for a later recap.
(c) The traditional method was more in depth and had more detail about the individual components of the plant.
(d) More information, text visible, easier to write and memorise information.
(e) Prefer learning style as information is provided in words.

Table 3 Survey results from both undergraduate and postgraduate students using a 7-point rating scale (Rating dimension for each question is given in the Appendix)

Questions	**Undergraduate**			**Postgraduate**			**Combined**		
	Ave. score		**Diff.**	**Ave. score**		**Diff.**	**Ave. score**		**Diff.**
	VR	**T**		**VR**	**T**		**VR**	**T**	
(a) How engaging was the content delivery method?	4.8	3.4	1.4	6.9	5.7	1.2	5.9	4.5	1.4
(b) How well do you think the copper processing flowsheet was explained to you?	4.4	3.5	0.9	6.3	5.0	1.3	5.4	4.3	1.1
(c) How enjoyable did you find the experience of learning about the copper processing flowsheet?	4.9	3.9	1.0	6.7	5.1	1.6	5.8	4.5	1.3
(d) How interested are you in learning about more processing flowsheets?	5.6	3.5	2.1	6.7	5.6	1.1	6.2	4.6	1.6
(e) How easy did you find it to understand the material used to explain the copper processing flowsheet?	5.0	3.3	1.7	5.7	4.0	1.7	5.4	3.7	1.7

Students were asked five open-ended questions where they were required to explain the operation of a particular equipment or understanding of a concept. A zero-to-one point rubric was created to score responses consistently. In scoring, the use of appropriately labelled diagrams and drawings that were part of the correct answer were accepted even when the question did not specifically request their use. One point was given when the student response was reasonably correct, and satisfactory, 0.5 point was given when the student response had minor omissions and/or some incorrect or irrelevant information, and 0 point was given when the student attempted the task, but the response was incorrect or inappropriate. The questions and the survey results are given in Table 4. Overall, the undergraduate students who took the VR delivery mode performed better than those taking the traditional or in-class teaching mode in answering the knowledge questions correctly. In all five questions asked, the undergraduate VR respondents gave better responses than the in-class respondents while the postgraduate VR respondents gave better responses to three of the five knowledge questions.

Table 4 Results of post-test knowledge of open-ended questions from both surveys study groups

Statement	Undergraduate % VR	Undergraduate % T	Undergraduate Diff.	Postgraduate % VR	Postgraduate % T	Postgraduate Diff.
(a) The grinding circuit consists of….	66.7	37.5	29.2	57.1	28.6	28.5
(b) Explain the role of the cone crusher in the grinding circuit.	38.9	6.3	32.6	21.4	35.6	-14.2
(c) Name each stage in the flotation circuit.	38.9	31.3	7.6	100	85.7	14.3
(d) Explain why flotation takes place in multiple stages.	72.2	50	22.2	71.4	64.3	7.1
(e) Which of the following statements are correct?	38.9	37.5	1.4	57.1	64.3	-7.2

4 Conclusion

An interactive base metal concentrator module has recently been developed at UNSW Sydney to bring a virtual mineral processing plant to the university environment, where students can experience a real plant and visualise unit operations in 3D. The virtual reality module has actively been integrated into teaching to enhance student engagement and learning. A survey was conducted to compare two different teaching delivery modes and assess their impact on students' learning outcomes.

The survey results showed that the majority of students preferred VR over the traditional method, with a higher proportion of postgraduate students preferring the VR delivery mode than undergraduate students. Comments from the students indicated that the VR mode provided a simulated and engaging environment due to its interactive nature. While VR was the preferred method by both groups of students, some students preferred the traditional, in-class teaching. This suggests that the VR mode should not replace face-to-face teaching completely but instead it can provide students with a valuable alternative educational media to convey engineering knowledge on processing plant operation.

Face-to-face courses are increasingly incorporating some alternative teaching strategies such as online components, and blended learning where traditional in-class activities are supplemented to improve student engagement and learning outcomes. The survey results suggest that the use of VR technology may be another option for complementing and supporting traditional teaching.

References

Ata, S., 2017. Interactive visualization of a base-metal concentrator. CIM Journal, **8**(**3**).

Bell, J.T. and H.S. Fogler, 1995. The investigation and application of virtual reality as an educational tool. Proceedings of the American Society for Engineering Education 1995 Annual Conference (ASEE), June, Anaheim, CA, **2**: 1718 - 1728.

Bell, J.T. and H.S. Fogler, 1996. Recent developments in virtual reality based education. Proceedings of the American Society for Engineering Education Annual Conference, June 23 - 26, Washington, DC, pp2669 - 2674

Bell, J.T. and H.S. Fogler, 1998. Virtual reality in chemical engineering education. Proceedings of the 1998 American Society for Engineering Education ASEE North Central Section Meeting, April 3 - 4, Detroit, MI.

Hsu, K.S., 2011. Application of a virtual reality entertainment system with human-machine sensor device. Journal of Applied Sciences, **11**(**12**): 2145 - 2153.

Jiang, M., 2011. Virtual reality boosting automotive development. In D. Ma, X. Fan, J. Gausemeier and M. Grafe (Eds.), Virtual reality & augmented reality in industry. Berlin, Heidelberg: Springer, pp171 - 180.

Laurence, D. and P. Stothard, 2010. Applications of simulation methodologies for a sustainable mining industry. Proceedings of Advanced Mining for Sustainable Development, Ha Long Bay, Vietnam, pp50 - 59.

Manojlovich, J., P. Prasithsangaree, S. Hughes, J. Chen and M. Lewis, 2003. UTSAF: A multi-agent-based framework for supporting military-based distributed interactive simulations in 3-D virtual environments. Proceedings of the Winter Simulation Conference, New Orleans, LA, USA, **1:** 960 - 968.

Mitra, R. and S. Saydam, 2011. Using virtual reality for improving health and safety of mine workers and improving mining engineering education in Australia. Proceedings of the 34th International Conference of Safety in Mines, New Delhi, India, pp625 - 636.

Saydam, S., R. Mitra and C. Russell, 2011. A four dimensional interactive learning system approach to mining engineering education. Proceedings of the Second International Future Mining Conference. In S. Saydam (Ed.), Proceedings of the Second International Future Mining Conference, Sydney, Australia, NSW, pp279 - 286.

Schofield, D., E. Lester and J.A. Wilson, 2005. Virtual reality based, interactive e-learning for chemical engineers. Proceedings of the Seventh World Congress of Chemical Engineering, Rugby, UK, Institution of Chemical Engineers.

Shin, Y.S., 2002. Virtual reality simulations in web-based science education. Computer Applications in Engineering Education, **10**(**1**): 18 - 25.

Squelch, A.P., 2001. Virtual reality for mine safety training in South Africa. The Journal of The South African Institute of Mining and Metallurgy, **101**(**4**): 209 - 216.

Squires, R.G., P.K. Andersen, G.V. Reklaitis, S. Jayakumar and D.S. Carmichael, 2015. Multimedia-based educational applications of computer simulations of chemical engineering processes. Computer Applications in Engineering Education, **1**(**1**): 25 - 32.

Zimmermann, P., 2008. Virtual reality aided design. A survey of the use of VR in automotive industry. In D. Talaba and A. Amditis (Eds.), Product engineering, Springer, Netherlands, pp277 - 296

.

Appendix – The five close-ended questions

(a) How engaging was the content delivery method?						
Extremely boring	Very boring	Slightly boring	Engaging	Moderately engaging	Highly engaging	Extremely engaging

(b) How well do you think the copper processing flowsheet was explained to you?						
Extremely poorly	Really poorly	Pretty poorly	Okay	Pretty well	Really well	Extremely well

(c) How enjoyable did you find the experience of learning about the copper processing flowsheet?						
Extremely boring	Very boring	Slightly boring	Okay	Moderately enjoyable	Highly enjoyable	Extremely enjoyable

(d) How interested are you in learning more about processing flowsheets?						
Extremely little	Very little	Not really	Indifferent	Pretty interested	Really interested	Extremely interested

(e) How easy did you find it to understand the material used to explain the copper processing flowsheet?						
Extremely difficult	Very difficult	Slightly difficult	Okay	Pretty easy	Very easy	Extremely easy

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 74-77

Available at http://ojs.library.dal.ca/ijge

Camdemia

Education

People Skills for Mining Engineers, an Important Addition to the Curriculum

Amy J. Richins*, Michael G. Nelson
Department of Mining Engineering, University of Utah, Salt Lake City, Utah, U.S.A.

Abstract: Engineering education is very effective at training students in critical thinking and analytical skills however, these engineers often transition into management in their organization. These roles require an additional set of skills. Obviously an understanding of business and finance is required but even more important is the ability to work effectively with people. Based on their experience in industry and academia the authors have developed methods to introduce these skills to engineering undergraduates. The mining safety and health management course that has been offered for several years at the University of Utah has been modified to include such topics as emotional intelligence, leadership, and corporate culture development. This paper describes those changes and students' reactions to them.

Keywords: management, leadership, education, emotional intelligence

1 Identification of the Need

The Center for Mining Safety and Health Excellence at the University of Utah is conducting a four-year study to assess the implementation effectiveness of safety and health managements systems. The study is funded by the Alpha Foundation for the Improvement of Mine Safety and Health.

A safety and health management system (SHMS) implements a series of protocols and procedures which if followed are expected to reduce the risks and improve safety for employees. However, protocols and procedures alone are unlikely to make lasting improvements in safety and health, so SHMSs also include processes to change behaviors and lifestyles.

The current study will assess the effective of safety and health management in several mines, each of which is in a different stage of implementing an SHMS. This is done by making two or three visits to each mine, assessing the status of the SHMS by observation and discussions with management, and assessing the perceptions of the workforce by administering a detailed survey. The results of each visit are analyzed statistically and compared with the pertinent safety data for each mine—incidence rates, near-miss rates, and citations.

During the initial round of mine visits, it became clear to the authors that, for improving and maintaining excellent safety performance, an SHMS could be very useful, but was neither necessary nor sufficient. The most important things in good safety management were clearly the relationships among the mine's employees, and especially between management and the hourly workers.

The importance of these relationships is recognized in all SHMSs, by the inclusion of components like "culture" and "leadership," but in at least some instances, the SHMS was not successful in developing these characteristics in the organization. Thus the need for including some training in these skills in the undergraduate curriculum was evident.

2 Safety and Health Management Systems

In a cross-sectional, structural comparison of SHMSs, Seiter (2017) examined eight international and national safety and health management system models, including : (1) National Mining Association (NMA) CORESafety, (2) International Organization for Standardization (ISO) 45001–draft, (3) International Labour Organization Occupational Safety and Health (ILO-OSH) 2001, (4) Occupational Safety and Health Administration (OSHA) Voluntary Protection Program (VPP), (5) Occupational Health and Safety Management System (OHSAS) 18001, (6) American National Standards Institute (ANSI) Z-10, (7) Canadian Standards Association (CSA) Z1000, and (8) British Standards (BS) 8800-2004.

Seiter used a modification of the analysis by Dalrymple et al (1998) to identify and classify the components of a complete SHMS, in what he called the Modified Dalrymple Scheme. It begins with the key element of all SMHSs, the "Plan, do, check, and act," (PDCA) process. The scheme includes five categories of additional SHMS components: Initiation, Formulation, Implementation/Operations, Evaluation, and Improvement/Integration. Included in these five categories are 35 detailed SHMS elements. Table 1 on the next page shows the Modified Dalrymple Scheme.

Seiter conducted an industry-specific, cross-sectional study of SHMS elements, including the eight international SHMSs mentioned above and SHMSs from 10 mining companies that are implementing a mining-specific SHMS such as CORESafety.

* Corresponding Author: Amy J. Richins, Email: amyrichins@hotmail.com, phone: +1 801 557 0467

DOI: 10.15273/ijge.2018.03.013

Seiter examined each SHMS for its implementation of each of the 35 elements of the Modified Dalrymple Scheme, using rankings of Present, Partially Present, and Not Present.

Table 1 Modified Dalrymple scheme for an SHMS
Source: After Seiter (2017)

	Plan, Do, Check, Act
	INITIATION
Inputs	Scope, Purpose, Application
	Initial Review
	Management Commitment and Resources
	Regulatory Compliance and HSMS Conformance
	Accountability, Responsibility, and Authority
	FORMULATION
Process	Occupational Health and Safety Policy
	Goals and Objectives
	Performance Measures
	System Planning and Development/Implementation
	Baseline Evaluation and Hazard/Risk Assessment
	OHSMS Manual and Procedures
	IMPLEMENTATION/OPERATIONS
	Training System
	Technical Expertise and Personnel Qualifications
	Hazard Control System
	Process Design/Management of Change
	Emergency Response
	Hazardous Agent Management
	Preventive and Corrective Actions
	Procurement and Contractor Selection
	EVALUATION
Feedback	Communication System
	Document and Record Management System
	Evaluation System
	Audit and Self-Inspection
	Incident Investigation and Root Cause Analysis
	Medical Program and Surveillance
	IMPROVEMENT/INTEGRATION
Open System Elements	Continual Improvement
	Integration
	Management Review
	Supplementary Information
	Success Factors
	Culture Enhancement
	Reinforcement and Recognition
	Behavior Optimization

Table 2 summarizes Seiter's results numerically, thus: Present = 2, Partially Present = 1, and Not Present = 0. The value shown as "Average Presence" for each category is the average for all of the elements in each category for each SHMS evaluated.

Table 2 Presence of components in 18 safety and health management systems

SHMS Category	Average Presence
Plan, Do, Check, Act	1.94
Initiation	1.83
Formulation	1.85
Implementation/Operations	1.81
Evaluation	1.87
Improvement/Integration	1.22

It is important to note that all of the systems reviewed by Seiter had near-complete inclusion of the components in the first five categories, while the inclusion of the components in the last category is much lower. The components in the first five categories are primarily procedural and routine when implemented correctly. The components in the last category also require carefully designed procedures, but their implementation requires skills in working with people.

3 Two Telling Examples

The effects of the discrepancy just noted were observed in several mine-site visits made by the authors. The two most prominent examples will be referred to as Mine #1 and Mine #2. Both sites are coal mines; Mine #1 has approximately 250 employees and Mine #2 has approximately 185. Mine #1 has implemented CORESafety from its beginning and has received many safety awards, while Mine #2, when asked if they had an SHMS, replied that they did not.

When visiting Mine #1, the authors had the opportunity to observe a semi-annual SHMS audit. We accompanied several auditors around the site, with clip-boards in hand, asking all of the questions required. This was done very systematically, one question at a time, with each requiring a yes or no answer. Based on these observations, we would have given the mine and its SHMS a positive review. However, as we shadowed the auditors, some of our team members would linger and talk with the employees. From this, we found that things weren't what they seemed at this mine. Several employees commented on how bad the safety culture was, noting that many incidents were unreported because employees feared that they would lose their jobs if the reported incidents. One employee in particular cut off his finger while on shift, and instead of following the proper procedures of reporting, wrapped it up and finished his shift then went to the hospital on his own, to take care of it later.

At Mine #2 we had a completely different experience. The management stated at the beginning of our visit that they had no formal SHMS. As we surveyed the hourly employees, we also asked them for their opinions on the safety culture at the mine. Several workers stated that they felt like they were all a large family, and noted how well the company took care of them. The mine manager told us that he makes time for a one-on-one meeting with *every* employee on site, at least once per year. He noted that, during these meetings, he gets a lot of feedback and uses that information to plan projects and activities to use in continue building the feeling of family and mutual support among employees.

Analysis of the data from the first visits to these mines indicates that the respective employees had vastly different perceptions of the Leadership, Culture, and Risk Management practices and execution at their workplaces, and that Mine #1's safety performance was not as good. Why is this the case? What is the missing piece?

4 A Clear and Present Need

When managing a mine, and also managing people, emotional intelligence is key. Emotional intelligence is the capacity to be aware of, control, and express one's emotions, and to handle interpersonal relationships judiciously and empathetically (Goleman 1998).

As technology continues to change how people live, our communication and people skills are often not as well developed. We have seen evidence of this at every mine site and in every classroom—it is a common problem that all industries are encountering. Employees who are intelligent and well-educated often don't know how to use their strengths or improve on their weaknesses, and most importantly, they don't know how to communicate with others.

As mentioned above, our research indicates that a rigorous, well-implemented SHMS almost always helps, but by itself it won't make a difference. Why is that? Because systems are run by people, and a system is only as good as the people using it. This means that the implementation, communication, and leadership components of any system are critical to its success.

5 Teaching Human Skills to Engineers

Teaching these skills to future engineers is of utmost importance, and will greatly improve their professional and personal lives. Based on the above observations, we restructured our safety and health management course to be more hands-on and discussion-based, moving away from the typical PowerPoint lecture approach.

Every week the students are given several articles to read and are required give a written critical response to those articles. Then in class there is a semi-structured discussion about the articles, where assigned student discussion leaders guide the class through main points and many side topics. During the next class period the students participate in a hands-on activity where they learn how to approach and deal with common problems on the subject. These activities not only help them learn about the subject at hand but they are also learning very important communication, leadership, emotional intelligence, and people skills.

6 A Sample Syllabus and Some Preliminary Results

A sample syllabus of the restructured safety and health management course is in Table 3.

Table 3 Syllabus for safety and health management

Week	Class	Planned Topic
1	1	Introduction and Concepts
	2	Organizations and Management
2	1	Martin Luther King Jr. Holiday
	2	Wellness and Mindfulness
3	1	Personal Safety
	2	Personal Safety
4	1	Safety in Mining--Historical
	2	Safety in Mining--Present
5	1	Occupational Health and Hygiene
	2	Hazard and Risk
6	1	Mining Hazards
	2	Risk Management
7	1	Presidents' Day Holiday
	2	Midterm Exam
8	1	SME—no class
	2	SME—no class
9	1	Risk Management Systems
	2	Incident Investigation
10	1	Review and discussion
	2	Midterm Exam
11	1	Spring Break—no class
	2	Spring Break—no class
12	1	Five Whys
	2	Root Cause Analysis
13	1	Ethics Discussion
	2	Ethics Exercise
14	1	Culture Discussion
	2	Culture Exercise
15	1	Leadership Discussion
	2	Leadership Exercise/Final Project
16	1	Final Project
	2	Reading Day- no class
17	–	Final Exam

The course was taught with the new approach in Spring Semester 2018, to a group of 14 students. After the first two weeks, it was clear that the more articulate and communicative students in the group were enjoying the course, participating actively in discussions and bringing in additional material for considerations. The more reserved students took some time to adapt to the new structure, but by the end of the semester, all 14 students were thoroughly engaged in the process.

It is also interesting that some students at first skeptical that this approach and these subjects were appropriate for, or even needed in an engineering curriculum, but by the end of the semester, those students were participating as actively and enthusiastically as the others.

In an informal evaluation in near the end of the semester, the students unanimously expressed their satisfaction with the course and the manner in which it was conducted. As instructors, we were pleased with this result, but we also came away with many ideas for future improvements in the materials and the methods.

Acknowledgements

The authors gratefully acknowledge the assistance of all of the mining companies that allow us to conduct and participate in our research.

References

Dalrymple, H., C. Redinger, D. Dyjack, S. Levine, and Z. Mansdorf, 1998. Occupational health and safety management systems: review and analysis of international, national, and regional systems; and proposal for a new international document. Geneva: International Labour Office.

Goleman, D., 1998. Working with emotional intelligence, New York: Bantam Dell. ISBN-13: 9780553378580.

Seiter, J.C., 2017. Safety and health management systems: A comparison of structural elements. M. E. report, University of Utah, Salt Lake City.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 78-85
Available at http://ojs.library.dal.ca/ijge

Camdemia
Education

A Framework of Safety Training Based on Augmented Reality and Cloud Computing Platform in Mines

Feifei Wang[1, 2], Enji Sun[1*], Haoyu Wang[1, 2], Shuangyue Liu[2]
[1] China Academy of Safety Science and Technology, Beijing, China, 100012
[2] University of Science and Technology Beijing, Beijing, China, 100083

Abstract: As the harsh environment of mines and complicated production processes may easily cause safety production accidents, safety training becomes one of the important ways to reduce personal injuries and property damages. Safety training and education have formed a set of standardized system in the mining enterprises, however, there are still many problems in the operation process of safety training. In order to solve these issues, Augmented Reality (AR) could be used in the traditional safety training based on the comparative analysis of the differences between traditional training and augmented reality-based training. A novel safety training framework is proposed based on AR and Cloud Computing (CC) platform. This framework chooses marker-based AR technology as the research method combined with CC platform for its multiple functions, large-scale and high reliability. Several modules are designed in this framework, which includes mine basic knowledge, equipment cognitive module, intelligent maintenance module, standardized operation module, remote help module, collaborative work module, capability assessment module as well as other functional modules. This framework also achieves the functions such as user registration and login, role management, safety knowledge production training, practical training and periodic assessment functions based on augmented reality. The basic knowledge of mines module is a comprehensive class which contains all the training classes and the regulations to enhance knowledge standard of workers. The equipment cognitive module aims to enhance the employee's mastery of the device. The standardized operation module and intelligent maintenance module utilizes the marker-based AR to improve the technical proficiency of actual practices and skills. The ability assessment module can judge the worker's quality of his work in mines. The background management module is designed for the system administrators to maintain the system and data on cloud platform. In this safety training system, the equipment profile, operating procedures and other training knowledge can be displayed in a more intuitive form. And the abstract training concepts are visualized and interactive. This safety training system can merge the training with the actual operation to improving training efficiency. In this way, it can break through the limitation of safety training methods, time, location, etc. in the traditional safety training. Moreover, it can increase employees understanding of theoretical knowledge and proficiency in operational skills. The AR and CC based training system can not only be used in mines, but also can be designed according to different needs of the corresponding system. It would have significant influence of practice and application to the universities, enterprises, government departments and other fields.

Keywords: augmented reality technology, cloud computing platform, mine safety, interactive system, safety training

1 Introduction

The production processes of mines is complex, involving exploration, ventilation, transportation, blasting, excavation and other issues (Liu et al 2007). In these issues, the harsh environment and multitudinous large equipment can easily lead to production safety accidents. Except for production factors, up to 50%-80% of industrial accidents are caused by human unsafe behaviors (Xu 2017). Training employees is one of the most important ways to reduce personal injuries as well as property damages. It can standardize their work processes, improve employees' safety awareness and the capacity of handling accident. Safety training in mining enterprises has formed a set of standardized system (Gao and Wang 2016). However there are still many problems due to the restrictions of places, dangers, economic benefits and other factors. The existing training method mainly includes the traditional teaching method, practical method, seminar method, the newly introduced virtual reality training and augmented reality training (Liu et al 2016).

Teaching method and seminar method are all centralized theoretical teaching. Although the operating points of mine work can be passed to employees in these two training methods, a great deal of practice is still necessary to operate flexibly. Practical method means that the experienced employees convey experience to new employees in combination with specific operations. It is limited by the habits or experience of the employees. Virtual reality training is that virtual environment is generated

* Corresponding Author: Enji Sun, Email: enjisun@gmail.com, phone: +86 10 8491 6155

DOI: 10.15273/ijge.2018.03.014

through virtual reality technology to enable trainees' immersion. Many scholars studied the use of VR in the mining industry, including risk pre-control, accident scene reappearance, self-rescue, emergency rescue, simulation training and employees training (Liu et al 2015 and Hong 2013). To some extent, virtual reality could make up for the lack of the combination of theory and practice in traditional training. However, employees are only immersed in the virtual environment, they are lack of interaction with the real scene. Augmented reality training uses augmented reality technology to combine realistic devices with virtual information based on real-world scenarios. Augmented reality technology has found preliminary applications in many fields including auxiliary maintenance, automobile manufacturing, machinery and tool manufacturing, industrial equipment and power grids. For instance, the German BMW laboratory is conducting research on the mechanical maintenance of car, where AR was used as an auxiliary means (Guo 2017). The employees of European Aeronautic Defense and Space Company completed high-density cabling on board with the help of augmented reality technology. Augmented reality technology takes into account both the real scenarios and the virtual scenarios, which have great assistance in improving the efficiency of employees training.

After analyzing the traditional training, a novel safety training framework is proposed based on augmented reality (AR) and cloud computing (CC) platform. This paper chooses Marker-based augmented reality (AR) technology as research method of the safety training framework. Several functional modules was designed such as mine basic knowledge, equipment cognitive module, intelligent maintenance module, standardized operation module, remote help module, collaborative work and capability assessment module. These modules achieve learning, maintenance, experts answer, evaluation and other functions. This framework helps employees to conduct efficient and interactive training on the operation site. It not only enhances the employees' theoretical knowledge but also increases their operating experience. The safety training system can be designed to the corresponding system according to different needs. It not only could be used in mines, but also has important practical significance and application value to the work of universities, enterprises, government departments and other fields.

2 Augmented Reality Technology

Augmented reality technology is developed on the basis of virtual reality technology. It superposes the virtual information generated by computer technology on the devices in the real environment (Cheng 2012). It can enhance the user's perception of the physical environment and reduce the cost of the real model (Liu et al 2014). Compared to virtual reality technology, it does not need to render all the real environment, which reduces the workload and ensures that the interaction between the employees and the real device. The augmented reality technology has great potential in many fields.

Augmented reality technology includes vision-based augmented reality, geo-location based augmented reality, projector-based augmented reality, and augmented reality based on real-time positioning and map construction technologies. Vision-based augmented reality uses computer vision to obtain real scene information and uses image processing to identify and track the real scene. It is divided into marker-based augmented reality and augmented reality based on natural features. Marker-based augmented reality has the characteristics of simple algorithm, high speed, low requirements for environmental conditions and hardware conditions, and strong scalability. The markers is set on the device in advance to assist in determining the spatial position of the camera and the target. Taking into account the system's requirements for real-time and accuracy, marker-based augmented reality was took as the research method.

Display technology, tracking registration technology, interactive technology are the key technology to support the operation of the augmented reality system. The basic process of augmented reality system is shown in Figure 1.

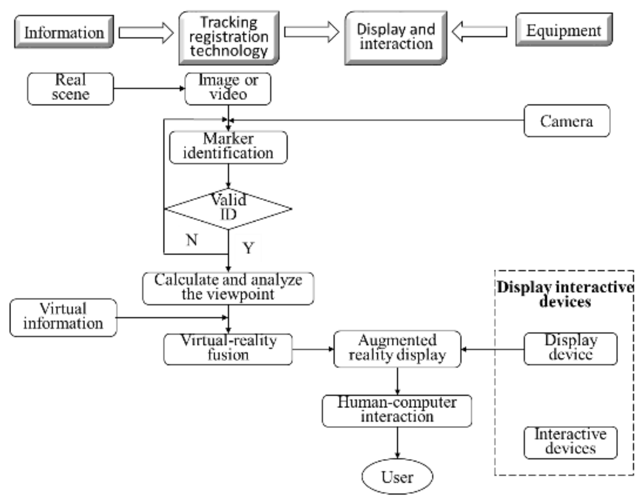


Figure 1 The basic process of augmented reality system

The implementation effects of marker-based augmented reality system is achieved through marker identification, viewpoint calculation, virtual information construction and virtual -reality fusion (Ni et al 2009). Mine employees wear augmented reality device to obtain real scene video by using acquisition equipment. The video is checked to detect the markers in the real scene. If the makers are successfully detected, the related information will be passed to the tracking registration module. This module performs a series of calculations to obtain the spatial location relationship between the users and the devices. Even if the location of the user changes, its spatial relationship with the device can be monitored in real time. According to the detected markers, the virtual information generating module calls the corresponding information to establish the virtual object. The virtual-reality fusion module adds the generated virtual object to the real scene closely on the basis of virtual object and the spatial location relationship. The virtual-reality fusion effect is output through the display device.

2.1 Display technology

The display technology is the key step to display fusion effects in augmented reality system. The fusion effects of the overlay scenes received by the users is determined by this technology. This technology makes the real scene information and the virtual scene information exist within the uses' visual range simultaneously through the display device and the display algorithm. The display devices include a helmet-mounted display device and a non-helmet-mounted display device. The helmet-mounted display device is divided into video see-through display device and optical see-through display device. The former combines the real scene information collected by a helmet-mounted camera and the calculated spatial location of the virtual information to get the virtual-reality fusion scene employees. The latter see the real world and virtual information meanwhile through the optical fusion device, which creates a feeling of combination between them.

The helmet-mounted display device presents a fusion effect between the equipment and auxiliary information needed for normal work. It enables employees to operate flexibly without spending too much energy on the auxiliary information. It liberates employees' hands and greatly facilitates employees training and daily work. The main principle is depicted in the Figure 2.

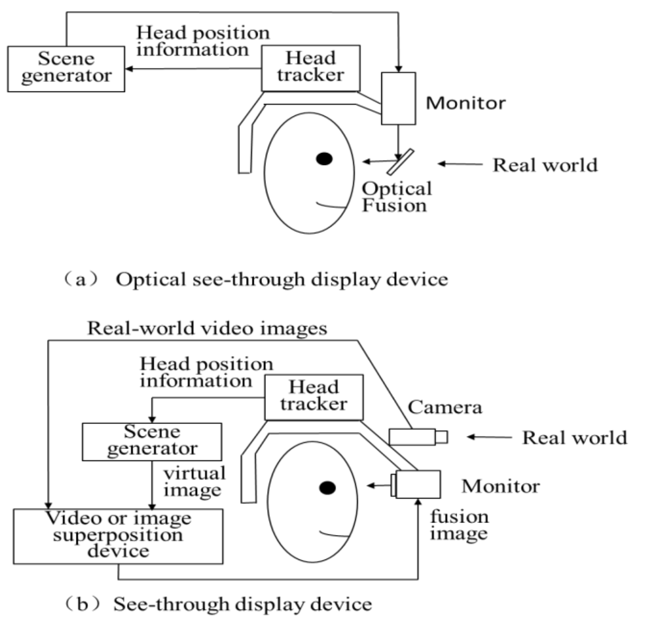


Figure 2 The helmet-mounted display device

2.2 Tracking registration technology

Tracking registration technology is one of the core technologies of augmented reality system. It greatly affects the development of augmented reality system. Superimposing the virtual scene information onto the real scene accurately is the main aim of this technology. Even in the case of moving, the seamless connection between the real scene information and the virtual information must be ensured. To achieve this goal, it is necessary to clarify the spatial location of the virtual information in the real environment. This process is registration. However, the spatial location of virtual information is not static. It changes with the user's spatial location or movement status. Tracking mainly focuses on the problem. The spatial location of the virtual information makes corresponding changes with viewpoint. If the tracking system cannot accurately track the user's viewpoint in real time, great errors will be caused by the augmented reality system when the actual situation and virtual information is merged.

The implementation effects are achieved through the conversion among different coordinate systems such as real scene coordinate system, camera coordinate system and the actual image (virtual information) coordinate system in marker-based tracking registration. The relationship among the three coordinate systems as shown in Figure 3.

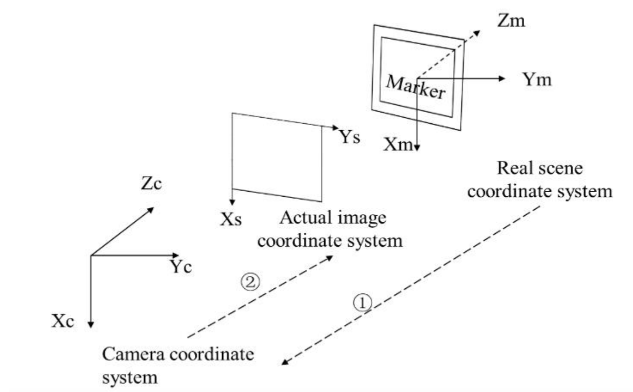


Figure 3 The conversion of tracking registered coordinate system

In order to obtain the accurate spatial location of virtual information, it mainly passes through the three stages of real scene-camera-virtual information. Augmented reality system transforms the real scene coordinate system into the camera coordinate system to get the user's viewpoint information. This process defines the relative position and direction between the real scene coordinate system and the camera. In the next place, the AR system will calculate the conversion relationship between the camera coordinate system and the actual image coordinate system. For the same point N, its coordinates in the real scene coordinate system, camera coordinate system and the actual image coordinate system is (X_m, Y_m, Z_m) , (X_c, Y_c, Z_c) and (X_s, Y_s). The relationship among the three coordinate systems can be established as the following formulas.

(1) The conversion relation between the real scene coordinate system and the camera coordinate system can be described by equation (1):

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = [R \quad T] \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} = \begin{bmatrix} r_1 & r_2 & r_3 & t_1 \\ r_4 & r_5 & r_6 & t_2 \\ r_7 & r_8 & r_9 & t_3 \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} = W \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} \qquad (1)$$

where, R is the rotation matrix, r_i is the rotation parameter, T is the translation matrix, t_j is the translation parameters, W is the total transformation matrix, X_c, Y_c, Z_c are the points in the camera coordinate system, X_m,Y_m,Z_m are the points in the real scene coordinate system

(2) The conversion relation between the camera coordinate system and the actual image coordinate system can be expressed as equation (2):

$$h\begin{bmatrix}X_s\\Y_s\\1\end{bmatrix}=\begin{bmatrix}S_xf & k & x_0\\0 & S_yf & y_0\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}X_c\\Y_c\\Z_c\end{bmatrix}=P\begin{bmatrix}X_c\\Y_c\\Z_c\end{bmatrix} \qquad (2)$$

where, h is the scale factor, f is the camera focal length, in millimeters, x_0 and y_0 are the camera center coordinates in pixels, S_x and S_y are the X-axis, Y-axis focal length scaling factor (pixel/mm), k is the distortion parameter, on behalf of the camera center offset, P is the camera internal parameter matrix. X_c, Y_c, Z_c are the points in the camera coordinate system, X_s and Y_s are the points in the actual image coordinate system.

(3) Combined equations (1) and (2), the conversion relation between the real scene coordinate system and the actual image coordinate system can be expressed as equation (3):

$$h\begin{bmatrix}X_s\\Y_s\\1\end{bmatrix}=P\begin{bmatrix}X_c\\Y_c\\Z_c\end{bmatrix}=PW\begin{bmatrix}X_m\\Y_m\\Z_m\end{bmatrix} \qquad (3)$$

2.3 Interactive technology

Improving the efficiency of work is the main purpose of interactive technology. This technology is an indispensable part of augmented reality system. The users issued commands. The interaction system obtains the instructions issued by the users and gives corresponding feedback after analysis and calculation based on related commands registered in advance (). In general, the choice of interaction mode depends on the nature of the works and the needs of the employees. Because of the complex production environment and large-scale equipment such as scraper, tunneling trolley and more in mining enterprises. The maneuvers are more agility and comfortable by operating with both hands. Interaction mode should not take up too much energy of employees in the process of the equipment operation. In view of this situation, voice interaction only requires employees to use the designated voice to interact with the system naturally. It is a great liberation of employees hands and more suitable for mine employees. The process of voice interaction system is shown in Figure 4.

From the time that the mine employees issue a command to the time the execution of the order, identifying the commands spoken by the employees is a crucial aspect of the voice interaction. Audio from the employees is converted into electrical signals. The electrical signals are sent to the recognition system. The pre-processing (such as noise reduction) is performed firstly to reduce the interference to subsequent steps. The processed electrical signal is framed by moving the window function and the audio features. The audio features are searched and matched with pre-stored acoustic models and language models to find the best match. Then, the commands get triggered to achieve the interaction.

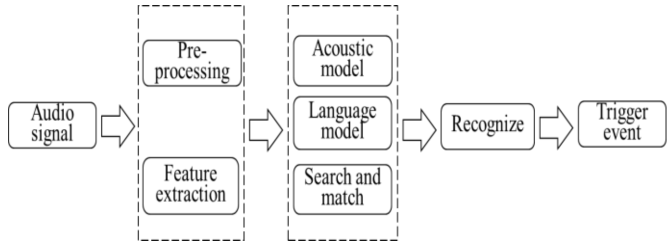


Figure 4 Voice interaction process

3 Cloud Platform

The resources required for mine employees training depend on the work area and types of employees. The management of resources is onerous as the complexity of mine production, especially the resources required for employees training are numerous. In order to solve this problem, the cloud platform was used in mine employees training (Sun et al 2012). Cloud platform is a form of cloud computing. Cloud computing is a super-computing model. It can integrate large-scale and scalable computing, storage, data, applications and other distributed computing resources to enable them to work together. The deployment of these server resources is carried out through the cloud platform (Li et al 2014). The advantages of introducing a cloud platform in mine training are as following.

(1) Massive scale

Mine enterprises have a large number of employees. Training multiple people simultaneously has high requirements on resources and system. The cloud platform could set up matching servers according to the scale of the mining enterprises. Through the management server, the massive data required for employee training can be processed and stored. Employees can train in system at the same time.

(2) High availability

Cloud platform has a wide range of applications. It supports the use of different enterprises and meets the diverse needs of users at the same time. The cloud platform can store training resources such as relevant laws, regulations, standardization tutorials, employee types, regionalization and characteristics of mines, etc. in multiple storage servers through distributed storage technologies. The application of cloud platform in mining enterprises helps to reduce the economic cost as well as improve resource utilization and system reliability.

(3) Stability

The safety training system of mining enterprises involves huge employees training data and the processing and analysis of these data. Data is of great importance to both companies and individuals. If the system goes wrong, it will cause serious consequences in the progress of training or some other areas. For example, system errors may result in the loss of data when employees are training basic knowledge of mines. During the actual operation training, the system is in error, the employees in training may get personal injury or meet death accident if he is unskilled or even does not know the next operation step. In view of this situation, the cloud platform adopts the multi-copy fault tolerance technology, which is greatly helpful for fault tolerance and recovery of data. The cloud platform has dedicated personnel to ensure data security and be not vulnerable to hacking and improve training safety.

(4) Elasticity

The resources of mining enterprises are dynamic process. The resources, such as regulations and equipment conditions of mine enterprises, will change to some extent when the equipment, employees' numbers and job information of mining enterprises change. For example, the system will add the relevant training materials, equipment profiles when new mine equipment was introduced. It can be seen that the system must be flexible to meet the dynamic needs of enterprises.

4 System Framework Design

4.1 Overall framework

In order to improve the efficiency of employees training in mining enterprises and reduce the risk of production, a novel cloud computing framework is proposed based on augmented reality. It includes user layer, data layer and application layer. The data layer is the foundation of application layer, and they work together to provide users with service. The relationship among these three parts is shown in Figure 5.

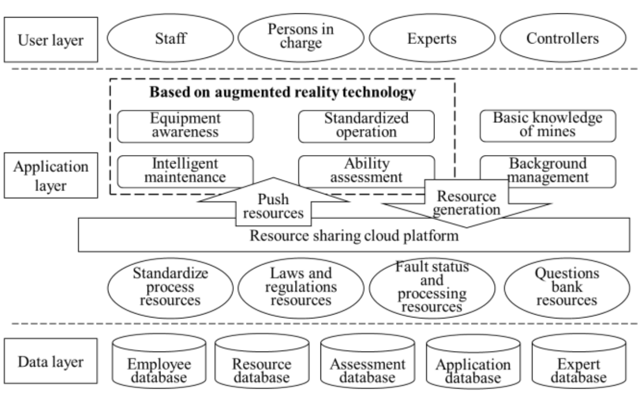


Figure 5 The framework of training in mine

Data layer includes employee database, resource database, assessment database, application database and expert database. The employee database mainly includes the information of mining employees, such as mine general employees, special operators, team leaders, safety managers, system administrators and mine managers. In particular, the certificate information of special operators must be recorded in system. The expert database involves the information of various experts and classifies these experts according to the field that they are good at. Resource database is a core part of the safety training system. It involves a variety of information required for employees training, such as laws, regulations, the structure and principles of equipment. The assessment database includes the information required for assessment of the mine employees' ability, such as the exam bank and the evaluation criteria. The application database is mainly applied to record employee's work and the information needed for actual work. These data stored in the data layer are the basis of the various modules to presentation in the application layer. The application layer sets up training modules such as mine basic knowledge, equipment cognition, intelligent maintenance and standardized operation to improve the ability of mine workers in tunneling, blasting, transportation and overhaul etc. Also it sets up a special ability assessment module to conduct performance assessment. The system is mainly provided to users including employees, experts, persons in charge, controllers and so on. Users call the resources needed to conduct different project training through the cloud platform, especially these four modules based on augmented reality have great help in improving the work ability of the employees. Meanwhile, the resulting resources are saved to the database in the opposite path.

4.2 Function module

4.2.1 The training models based on theory

The basic knowledge of mines module pre-stores the theoretical knowledge required by employees for daily work in the database, including the mine's production environment, regional division, the role of each region, equipment in different regions, different work types of mine, standardized processes of production operation, safety regulations need to be comply with by miners and other aspects of the theoretical knowledge in mine. In the database, users call or download these resources through the cloud platform for training and learning. The module helps employees grasp the theoretical knowledge, which lays a solid foundation for employees to work in mines.

4.2.2 The training models based on site

Equipment awareness, intelligent maintenance, standardized operation combineS theoretical knowledge with equipment at the production site through augmented reality technology. And they use cloud platform as a training tool to present the effect of augmented reality, which have improved the form of purely theoretical teaching in traditional training. Instead. The specific process is shown in Figure 6.

According to the training modules and equipment selected by the employees, the system searches relevant data from the database and performs certain processing to form the auxiliary information needed for the training of employees. These information are formed into a virtual list in the physical operation process or pushed to users in various forms, such as video, audio, images, text and other forms, to prompt the user how to conduct the next operation. Augmented reality training provides employees with the training environment in which virtual information guidance and physical operations are synchronized. It ensures that auxiliary information changes with the position of the person in real scene, making the real scene and the virtual information within the range of sight seamlessly connect. The system gives the corresponding response according to different orders. The AR training module such as device recognition, standardized operation, and intelligent maintenance will be described in detail below.

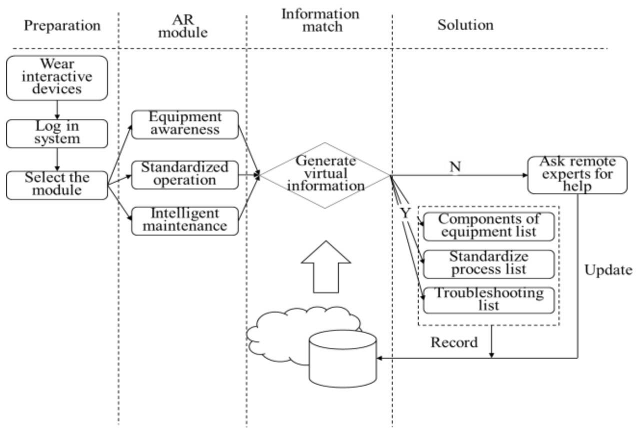


Figure 6 The training process based on field equipment

(1) Equipment cognitive module

The common preconditions for employees of different works is to understand the composition of the equipment involved in the work and the functions of each part. The production facilities in mines are numerous, the production equipment operated by different posts and the standards they need to follow are different. Therefore, it is necessary to carry out targeted training according to the actual situation of various employees. The main training process is shown in Figure 7.

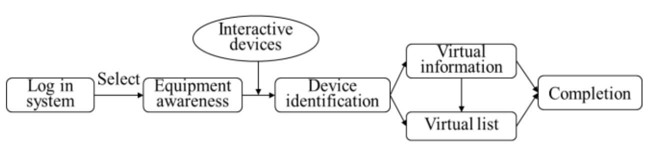


Figure 7 The process of equipment awareness training

After logging in the training safety system and choose the equipment cognitive module, the employees scan the equipment need to be recognized through the interactive equipment worn. This system identifies device, calls the corresponding virtual information and superimposes the virtual information on the equipment through the tracking registration technology. Meanwhile, it generates the virtual list of all the parts of the device. Each completed item can be annotated and recorded in the list by means of voice interaction. Under the module, employees can view the three-dimensional model of devices, understand the functions of various operation buttons of the device, disassemble the device and view the internal structure by using gestures such as dragging. This module expresses the theoretical knowledge in traditional training in an easier-to-understand manner, which helps employees understand and remember theoretical knowledge. It is suitable for pre-job training for employees and lays a solid foundation for formal work.

(2) Standardized operation module

At present, the on-site employees training is mostly conducted under the leadership of experienced veteran employees, involving the field and operation internship. Subject to the experience or habits of old employees, some of teach contents are wrong, even some are contrary to the standard. All these can lead to safety accidents. In order to reduce the safety risks caused by non-standard operation, it is imperative to standardize the operation of employees. For those who are about to enter the mining enterprise, standardized training will help them to develop their safety awareness and standard behavior. For employees who have been working for several years, standardization can correct their erroneous behavior. In short, standardized training has a wide range of applications. The training of standardized operation is shown in Figure 8.

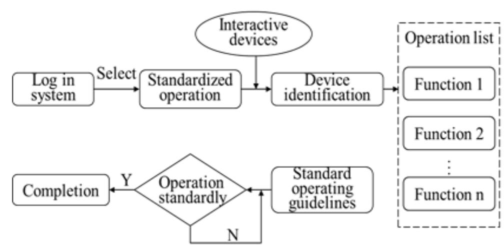


Figure 8 Standardized operation training process

When the employee enters the standardized operation module training, the system identifies device and generates a list of operational functions that the device can perform according to the equipment type. Then the employees select one project to complete by voice interaction. For example, the vehicle's reversing function, forward function during transport. The system generates standardized operation guidance steps according to the project selected by the employees, and verifies the correct operation of each step of the employees. If successful, the next step is taken. Otherwise, the error step is repeated until the operation is completed.

(3)Intelligent maintenance module

There are many reasons that lead to a fault condition. The faults that employees encounter are limited, and some faults exceed the ability of the maintenance workers. In view of this situation, a renewed safety training system with specific steps is particularly important. Maintenance module of the frame includes fault repair and periodic inspection. The training process is shown in Figure 9.

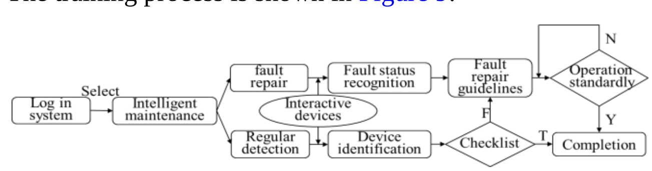


Figure 9 Intelligent maintenance training process

Periodic inspections are performed by employees to check for weak links and status parameters. Fault repair is the process that employees return the equipment to its normal operating state. According to own needs, the employees choose one from two modes which includes fault repair and periodic inspection. For the fault repair mode, the employees scans the faulted device through the worn interactive device to identify the fault status. The system generates a solution scheme about solving the fault. The employees repairs the equipment according to the fault maintenance guideline. In this process, the system checks whether each step reaches the operation standard. If the standard is reached, the next operation step is performed. If the standard is not reached, the employees repeats this step until the equipment is repaired successfully. For periodic inspection mode, this mode is mainly for the equipment that need regular inspection in mine. The system has the functions of pre-warning the overhaul workers, generating the virtual inspection list and recording the overhaul items. If the fault state is detected during the overhaul, the system will generate corresponding maintenance guidelines to instruct the employees to repair until the fault item completed and recorded.

(4) Remote help module

Equipment awareness, standardized operation, intelligent maintenance are all supported by the resources contained in the database. Due to the complexity of on-site issues, employees are most likely to encounter problems beyond the scope of the system knowledge base. The remote help module is mainly used to solve these problems that go beyond the scope of employees. Employees can ask the experts in remote areas for help through this module. After the employees passing the scenes on site to the expert through the cloud platform, the expert can guide the on-site employees in the form of voice, picture and video. At the same time, the system updates and supplements the database to avoid the same type of problem.

(5) Collaborative work module

Poor communication may lead to unpredictable consequences as the complex mining processes and multiple tasks at once. The collaborative work module is introduced in the system to avoid accidents caused by poor communication. With the development of information technology, employees' behavior can be monitored in real time (Sun et al 2010). When a worker enters a designated area, the system will remind the worker of the hazardous conditions in the area and corresponding precautions. For example, when the blasting work in mines is carried out, the system reminds employees who are going to enter the blasting area in advance by judging the traveling direction of employees. When multiple people carry out a certain work at the same time, they can check the working status of the others and avoid accidents caused by improper operation timing. When the electrician carries out the overhaul work, the system generates a reminder, such as “under repair”, prohibiting the nearby employees from turning on the power switch of the overhaul. When the overhaul work is completed, the system reminds the nearby employees to work normally.

4.2.3 Ability assessment module

The ability assessment has three parts. One part is the usual performance appraisal, which gives the corresponding score according to the employees’ performance on daily work. The second part is the personal assessment. The system randomly selects different topics for assessment from the existing questions bank according to the needs of different types of work. It will automatically generate results, analyses and records the situation of assessment. The third part is the collaborative assessment. It pays more attention to assessing the ability of collaborative work when testing each person's ability to do things independently. Employees query scores through the examination subjects, departments, and types of work, user information or other information. The person in charge can check the examination results and analysis of all the employees in a department.

AR assessment is the part that is different from the traditional assessment in the system. After employees login into the system and select assessment mode, the system will choose appropriate problems to assess the employees according to their positions, train projects and other information. The employees need to complete the work independently within the limited time. The system assesses operations of employees and gives corresponding opinions according to the missing items. It also records these missing items as the key items and increases the frequency of appearances in the subsequent examinations. All these help employees to form the correct self-awareness, and motivate employees constantly to improve themselves. Only the missing items are corrected in training, the unsafe behavior of employees at work can be reduced. Operate correctly can reduce possible errors in the work process to achieve the purpose of safety production.

4.2.4 Background management module

Background management module mainly involves the following two aspects. One part is the management of various roles, such as employees, responsible persons, experts, administrators and other roles. Different users have different permissions. For example, the maintenance worker in charge of the circuit can only see the experts in the circuit. When uploading or downloading the resources, the users of different types of work can only operate the resources related to the positions. The responsible persons can import the users in batches, view different employees' learning records or assessment results, and determine its ability to be competent for the work according to the employees’ performance. The second part is the daily work of the administrator, including maintain the system, update database, resource classification, expert management and other aspects of work. Its purpose is to achieve stable and orderly operation of the system.

5 Conclusion

The framework of mine safety training system based on augmented reality (AR) and cloud platform (CC) is put forward after comparing the existing training methods. Some conclusions could be drawn as following:

(1) Augmented reality technology could create a mine safety training environment where both mine theoretical knowledge and practical operation can exist simultaneously.

(2) Marker-based AR has the advantages of simple algorithm, high speed and low requirements on environmental conditions etc. It could meet the requirements of real-time and accuracy in mine training.

(3) The realization of AR training modules mainly depends on technologies such as display technology, tracking registration technology and interactive technology.

(4) The cloud platform is characterized as large scale, elasticity, and high stability. These characteristics determine that the cloud platform can be applied to mine safety training.

(5) The cloud platform can store large amounts of mine data and adjust these data according to the actual situation.

(6) This safety train framework includes several functional modules and their operation flows. These modules achieve the functions such as behavioral standardization and theoretical knowledge learning.

This system brings great convenience to mine training. It saves training costs, reduces the risks of actual operation and contributes to the formation of employees' safety awareness. It is of great significance to cultivate talents in mining enterprises and realize safe production. The safety training system could not only be applied to mines, but also could be designed into the corresponding system to meet the needs of various enterprises. For college students, the introduction of this safety training system can improve the form of teaching. It combines the theoretical knowledge with practical work, achieving the transition to work at school. For enterprises and government departments, the system can be designed into a display system. It can introduce products in a more vivid way, which not only enrich the form of work, but also save time and resources. The safety training system has broad application prospects.

Acknowledgement

This research project is made possible through the financial support from National Key R&D Program of China (2017YFC0805100, 2016YFC0801305).

References

Cheng, Z., 2012. Research on architecture and educational application of smartphone augmented reality system. China Educational Technology, (**08**): 134 - 138. (in Chinese)

Gao, G.F. and F. Wang, 2016. Talking about the problems and countermeasures of mining staff training. Science & Technology Economy Market, 150 - 151. (in Chinese)

Guo, W., 2017. The development and application of augmented reality technology. Technology Innovation and Application, (**20**): 180 - 182. (in Chinese)

Hong, Y.L., 2013. Coal mine accident simulation and safety training system base on virtual reality technology. Safety in Coal Mines, **44**(**08**): 96 - 98. (in Chinese)

Li, G.R., P.F. Tian and H.B. Liu, 2014. Coal mine safety risk pre-control management cloud platform design. China Safety Science Journal, **24**(**02**):138 - 144. (in Chinese)

Liu, F., Y.C. Ye and Y. Huang, 2007. Discussion on safety management system for metallic mine. Industrial Safety and Environmental Protection, **33**(**9**): 58 - 61. (in Chinese)

Liu, Y., S.Q. Li and J.F. Wang, 2014. Interactive operation of physically-based slender flexible parts in an augmented reality environment. Science China Technological Sciences, **57**(**7**): 1383 - 1391.

Liu, Y., L.F. Hu and Z.L. Tan, 2015. Research on visualization safety training of coal mine based on virtual reality. China Coal, **41**(**06**): 79 - 83. (in Chinese)

Liu, G., L. Li. and Z.Q. Wang, et al, 2016. Research on the method about on-site training of safety production for the large petrochemical equipment based on augmented reality. Safety Health & Environment, **16**(**12**): 52 - 55. (in Chinese)

Ni, X.Y., J.R. Zheng and W. Zhou, 2009. Design and implementation of augmented reality software system. Computer Engineering and Design, **30**(**9**):2297 - 2300. (in Chinese)

Sun, E.J., A Nieto, and Z.X. Li, 2010. GPS and Google Earth based 3D assisted driving system for trucks in surface mines. Mining Science and Technology, **20**(**1**): 138 - 142.

Sun, E.J., X.K. Zhang, and Z.X. Li, 2012. The internet of things (IOT) and cloud computing (CC) based tailings dam monitoring and pre-alarm system in mines. Safety Science, **50**(**4**): 811 - 815.

Xu, H.L., 2017. Research on mine disaster simulation and rescue training system. China Coal, (**11)**: 69 - 73. (in Chinese)

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 86-91
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

The Potentials of Scientific and Industrial Collaborations in the Field of REE through China's Belt and Road Initiative

George Barakos*, Helmut Mischo
Institute of Mining and Special Civil Engineering, TU Bergakademie Freiberg, Freiberg, Germany

Abstract: Within the framework of trade deals and infrastructure investments, China also wants to build a "belt of scientific cooperation" with countries and international organisations involved in the Belt and Road Initiative. This could create an opportunity for involvement of several European countries that have so far treated China's initiative with skepticism about the coherence and practicality of the project. A crucial issue that concerns both China and the European Union in the recent years is the establishment of an undisrupted supply of critical raw materials to satisfy the consumption demands of the modern high-tech world that we live in. Among the listed critical raw materials are the rare earth elements (REE). Accordingly, the development of an extended and sustainable REE supply chain is a significant research field in which both sides could collaborate and benefit from. It is crucial for the involved countries to utilise their advantages, work together and share knowledge to tackle technical, economic and environmental issues that govern the global rare earth industry. Hence, in this paper the possibilities of a potential cooperation are investigated in the context of collaborative research projects, academic networking, workshops and training for young scientists. The aim is to seek, find and bridge any gaps that exist between the two sides with a view to strong academic and industrial collaborations.

Keywords: rare earth elements, REE supply chain, raw materials, scientific collaboration

1 Introduction

Rapid economic growth of the Chinese economy in the past decade and its potential for strong growth into the foreseeable future have turned China into an important exporter of capital, both in massive foreign exchange reserves as well as in direct investment (Du and Zhang 2018, Zhai 2018).

Looking forward, the governmental policies and initiatives will continue to help support the rapid expansion of the Chinese economy. Among them, the recent "Belt and Road Initiative" (BRI), otherwise known as "One Belt One Road", is likely the most significant in China's international economic policy and will provide fresh momentum to the economic growth of the country in the coming decades.

Launched in 2013 the Belt and Road Initiative is a series of potential interconnected bi-lateral trade deals and infrastructure projects that seek to establish enhanced trade routes and communication networks from China through other Asian countries to Europe and Africa (NDRC 2015). In its broadest definition, the BRI could cover more than 65 countries, 4.4 billion in population, and nearly 30% of the global GDP (Zhai 2018). In other words, it is an ambitious plan of the Chinese President Xi Jinping to revive the ancient Silk Road trade routes from Asia to Europe.

China intends to connect with the involved countries along several routes (NDRC 2015). The 'Belt' aims to link the less developed western regions of China through various economic corridors to Russia, Central Asia, and Europe. Meanwhile, the 'Road' is a sea route designed to link China's coastal provinces to Southeast and South Asia through the South China Sea and to Europe and Africa through the Indian Ocean, Persian Gulf and Mediterranean Sea (Figure 1).

China has also expressed interest in joint economic development in the Artic (NDRC 2017) and has introduced a third specific sea route through the Northern Sea for faster cargo transits between Europe and Asia (Figure 1).

With a monumental US$1.4 trillion worth of planned investments to build railways, ports and other infrastructure in involved countries along the aforementioned routes, the BRI is historically the biggest foreign investment strategy by any single country in world history; multiple times bigger than the Marshall Plan that was deployed to rebuild Europe in the post- World War II era (Cheng 2016, Zhai 2018).

China itself will naturally benefit from the new Silk Road as it will expand its trade connections with Europe, its biggest export market, and Africa, potentially the continent of future growth. Investment in countries along the way could help Chinese companies to expand abroad just as economic growth and heavy investments are slowing at home. The BRI would also promote the internationalisation of the Chinese currency and bolster China's political

* Corresponding Author: Georgios Barakos, Email: Georgios.Barakos@mabb.tu-freiberg.de, phone: +49 3731 393602

DOI: 10.15273/ijge.2018.03.015

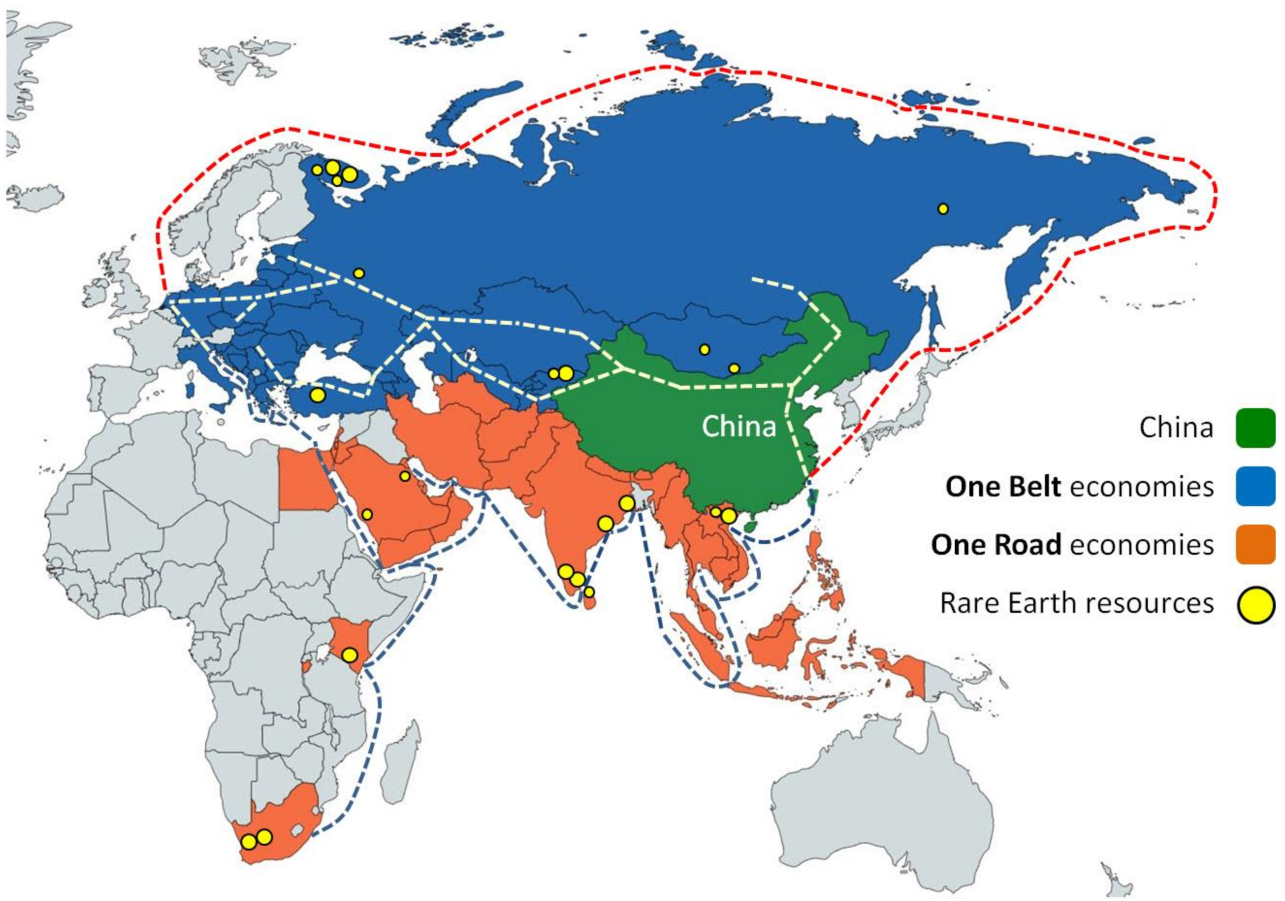


Figure 1 The Belt and Road Initiative Roadmap including REE sources found in countries involved

Influence abroad (Cheng 2016, Du and Zhang 2018).

However, the challenge for China is to convince other countries, especially in Europe, that the Initiative is a train worth jumping aboard and that it is not just an attempt to tie other countries into a China-centred production network.

Within the European Union there has been no unified perspective on the BRI. At the individual EU member state level, however, a large number of countries, mostly in the south, center, and east that have infrastructure deficits or pressing unemployment and economic growth challenges have already warmly embraced the initiative and have commenced cooperation (Herrero and Xu 2017). The Scandinavian countries have shown little interest so far, partially due to the fact that they are economically developed, well connected, and situated in a corner of Europe that sees, comparatively, little transit activity. Germany and The Netherlands have shown interest and have commenced engagement, yet at the same time they are evaluating the BRI's long-term strategic implications - mainly economic - at a national and EU level. Evidently, the level of interest shown already by several EU states in the Initiative will compel the European Union to come up with strategic policy decisions on BRI engagement.

In this instance, common ground needs to be found that will foster closer collaboration between China and the EU within the BRI framework. Such a case is the supply of critical raw materials, including the rare earth elements, to meet the consumption demands of our high-tech era.

As is well known, the monopolistic control of China over the global REE market remains unchangeable, while the EU is one of the biggest importers of rare earths from China (Barakos et al 2016a). Nevertheless, both China and the EU are dealing with issues that govern the REE industry in national and international level. Thus, cooperation may take place between the two sides in the context of the BRI framework to resolve all issues in the rare earths industry. This cooperation can be established in both an academic and industrial level.

This way, China can dissolve all doubts and prove its cooperative intentions that come with the development of the Belt and Road Initiative. Besides, China claims to seek not only for the commercial and industrial cooperation with the involved countries, but also the academic collaboration and exchange of knowledge through research projects and joint organisation of workshops and conferences.

2 Methodology

To be able to establish collaboration we first need to determine the issues that exist in the REE industry and how these can be solved. In this paper a first attempt is made to spot and analyse the basic problems that each side is facing.

Then a framework is developed with respect to the know-how that China and the EU have and thus, can exchange with respect to solving the issues that have arisen.

Finally, this framework is used as a guide for potential academic and industrial collaboration between China and the EU in order to establish a balanced and transparent REE market and an undisrupted supply of rare earths.

3 Issues Facing the REE Industry

The world of rare earth elements is far more complex and cannot be scrutinized as easily as other commodities like copper, or coal. The REE industry has many features and is facing significant challenges that are differentiated locally.

3.1 REE issues in China

At the time of writing this paper China is accounting for almost 90% of the global REE production and 70% of the global consumption. By taking advantage of the large domestic REE resources and by implementing a carefully-crafted, dynamic long-term strategic plan, China is dominating the global REE industry for more than three decades (Barakos et al 2016b).

Nevertheless, the Chinese REE industry is facing big problems. In the aftermath of the REE crisis and price-spike of 2011 the interest for REE production has soared worldwide (Barakos et al 2016b), let alone inside of China. The prices plummeted in a short time and many of the potential producers around the world took a step back. In China, however, small-scale - mostly unregulated - mining flourished, thus raising issues to the domestic REE sector over the years (Shen et al 2017).

Illegal, unplanned production resulted in chains of black interests involving mining, processing, circulation and smuggling of rare earths outside of China (Packey and Kingsnorth 2016, Shen et al 2017). This has seriously disrupted the REE market order and led to a substantial decline in the prices of rare earth products. At the time of writing, the low level of prices has made extraction and processing of rare earths a money-losing business even for Chinese producers; only domestic downstream companies are still profitable (Packey and Kingsnorth 2016).

Furthermore, unregulated production has resulted into uncontrolled depletion of domestic REE resources. Given the transient nature of unregulated mining, illegal miners usually take only the high grade ore leaving the medium and low grade ores behind, unlike a regular mine plan that dictates the recovery through a mix of high, medium and low grade ores (Packey and Kingsnorth 2016).

Another consequence of illegal REE production is the serious damage that is caused to local ecosystems. Mining and processing of rare earths poses challenges and risks, let alone when it is unregulated. Their association with the radioactive elements thorium and uranium, as well as the use of dangerous chemicals and toxic compounds during REE processing demand expensive mitigation measures to ensure efficient environmental protection and workers' safety. At this point it should be mentioned that the environmental degradation in China comes as a result of lax regulations for both legal and illegal mining. In Baotou, Inner Mongolia, illegal mining has resulted in extended water pollution while in Ganzhou, Jiangxi, regulated yet excessive mining and extraction of rare earths have severely damaged the Dongjiang River (Shen et al 2017).

It is estimated that a kilogram of rare earths produced in China has an environmental cost of US $5.60, whereas the sale price of several individual REE like lanthanum, cerium and yttrium is currently lower than that. In addition to that, the cost of rehabilitating the REE mines, tailing dumps and disused processing facilities is more than tenfold the current gross revenue of the domestic rare earths industry (Packey and Kingsnorth 2016). Resultantly, the gap between the price and the true cost of rare earths is significant.

As part of its effort to protect domestic resources and the environment, the Chinese government has imposed export quotas and management measures on rare earths and related products (Barakos et al 2016a). This policy, however, did not confine illegal production, while it was identified as not conforming by the World Trade Organisation (WTO). After that, the Chinese government initiated a consolidation plan of the domestic REE industry; more than 67 REE mining licences and 99 REE processing companies are now controlled by a handful of state-owned enterprise groups (Packey and Kingsnorth 2016, Shen et al 2017). Howbeit, this plan has proved to be inadequate as well. Illegal production is constantly growing over the years and accounts for nearly 40-50% of the total production in China (Table 1).

Table 1 Illegal production of rare earths over the years in China (Packey and Kingsnorth 2016)

Year	Production in China	Illegal mining	ROW
2010	89,200 t	25-30,000 t	5,000 t
2011	93,800 t	25-30,000 t	6,000 t
2012	93,800 t	25-30,000 t	8,000 t
2013	105,000 t	25-35,000 t	12,000 t
2014	105,000 t	40-50,000 t	15,000 t
2015	105,000 t	70-90,000 t	19,000 t
2016	105,000 t	80-100,000 t	24,000 t

The ongoing export quotas on REE and related products are contributing towards the growing of illegal mining and smuggling out of China. If this continues, it will decrease the financial attractiveness to develop REE projects outside of China and will consequently lead the international community to continue purchasing rare earths at lower prices from smugglers.

3.2 REE issues in Europe

Unlike China, Europe should not be considered a producer but rather a major consumer of rare earths. It took a REE-crisis for the EU (and the rest of the world) to realise its full dependency on Chinese REE production and export quotas. Following the crisis, actions were taken, but the nosediving of the prices and their prolonged low level has affected the

European REE industry from its very first steps.

Yet, the main reason for not being able to make a difference in the global REE market is because of Europe's small output compared to China's overwhelming global monopoly.

There are a handful of REE-rich ore deposits found in Europe as well. Ongoing exploration activities primarily in Sweden and Greenland have resulted in the discovery of relatively big REE resources. However, it is difficult to say that these exploration projects can translate into active rare earth mines in the foreseeable future (Barakos et al 2016b).

This is supported by the high capital and operating costs and expensive measures of reducing risks associated with rare earth extraction and processing, and thus has resulted in the EU being a cog in the wheel of global REE production. For instance, the labour costs in Europe cannot be compared to the cheap labour in China, while the strict regulation framework that is implemented in all European countries further increases the level of costs for any potential REE mining and processing project.

On top of that, the European REE industry lags behind in know-how and production capacity when it comes to developing a fully integrated rare earth supply chain. It has taken more than three decades for China to achieve current capacities and capabilities in mining, processing, separating and refining rare earth elements and this is something that cannot be copied in a short term (Barakos et al 2016a). Without doubt, innovations have been accomplished and remarkable milestones have been reached in small scale processing and separation of REE and in finding new applications for them. This, however, apparently is not enough.

Last but not least among the issues that govern the REE industry in Europe is the acquisition of a social licence to operate. Terms like greenfield mining and responsible sourcing are included in all relevant legislation instruments in the EU showing how important it is to engage with the local and (general) EU community so as to ensure full agreement amongst all stakeholders and go beyond the NIMBY-syndrome (Not In My Back Yard). This policy has been further developed in the recent years as an aftereffect of the environmental problems in China.

4 A Collaboration Framework for the REE Industry

Apparently there are different issues but also some common problems that need to be resolved for both China and the EU. Contrary to the issues, there is expertise and know-how that one side can offer to the other in the collaborative context of the Belt and Road Initiative.

Thus, a framework is being developed hereinafter with respect to mutual beneficiation cooperation for the exploitation of REE resources and the smooth-running of the REE industry. This framework promotes collaboration in both a scientific and industrial environment.

4.1 Development of REE projects

As already mentioned, China plays host to a considerable amount of the world's proven rare earth reserves; nearly one third of them. Due to their depletion, however, China is constantly seeking to invest in foreign exploration REE projects. The most typical example of China's policy is the purchase of Mountain Pass in California by a Chinese-led consortium in mid-2017, meaning that Beijing will have an influence over the development and direction of the biggest U.S. REE resource from now on (Roskill 2017). Similarly, Chinese companies tried in the past years to acquire the majority stake of Lynas Corp. and Arafura Resources in Australia, but without success.

Accordingly, it could be said that China will be making direct investments in some of the countries involved in the BRI in order to secure supply of REE resources that have been found in these countries. Truth be told, there are some remarkable rare earth resources through the Belt and Road routes as illustrated in Figure 1. Russia, Vietnam and India hold the biggest REE resources among the countries that are covered by the BRI, while there are significant ongoing REE exploration activities in Kyrgyzstan, South Africa and Turkey (Table 2). Including China, the REE resources found in BRI countries exceed 50% of the world's total. It should be repeated here that Greenland and Sweden are hosting notable amounts of REE resources as well, but are not (yet) part of the Belt and Road Initiative consortium.

Table 2 Potential of REE Resources in BRI involved economies (Weng et al 2015, Zhou et al 2017)

	Country	REO (Mt)	%
Belt and Road Initiative Economies	China	164.34	34.37
	India	5.97	1.25
	Kenya	6.15	1.29
	Kyrgyzstan	1.60	0.34
	Mongolia	1.28	0.27
	Russia	48.16	10.07
	S. Arabia	0.94	0.19
	S. Africa	2.06	0.43
	Sri Lanka	0.001	0.0
	Turkey	0.48	0.1
	Vietnam	15.44	3.23
	Australia	49.12	10.27
	Brazil	53.38	11.17
	Canada	34.75	7.27
	Greenland	42.95	8.98
	Sweden	30.19	6.31
	USA	13.48	2.82
	ROW	7.82	1.64

Several countries involved in the Initiative are low-income economies. Yet, the rapid developments of economy and infrastructure construction shall increase the demands for mineral resources in these countries (Liu et al 2017). Therefore, the BRI provides an opportunity for mutual beneficial cooperation to explore and exploit potential rare earth resources in these lands. Besides, there is potential for discovering new REE resources, among other commodities in unexplored areas and countries covered by the Initiative. Afghanistan and Pakistan are such two countries, whose unexplored mineral resources could become the bone of contention between several nations in the near future. Nevertheless, China would and should never plunge into such battlefields alone, due to the foreseeable risks and costs, especially in the view of their possible defection to the U.S.-led camp in Afghanistan for example (Cheng 2016). Collaboration with the EU in the context of the Belt and Road Initiative could ease the access to these countries' potentially valuable resources.

4.2 Industrial collaboration opportunities

Aside from policies and strategies, there can be cooperation also at the industrial level. The source of most problems, especially for China is the existence and constant growth of illegal REE mining. China failed to curb illegal REE producers even after the restructuring of its regulations and the consolidation of the domestic REE industry. This issue gives room to the EU to intervene and transfer its respective know-how to China.

The mining and processing of REE in Europe falls into the scope of a wide variety of EU directives that cover every aspect of potential risks in the REE industry sector (Barakos et al 2016c). The Mining Waste Directive (Directive, 2006/21/EC), is a significant legislation instrument for REE mining and for the management of groundwater. The Waste Framework Directive (Directive, 2008/98/EC) deals with solid wastes, while the Environmental Impact Assessment (Directive, 2011/92/EU) is the regulation where pit mines and quarries fall into. China's alignment with a regulation framework that is based on the European standards will contribute towards restricting unregulated REE mining and tackling the environmental disaster in the affected areas.

Another step towards this direction is the optimisation of the overall process through the automation of operations and digitalisation of all mining and processing activities. With the extended use of computer-integrated mining, the Chinese REE industry can be further consolidated, the uncontrolled depletion of REE reserves can be monitored efficiently, and the current erroneous practices that threaten the environment as well as the health and safety of staff and inhabitants can be reduced significantly. It could be well said that the respective cost is high compared to the cheap Chinese labour cost. Yet, the true cost that was mentioned previously and that includes the environmental cost of REE production will eventually be lower.

Digital effectiveness has become a top priority for mining companies and environmental agencies in Europe and the acquisition of know-how is now a valuable asset that the European Union could share with China.

The digitalisation of the REE industry in China could be well combined with the development of a vertically integrated REE supply chain in Europe. The evident lack of intellectual capital outside of China reinforces concerns and arguments regarding the potential of the European REE industry to compete with China and the capability to avoid environmental pollution with detrimental effects on local societies. There is limited availability of experienced staff to work in REE mines or processing plants. Hence, the EU relies upon China to transfer its REE processing, refining and fabricating know-how to Europe in the collaborative context of the Belt and Road Initiative.

4.3 Academic collaboration opportunities

Another perspective would be the scientific cooperation through the BRI. Given the nature of the aforementioned industrial cooperation potentials, there is plenty of room for interaction between academia and the REE industry. After all, China wants to build a "belt of scientific cooperation" as well with countries involved in the Initiative and aims to complete a basic cooperation network in science and technology by 2030 (NDRC 2015, 2017).

Since the initiative was proposed in 2013, the Chinese Academy of Sciences has expanded its global cooperation and outreach by providing technological support and services to help countries tackle practical issues. For example, the Digital Silk Road program was formally proposed in 2016 in order to bring together scientists from 40 countries to cooperate on space-based Earth observations that might help identify and manage natural resources, and protect the environment (Jia 2017).

Focusing on the REE research sector, there are several running projects in Europe that aim to give answers to research questions related with the market and the industry of rare earth elements. To give an instance, the EuRARE research project was funded by the European Commission for developing a sustainable exploitation scheme for Europe's REE ore deposits. Universities and research organisations from 10 countries all over Europe were part of this project. Furthermore, there are well established institutes like the Helmholtz Institute Freiberg in Germany that conducts research in all disciplines related to the REE (exploration, mining, processing, and recycling).

Simultaneously, there are well established institutes in China conducting research solely on rare earth elements. The Baotou Research Institute of Rare Earths, established in 1963 in Inner Mongolia, is the world's largest, employing about 700 people. Two other notable institutes are the State Key Laboratory of Rare Earth Materials Chemistry and Applications affiliate with Peking University, and the State Key Laboratory of Rare Earth Resource Utilization, affiliated with Changchun University in the province of Jilin and belonging to the Chinese Academy of Sciences.

As a result of this research flurry, there are thousands of scientific publications each year coming from scientists located in BRI involved countries and that are related to rare earths. Apparently, a big amount of these publications are coming from China and the EU. However, the independent publications outnumber the internationally co-authored papers (Jia 2017). Evidently there is no cooperation between Chinese and European research institutes and organisations, at least to the authors' knowledge.

This low collaboration level offers a great opportunity for China and the EU to foster joint innovative research on the field of REE. The Initiative can be a solid platform for facilitating multinational research projects, international workshops, academic networking, joint, laboratories, and training for young scientists. Numerous foreign scholars have already visited the Chinese Academy of Sciences to take part in short-term research visits (Jia 2017); this could be done for scientists that conduct research on REE as well.

5 Concluding Remarks

Ultimately, there are several opportunities for collaboration between China and the EU even if these are still loosely defined in the BRI. Nevertheless, the inclusion of the Belt and Road Initiative in the Chinese constitution is a major step towards solidifying it as a core plan of action and proves that this concept has a significant place in China's foreign policy going forward.

However, this challenging plan involves notable risk. The political motivation in the Belt and Road initiative could run against commercial logic and genuine scientific or infrastructure needs in different countries, leading either to bad investment and financial losses, or to mismanagement and erroneous research practices.

The collaboration through the Initiative must be sincere and fair, and benefit every nation and all participants, especially in key areas such as the supply of raw materials. China needs to convince its potential partners and especially the EU of its intentions. The BRI is a platform on which the EU could definitely exercise some influence, for instance by assisting participating states with issues such as business reform and socioeconomic policies. There are countries in Asia in which there are concerns over overreliance on China through the BRI, and thus an economic behemoth like Europe could function as a counterweight.

When it comes to the key REE industry sector, it is important that China will reform its policy and be more cooperative. As described in this paper, there is plenty of room for joint research and industrial collaboration in the field of rare earths. A combination of know-how and its transfer also to low-income economies holding REE resources would be to the benefit of both China and the EU.

After all, what Europe seeks to gain from the BRI is not another link to the Chinese market but a fair and equal scientific, commercial and industrial cooperation. If the Belt and Road Initiative will be the basis for the formation of a supercontinent in terms of trade, distrust and competing visions between its members will only result in friction and greater potential for (proxy) conflict.

References

Barakos, G., J. Gutzmer and H. Mischo, 2016a. Strategic evaluations and mining process optimisation towards a strong global REE supply chain. Journal of Sustainable Mining, **15**(**1**): 26 - 35.

Barakos, G., H. Mischo and J. Gutzmer, 2016b. An outlook on the rare earth elements mining industry. In, Bulletin TA, editor.

Barakos, G., H. Mischo and J. Gutzmer, 2016c. Legislation; Challenges and policy strategies: In search for a regulatory framework for sustainable development in the rare earths mining industry. In Proc. of the 2016 SME Annual Conference, Phoenix, AZ, USA, 250 - 255.

Cheng, L.K., 2016. Three questions on China's "Belt and Road Initiative". China Economic Review, **40**: 309 - 313.

Du, J. and Y. Zhang, 2018. Does One Belt One road initiative promote Chinese overseas direct investment? China Economic Review, **47**(**C**): 189 - 205.

Herrero, A.G. and J. Xu, 2017. China's Belt and Road Initiative: Can Europe expect trade gains? China and World Economy, **25**(**6**): 84 - 99.

Jia, H., 2017. Scientific collaborations shine on Belt and Road. National Science Review, **4**(**4**): 652 - 657. (in Chinese)

Liu, C., Q. Liu, J. Li, Y. Li and A. Wang, 2017. China's Belt and Road Initiative in support of the Resourcing Future Generations Program. Natural Resources Research, **27**(**2**): 257 - 274.

National Development and Reform Commission (NDRC), Ministry of Foreign Affairs, and Ministry of Commerce, People's Republic of China, 2015. Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road. https://www.yidaiyilu.gov.cn/wcm.files/upload/CMSydylgw/201705/201705161049036.pdf.

National Development and Reform Commission (NDRC), Ministry of Foreign Affairs, and Ministry of Commerce, People's Republic of China, 2017. Vision for Maritime Cooperation under the Belt and Road Initiative. https://www.yidaiyilu.gov.cn/wcm.files/upload/CMSydylgw/201706/201706200153032.pdf.

Packey, D.J. and D. Kingsnorth, 2016. The impact of unregulated ionic clay rare earth mining in China. Resources Policy, **48**: 112 - 116.

Roskill, 2017. Rare earths: Mountain Pass sold to Chinese-led consortium. https://roskill.com/news/ rare-earths-mountain-passsold-chinese-led-consortium/.

Shen, L., N. Wu, S. Zhong and L. Gao, 2017. Overview on China's rare earth industry restructuring and regulation reforms. J. Resour. Ecol., **8**(**3**): 213 - 222.

Weng, Z., S.M. Jowitt, G.M. Mudd and N. Haque, 2015. A detailed assessment of global rare earth element resources: Opportunities and challenges. Economic Geology, **110**(**8**): 1925 - 1952.

Zhai, F., 2018. China's belt and road initiative: A preliminary quantitative assessment. Journal of Asian Economics, **55**: 84 - 92.

Zhou, B., Z. Li and C. Chen, 2017. Global potential of rare earth resources and rare earth demand from clean technologies. Minerals, **7**(**11**): 203.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 92-98
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Safety – a Business Imperative

Kobus de Jager*
School of Mining Engineering, University of the Witwatersrand, Johannesburg, South Africa

Abstract: The safety performance in the South African mining industry has been a contentious issue for decades when compared to international benchmarks. Although mining safely has always been part of the mining business proposition, a step change was required as the unacceptable safety performance threatened the sustainability of mining. The South African mining industry has in recent times made significant inroads in improving safety as it is viewed as a business imperative to ensure long term sustainability. Fatalities reduced from 219 in 2007 to 73 in 2016, however, the industry recognises that much remains to be done as one fatality is one too many. Research was recently conducted to determine the emerging themes that resulted in the improved safety performance of six major South African gold and platinum deep level mines, between 2007 to 2016. It was concluded that the leadership of the mining companies followed a multi-tiered approach in order to reduce safety related incidents in mines. It is imperative to appreciate the element interdependencies of the 'Zero Harm' safety approach in order to sustain the safety culture that is evolving in the South African mining industry.

Keywords: advocacy, governance, safety, sustainability, systems, leadership, risk management

1 Introduction

Safety has always been part of mining world-wide, however, the importance of being safe differs historically between countries and different generations.

During the period 2007 to 2016, 1246 persons died in the South African mining industry. The fatalities reduced from 219 per annum in 2007 to 73 per annum in 2016 which is a 67% improvement.

Safety remains a very important part of the social license to mine in South Africa. Although the number of fatalities has decreased significantly in recent times, it still occurs too often to be acceptable by society.

The overriding question is what has had to change to realise this significant improvement? Was the answer in new leadership, technology, processes, systems, legislation or applying that was known before?

2 Background

The amount of deaths in the South African mining industry during the past 100 years exceeds 51 000 between 1917 and 2016, as shown in Figure 1. Although the number of deaths has been decreasing substantially during the past 30 years since 1987, it remains unacceptably high at 73 fatalities in 2016, as shown in Figure 2 and 3.

This reduction in fatalities has been partly as a consequence of the reduced number of employees up to about 2003 as shown in Figure 2. However, it can also be seen that subsequently there is no correlation between the number of employees and fatalities as the risk exposure has been reduced.

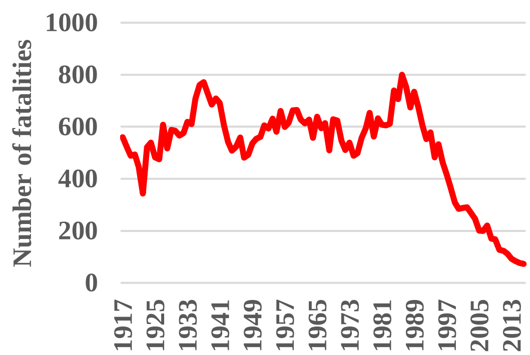


Figure 1 Fatalities of mining industry in South Africa between 1917 and 2016

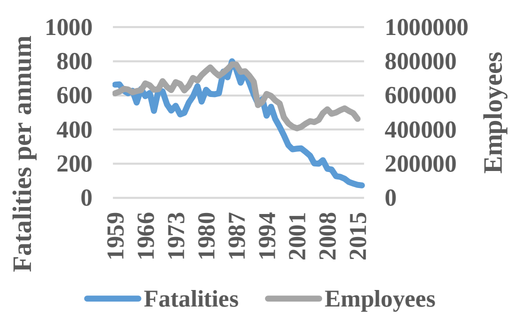


Figure 2 Fatalities and employees of mining industry in South Africa between 1959 and 2016

* Corresponding Author: Kobus de Jager, Email: kobusdj@iafrica.com, phone: +27 82 776 3560

DOI: 10.15273/ijge.2018.03.016

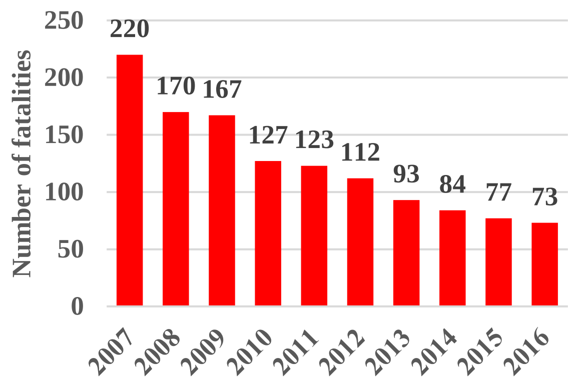


Figure 3 Fatalities of mining industry in South Africa between 2007 and 2016

In 1983 National Union of Mineworkers (NUM) was recognised by the South African Chamber of Mines as a representative union. In the same year Hlobane colliery methane explosion resulted in 68 fatalities. In 1985 NUM expressed concern over the mining industry safety record.

In 1986 the Kinross fire resulted in 177 fatalities followed in 1987 by a methane explosion in the Ermelo coal mine which resulted in 34 fatalities. In the same year St Helena mine had a shaft explosion causing the cage to fall down the shaft resulting in 67 fatalities. NUM had a National strike for 3 weeks in 1987 (Leon Commission of Inquiry report 1995).

In 1988, the Association of Mine Managers Council decided that safety would be at the top of all agendas and AMMSA organised a safety symposium (Hocking 1997).

The safety improvement in the South African mining industry basically commenced in 1987, as shown in Figure 1. At the time there was significant company restructuring and refocusing as some mature shafts were closed, some shafts were sold to 2nd and 3rd tier companies and NUM's presence was felt in the mining industry.

In 1993, yet another Commission of Inquiry, the Leon Commission, was launched into safety and health in the mining industry with wide terms of reference to inquire into all aspects of the Regulation of OHS. The findings built on previous Inquiries done in 1911, 1925, 1960.

In 2007, the then CEO of Anglo American, closed two platinum shafts in South Africa following a number of fatalities until the workforce received more safety training. This level of consequence management was unheard of in South Africa at the time.

The DMR has subsequently been stopping shafts or part of the operations at regular intervals for transgressions, despite lacking consistency in the approach.

In 2008 the Presidential Mine Health and Safety Audit was commissioned, and recurring themes were again recognised as was the case in the 1960 Marais Commission. (Leon Commission 1995).

A Tripartite Safety Summit was held in 2008 with union, government and industry representatives to address safety concerns in the mining industry.

Why were some of these recommendations not implemented at the time? The compelling answer is probably that the mining industry at large was not held accountable for their actions and non-compliance had insignificant consequences for the individual companies in the past.

The mining industry response to safety has changed significantly in the past two decades and the historical prerogative to 'ignore' safety issues is no longer an option as mining companies are being held accountable for their actions.

3 Theoretical Approach to Achieve 'Zero Harm'

It is imperative that leaders involved in safety and health holistically understand the interdependencies of various safety aspects in dealing with the concept of 'zero harm' and how to achieve it. It has been experienced that that in large organisations, very few individuals actually understood the interdependencies of the overall safety management 'system' as a whole.

It's critical to recognise that safety success isn't an 'or' issue (one strategy or another), but rather an 'and' issue (one strategy and another). Safety excellence isn't the result of a singular strategy. There are no universal answers.

In a complex environment or a very large organisation, it is conceivable that only a few people, if any at all, understands the overall interdependencies of all the aspects of the 'Safety Management System'. There should therefore be a consistent, simplified safety storyline available so that the majority of the staff understands how the various components fit together as a whole in order to achieve 'zero harm'.

As a start, the Leadership of a company must have 'zero harm' as a non-negotiable value for the company. However, it should be understood that 'zero harm' is a reactive mindset in that it implies that an incident is expected to occur, but that the consequences should result in 'zero harm'. The next desirable pro-active mindset is that of 'zero incidents', meaning that all risk management controls are appropriate and applied.

Genuine caring for people creates an environment conducive for 'zero harm'. 'Values' on a wall poster that are not being applied, especially by leadership, have significant negative consequences on the safety culture in the longer term. Management must be seen to live the values and lead by example.

The company's safety efforts should be documented and contained in a Safety Management System (SMS), agreed to by all and applied by all stakeholders in the company. Participative management is important to the success of the 'zero harm' concept.

The SMS must be underpinned by a credible dynamic Risk Management process. Risks at all levels of the organization must be identified and controls instituted. Controls must be applied by all so as to ensure that activities are within the company's residual risk tolerances.

Safety is a result of pro-active risk management and is a concurrent activity to ensure that controls are in place before and during the execution of any task and not something that is done subsequently. For every task to be performed there should be an agreed safety procedure available and all staff should agree to work to it.

What gets measured gets done. The safety information system must be appropriate for the company with leading and lagging indicators which are relevant, accurate and available timeously. More importantly, appropriate action should be taken should indicators trend negatively.

Human factors, which include the theory of behaviour as well as human errors, should be well understood, including human limitations. This will include the behavior of leadership as well as the individual who is in the line of fire. Behaviour turns systems and procedures into reality.

Benchmarking of relative industry performance should be undertaken, and system audits should be done regularly to ensure compliance of the company's Safety Policy. The company should strive for continual improvement of their safety performance (de Jager 2015).

4 Safety is a Business Imperative

The safety expectations by individuals, society-at-large as well as companies, matured over time. What was acceptable in the past is no longer acceptable and will evolve further in future.

In the past the majority employees in the mining industry were illiterate and was required to do manual labour underground in challenging conditions. The mineworkers were largely recruited from remote labour sending areas and neighbouring countries and were housed on the mine in hostels, away from their families. They had an expectation to earn a wage to support their families and irked out a living. At the same time, they expected to potentially contract phthisis and lose hearing over time due to their exposure to dust and noise. Additionally, they could get injured, be maimed or die as a result of the nature of their work. Such was life.

However, over time, the individual's expectations matured and now expects a decent wage and benefits, living with their families in houses as well as not to be injured at all or exposed to other occupational diseases.

Company and other stakeholders' expectations have increased dramatically over time resulting in increased complexity and effort to have a sustainable business. Making adequate returns on investments is paramount to ensure business success but it cannot be done at the expense of society expectations. Mining companies cannot operate in isolation and society creates an enabling environment if expectations are met and the opposite if it is not met.

Exposure to occupational risks that results in diseases, injuries and fatalities are not acceptable and some investors and clients are no longer willing to deal with mining companies that has unacceptable safety performance. Times have changed and if companies do not adapt, how long will they survive?

4.1 Society's view on accidents

Society has different views about public commuting deaths versus a similar incident in a mine and the reactions are vastly different.

A hypothetical example of a taxi commuting accident versus an underground people transportation accident is used to illustrate the different potential consequence.

If the public use cars, taxis, trucks and buses on public roads, there are common rules applicable with respect to road safety. Adhering to the rules of the road seems to be optional in many cases in South Africa. In the case of speeding, as an example, the adherence to road rules are randomly checked by the traffic officers and violations are dealt with, largely in the form of fines, which are to be paid subsequently.

Pro-active collision avoidance driver competencies such as advanced driver training is dependent on the attitude and requirements of the individual driver, unless prescribed by company rules. Collision avoidance technology in a vehicle, such as park distance control, cameras, ABS, EBD, lane change assist are vehicle manufacturer's self-imposed requirements, which maybe a requirement by some countries. In some countries, failure to produce a safe car could result in class action suits against the manufacturers, which could have a significant negative impact of a brand. Just about none of these controls are available in the taxi industry in South Africa.

Consequence controls in a car such as airbags and crumble zones are requirements set by manufacturing bodies and it has different requirements throughout the world. Vehicles used on public roads are supposed to be roadworthy and from a safety perspective, only the wearing of seatbelts in certain types of vehicles are prescribed by law in South Africa.

In the case of an accident by a taxi in South Africa, which results in multiple injuries and fatalities, which happens too regularly, it becomes news, not headline news. These accidents invariably happen when an over tired driver, pushed for turnover, drives an un-roadworthy vehicle, probably disregarding the rules of the road, takes another chance and this time it fails.

The victims are buried, the families are distressed, bread winners may be lost, some passengers may be maimed, and others are lucky to escape unhurt. The driver may get a fine, but it is not inconceivable that he or she would be back on the road in due course carrying on with the same old habits.

There may even be an outcry by the local authorities and at times even an outcry by the government which fades fast. If the locals complain about a driver's recklessness, they won't have a lift the next day.

Other than sharing the intent that all drivers must comply with the traffic rules, there is no government requirement that subsequent to taxi fatality that all drivers must be retrained, all taxi services be stopped to facilitate the retraining, all un-roadworthy taxis be scrapped, new on-board technology for collision avoidance be introduced etc. The same old just continues and it is business as usual.

Therefore, the society has come to accept that riding a taxi is just part of life and the potential negative consequences has become part of the South African culture.

In 2016 there were 14 071 road accident related fatalities in South Africa. (RTMC 2016) The equivalent number in Australia was 1290 fatalities during 2016 (Bitre 2017).

To the contrary, if an accident which results in multiple fatalities occurs underground, while transporting employees, the mine will be stopped; the driver probably be relieved of his duties and lose his or her job; the manager and the company may be fined; significant retraining to be done by all the drivers and new technology expected to be introduced to prevent a reoccurrence.

The original equipment manufacturers could be bought in and in a tripartite process be established to find a solution. It would probably become an industry strategic safety thrust; case studies will be done, and papers written about the remedial measures. Significant cost will be associated with this mishap; the company and mining industry image will be tarnished; the unions could even strike, and investors could become reluctant to be further associated with the company concerned.

4.2 Safety is a business imperative

This exaggerated rendition of similar accidents in a different context and varying society and government expectations, points out that the consequences of mishaps for the mining industry is enormous.

The Chamber of Mines of South Africa (COM) estimated that the Department of Mineral Resources (DMR) Section 54 instructions to stop mines or part thereof, as a consequence of safety related transgressions, cost the industry some R13.6 billion between 2013 to 2015. (Moneyweb 2017)

There are therefore compelling reasons for a company to mine safely and to regard it as a moral and business imperative to ensure sustainability.

5 Is 'Zero Harm' Possible?

The society at large is increasingly expecting that for mining to be sustainable, the safety performance must improve dramatically. It has never been acceptable to kill somebody in the course of their work. Society's expectations and the mining industry's response has moved closer over time the mutual vision of 'zero harm' was adopted although it has not been achieved as yet.

Will 'zero harm' ultimately be reached? Probably not as mining is inherently dangerous, and people make mistakes. The focus of the mining industry is to make the mining process safer and for people to make fewer mistakes.

5.1 Mining context

Mining is not a steady state operation and is very dynamic as the environment is constantly changing and it is therefore an abnormal normal environment. The mining method employed such as conventional drilling and blasting, mechanisation and automation largely dictates the potential safety outcome. This outcome is fine-tuned by the interface between humans, machinery and the environment created.

In the South African mining industry, there are a significant number of elements that creates the context within which miners are expected to operate. It includes mature mines, pillar mining, mining at depth, heat, significant underground travelling distances, and seismicity, amongst others.

The mining method, taking into consideration the inherent characteristics of the orebody, is the singular most important predictor of the safety outcomes as everybody working in the resultant environment will be exposed to the risks created by design.

There is a direct relationship between energy used to mine and the potential consequences of it used in a positive or negative manner. In mining the amount of energy used is invariably significant to turn ore reserves ultimately into a saleable product.

Mining involves intruding into an inherently high-energy space and environment. The very rocks surrounding the excavated openings are charged with latent energy. The way how to manage this latent or potential energy has a lot to do with safety.

The laws of thermodynamics and entropy mean that latent energy stored in the rocks surrounding any excavation is looking for a way of release. The very environment in which mining takes place is charged with energy and any irresponsible behaviours could result in an unwelcome release of that energy. It is therefore no surprise to conclude that the safest mining is no mining at all.

5.2 Risk management

There is no single answer to achieve 'zero harm' as the overall efforts necessary to ensure that the residual risks created by deep level, hard rock mining is enormous and complicated. Continuous improvement is required in order to move closer to achieving 'zero harm'.

The South African mining companies in general have put in significant efforts to reduce the residual risks. The mining industry has renewed their efforts to apply known solutions better in the prevailing circumstances.

Certain practices were stopped, such as mining in seismically active areas and new ones introduced such collision avoidance technology in horizontal transport underground. This has resulted in improved safety results. However, more of the same can only do so much and something new is required to create the step change in safety performance.

Risk management processes has not changed in the past 80 or so years. The application methodology and monitoring thereof has become more sophisticated over time. Unfortunately, if the collective wisdom by all stakeholders fails to identify the risk, nothing else matters. What will be will be.

Paper solutions are patient, but the reality is that the mining environment is dynamic, and conditions changes continuously. The company leadership should cater for the possibility that the requirements to achieve 'zero harm' will not always be executed perfectly. This resultant gap is where incidents occur that can cause harm.

If a risk is not identified upfront, the rest of the available potential controls are all irrelevant. However, if the risk has been identified and the controls are inadequate, the correct application thereof could still result in an incident.

People are exposed to the real environment and will have to take these dynamics into consideration to make informed decisions on the spot. The result of these decisions will determine whether 'zero harm' is achieved, or not. The perfect human being has not been found as yet and the rest of society is still fallible and has the potential to make mistakes.

If the risk was identified and the controls are adequate, behavioural safety can make the difference between success and failure when the individual decides to apply the intended risk controls or not.

5.3 Inadequate risk controls

Fatalities will not occur if the risk controls in place were adequate and applied perfectly. If one considers the 73 fatalities that occurred in the South African mining industry during 2016, how many of the fatalities were due to inadequate controls being in place?

Some generalities are bandied about by the individual companies that 70-80% of accidents are due to human behaviour, which normally refers to the behaviour of the individual that was injured. This means that the risk controls were in place but not adequately applied which resulted in harm.

The converse must then be true that 20-30% of incidents had inadequate risk controls in place, designed by the company leadership. That being the case, is this oversight due to mistake or is it a violation? Ignorance is bliss, but unacceptable in mining.

The residual risk is the interface by the individual to this environment by a prescribed working methodology using prescribed equipment. The onus of ensuring that this interface can conceptually be safe rests with the company's leadership to determine policies that will create an enabling environment to achieve the lowest possible anticipated residual risk. It is only by the perfect application of this strategic intent that the real residual risk will equate to the planned residual risk.

5.4 Seismicity

If mining takes place in seismic areas, as an example, and the industry acknowledge that further research is necessary to manage the risks better, it means that inadequate knowledge is currently available.

If mining in seismic areas is continued in the meantime, it is done knowingly that the controls in place are probably inadequate. In this instance, the leadership behaviour could be classified as a wilful violation as it is a known unknown. This in turn becomes a moral debate and no longer a technical debate.

5.5 Safety by design

The conceptual level the focus of the South African mining industry is to remove people from risk by changing mining methods and by introducing new technology. This approach has had some success, but its full potential is still to be achieved. The primary reason for this is that most of the current mines operate mainly using conventional methods which continuous to expose people to risk.

Mining is dangerous, and it is not possible to eliminate all risks completely, as ultimately there is a dependence on human behaviour. Humans are not perfect, and mistakes do happen. However, 'zero harm' is an important mindset and goal that should be relentlessly pursued, and the safety culture be enhanced continually.

The law makers, mine designers, process and procedure designers, equipment manufacturers, trainers and individuals regard safety as a priority and a non-negotiable. There are probably no individuals who has the wilful intention to design unsafe conditions. At worst, in isolated cases it is possible to make a mistake, primarily due to insufficient knowledge, that a design is inadequate.

Can it be true that if there is an accident, that in most cases, the response at company level is that the individual concerned has erred? It comes down to a perceived wilful violation by the individual as he or she was trained to do the job properly but did not do what he or she was supposed to do, for whatever reason.

Is it possible that the prevailing conditions was such that the individual concerned made a mistake in that what was trained was not quite applicable to the situation encountered? How many people would wilfully violate an agreed process and specifically have the desire to be injured or killed?

5.6 The residual risk is still too high

When risk controls are devised, it is envisaged that when it is perfectly applied, the residual risk will be acceptable. The tolerance for non-adherence of the control requirements is minimal in the instances where the potential energy that the individual is exposed to is beyond human tolerance.

The unintended release of energy such as a fall of rock, blasting, fall from height, in the way of equipment, misuse of energy normally exceeds human tolerance and results in harm. These releases of energy, where an individual could potentially be exposed to, invariably does not fail to safe, as would normally be the case with electricity that has a trip switch.

Maybe the consequence of a 'small' non-adherence to agreed procedures is such that the consequences are disastrous. Surely one must then query whether adequate controls are in place to deal with such situations.

It can therefore be concluded that the residual risk could be too high and should be engineered such that the consequences of potential mishaps are minimised. It is inappropriate to place such a significant dependence on the behaviour of individuals in the cases of accidental energy releases beyond human threshold.

5.7 Behavioural safety

When risk controls are formulated, it caters for a broad range of possible eventualities and it is perceived that the residual risk will be within the acceptable risk tolerances. This will only be achieved by the perfect application of the prescribed rules.

Danger is real, but it is the individual's interpretation of the perceived future residual risk that will determine his or her actions. It is possible that an individual could find him or herself in a situation where there is no ready-made solution available and that an on the spot solution needs to be made to deal adequately with the risk at hand. If the outcome is misinterpreted, the risk mitigation will be inappropriate which could result in harm.

It is for this reason that a significant amount of technical training is imparted to the individual as an enabler to envisage potential solutions of unanticipated situations. This training is augmented by behavioural safety training to equip the individual with the necessary emotional intelligence to make informed decisions to avoid harm.

6 Towards Achieving 'Zero Harm'

Research was done to determine what actions were taken to improve safety in six South African deep level mines using publically available information for the period 2007-16. All the mines were GRI compliant.

The conclusion was that the acceptance of global and national societal expectations; the embracing of these requirements; the creation of an enabling environment; the real reduction of risk in most cases and being held accountable, resulted in the reduction of fatalities in the South African mining industry over the past decade.

Emerging themes were observed which enabled the companies to create sustainable safety outcomes. This high-level approach could be adopted by the relevant companies and organisation in a country to improve the safety performance.

Most importantly, society norms and expectations need to be articulated consistently through various institutions, organisations and actions to enable the mining industry leaders to clearly understand what is expected from them. Other major themes include:

(1) The country/ company's leadership to take heed of the broader society's expectation that mining must take place safely;

(2) The country/company leadership to institutionalise the approach to 'zero harm' by articulating the strategic intent and to create an enabling environment to achieve 'zero harm';

(3) Systemise all the activities required to achieve 'zero harm';

(4) Humanise the systems to transfer relevant knowledge and establish behaviours of all individuals throughout the organisation to enable the achievement of 'zero harm';

(5) Operationalise the safety management system by removing or reducing the risk to acceptable levels in the workplace;

(6) Monitor and manage the company safety outcomes;

(7) Embrace continual improvement.

7 Summary

There is no one specific action that improved the safety performance in a mature mining industry in South Africa. It requires a combined effort by all stakeholders including, companies, government, organised labour, relevant organisations and employees, aspiring to achieve 'zero harm', to turn the vision into action.

National and international society expectations were acknowledged and turned into actions by the mining industry to improve the safety performance. It included:

(1) A tripartite mining industry safety game plan facilitated by the Mine Health and Safety Council of South Africa was developed and re-focused bi-annually, where necessary;

(2) Measureable industry safety goals was determined and agreed to by the tripartite alliance which includes, government, organised labour and mining companies;

(3) The mining industry is being held accountable for their safety performance by shareholders, organised labour, the Department of Mineral Resources and by the company boards;

(3) The Chamber of Mines of South Africa is acting as a collective enabler for industry's safety initiatives;

(4) Guidance safety principles and processes provided by the International Council on Mining and Metallurgy is used;

(5) The mining industry established a co-operative Chief Executive Officer's working group to reduce fatalities by initially focusing on specific initiatives such as fall of ground and underground horisontal transport. The results were highly successful;

(6) Believing that 'zero harm' is possible, despite it being business in progress;

(7) Commitment by company boards, leadership and employees to achieving 'zero harm';

(8) Consistently articulating the strategic intent to achieve 'zero harm';

(9) Institutionalise 'zero harm' as an outcome through company values, policies, procedures and governance processes and definite plans to achieve it;

(10) Manage the interdependencies of all requirements to achieve 'zero harm' by systemising it. (Plan, do, check, act.) It includes all aspects of the zero-harm approach including enhanced risk management methodologies, international certification, audits, reviews, investigations, critical control measures, information systems, contractor management, etc;

(11) Spend significant efforts on enabling employees to achieve 'zero harm' by creating a safety culture focused on 'zero harm'. Some of the aspects included involvement by all relevant parties; safety culture transformation, wellness of the workforce; significant training; enhanced behavioural safety programmes; fatigue management; campaigns, leadership training programmes, stakeholder relationships, women in mining, absenteeism, incentives, disciplinary processes, etc;

(12) Operationalise the collective efforts by the 'real' reduction or elimination of risk. It includes reviewing and changing mining methods, technology introduction, mechanisation and automation, seismicity, rock bolting, netting, collision avoidance in horizontal transport, fire

prevention, maintenance of infrastructure, enhanced secondary support, amongst others;

(13) Measure and manage the safety performance at company and industry level;

(14) Aspiring to continual improvement.

8 Conclusion

It is acknowledged that the South African mining industry has still got significant room for improvement in its safety performance. However, the South African mining industry has a collective know how which can assist other countries to improve their safety performance.

Acknowledgement

This research is a summary of the major findings for a PhD (Mining Engineering) at the University of the Witwatersrand, Johannesburg, South Africa. Thank you to the University for allowing me to publish this work and for making it possible to attend SOMP 2018 in Beijing, China.

References

Bitre, 2017. Road deaths in Australia. https://bitre.gov.au/publications/ongoing/road_deaths_australia_annual_summaries.aspx.

de Jager, E.J., 2015. Safety and Health Leadership and Human factors. Proceedings of the 26th Conference of the Society of Mining Professors. June 21-26 June 2015. TU Bergakademie Freiberg, Germany.

Hocking, A., 1997. Court of Kings. The story of South Africa's Association of Mine Managers. Standard edition ISBN 0-620-20943-7.

Leon Commission of Inquiry report, 1995. www.dmr.gov.za/other-reports/...reports/483-leon-commission-reportvolume-1.html.

Moneyweb, 2017. Suing-over-section-54-is-this-a-solution? https://www.moneyweb.co.za/moneyweb-opinion/suing-over-section-54-is-this-a-solution/.

RTMC, 2016. Cost of Road Crashes in South Africa. https://www.arrivealive.co.za/documents/Cost-of-Crashes-in-South-Africa-RTMC-September-2016.pdf&usg=AOvVaw1ct-xO2REnh2RD5ynQ9z42.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 99-104
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Social Dimension of the Successful Development of Mining Projects – a Focus on Artisanal and Small-Scale Mining

Nicole Smith[1], Juan Lucena[1], Jessica Smith[1], Oscar Jaime Restrepo Baena[2*], Gustavo Aristizabal[2], Alejandro Delgado[2]
[1] Colorado School of Mines, USA
[2] Minerals Institute – CIMEX, School of Mines Universidad Nacional de Colombia

Abstract: In Colombia, Peru, and other Latin American countries, different scales of mining activity usually develop in areas with high social, economic and environmental complexity. Artisanal and small-scale mining (ASM) is one mining sector that continues to grow and pose both opportunities and challenges for governments, industry, communities, and academics. While the analysis of economic and environmental aspects of ASM has well-developed technical, scientific, and normative tools, the social dimensions tend to generate great uncertainty. The models and instruments for the study and management of ASM activities and its social components must address – at the earliest stage of development – the diverse expectations, groups, and complicated interactions between the various actors involved in these systems. Based on the dynamics and socio-economic diversity of the mining-sustainable development relationship, an approach has been proposed that addresses the contributions that ASM can make to benefit territories and rural communities. However, current in-country situations present major challenges, which hinder already complex scenarios. Thus, efforts should be directed at building trust to strengthen a multi sector dialogue where various actors converge including: institutions (local, regional and national), communities, associations, companies and academia, especially with the purpose of finding inclusive solutions in which all stakeholder needs are identified and addressed. Understanding the conditions that may contribute to the development of more effective relationships and the achievement of results in accordance with the contexts in which mining development takes place is an issue of vital importance. The School of Mines of Universidad Nacional de Colombia, through the Institute of Minerals – CIMEX, wants to contribute to these discussions and initiatives. For this reason, we advance the project "Implementation of sustainable technologies for the recovery of environmental liabilities and the elimination of mercury use in mining artisanal gold in the municipality of Andes - Antioquia," which was presented in the framework of the National Call for Solidarity Extension - 2016 Universidad Nacional (NU) of Colombia: Social innovation for peace. Also, the Colorado School of Mines received a grant from the National Science Foundation (NSF) of the United States through the program Partnerships in International Research and Education (PIRE) for the project "Sustainable Communities and Gold Supply Chains: Integrating responsible engineering and local knowledge to the design, implementation and evaluation of solutions for artisanal mining in Latin America."

Keywords: artisanal and small-scale mining (ASM), mining-sustainable development, mining communities, social innovation, humanitarian engineering

1 Introduction

The lead institution, Colorado School of Mines (CSM), is one of the world's premier engineering universities with a specialty in natural resource production and protection, on the one hand, and the country's greatest concentration of research and education on engineering, social justice, and social responsibility, on the other.

As one of four armed forces academies, the US Air Force Academy (USAFA) educates engineering student-cadets through a combination of engineering, humanities and social sciences (HU/SS), and leadership courses with the goal of producing leaders who will serve the country in many areas, including humanitarian missions and the construction of sustainable civil and environmental systems.

The University of Colorado at Boulder (CU) houses a world-class environmental studies program with a strong commitment to applied research with communities, the Governors' Climate and Forests Task Force (GCF), and the Mortenson Center in Engineering for Developing Communities. The Universidad Nacional de Colombia's Facultad de Minas (FdM) was the first school of engineering in Colombia and has been working with gold miners for more than 130 years. Their faculty members have an extensive knowledge base in mining and metallurgy complemented by a Center for Social Responsibility in Mining. The Corporación Universitaria Minuto de Dios (UNIMINUTO) has a Social Innovation Science Park

* Corresponding Author: Oscar Jaime Restrepo Baena, Email: ojrestre@unal.edu.co, phone: +57 3007829270

DOI: 10.15273/ijge.2018.03.017

dedicated to delivering social justice and community development to the most vulnerable communities.

With deep connections in Peru and Colombia, the Alliance for Responsible Mining (ARM) sets standards for responsible ASGM and supports and enables producers to deliver "Fairmined" certified metals and minerals through economically just supply chains.

In Peru, the Pontificia Universidad Catolica de Peru (PUCP) is the oldest and most prestigious private university in the country, dedicated to teaching and research that contribute to social justice and national development and their relationship to mining. The University of Technology and Engineering (UTEC) maintains state-of-the-art laboratories for engineering analyses, and its faculty members contribute expertise in mining engineering and the mining-water nexus.

2 Background

Artisanal and Small-Scale Gold Mining (ASGM) is widespread in mineral rich developing countries and is credited with producing about 20-30% of all the extracted gold in the world used in jewelry, finances, electronics, aerospace, and medicine. The ASGM sector is extremely diverse in scale, legality (Rolston 2013), demographics, and seasonality, and definitions vary according to who is defining the sector and for what purpose (Ottinger 2013). Most generally, ASGM includes activities that contrast corporate led large-scale mining activities by requiring relatively low capital inputs and labor-intensive processes to exploit marginal or small deposits. The low cost of entry into ASGM and the increasing need to diversify rural livelihoods impacted by climate change, processes of deagrarianization, and increasing population pressures means that ASGM is a critical livelihood strategy for millions of people worldwide (Smith and Tidwell 2016). However, it poses significant health and environmental hazards at local and global levels. ASGM is one of the largest contributors to deforestation and atmospheric mercury pollution in the world, resulting in widespread land, water, and air quality harms for rural and indigenous communities. In the Amazon Basin, one of the world's most bio-diverse ecosystems, ASGM results in large-scale deforestation, air and water contamination, and human health risks, especially from the mercury used by miners to process the ore (Rajak 2011).

Governments, industries, and development agencies currently struggle with regulating and minimizing the negative impacts of ASGM while also supporting rural livelihoods (Wisnioski 2012). Few efforts to develop more sustainable ASGM technologies and practices have achieved longevity, mainly because they were developed for miners rather than with miners and affected communities (Kirsch 2014). Most current interventions treat technology as a panacea for solving ASGM's many problems. These do not consider the full socio-economic and ecological context of why and how people choose to mine, nor do they integrate the knowledge miners and communities already possess about hazards and mitigation strategies and their own desires for sustainable livelihoods into proposed solutions. The goal of this research is to reverse this trend. As studies of adoption or appropriation of technology have shown, communities adopt technologies long-term when they are involved in problem definition, solution generation, and goal setting from the beginning of a process (Layton 1986).

The practical and academic challenges posed by ASGM are inherently international in nature, linking producers in the developing world with suppliers and consumers around the globe, hence requiring an international collaboration to be addressed (Bakker and Bridge 2006). Our project focuses on Colombia and Peru, two of the top four biggest exporters of gold to the US. In Colombia, approximately 70% of the national gold production comes from ASGM, while in Peru only 15% of the gold comes from ASGM; however, because of the vast amounts of gold produced by large-scale industrial mining in Peru, the proportion of gold coming from ASGM in this country is significant. The characteristics of ASGM communities and the unique challenges they encounter (e.g., geography, political, economic, etc.) present different ASGM scenarios worth comparing in order to provide lessons for a variety of contexts in the Andean and Amazonian regions. The urgency of the ASGM challenges in Colombia and Peru make our project vitally important not only for scholarly communities, but also for the people who practice and are impacted by ASGM, local and national governments, the mining industry, and development networks (Cech 2014). Over 400,000 people work in the ASGM sector in Colombia and Peru, providing rural communities with employment, a source of identity and cultural belonging, and increased participation in schooling and business activities. ASGM activities will continue to increase. Since our pre-proposal, the Peace Accords between the leftist guerrillas and Colombian government have been ratified by the Colombian Congress. As thousands of guerilla fighters leave the mineral rich mountainous regions, the ceasing of conflict is drawing many more thousands of people to engage in ASGM. Although PIRE participants will not be going to these zones of peace-building (zonas de distension), the lessons learned from this project will contribute to the ways in which local governments and universities can work with ASGM communities in these zones in the future.

Each country's evolving governance structure for ASGM will support our project and its dissemination to key stakeholders in government and civil society. Both Peru and Colombia are signatories to the Minamata Convention, demonstrating their commitment to eliminating mercury use in ASGM. Both governments recognize the ASGM sector and have made numerous attempts to formalize and regulate it (as described below). In both countries, however, only a small proportion of miners have completed the formalization process because of a lack of capacity among government agencies to oversee and regulate the sector, the absence of miners and ASGM communities in designing processes and techniques, and complex bureaucratic formalization procedures. Our project will support ongoing formalization efforts by bringing together academic faculty and students, government officials, nongovernmental (NGO) workers, and the private sector in research and practical applications that address the socio-technical dimensions of ASGM systems.

ASGM thus presents crucial international challenges that are simultaneously technological, social, economic, political, geological, and environmental, requiring research that transcends disciplinary silos and reaches across national borders. Our project breaks new ground by developing an integrated, interdisciplinary, community-centered approach to addressing the overarching research question: How do the social, environmental, and technical dynamics of ASGM systems in Colombia and Peru intersect and influence one another, posing both risks and opportunities for miners, communities, and environments? ASGM systems encompass technologies, practices, and social institutions. Grounded in the unique contexts in which they take place, these systems present risks and opportunities that are differently perceived and acted upon by diverse actors, from miners to environmental activists. To design, implement, evaluate, and ensure the long-term sustainability of ASGM, therefore, it is necessary to have a comprehensive understanding of these systems, their interrelationships, and these actors. Our project will provide the first opportunity for faculty and students from the US, Peru, and Colombia to work together directly to develop socio-technical innovations, combining improved technologies and techniques with new social organizations and networks to make ASGM cleaner, safer, and more sustainable (Davis and Franks 2014).

3 Research Sites

For the field research, the team has selected comparable, yet distinct contexts for investigating how ASGM relates to the larger social and environmental dimensions of each country. This presents illuminating comparative studies for our research and unique opportunities for our students to learn how to define and provide solutions in differing contexts. In addition to the comparison of Colombia and Peru, we have selected two distinct ASGM sites in each country. In Colombia, the team will conduct research in each of two primary ASGM regions of the department (state) of Antioquia. Antioquia is the leading producer of gold in Colombia, and has a long-standing tradition of gold mining. It has the strongest institutional framework for governing ASGM, whereby the Governor's office can decide on mining title applications. Nevertheless, it holds the reputation for being the world's largest mercury polluter per capita from ASGM (Ferry and Limbert 2008). In addition to ASGM activities, there are two active gold mines and several others under development that are owned and operated by international junior mining companies. Because Antioquia holds some of the most promising gold mining deposits, it has experienced waves of in-migration by miners from other departments of Colombia, as well as from other countries such as Brazil (Li 2011). In northeast Antioquia, the research team will focus on artisanal and small-scale miners who are mining hard rock deposits in underground workings, whereas in the Bajo Cauca Region, the team will focus on miners engaged in alluvial mining. Members of the project team have long-standing relationships with ASGM communities, and UNIMINUTO, one of our partners, has extension sites in these areas that will be used to host PIRE project activities (see the letters of support).

In Peru, the research team will focus on one ASGM site in the department of Arequipa, where underground, hard rock mining takes place, and one site in the department of Madre de Dios with alluvial mining. In the department of Arequipa, many small-scale mining operations are located in former large-scale mining sites and the area is home to extensive ASM processing centers that purchase ore from mining operations located up to 1100 km away. Because of the arid climate characteristic to this region, tailings dust and mercury vapor pose serious threats to human health and the environment. In Madre de Dios, infrastructural developments such as the Interoceanic Highway connecting the coasts of Brazil and Peru have prompted an influx of migrant miners, expanding the mining frontier (Riley 2008). Massive deforestation has occurred in the area and the riparian landscape has been severely degraded. Members of the research team are currently working in Arequipa and Madre de Dios, and the governor of Madre de Dios is a member of our partner, the University of Colorado's Governors Task Force on Climate Change (O'Reilly 2016).

4 Plan for Educational Activities and Research

Closely integrated with the research dimensions of this project, the proposed educational activities will contribute to the development of a global engineering workforce through interdisciplinary collaboration in a very relevant yet invisible problem that implicates consumers around the globe. US faculty and student participants will work with their science and engineering counterparts and with artisanal and small-scale gold miners and communities in Colombia and Peru to research, define, design, implement, and monitor socio-technical innovations that improve mining and processing systems, decrease and mitigate environmental and human health risks, and contribute to more sustainable livelihoods in Latin America. The main expected educational outcomes are socio-technical global competency, situated learning, and broadened participation in engineering. In addition, our unique partnership between CSM and USAFA will allow us to test the efficacy of two different models for engineering education for achieving those outcomes.

4.1 Socio-technical global competency

This project will create International research and teaching experiences for US graduate students and faculty (especially early career researchers) and problem definition, solution, and design experiences for undergraduate students in socio-technical settings. Beyond basic language and cultural competency, faculty and students will learn how to understand engineering problems as socio-technical in different engineering and community settings through highly integrated classroom, project-based, research, and field experiences both in the US and abroad. The expected outcome is socio-technical global competency defined as having the knowledge, skills, and attitudes to research, define and solve problems in different international settings. Knowledge understands how engineering problems and research questions as socio-technical are shaped by the historical, cultural, economic, and physical dimensions of a place. Skills are learning to define and solve problems and research questions with perspectives different than their own. Attitudes are the desires to continue engaging other expert and non-expert perspectives, working abroad, and serving communities after graduation.

4.2 Situated learning

Our project will create new knowledge of how different forms of a) social relations (graduate or undergraduate; expert or non-expert; CSM, USAFA or CU; US or non-US, etc.); b) pedagogical strategies for engineering problem definition, solution, design, and research; and c) different contexts (CSM vs. USAFA; US vs. Colombia vs. Peru) affect faculty and student learning. We will explore situativity – the central role that physical and social context of an educational environment plays in learning – in different institutional, national, and classroom contexts. Specifically, we will assess the differences between a) modules (e.g., to be given to USAFA students who cannot complete full courses related to ASGM) and courses (to be given to CSM students); b) in-classroom research-question and problem definition (PIRE grad seminar and undergrad courses) and in-field experiences with multiple stakeholders (summer field sessions); and c) faculty-led (PIRE seminar) and student-led (Projects for People) contexts.

4.3 Broadened participation in engineering

Engineering students are underrepresented among STEM students studying abroad, and students who are ethnic and racial minorities or come from low-income backgrounds are especially underrepresented in engineering study abroad programs as well as engineering as a whole. Our project will make an explicit, concerted effort to recruit students from underrepresented groups in engineering. We are familiar with the challenges that these students face in engineering: two of the PIs have led research and education efforts to diversify engineering, especially by working with low-income students, and are active participants in the CO-WY Alliance for Minority Participation, which provides us with additional funding (up to $10,000 per year) for minority students to travel and engage in international research. Because explicit ties to community engagement and social justice in engineering, as present in this PIRE project, have lead to higher interest and retention of underrepresented groups in engineering we hypothesize that participation in the PIRE project will help broaden participation in engineering.

5 Research Advances through International Collaboration

The synergy of partners from US, Colombian, and Peruvian universities provides a robust platform for achieving research and educational outcomes in all the areas above. The participating institutions complement each other with their different disciplinary strengths and their expertise along the distinct stages of gold mining, processing, and remediation, and engineering education. This proposal will bring our existing ASGM research into direct collaboration with the Facultad de Minas' innovative research and technology development on mercury-free gold processing, Uniminuto's unique tools for developing economic opportunities in marginal communities, CU's expertise in social-ecological landscape changes and jurisdictional programs for reducing emissions from deforestation, PUCP's and UTEC's involvement in ASGM in Peru, USAFA's and CSM's expertise in site remediation engineering, and CSM's unique program in humanitarian engineering. Together this team will transform ASGM research to be truly international, inter-institutional, community-based, and interdisciplinary.

Faculty from the lead institution of the Colorado School of Mines (CSM) created the country's first Humanitarian Engineering (HE) program in 2003, whose students now learn about the intersection of mineral extraction and community development. The CSM faculty are internationally recognized for their research and teaching in ASGM, community-based research, engineering education, corporate social responsibility, environmental remediation, mining, and geochemistry. They have a history of positive collaboration with the other project partners, including those in Colombia and Peru and of securing funding for ASGM-related projects. J. Smith and N. Smith are both anthropologists who study mining and mining communities, having over 20 years of combined experience conducting research in both large-scale mines and ASGM communities. In particular, N. Smith is PI on an U.S. EPA project supporting an interdisciplinary team of undergraduate engineering students to design more sustainable ASGM mineral processing systems in Suriname. She is also PI on a US Dept. of State funded project assessing the effectiveness of mobile training units for more sustainable ASGM livelihoods in Bolivia and Peru. This includes collaborative activities with the two Peruvian universities included in this proposal and ARM, providing a beginning framework for understanding and working with miners and communities. Lucena has been studying engineering cultures, and engineers working with communities in multiple parts of the world for more than 20 years. Holley has a mining industry background and has orchestrated collaboration between small and large-scale miners while leading gold exploration teams in South America. Holley has published on the geochemistry of mercury contamination from ASGM, geological criteria for hard rock gold exploration, and public participation in mining. Holley is currently working on related projects, including one developing innovative methods for gold exploration (NSF, PI) and another evaluating collaborative mining company-community mine design as a tool for managing social and environmental risk

(Gates Foundation, PI). K Smits is currently teaching and researching site remediation in the developing world.

The United States Air Force Academy (USAFA) Department of Civil & Environmental Engineering brings faculty expertise in hydrology, sustainability, and engineering education plus student cohorts, who, during semester- to year-long independent studies, will develop their understanding of the complex nexus of technical, ecological, and cultural factors affecting ASGM in Latin America. Specific to the project, T. Phelan has expertise in water treatment and site remediation, environmental fate and transport, and construction in developing environments. USAFA also hosts a Field Engineering and Readiness Laboratory where its cadets have the opportunity to learn the skills necessary to implement engineering solutions in the field and have access to the U.S. Department of Defense High Performance Computing Network and water/wastewater, hydraulics, and geotechnical engineering laboratories.

The University of Colorado at Boulder (CU) will provide environmental studies faculty with expertise in using household surveys, GIS data, and remote sensing to promote sustainable livelihoods and assess perceptions of risk. Hartter is a geographer who specializes in the study of human-environment interactions in communities across the developing world. For the last 15 years, he has directed projects involving interdisciplinary teams of scientists, engineers, students, professionals, and stakeholder groups focused on the impacts of land conversion, resource use, and global change on rural livelihoods. CU also hosts the Governors Climate and Forests Task Force (GCF) network, where Scanlan-Lyons serves as the Project Director. The GCF focuses on reducing emissions from deforestation and establishing lasting frameworks for low emissions development, including those related to ASGM. The GCF has members in 35 states and provinces from nine countries (Brazil, Indonesia, Peru, Mexico, Colombia, Nigeria, the Ivory Coast, Catalonia, and the US). As a key actor in facilitating the exchange of experiences and lessons across states, provinces, and municipalities and supporting processes for multi-stakeholder participation and engagement, the GCF will be instrumental in the dissemination of lessons learned across the countries of Peru and Colombia and later to other countries dealing with the environmental impacts of ASGM.

More than an entry point to and contacts in their countries, the four non-US universities involved in this project provide: a) bilingual teaching and expertise related to ASGM, as all faculty involved can teach in English; b) relevant knowledge of the history and current state of ASGM in their countries, including what has been tried, worked, and failed to make ASGM more sustainable; c) key and relevant lab, classroom, and library facilities that US students and faculty can use; and d) in-depth connections to local governments and associations related to ASGM (Davis and Franks 2014). In Colombia the Facultad de Minas de Medellin at the Universidad Nacional de Colombia (FdM), will contribute their teaching and research expertise in mining and metallurgy including: a) techniques for gold mining and extractive metallurgy; b) community engagement and technical support to artisanal miners; and c) sustainability in mining. FdM houses a Center for Social Responsibility in Mining and has been working with miners from Colombia's gold regions for more than 130 years, providing links between project partners and communities. Our main country lead in Colombia, Prof. Oscar Restrepo has expertise in both mining and metallurgy and experiments with mercury-free technologies and techniques in ASGM communities based on gravitational techniques that separate precious metals from accompanying minerals. These technologies also include training mining communities to build, operate, and maintain equipment with the goal of improving community revenues without using mercury. FdM works with national and state governments in securing, managing, and analyzing data related to ASGM and has agreed to support this project by providing its long-standing contacts with the Ministry of Mines of Antioquia and ASGM associations. FdM has received funding from the Colombian government for a reciprocal project to this PIRE project titled "Sustainable Technologies to Eliminate Mercury in ASGM in Antioquia." ($18,000)

The Corporación Universitaria Minuto de Dios (UNIMINUTO) has a vast and effective network of education/training and social innovation programs aimed at Colombia's poorest communities. For this project, their Social Innovation Science Park supports community-based social innovation projects and ventures by connecting miners, as social entrepreneurs, with public and private enterprises to enhance communities' capacities to generate new forms of revenue that will incentivize them to use mercury-free techniques. Its faculty involved this project has extensive expertise in social innovation, academic administration, and the development of community-based green business. UNIMINUTO has six campuses in Antioquia (our main region of operations in Colombia) with programs to educate communities about the advantages of mercury-free mineral processing and entrepreneurship.

The Alliance for Responsible Mining (ARM), global leader of responsible ASGM, has strong connections with miners and communities in Peru and Colombia. They will facilitate relationship building among the project team and miners and communities. Specifically in Antioquia, ARM has benefited more than 30 ASGM organizations through the processes of formalization, capacity building, safety education, health, and mining. ARM also facilitates transfer between experts and communities of geological, geotechnical, metallurgical, and environmental knowledge.

The Pontificia Universidad Catolica de Peru (PUCP), the oldest private and most prestigious university in Peru, is dedicated to teaching and research that contribute to social justice and national development. Its faculty from the Department of Mining Engineering and the Department of Geography will contribute their expertise in geology and mining, metallurgy, chemistry of environmental recovery of metal substances in mining water, geospatial analysis of socio-environment dynamics in rural communities, and social networks of ASGM practices. As the only ABET (American Board of Engineering and Technology) accredited Mining Engineering Department of Peru, PUCP's Mining Engineering Department has extensive experience working with ASGM communities in the Arequipa and Ayacucho Regions. Inside such projects, faculty and students advised ASGM communities in the topographic location of claim boundaries, safety in mining practices, spatial distribution of mining operations versus domestic uses of the locality, and technical measurements for extraction. PUCP's faculty have close relationships with the Sociedad Nacional de Minería Petróleo y Energía (SNMPE—The National Society for Mining Oil and Energy), local mining companies, and the Sociedad Nacional de Mineria en Pequena Escala (SONAMIPE—The National Society of Small Scale Mining) (see letters of support).

In Peru, faculty from Environmental, Mining Engineering and the Center for Water Research and Technology (CITA) at the University of Technology and Engineering (UTEC) will contribute their existing research on ASGM in Colombia and Peru, including knowledge of the mining process and expertise in the mining-water nexus. UTEC will contribute in Mining (Pareja) and Environmental and Water issues (Abad). UTEC's CITA is developing expertise on hydrogeology, hydro climatology, tele-detection and remote sensing, and hydrochemistry; each of these research areas has a state-of-the-art laboratory. CITA has an ongoing project with SNMPE to monitor two watersheds, one related to the mining-water nexus. UTEC's scientist are measuring water quantity and quality at these watersheds and implementing community-based monitoring activities. Contributions from UTEC include logistics in all Peruvian regions, access to laboratories, and research-oriented collaboration.

6 Conclusions

PIRE projects are highly interdisciplinary, international, inter-institutional, and intergenerational in nature, hence extremely complex to manage. To ensure success, the proposed project will be founded on well-established best practices of collaborative research based on the following principles: trust, commitment, ability, leadership, transparency, clarity, communication, and monitoring. During the pre-proposal stage, participants were carefully selected based on their commitment to these principles. During the proposal preparation stage, we found opportunities for the entire team to get together (Colombian and Peruvian partners flew to the US), get to know each other, exchange ideas, clarify expectations, identify leads for specific sites and topic areas, and reaffirm our commitment to these principles. All partners participated in the writing of the proposal.

References

Bakker, K., and G. Bridge, 2006. Material worlds? resource geographies and the 'Matter of Nature'. Progress in Human Geography, **30** (**1**): 5 - 27.

Cech, E., 2014. Culture of disengagement in engineering education? Science, Technology & Human Values, **39** (**1**): 42 - 72.

Davis, R. and D.M. Franks, 2014. Costs of company-community conflict in the extractive sector. Corporate Social Responsibility Initiative Report (John F. Kennedy School of Government, Harvard University, Cambridge, MA). http://www.hks.harvard.edu/mrcbg/CSRI/research/Costs%20of%20Conflict_Davis%20%20Franks.pdf.

Ferry, E. and M.E. Limbert, 2008. Timely Assets: The Politics of Resources and Their Temporalities. School for Advanced Research Press, Santa Fe.

Kirsch, S., 2014. Mining Capitalism: The Relationship between Corporations and Their Critics. University of California Press, Berkeley, California; Los Angeles, California; London.

Layton, E., 1986. The Revolt of the Engineers: Social Responsibility and the American Engineering Profession. The Johns Hopkins University Press, Baltimore, Md.

Li, F., 2011. Engineering responsibility: environmental mitigation and the limits of commensuration in a Chilean mining project. Focal, **60**: 61 - 73.

O'Reilly, J., 2016. Sensing the ice: field science, models, and expert intimacy with knowledge. Journal of the Royal Anthropological Institute, **22** (**S1**): 27 - 45.

Ottinger, G., 2013. Refining Expertise How Responsible Engineers Subvert Environmental Justice Challenges. New York University Press, New York.

Rajak, D., 2011. In Good Company: An Anatomy of Corporate Social Responsibility. Stanford University Press, Palo Alto.

Riley, D., 2008. Engineering and social justice. Synthesis Lectures on Engineers. Technology, and Society, **3** (**1**): 1 - 152.

Rolston, J.S., 2013. The politics of pits and the materiality of mine labor: making natural resources in the American West." American Anthropologist, **115** (**4**): 582 - 594.

Smith, J.M. and A.S.D. Tidwell. 2016. The everyday lives of energy transitions: contested sociotechnical imaginaries in the American West. Social Studies of Science, **46** (**3**): 327 - 350.

Wisnioski, M., 2012. Engineers for Change: Competing Visions of Technology in 1960s America. The MIT Press, Cambridge, Massachusetts, United States.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 105-114
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Development of a Laboratory for Testing the Accuracy of Terrestrial 3D Laser Scanning Technologies

Frederick Cawood[1*], Mei Yu[2], Peter Kolapo[1], Changbiao Qin[1]
[1] Wits Mining Institute, University of the Witwatersrand, Johannesburg, South Africa
[2] School of Environmental and Spatial Informatics, China University of Mining and Technology, Xuzhou, China

Abstract: The mining market is currently overwhelmed by technology vendors offering scanning equipment as 'solutions' for real time mapping and monitoring rock mass movement for mine safety. Mines are left with a problem in that the technology is mostly unproven and not originally designed for mine safety accuracies. Scanning system accuracy assessment needs to be done so as to increase the level of confidence and trust in the quality of the results. The scope of this research is set a laboratory for testing terrestrial laser scanning (TLS) systems – complete with targets fix on the wall of the testing laboratory, which plays a vital role in creating high quality and reliable digital point clouds. To improve the accuracy test of the scanning system, we support exact positioning and distance measurement of points cloud by providing revolutionizing surveying solutions and infrastructure development. The FARO, a static 3D laser scanner and uGPS, a mobile 3D laser scanning system are tested in this research. If the level of accuracy of these TLS systems can be ascertained, this can fit into the production process, ore flow analysis to measure discrepancy and metal accounting principles. Notably, this will add value to mining operations chains through measurement and adequate monitoring of process by revealing the modifying factor contributing to mine loss. More importantly good decisions can be made on mine evacuation when point cloud comparisons raise alarm on rock mass movement. With this laboratory, we can offer a vital service to the mining industry by certifying new scanning solutions as these arrive on the market. This will make mines safer.

Keywords: mine safety, TLS, accuracy evaluation, FARO, mobile 3D laser scanning system

1 Introduction

The aim of this study is to test the point clouds generated by scanning systems for both precision and accuracy. Both criteria are important when applying scanning data to mining problems such as surveying, mapping and monitoring surfaces for rock engineering use. The need for this study was raised by Gold Fields' South Deep mine, which is an underground South African mine who bought such a system to establish rock movement over time. The initial results obtained at South Deep were questionable and the Wits Mining Institute (WMI) was requested to do more testing in a laboratory set-up for this purpose. The work is significant because scanning systems have the potential to contribute to real-time positioning, mapping, navigation and monitoring rock movements in the underground mining environment. Scanning systems are therefore an enabler for good safety, health and economic decisions in mining. What's special about our approach is its fundamental nature to analyse point cloud data from both precision and accuracy perspectives. Such tests were conducted in a fit-for-purpose laboratory. The results certainly contribute to a better understanding of a fairly new topic in mining.

This article contains first, a literature review on the topic. This is followed by a description of the short-range laboratory, where after the establishment of accurate survey control inside the laboratory is explained. Sections five and six describe the scanners and the data analysis, followed by the conclusion and recommendation. The main findings were that first, scanning systems are very useful in mining and second, deep understanding of the fundamentals are required in order to achieve both accuracy and precision – especially when scanning from a moving platform.

2 Literature Review

2.1 3D laser scanning

3D Laser Scanning is a non-contact, non-destructive technology that digitally captures the shape of physical objects using a line of laser light. Because of the ability of fast, reliable and inexpensive 3D survey, it has become popularly used in variety applications such as change detection (Vaaja et al 2011, Lindenbergh and Pietrzyk 2015, Mukupa et al 2016) and deformation tracking (Mukupa et al 2016, Jafari et al 2017), cave and mine surveying (Zlot and Bosse 2014a, Zlot and Bosse 2014b, Grehl et al 2015) etc. The laser scanner is able to record millions of 3D points. These X, Y, Z measurements can be imported into specific CAD design software and displayed on a computer monitor

* Corresponding Author: Frederick Cawood, Email: Frederick.Cawood@wits.ac.za, phone: +27 11 717 7428

DOI: 10.15273/ijge.2018.03.018

as ‘point clouds’, which have photographic qualities portrayed in one-color, grayscale, false-colour or even true colour. The files with the point clouds can be viewed, navigated, measured and analysed as 3D models (Puente et al 2013).

2.2 Principle of laser scanning

In current laser scanning systems, two techniques are mainly used for range measurements time-of-flight (TOF) and phase shift. TOF scanner sends a short laser pulse to the target, and the time difference between the emitted and received pulses is used to determine the range. The range r is calculated the following equation:

$$r = \frac{1}{2} c \Delta t \tag{1}$$

where c is the speed of light and Δt is the time of flight of the pulse.

In contrast, phase-based laser scanners use the phase difference between the emitted and received backscattered signal of an amplitude modulated continuous wave (AM CW) to determine the range. Phase shift laser scanners are more accurate, but their measurement range is shorter. The relationship between the phase shift and range is provided by the following equation:

$$r = \frac{\Delta\varphi}{2\pi}\frac{\lambda}{2} + \frac{\lambda}{2} n \tag{2}$$

where λ is the modulation wavelength, φ is the phase shift and n is the unknown number of full wavelengths between the sensor system and the reflecting object.

The coordinate of target in scanner coordinate system (in Figure 1) is calculated according to the range r, horizontal scanning angle α and vertical scanning angle θ following (3). α And θ are measured by high-precision engineered encoders.

$$\left.\begin{aligned} X &= r\cos\theta\cos\alpha \\ Y &= r\cos\theta\sin\alpha \\ Z &= r\sin\theta \end{aligned}\right\} \tag{3}$$

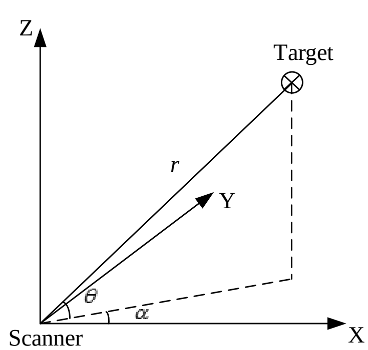


Figure 1 The coordinate of target in scanner coordinate system

2.3 Mobile laser scanning

Mobile laser scanning (MLS) is a ground-based laser scanning technology that obtain 3D points by using a laser scanner mounted on mobile system like vessel and land vehicle. It is more safety and efficiency compared with static laser scanning (Williams et al 2013).

MLS system generally consists of five subsystems: mobile platform, laser scanner, position system consisting of Global Navigation Satellite System (GNSS), Inertial Measurement Unit (IMU) inertial unit and Distance Measurement Indicators (DMIs), photogrammetric cameras or video cameras and on-board computer for controlling these components. Regarding the navigation technologies, the simultaneous localization and mapping (SLAM) is possibly used in MLS to decrease the cost of the IMU system required (Puente et al 2013).

2.4 Principle of MLS

The laser range of MLS is similar to static laser scanning containing TOF and phase shift two kinds. What’s different is MLS use Global Navigation Satellite System (GNSS), Inertial Measurement Unit (IMU), Directional Movement Index (DMI) and simultaneous localization and mapping (SLAM) to determinate the time-variable position and orientation parameters for MLS system direct geo-referencing. Combining the laser range, scan angle obtained using high-precision engineered encoders, and laser position from position system, coordinates of the ground points for each laser pulse can be calculated (Puente et al 2013).

In MLS, there are three coordinate systems: the geo-spatial coordinate system (GCS-O), the POS body coordinate system (PCS-O) and the laser scanner coordinate system (LCS-O) (Mao et al 2015). The relationship between the three coordinate systems is displayed in Figure 2.

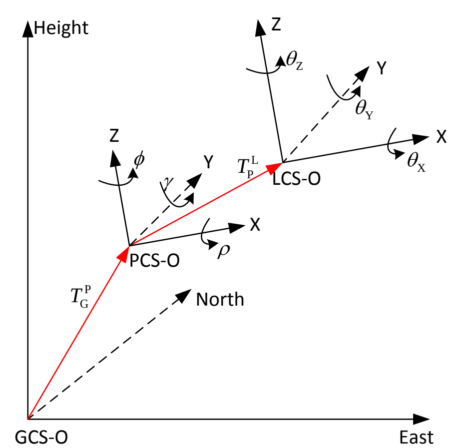


Figure 2 Relationship of geo-spatial coordinate system (GCS-O), POS body coordinate system (PCS-O) and laser scanner coordinate system (LCS-O)

The GCS-O is usually the Gauss coordinate system in which the X axis points to the east, the Y axis to the north and the Z axis up. The coordinates of LiDAR point clouds and control points fall under this coordinate system. The PCS-O is a right-handed system and is attached to the IMU: the origin is located in the IMU navigation centre, with the X axis pointing to the right, the Y axis pointing forward and the Z axis pointing up. The LCS-O is also a right-handed system in which the X axis overlaps with the zero-degree laser beam, the Y axis is perpendicular to the X axis in the scanning plane and the Z axis is perpendicular to the scanning plane. The relationship between these coordinate systems is shown in Figure 2 (Mao et al 2015).

The raw data of the laser scanner were in the LCS-O and then transformed into the PCS-O with spatial alignment parameters, including three translations and three rotations, and, finally, transformed into the GCS-O with the position and orientation measured by the POS-O.

$$X_{\mathrm{G}} = T_{\mathrm{G}}^{\mathrm{P}} + R_{\mathrm{G}}^{\mathrm{P}}(R_{\mathrm{P}}^{\mathrm{L}} X_{\mathrm{L}} + T_{\mathrm{P}}^{\mathrm{L}}) \quad (4)$$

where the subscripts G, P , L indicate the GCS-O, PCS-O and LCS-O coordinate systems, respectively, X_{G} is the coordinate vector of the LiDAR point in the GCS-O, $T_{\mathrm{G}}^{\mathrm{P}} = [T_{\mathrm{E}} \quad T_{\mathrm{N}} \quad T_{\mathrm{H}}]^{\mathrm{T}}$ is the coordinate vector of the POS-O navigation centre in the GCS-O, $R_{\mathrm{G}}^{\mathrm{P}}$ is the rotation matrix from the PCS-O to GCS-O constituted from the orientation o ($o = [\gamma \quad \rho \quad \phi]^{\mathrm{T}}$, γ roll, ρ pitch, ϕ heading), X_{L} is the coordinate vector of the laser scanner measurement in the LCS-O, $T_{\mathrm{P}}^{\mathrm{L}} = [T_{\mathrm{X}} \quad T_{\mathrm{Y}} \quad T_{\mathrm{Z}}]^{\mathrm{T}}$ is the translation vector from the LCS-O to the PCS-O and $R_{\mathrm{P}}^{\mathrm{L}}$ is the rotation matrix constituted from the alignment angles ($\theta = [\theta_{\mathrm{X}} \quad \theta_{\mathrm{Y}} \quad \theta_{\mathrm{Z}}]^{\mathrm{T}}$).

The final MLS dataset represents millions of points with three-dimensional coordinates in the GCS-O.

2.5 Accuracy evaluation of MLS

In recent times, outstanding research has been conducted in order to establish the accuracy of MLS system. The accuracy assessment and control technologies can be classified as data driven or model driven. Data-driven technologies directly correct the point clouds using ground control points (GCPs). Model-driven technology analyses the error sources in the MLS and their impact on points and then proposes methods for the elimination and reduction of these errors (Mao et al 2015).

Barber et al (2008) assessed the precision and accuracy of data collected using the Street Mapper system. It shown the Street Mapper system is able to produce data with an RMS error in elevation of approximately 3 cm compared with RTK GPS and provide a measurement precision of similar order from the comparison of repeated data collection. This result demonstrated that systems can be successfully used in relatively built up areas.

Botes (2013) compared MLS with airborne laser scanning (ALS), photogrammetry and traditional ground surveying methods and shown MLS is capable of measuring at similar or better accuracies. They also assured that the quality of the product is well within the range of total station/GPS accuracies.

Kaartinen et al (2012) established a permanent urban test field to compare the point clouds generated by RIEGL, Optech and Street Mapper etc. Their experiment revealed that high-quality point clouds can be generated by all MLS systems under good GNSS conditions. With all professional systems properly calibrated, the elevation accuracy was better than 3.5 cm up to a range of 35 m. The best system had a planimetric accuracy of 2.5 cm even with range of 45 m.

Due to the difficulty of operating MLS without GNSS coverage, mapping a large-scale undergrounding mine in 3D is rarely accomplished. Zlot and Bosse used MLS for the first time to generate the 3D map of cave (Zlot and Bosse 2014a). They presented a laser-based SLAM solution to generate vehicle trajectory and 3D point cloud from data acquired while the vehicle continuously drives through an underground mine (Zlot and Bosse 2014b).

Permanent test field with accurate ground truth are valuable tools for analysing the performance of remote sensing systems and methods (Kaartinen et al 2012).

3 Laboratory Set up

3.1 Laboratory description

The scanning laboratory is located in the reception area of Wits Mining Institute (WMI) on the basement floor of chambers of mining building, the plan as shown in Figure 3. This space also serves as the kitchen and dining area for the institute with two major entrances. The space has an irregular shape with the dimension of 14.2m × 8.2m × 4.4m. This makes it difficult for the field of view due to the asymmetric pattern of the space from some scan positions. This requires proper planning and measurement that enable visibility of all the targets.

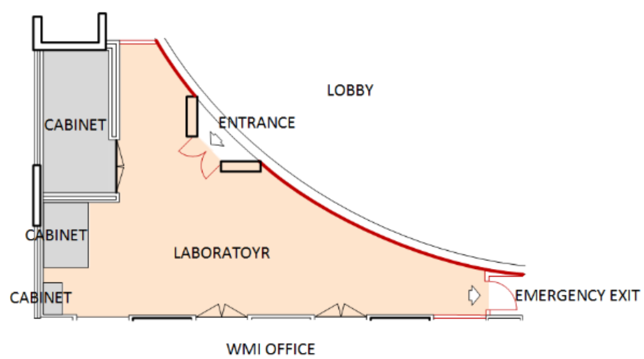
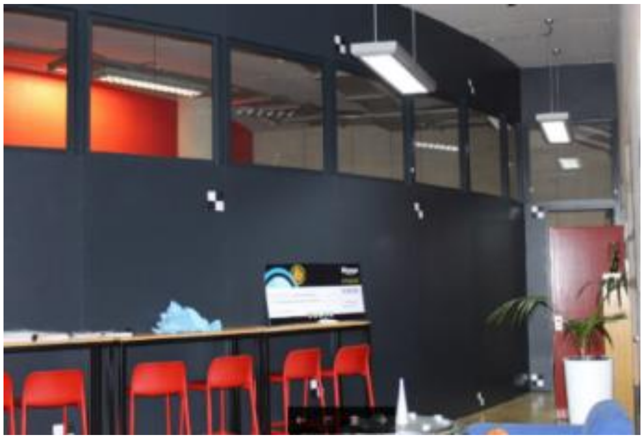


Figure 3 Plan view of the laboratory

The distance from the floor to the roof is measured to be approximately 5m. The space walls are combinations of steel and concrete walls with smooth surfaces, as displayed in Figure 4. The accuracy of the range measurement depends on the scanned surface and the conditions of the experiment environment. The texture of the walls was checked before placing the target. The concrete walls are planar while the steel wall is cylindrical in shape.

The thermal property of the steel wall needs to be considered during the scanning of the laboratory because the steel wall is prone to expansion and contraction when there is a change in temperature. This will also affect the reflectivity of the surface. The temperature fluctuations occur especially during the daytime when the temperature goes higher and become lower in the evening. Therefore, the surrounding temperatures need to be taken into account during scanning in order to restrain the impact of the thermal movement of the steel wall.



(a) The steel wall

(b) The concrete wall

Figure 4 The space walls of the laboratory

The scanning laboratory was set up with total number of 40 Trimble checkboard targets (in Figure 5), with 34 targets placed on the walls and 5 targets on the roof. The length of the space was approximately 15m. At this observable distance, the scanner can acquire point cloud at high scanning speed and wide field of view that can rotate in both the vertical and horizontal range through 360-degree view. With this short-range space, there will be higher accuracy, as the distance becomes longer the lesser the accuracy of the scan produced (Feng 2012). The positioning of the beacon is important in order to ensure full visibility of all the targets from the control beacon (seeing in Figure 6). These range and angular observations depend on the set up of this beacon to prevent poor visibility and obstructions of the scan. It is obvious that the position of the scanner has an influence on the angle of incidence. The larger the incidence the lower the density of the resulting point clouds. Also, the increase in incidence angle leads to reduction in the intensity of the reflected beam. All these factors were considered in the positioning of the control beacon.

Figure 5 An example of Trimble checkboard target

Figure 6 The control beacon bolted on the floor

3.2 Control beacon design

In ensuring accurate and high precision scans, 1.2m height control beacon with 5/8 inches thread was set up for the positioning of the scanners. The use of the beacon will add value to the quality of the scans by preventing error that may occur due to the movement of the tripod and tribrach. This 5/8 inches thread is a standard dimension that works perfectly with all kinds of surveying instruments. The control beacon was bolted to the floor to ensure its stability. After considering the geometry of the space, the position of the beacon was selected to allow all the targets to be seen during scanning. Photos of this beacon will be displayed at the later stage in the paper.

The materials used for the construction of the beacon are sand, stone, cement, anchor rod, forced-centring plate, and thick plastic pipe. The concrete mix proportions for the construction of the beacon depends on required uniaxial compressive strength level of the resulting beacon. The cure period for the construction of the beacon should be at least 28 days.

3.3 Target design and placement

Trimble laser scanning checkboard target was used for the scanning laboratory. This lightweight 3D imaging target have adhesive material for easier placement on a smooth surface without drilling holes or using any additional messy adhesive. This selected target was made of four alternating black and white squares with edges touching one another at the centre. The dimension of the target was designed based on the distance between the scanner and the control targets. At maximum range of 15m it is possible to view all the targets, 15cm × 15cm dimension of the target will be a good design for the scanning laboratory. The targets were systematically placed on the walls and the roof thereby ensuring visibility from the control beacon. A total number of 40 targets were used, with 11 targets on the steel wall, 23 on the concrete wall and the other 5 targets were placed on the roof. All the targets were placed for sufficient coverage and angular readings, so as to avoid incidence where the scanner could not see all the targets. These targets were named according to the placement in the room. Targets were placed at various elevations and distributed spatially as evenly as possible in order to obtain a spatially uniform registration error. Presence of shiny materials such as metals or mirror surfaces are avoided in the laboratory due to the specular reflective nature. Materials of this nature reflect few or no signal back to the laser scanner.

4 Surveying Control

The survey of the traversing and levelling took a few stages which are discussed in detail below.

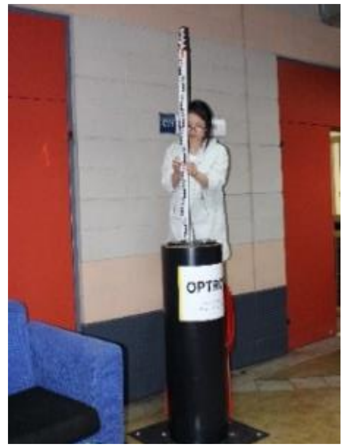
4.1 Survey of the control beacon

We did the survey work during stable environment in order to limit the problems associated with high traffic and high level of student activity. The sketch Figure 7(c) shows the closed traversing method. The coordinates of the control points are displayed in Table 1.

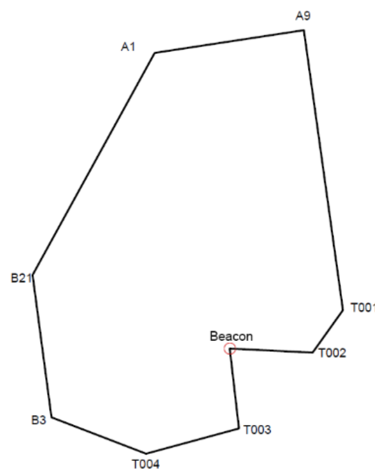
4.2 Survey of the targets

In order to get the targets coordinates, besides the Control Beacon and control points T002 and T003, an additional two temporary setups were added throughout the available space in the scanning part with the idea in mind of good network geometry, namely strong angles between the setups that are between 45 and 90 degrees and avoiding small

(a) Images of survey



(b) Images of survey



(c) The closed traverse route

Figure 7 Survey of the control beacon

Table 1 The coordinates of the control points

Point	Coordinate		
	Y (m)	**X (m)**	**Z (m)**
A1	97282.276	2898380.165	1758.7350
A9	97262.063	2898377.089	1759.2363
T001	97256.788	2898414.891	1760.8756
T002	97260.880	2898420.645	1760.8829
Beacon	97272.103	2898420.075	1762.0062
T003	97270.861	2898430.888	1760.8805
T004	97283.443	2898434.292	1760.8838
B3	97296.235	2898429.386	1761.6711
B21	97298.807	2898410.153	1760.4144

angles or larger angles close to 180 degrees, between the setups. The positions of the temporary setups were also chosen to allow the maximum number of targets to be seen at each setup, ensuring covering all targets.

The targets coordinates are obtained from the distance and angular measurements based on the knowledge of the location of the Control Beacon and three temporary setups. The surveying coordinates of all targets are displayed in Table 2.

Table 2 Coordinates of targets

Number	Y (m)	X (m)	Z (m)
R1	97270.909	2898426.826	1765.157
R2	97269.975	2898423.717	1765.163
R3	97271.510	2898422.380	1765.168
R4	97271.625	2898418.915	1765.151
R5	97267.201	2898418.813	1765.155
S2	97264.912	2898418.160	1763.064
S3	97264.951	2898417.839	1761.010
S4	97268.548	2898422.871	1764.736
S5	97269.092	2898424.013	1763.036
S6	97268.540	2898422.854	1761.338
S8	97269.597	2898425.387	1764.559
S9	97269.911	2898426.575	1763.074
S10	97270.131	2898427.891	1764.569
S11	97270.134	2898427.922	1761.022
S12	97270.442	2898429.787	1763.222
S13	97270.373	2898429.780	1761.036
C1	97265.586	2898417.142	1764.191
C2	97267.198	2898417.352	1764.207
C3	97269.603	2898417.662	1764.209
C4	97269.605	2898417.671	1762.607
C5	97269.604	2898417.675	1760.994
C7	97269.800	2898416.984	1762.600
C8	97269.801	2898417.005	1760.991
C9	97269.945	2898415.806	1764.194
C10	97270.930	2898415.615	1764.188
C11	97272.909	2898415.880	1763.790
C12	97273.055	2898418.425	1764.185
C13	97273.011	2898418.751	1761.183
C14	97272.781	2898420.425	1763.185
C15	97272.353	2898423.562	1764.789
C16	97272.524	2898422.333	1762.989
C17	97272.314	2898423.853	1761.395
C18	97272.030	2898425.914	1764.789
C19	97272.195	2898424.753	1763.587
C20	97271.843	2898427.375	1762.992
C21	97264.976	2898416.975	1763.768
C24	97268.311	2898420.938	1764.917
C25	97268.196	2898421.781	1763.238
C26	97268.294	2898421.123	1760.999

5 The Scanners

The FARO, a static 3D laser scanner and uGPS, a mobile 3D laser scanning system are tested in this research.

5.1 FARO

The FARO® Laser Scanner Focus3D X130, shown in Figure 8, is a high-speed three-dimensional laser scanner for detailed measurement and documentation. The FARO Focus3D X130 uses laser technology to produce exceedingly detailed three-dimensional images of complex environments and geometries in only a few minutes. The resulting images are an assembly of millions of 3D measurement points. This scanner has a maximum range of 130 meters and collects laser observations between 122000 and 976000 points per second. In addition to the laser observations, the scanner is also fitted with a camera able to capture 360-degree imagery. By utilizing the captured imagery, the point cloud can be colorized creating a true 3D colour environment of the captured data. This scanner is able to do a full 360-degree scan in less than 10 minutes depending on the requirements. It is fitted with GPS, Barometer, Compass and Dual Axis Compensator. The performance specification is displayed in Table 3.

Figure 8 FARO® Laser Scanner Focus3D X130

5.2 uGPS Rapid Mapper™

uGPS Rapid Mapper™, shown in Figure 9, generates accurate 3D point cloud data from a mobile platform, allowing for large areas to be scanned very rapidly. This functionality creates opportunities for a wide range of mining applications, such as mine planning, shaft/raise inspection, geotechnical control and ventilation monitoring. The performance specification is displayed in Table 4.

The uGPS Rapid Mapper™ is a cutting-edge scanning tool with 3D tunnel mapping capabilities- all in a small, portable and versatile package. With its unmatched mobile capabilities and ease of use straight out of the box, this technology is a welcome solution for the modern underground mines of today.

uGPS Rapid Mapper™ offers unprecedented performance due to its construction, which includes 2 laser scanners, an inertial sensor, an on-board computer, optional Wi-Fi connectivity, and an RFID tag reader. This widens your potential uses to incorporate open loop scanning, closed loop scanning, and even vertical scanning, too.

Table 3 Performance specification of FARO® Laser Scanner Focus3D X130

Range	0.6-130m
Measurement speed	up to 976,000 points/second
Ranging error2	±2mm
Ranging noise	@10m – raw data: 0.3mm @90% refl. @25m – raw data: 0.3mm @90% refl. @25m – raw data: 0.3mm @91% refl. @25m – raw data: 0.3mm @92% refl.
Integr. colour camera	Up to 70 mio. Pixel
Laser class	Laser class 1
Weight	5.2kg
Multi-Sensor	GPS, Compass, Height Sensor, Dual Axis Compensator
Size	240 × 200 × 100mm
Scanner control	via touchscreen display and WLAN

Figure 9 uGPS Rapid Mapper™

Table 4 Performance specification of uGPS Rapid Mapper™

Maximum range	20 m
Data acquisition rate	10,820 points per second
Scanner line speed	20 Hz
Resolution	0.5° in cross-section
Field of view	270°
Laser safety class	Class 1 (eye safe)
Accuracy (open-loop)	0.5% of distance travelled
Accuracy (closed-loop)	< 0.05 m at control points
Weight	12 kg
Size	200 × 300 × 300mm

6 Experiment and Data Analysis

6.1 Data acquisition

6.1.1 Master scanning

The FARO® Laser Scanner Focus3D X 130 was used to acquire master point clouds of the laboratory, supported by Eugene Pretorius and Associates (EPA) Ltd. 5 different scans were necessary to achieve a complete 3D reconstruction of the scene. The master point cloud was registered based on 39 targets (the coordinates can be seen in Table 2) which were coordinated with Trimble total station as described in Section 4. The final registration error was about 1 cm, which contains the point clouds stitching error and artificial point selection error. The master point cloud contains more than 27 million points, visualized in Cloud Compare (http://www.cloudcompare.org/) and shown in Figure 10.

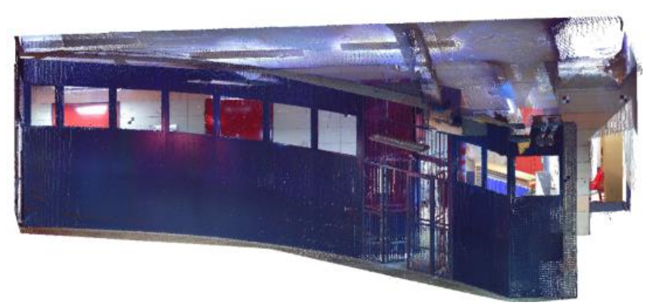


Figure 10 Point cloud of laboratory acquired by FARO.

6.1.2 MLS scanning

The uGPS Rapid Mapper™ was used to MLS point cloud mounted on a trolley (in Figure 11). The moving speed is about 1 km/h. We employed both open route and closed route to acquire two point clouds under different accuracy for the laboratory, supported by RAMJACK Technology Solutions.

The MLS point cloud contains more than 27 million points, visualized in Cloud Compare and shown in Figure 12.

Figure 11 MLS using uGPS Rapid Mapper™

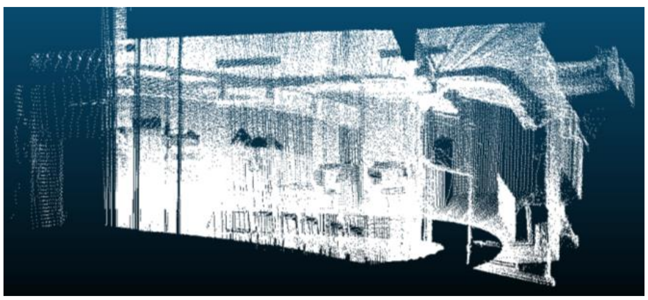


Figure 12 Point cloud of laboratory acquired by uGPS at open route

6.2 Software and process

6.2.1 Software

The accuracy testing experiment of the master point cloud and the MLS point cloud is completed in Cloud Compare (http://www.danielgm.net/cc/), a 3D point cloud editing and processing software. Originally, Cloud Compare has been designed to perform direct comparison between dense 3D point clouds. It relies on a specific octree structure that enables great performances when performing this kind of task. Moreover, as most point clouds were acquired by terrestrial laser scanners, Cloud Compare was meant to deal with huge point clouds on a standard laptop-typically more than 10 million points. Soon after, comparison between a point cloud and a triangular mesh has been supported. Afterwards, many other point cloud processing algorithms (such as registration, resampling, statistics computation, etc.) have followed as well as display enhancement tools (custom colour ramps, colour & normal vectors handling, calibrated pictures handling, OpenGL shaders, plugins, etc.). Moreover, the M3C2 plugin, which is a unique way to compute signed and robust distances directly between two point clouds, is available to compare two clouds directly for users these years. Taking into account its advantages, this study chose Cloud Compare for point cloud processing.

6.2.2 Process

Because of the points obtained by MLS are uncoloured and sparse, the targets can't be verified in the cloud. Therefore, we compared the M3C2 distance between MLS cloud and master cloud.

The MLS point cloud from uGPS Rapid Mapper™ is aligned to the cleaned master point cloud by means of the iterative closest point (ICP) registration method implemented in Cloud Compare. Then Point clouds of furniture and other movable objects are manually deleted in both master point cloud and MLS point cloud to avoid the experimental error caused by object movement (James et al 2017). The aligned point cloud is shown in Figure 13.

Figure 13 The aligned point cloud. The color points are from FARO and the white points are from uGPS

The signed distance between the MLS point cloud and master point clouds are then computed, using the Cloud Compare M3C2 plugin, which implements the Multiscale Model to Model Cloud Comparison method. It allows a direct comparison of 3D points, without the need of a preliminary meshing or gridding phase. For M3C2 process, cloud #1 is uGPS cloud, cloud #2 is FARO cloud. We use the 'Guess params' function to get appropriate parameters for M3C2 distance calculating, and the core point is cloud #1. The normal scale is set to 0.028732, projection scale is set to 0.028732, max depth is set to 0.877179, and the registration error is set to 0. The M3C2 cloud is shown in Figure 14. The histogram of the M3C2 distance is shown in Figure 15.

Figure 14 M3C2 cloud. The grey points are the points without any corresponding points in the MLS cloud

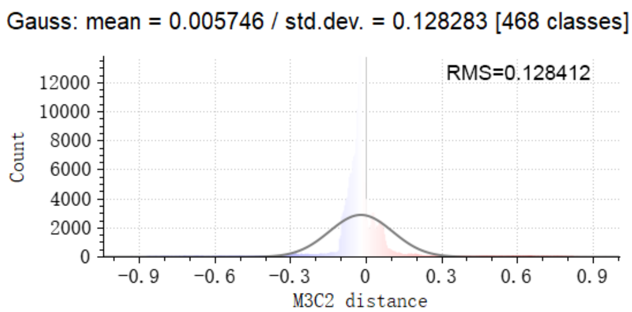


Figure 15 Histogram of the M3C2 distance (m).

6.3 Data analysis

6.3.1 Master point cloud

The targets' centre in the master cloud are localizing and the coordinates are compared with true value (surveying coordinates). The differences are displayed in Table 5. As we can see, the maximum σ is 2.38 cm. The standard deviation of σ is equal to 1.08 cm that means the master point cloud is of a relatively high accuracy.

Table 5 Differences between the targets' coordinate from master cloud and survey

Number	DY (m)	DX (m)	DZ (m)	σ (m)
R1	-0.001	-0.022	-0.009	0.0238
R2	0.006	-0.014	-0.004	0.0157
R3	-0.004	0.000	0.006	0.0077
R4	0.001	0.003	-0.008	0.0086
R5	0.005	-0.005	-0.006	0.0093
S2	-0.007	-0.008	0.000	0.0106
S3	-0.005	-0.001	0.001	0.0052
S4	-0.001	-0.005	0.003	0.0059
S5	0.001	-0.007	0.004	0.0079
S6	0.001	0.001	0.006	0.0058
S8	0.002	0.002	0.005	0.0058
S9	0.001	-0.008	0.001	0.0085
S10	-0.001	-0.006	-0.004	0.0073
S11	0.006	-0.016	-0.005	0.0182
S12	0.002	-0.007	-0.002	0.0075
S13	0.002	-0.010	-0.003	0.0106
C1	0.003	-0.004	-0.001	0.0051
C2	-0.002	-0.004	0.002	0.0049
C3	-0.007	-0.009	0.003	0.0118
C4	-0.004	-0.008	0.002	0.0092
C5	0.001	-0.004	0.006	0.0073
C7	-0.008	-0.011	-0.003	0.0145
C8	-0.009	-0.009	-0.004	0.0133
C9	-0.008	-0.005	-0.002	0.0101
C10	-0.008	-0.010	-0.004	0.0136
C11	-0.006	-0.014	0.001	0.0153
C12	-0.002	-0.012	-0.001	0.0122
C13	-0.011	0.008	0.000	0.0136
C14	-0.004	-0.005	-0.001	0.0068
C15	-0.004	-0.008	-0.002	0.0089
C16	-0.002	-0.007	-0.003	0.0079
C17	-0.006	-0.005	0.002	0.0081
C18	-0.004	-0.006	-0.009	0.0115
C19	0.005	-0.010	0.003	0.0114
C20	0.006	-0.002	-0.001	0.0065
C21	-0.006	-0.009	0.002	0.0110
C24	-0.010	-0.007	0.003	0.0126
C25	-0.005	-0.006	0.003	0.0084
C26	0.002	-0.010	0.003	0.0106

Note: $\sigma = \sqrt{DY^2 + DX^2 + DZ^2}$

6.3.2 MLS point cloud

As shown in Figure 15, the histogram of the M3C2 distance tends to normally distributed. The mean of 0.57 cm proves that there is no significant offset between the point clouds. It means that we have done an excellent alignment between MLS cloud and master cloud. While the standard deviation of 12.83 cm and the RMS of 12.84 cm mean the noise is relatively significant, which expose relatively low accuracy of the uGPS scanning without control point.

7 Conclusion and Recommendation

Since laser scanning systems become more and more popular in mining, we set a laboratory for TLS systems' accuracy and precision testing. Forty high quality and reliable targets were attached to the walls and ceiling to evaluate the accuracy of FARO® Laser Scanner Focus3D X130. Comparing the difference between the coordinates in FARO point cloud and of surveying, the accuracy of FARO is almost 1 cm in our experiment. It shown FARO is at relatively high accuracy level. The uGPS Rapid Mapper™ got the laboratory point cloud much fast than FARO. However, it is not suitable for mining surveying because the accuracy of the uGPS scanning without control point is relatively low.

References

Barber, D., J. Mills and S. Smith-Voysey, 2008. Geometric validation of a ground-based mobile laser scanning system. Isprs Journal of Photogrammetry & Remote Sensing, **63**(**1**): 128 - 141.

Botes, D., 2013. Accuracy assessment: Mobile laser scanning versus competing methods. The South African Surveying and Geomatics Indaba (SASGI) Proceedings, Ekurhuleni, South Africa, July 23 - 24, 2013.

Feng, Q., 2012. Practical application of 3D laser scanning techniques to underground projects. ISRM-Swedish national task A survey of 3d laser scanning techniques for application to rock mechanic. BeFo Report, **114**, 67.

Grehl, S., M. Donner, M. Ferber, A. Dietze, H. Mischo and B. Jung, 2015. Mining-rox-mobile robots in underground mining. International Future Mining Conference, Sydney, NSW, November 4 - 6, 2015

Jafari, B., A. Khaloo and D. Lattanzi, 2017. Deformation tracking in 3D point clouds via statistical sampling of direct cloud-to-cloud distances. Journal of Nondestructive Evaluation, **36**(**4**): 65.

James, M.R., S. Robson and M.W. Smith, 2017. 3-D uncertainty-based topographic change detection with structure-from-motion photogrammetry: precision maps for ground control and directly georeferenced surveys. Earth Surface Processes & Landforms, **42(12)**: 1769 - 1788.

Kaartinen, H., J. Hyyppä, A. Kukko, A. Jaakkola and H. Hyyppä, 2012. Benchmarking the performance of mobile laser scanning systems using a permanent test field. Sensors, **12**(**9**): 12814 - 12835.

Lindenbergh, R. and P. Pietrzyk, 2015. Change detection and deformation analysis using static and mobile laser scanning. Applied Geomatics, **7**(**2**): 65 - 74.

Mao, Q., L. Zhang, Q. Li, Q. Hu, J. Yu, S. Feng, W. Ochieng and H. Gong, 2015. A least squares collocation method for accuracy improvement of mobile LiDAR systems. Remote Sensing, **7**(**6**): 7402 - 7424.

Mukupa, W., G. W. Roberts, C. M. Hancock and K. Al-Manasir, 2016. A review of the use of terrestrial laser scanning application for change detection and deformation monitoring of structures. Empire Survey Review, **49**(**353**): 99 - 116.

Puente, I., H. González-Jorge, J. Martínez and P. Arias, 2013. Review of mobile mapping and surveying technologies. Measurement Journal of the International Measurement Confederation, **46**(**7**): 2127 - 2145.

Vaaja, M., J. Hyyppä, A. Kukko, H. Kaartinen, H. Hyyppä and P. Alho, 2011. Mapping topography changes and elevation accuracies using a mobile laser scanner. Remote Sensing, **3**(**12**): 587 - 600.

Williams, K., M. J. Olsen, G. V. Roe and C. Glennie, 2013. Synthesis of transportation applications of mobile LIDAR. Remote Sensing, **5**(**9**): 4652 - 4692.

Zlot, R. and M. Bosse, 2014a. Three-dimensional mobile mapping of caves. Journal of Cave & Karst Studies the National Speleological Society Bulletin, **76**(**3**): 191 - 206

Zlot, R. and M. Bosse, 2014b. Efficient large-scale three-dimensional mobile mapping for underground mines. Journal of Field Robotics, **31**(**5**): 731 - 752.

.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 115-119
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Smart Sensing for Mineral Exploration through to Mine Closure

Simit Raval*
Australian Centre for Sustainable Mining Practices, School of Mining Engineering, University of New South Wales, Sydney, Australia

Abstract: This presentation provides an overview of advanced sensing systems to monitor various aspects of mining operations from mineral explorations through to mine closures. A review of the case studies utilising multispectral, hyperspectral, thermal, LiDAR and RADAR sensors, in both surface and underground mines, is highlighted with the associated capabilities and challenges. The examples include sensors mounted on satellites, aircrafts and more recently Unmanned Aerial Vehicles (UAVs)/drones. Monitoring for socio-environmental aspects of mining at regional and site levels are outlined. The appropriateness of a sensor-platform combination has been found critical for different applications in mining. Finally, an integrated intelligent sensor system network is projected for a futuristic mine vision.

Keywords: remote sensing, mine environment, UAV, multispectral, hyperspectral, LiDAR and RADAR

1 Introduction

In the recent past, there have been significant advancements in the development of remote sensing platforms (satellite, aircraft and Unmanned Aerial Vehicles – UAVs) as well as sensor systems (multispectral, hyperspectral, thermal, light detection and ranging (LiDAR) and radar). However, the selection of appropriate remote sensing techniques for a mining application remains complex and requires scrutiny on multiple scales including spatial, temporal and imaging capabilities (Banerjee and Raval 2016).

To this end, the Australian Centre for Sustainable Mining Practices (ACSMP) at the University of New South Wales (UNSW), Sydney, Australia has developed a very unique Laboratory for Imaging of the Mining Environment (LIME) in 2010 to apply smart sensing technologies to advance sustainable mining practices. LIME is engaged in developing applications of smart sensing for mining by using satellite, airborne, UAVs and ground-based sensors.

2 Regional Scale Surveillance

The large consortium of current satellites provides effective and near-real-time observation opportunities for environmental and safety monitoring at a wider spatial extent. Aircrafts and UAVs are also constantly advancing their flying capabilities to cover larger area at a regional scale.

2.1 Exploration

Traditionally, hyperspectral sensors on satellites (Hyperion, ASTER) and airborne systems (HyMap, AVIRIS, CASI, HySpex, CHAI) have been used for mineral exploration. However, recent advancements in drones and light-weight sensors, such as hyperspectral, provide renewed opportunity for higher spatial and spectral data collection with higher signal to noise characteristics.

2.2 Vegetation

The historical time series data from satellites, such as Landsat (1972-present), SPOT (1986-present), and World View (2007-present) are very useful in identification of long-term changes in vegetation health as well as in establishing baseline conditions, if no reliable historical data is available. Data acquired from satellite and airborne platforms now provide improved ability to assess biodiversity and vegetation stresses (Jin et al 2013) through multispectral and hyperspectral sensors. Raval et al (2014) indicated usefulness of satellite data in estimating biomass of the experimental production plots on reclaimed mine sites established in Wise County, Virginia (USA).

The new generation of low-flying hyperspectral sensors present an emerging opportunity to map bio-physio-chemical constituents of baseline vegetation status at much finer level (Banerjee et al 2017a). The UAV-LiDAR systems are able to provide better understanding and accuracy around vegetation community structural attributes. Digital sensor technology-based assessment of progressive rehabilitation (Raval et al 2013) will assist, both regulators and operators, to better quantify the success by removing subjectivity in the observations (Figure 1).

A recent study at LIME used a set of thirteen vegetation health indices related to chlorophyll, xanthophyll, blue/green/red ratio, and structure from airborne hyperspectral reflectance data collected around abandoned

* Corresponding Author: Simit Raval, Email: simit@unsw.edu.au, phone: +61 433 663 423

DOI: 10.15273/ijge.2018.03.019

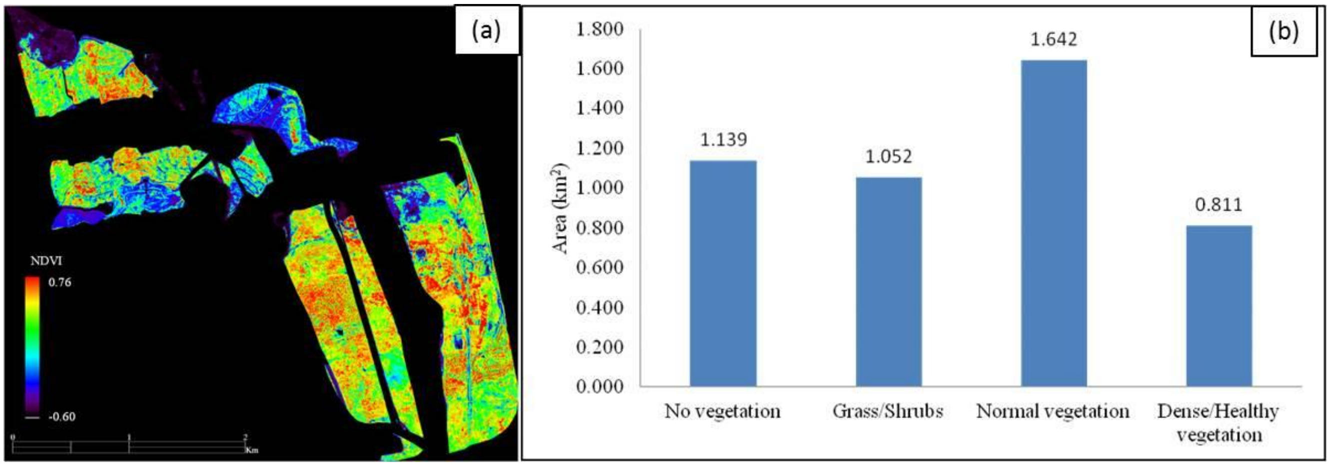


Figure 1 (a) Satellite based mine rehabilitation health assessments and (b) Quantitative reporting for progressive rehabilitation (Raval et al 2013)

mines area in Yerranderie, New South Wales, Australia (Banerjee et al 2017b). The study site has a total of eleven historic mine shafts and has a legacy of heavy metals and acidic leachates in a pristine ecosystem now recognised as Great Blue Mountain World Heritage Area.

2.3 Water

Spectroscopic techniques are used routinely on ground, from space and using airborne platforms to monitor acid mine drainage (AMD). Time-series data from satellite provides continuous change detection for surface water including wetlands that is subjected to potential mining impacts (Banerjee et al 2016). A digital elevation model (DEM) derived from optical satellite stereo pairs could provide vertical accuracy in the range of 15cm to 30cm; this could be useful to assess regional scale erosion patterns.

2.4 Air

Greenhouse gases (CO_2 and CH_4) and particulate matter are measured on a global scale using satellite spectrometry. More recently, lightweight environmental monitoring sensors on UAVs have made it possible to remotely measure the low altitude CO_2 (Malaver et al 2015) and dust (Alvarado et al 2015). These are important developments for a timely intervention to minimise the impact of mining operations on surroundings.

2.5 Soil

Various studies have investigated heavy metal pollution in soil using satellite based multispectral (Jin et al 2015) and airborne hyperspectral data (Shamsoddini et al 2014). New satellites with hyperspectral, thermal, and microwave L-band active sensors provide more detailed measurements of soil moisture although the lower resolution makes it unsuitable for a mine site application. The development of mini-SAR sensor mounted on a low-flying platform carries potential for soil moisture measurements (Acevo-Herrera et al 2010) at the accuracy required for mining operations.

2.6 Land use changes

Sustainable management of land requires regular acquisition of qualitative information regarding the status of its use. It is especially important to track the changes relating to the land's competitive development needs such as mining and agriculture. Raval and Shamsoddini (2014) demonstrated the use of satellite remote sensing data as cost-effective alternatives for the conventional methods of land use/land cover (LULC) monitoring. This study provided a practical framework for rapid mapping of the land cover changes around open-cut kaolin mining area using freely available Landsat data.

3 Site Level Vigilance

3.1 Operational aspects

A mine site has different monitoring and mapping requirements such as routine stock calculation of the extracted ore, monitoring the condition of haul roads and engineering inspections. UAVs based observations are emerging as effective techniques to address some of the day-to-day operational requirements at a mine site. Traditionally UAV photogrammetry and more recently UAV-LiDAR systems have been proved useful for accurate volumetric measurements of stockpiles. UAV based imaging system has a potential to assess haul road conditions autonomously and continuously. Furthermore, monitoring the condition of conveyor belts, draglines, and other engineering structures could be effectively done using UAV-RGB and thermal cameras. UAV-photogrammetry is also effective in updating the map of a dynamic mine site which is useful in future mine planning works. Paired with in-situ sensors on vehicles and machineries, a robust collision avoidance system could be achieved for underground operations.

3.2 Environmental aspects

UNSW LIME has used UAV-based thermal imaging to monitor the risk of the spontaneous combustion of coal stockpiles (Figure 2). In other areas, such as water quality monitoring application, UAVs could be equally effective.

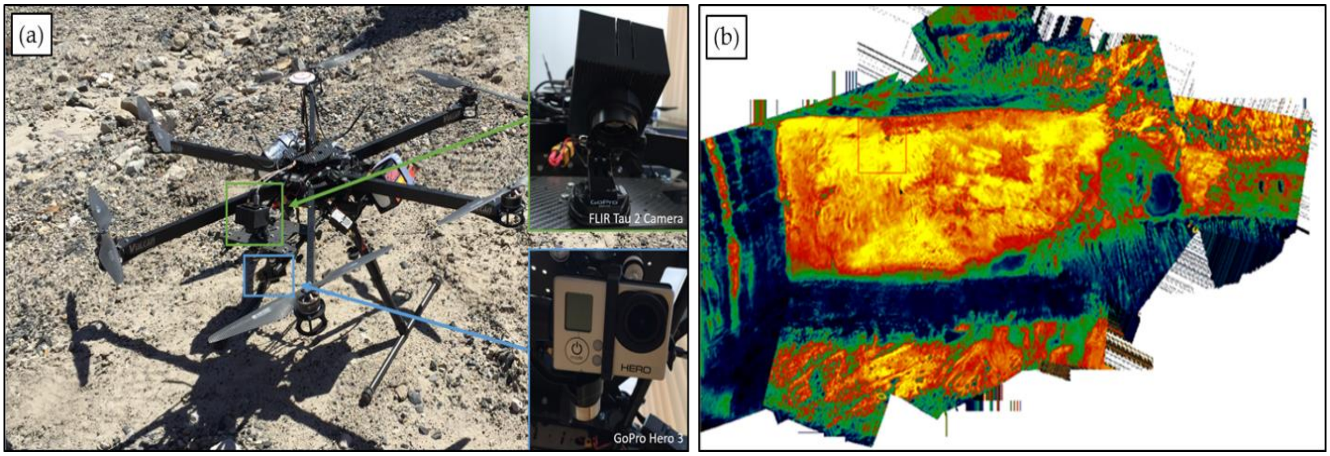


Figure 2 (a) A UAV integrated with a FLIR Tau2 and a GoPro Hero3 camera system and (b) thermal anomaly map of the coal dump

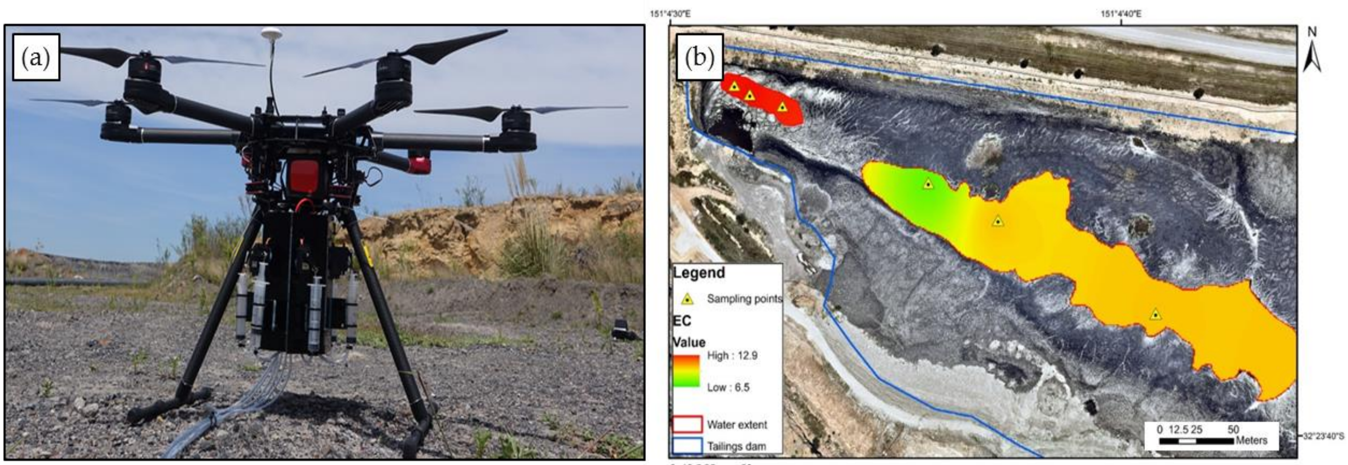


Figure 3 (a) A UAV integrated with a water sampling system designed in LIME and (b) interpolated map of Electric Conductivity (EC) for the tailing dam water

UNSW LIME has recently integrated and tested a UAV based water quality sampling system for mine tailings (Figure 3). The test has demonstrated that UAV based water collection devices could be effective in collecting water from hazardous environments such as mine tailings without influencing the chemical properties of the water.

Other UAV based solutions such as air quality monitoring around mine site is becoming increasingly promising for near future applications.

3.3 Safety aspects

UNSW LIME is involved in promoting InSAR based subsidence monitoring. Earlier studies involved ENVISAT (Ng et al 2011) and ALOS PALSAR (Ng et al 2012) data. Later, advanced PsInSAR (Morgan et al 2013) approaches were adopted to monitor the ground displacement at sub-centimetre scale.

It is critical yet challenging to effectively map the structure of pit-walls at the required textural and spatial scales that would enable geotechnical analysis and early warning of slope failure. UNSW LIME has integrated a state-of-the-art LiDAR system (Phoenix Aerial Scout) on a UAV platform (Figure 4) for advanced structural characterisation of the rock mass.

Several underground safety aspects such as the stability of the tunnels and roof support structures can now be monitored through mobile scanning systems. These mobile scanning systems (handheld or UAV borne) provides improved characterisation of discontinuities, early warnings of potential stability hazards, frequent reconciliations and reporting of positional changes, etc. Other technologies for continuous in-situ sampling of temperature, gas (CO_x, NO_x, SO_x), moisture, etc. are being presently under development at UNSW LIME.

4 The Future

4.1 Futuristic mining regions

Mining industry continuously seeks improvement in environmental performances to set leading practice examples across the globe. To this end, there is a need to develop an automated system that could integrate varied sources of

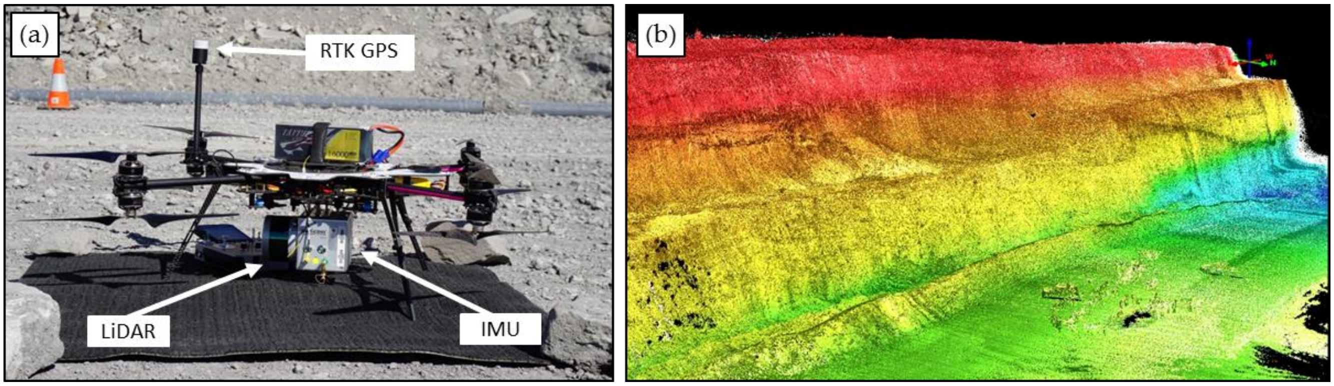


Figure 4 (a) A UAV integrated with a Velodyne LiDAR, IMU, and RTK GPS (Phoenix LiDAR system) and (b) colourised point cloud map of the highwall

remotely obtained data from various platforms to detect changes in sensitive ecosystem within active and post mining landscapes. A 4D (space and time) data visualisation tool could be developed to facilitate quick and holistic review of the functioning of the ecosystem elements exposed to potential mining impacts. Data mining routines will be developed to operate on thematic, non-thematic, backscatter data products acquired from multi-imaging platforms (satellites, aircrafts, UAVs) and GIS layers. The assessment will produce spatio-temporal trajectories of vegetation, water, and land parameters to assist multi-stake holders (mining industries, regulators, communities) in decision-making. This smart integrated sensing system will provide improved confidence in tracking the changes for timely interventions.

4.2 Futuristic mine sites

Technological advances over the last six or seven years have made so many more things possible, and the systems continue to advance at a rapid rate. Not only do we have access to increasingly powerful, light weight and cost-effective sensors but, simultaneously, we have access to increasingly powerful drones/UAVs with a higher load carrying capacity. On the other hand, algorithms to handle the generated data are getting smarter too. What is necessary is to intelligently mould them for specific applications. The futuristic vision for a mine site is to have a number of smart sensors making automated observations that feed into an integrated system to predict areas of concern and mitigate against them leading to a zero harm mining.

References

Acevo-Herrera, R., A. Aguasca, X. Bosch-Lluis, A. Camps, J. Martínez-Fernández, N. Sánchez-Martín and C. Pérez-Gutiérrez, 2010. Design and first results of an UAV-borne L-band radiometer for multiple monitoring purposes. Remote Sensing, **2**(**7**): 1662 - 1679.

Alvarado, M., F. Gonzalez, A. Fletcher and A. Doshi, 2015. Towards the development of a low cost airborne sensing system to monitor dust particles after blasting at open-pit mine sites. Sensors, **15**(**8**): 19667 - 19687.

Banerjee, B.P. and S. Raval, 2016. Applications of Advanced Remote Sensing Systems During a Mine Life. Life-of-Mine, Brisbane, Queensland, Australia.

Banerjee, B.P., S. Raval and W. Timms, 2016. Evaluation of rainfall and wetland water area variability at Thirlmere Lakes using Landsat time-series data. International Journal of Environmental Science and Technology, **13**(**7**): 1781 - 1792.

Banerjee, B.P., S. Raval and P.J. Cullen, 2017a. High-resolution mapping of upland swamp vegetation using an unmanned aerial vehicle-hyperspectral system. Journal of Spectral Imaging, **6(a6)**: 1 - 8.

Banerjee, B.P., S. Raval, H. Zhai and P.J. Cullen, 2017b. Health condition assessment for vegetation exposed to heavy metal pollution through airborne hyperspectral data. Environmental Monitoring and Assessment, **189**(**12**): 604.

Jin, J., H. Jiang, X. Zhang, Y. Wang and X. Song, 2013. Detecting the responses of Masson pine to acid stress using hyperspectral and multispectral remote sensing. International Journal of Remote Sensing, **34**(**20**): 7340 - 7355.

Jin, M., X. Liu, L. Wu and M. Liu, 2015. An improved assimilation method with stress factors incorporated in the WOFOST model for the efficient assessment of heavy metal stress levels in rice. International Journal of Applied Earth Observation and Geoinformation, **41**:118 - 129.

Malaver, R., A. Jairo, L.F. Gonzalez, N.V. Motta, F. Tommaso, V.K. Etse and P. Eduard, 2015. Design and flight testing of an integrated solar powered UAV and WSN for greenhouse gas monitoring emissions in agricultural farms. IEEE/RSJ International Conference on Intelligent Robots and Systems, Hamburg, Germany, pp1 - 6.

Morgan, J., S. Raval, B. Macdonald, G. Falorni and J. Iannacone, 2013. Application of advanced InSAR techniques to detect vertical and horizontal displacements. Proceedings of International Symposium in Slope Stability in Open Pit Mining and Civil Engineering, Brisbane, Australia.

Ng, A., L. Ge and K. Zhang, 2011. Application of persistent scatter interferometry for land subsidence monitoring in

Sydney, Australia using ENVISAT ASAR data. 34th International Symposium on Remote Sensing of Environment, April 10 - 15, Sydney, Australia.

Ng, A., L. Ge, X. Li, H.Z. Abidin, H. Andreas and K. Zhang, 2012. Mapping land subsidence in Jakarta, Indonesia using persistent scatterer interferometry (PSI) technique with ALOS PALSAR. International Journal of Applied Earth Observation and Geo-information **18**(**Supplement C**): 232 - 242.

Raval, S., R. Merton and D. Laurence, 2013. Satellite based mine rehabilitation monitoring using WorldView-2 imagery. Mining Technology, **122**(**4**): 200 - 207.

Raval, S., E. Sarver, A. Shamsoddini, C. Zipper, P. Donovan, D. Evans and H.T. Chu, 2014. Satellite remote sensing-based estimates of biomass production on reclaimed coal mines. Mining Engineering, **66**(**4**): 76 - 82.

Raval, S. and A. Shamsoddini, 2014. A monitoring framework for land use around kaolin mining areas through Landsat TM images. Earth Science Informatics, **7**(**3**): 153 - 163.

Shamsoddini, A., S. Raval and R. Taplin, 2014. Spectroscopic analysis of soil metal contamination around a derelict mine site in the Blue Mountains, Australia. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, **2**(**7**): 75.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 120-126
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Hazards Detection System Based on 3D Panorama for Tailings Dam in Mining

Enji Sun[1*], Cong Shi[2], Cuiping Li[2]
[1] China Academy of Safety Science and Technology, Beijing, China
[2] University of Science and Technology Beijing, Beijing, China

Abstract: Tailings dam is a key facility for the mining process, which is also the major hazards for the surrounding environments. It could cause catastrophic accidents and severe personal injuries if the tailings dam failed. The occurrence of tailings dam accidents will greatly damage the life and property of the people in the surrounding areas and damage the ecological environment around the region. In recent years, Chinese government has introduced policies to step up investigation and management of mine tailings potential hazards and results in great achievements. However, a large part of the tailings dam still has prominent safety problems due to long-term site selection, design, system construction and management. Flood drainage system plays an important role both in the mining process and in the tailings dam safety. Through the analysis of the causes of tailings dam accidents, this paper discoveries that a number of accidents caused by the failure or damage of flood drainage facilities, and the risk in flood season is especially prominent. The safety hazards detection of the flood drainage is vital to secure the tailings dam safety. A safety hazards detection system based on 3D panorama technology has been achieved in this paper. It provided a new way to detect the safety hazards remotely on portable devices. Firstly, the 3D panorama data acquisition device was designed and developed. The functions and requirements of 3D panorama data acquisition device were investigated according to the actual environment of flood culvert. The structure and hardware of the device were calculated according to the target functions. Three-dimensional environment image data for rapid acquisition, and the use of feature matching and optical flow principle of the collected images were spliced to generate a 3D panoramic image of flood drainage of tailings dam in mining. The safety hazards detection system includes 3D panorama client and panorama images cloud database. It has five layers which are basic configuration layer, interface presentation layer, data management layer, function module layer and background management layer. The functional module layer has five functional modules, including mine personnel management module, tailings pond panoramic scene module, culvert potential danger detection module, interface menu navigation module and material information management module. It can help safety inspectors to detect and investigate potential safety hazards in flood drainage culverts, which would strengthen the safe operation of tailings dam and maintain the safe and sustainable production of mines. This system has been applied to the tailings dam of a mine to collect 3D environmental image data of the flood drainage culvert. The panoramic image is spliced to generate a panoramic view through the cloud platform. The results show that this system can be used in mine drainage culvert safety hazards detection.

Keywords: tailings dam, flood drainage system, virtual reality, 3D panorama, safety hazards detection

1 Introduction

Tailings dam is a key facility for the mining process, which is also the major hazards for the surrounding environments. It could cause catastrophic accidents and severe personal injuries if the tailings dam failed. It is reported by Xie et al (2009) that tailings dam are necessary facilities for mine production and places which constructed by damming troughs or encirclement used to store tailings that eliminated after ore selection in Metal and non-metallic mines. It is reported by Mei and Wu (2012) that tailings dam is a dangerous source of high-energy man-made debris flow, the collapse of the tailings dam takes devastating damage, which seriously threatens the safety of life and property of the enterprises and the downstream residents. The occurrence of tailings dam accidents will greatly damage the life and property of the people in the surrounding areas and damage the ecological environment around the region. The collapse of the tailings dam can also cause secondary disasters such as environmental pollution at the same time. It's a serious impact on regional economic development and social stability.

In recent years, Chinese government has introduced policies to step up investigation and management of mine tailings potential hazards and results in great achievements. However, a large part of the tailings dam still has prominent safety problems due to long-term site selection, design, system construction and management. Flood drainage system plays an important role both in the mining process and in the tailings dam safety. Through the analysis of the

* Corresponding Author: Enji Sun, Email: enjisun@gmail.com, phone: +86 10 8491 6155

DOI: 10.15273/ijge.2018.03.020

causes of tailings dam accidents, this paper discoveries that a number of accidents caused by the failure or damage of flood drainage facilities, and the risk in flood season is especially prominent.

The phenomenon of collapse of destruction is general excessively of tailings dams in China. It is reported by Zhang et al (2011) that most of these phenomena are caused by flood over the top of dams. The main reason is the lack of capacity or the failure of the drainage system. There are also accidents caused by the failure of drainage system in foreign countries in recent years. For example, November 5th 2015, the tailing dams collapsed because of the insufficient drainage capacity of the Germano mining area in Germano Mariana area in central Minas Gerais state in Brazil. After a small post-earthquake, the liquefied tailings fill sand submerge downstream cities and towns. It finally destroyed 158 houses, killed at least 17 people, polluted 663km river and destroyed 15 square kilometres of land along the river. It is reported by Rico et al (2008) that it's necessary to continuous monitor and control the tailings drainage system in order to reduce the occurrence of tailings accidents and guarantee the sustainable production of the mine. The traditional artificial detection methods of flood drainage system of tailings dam exist many problems such as heavy workload, low efficiency, and susceptible to meteorological conditions. And it is reported by Luo (2013) that the tailings dam wastewater is corrosive which result a certain disease in flood discharge facilities such as tailings drainage culvert, etc. In order to realize the effective monitoring, management and maintenance of flood drainage system of tailings dam, advanced technologies need to be used to acquire the information of collection and management of flood drainage facilities of tailings dam.

With the development of Virtual Reality (VR) technology, VR has been studied and applied in more and more fields. It is reported by Wang et al (2010) that virtual reality technology has been included in one of the 3 cutting-edge technology which needs to focus on the development in the field of information technology in Medium and Long Term Plan Compendium of Development of Science and Technology of China (2006-2020). It is reported by Zhou and Hu (2012) that three-dimensional panorama technique of virtual reality technology based on the digital real scene by panoramic image. This technology uses cameras to take pictures of 360 degrees real scene and generates panoramic images with 3D experience.

A safety hazards detection system based on 3D panorama technology has been achieved in this paper. It provided a new way to detect the safety hazards remotely on portable devices. Firstly, the 3D panorama data acquisition device was designed and developed. The functions and requirements of 3D panorama data acquisition device were investigated according to the actual environment of flood culvert. The structure and hardware of the device were calculated according to the target functions. Three-dimensional environment image data for rapid acquisition, and the use of feature matching and optical flow principle of the collected images were spliced to generate a 3D panoramic image of flood drainage of tailings dam in mining. The safety hazards detection system includes 3D panorama client and panorama images cloud database. It has five layers which are basic configuration layer, interface presentation layer, data management layer, function module layer and background management layer. The functional module layer has five functional modules, including mine personnel management module, tailings pond panoramic scene module, culvert potential danger detection module, interface menu navigation module and material information management module.

2 The Framework of Hazards Detection System

A safety hazards detection system based on 3D panorama technology is mainly composed of three parts: the panoramic image collector, the image data processing terminal and the panoramic information display platform.

2.1 3D panorama data acquisition collector

3D panorama data acquisition collector

The collector configuration uses 17 camera lenses (a total of 14 camera lenses with wide-angle angles arranged on the side of the device in a circle of 360°, a fisheye lens on the upper layer, and 2 fisheye lenses on the lower layer). The assembly is complete. Mounted on a disk-shaped platform, each camera lens is an HDTV lens with more than 16 million pixels. The camera lens arrangement is shown in Figure 1.

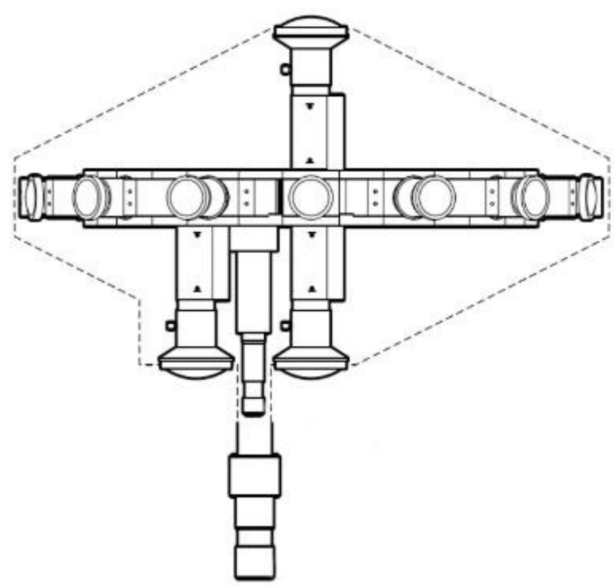
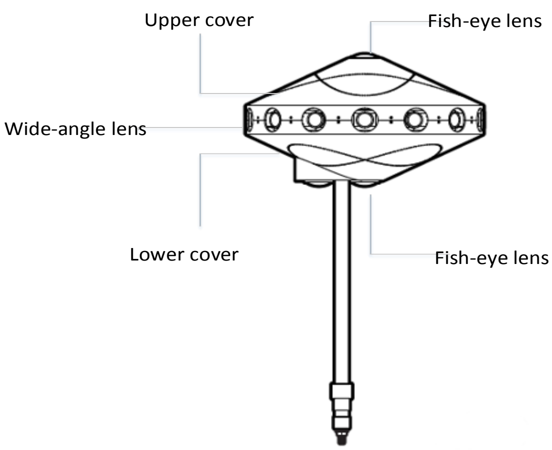


Figure 1 3D Panorama image collector camera lens arrangement

When collecting image data in the tailings reservoir flood culvert, the entire equipment rack works on the tripod, and the three-dimensional spatial image data of each location in the flood drainage culvert can be captured by the personnel's movement of the tripod. The main feature of the collector is the rapid completion of image acquisition. While maintaining the high resolution of the image, it can accurately describe the three-dimensional space environment and bring a good sense of space. The 14 cameras in the ring layout of the collector can shoot angles of up to 77 degrees. With one shot, the image data of 360°×180° environment can be acquired. Each camera can acquire images up to 4k and can achieve 60 frames per second. 3D Panorama image collector is combined by the upper cover, under the cover, the wide-angle lens, top fisheye lens, bottom of the fisheye lens, lens sleeve, support rod and other components. Among them, the side wide-angle lens total of 14, the top fisheye lens 1, the bottom of the fisheye lens 2. 3D Panorama image collector as displayed in Figure 2.



(a) Composition

(b) Photo

Figure 2 3D Panorama data acquisition collector

2.2 Data processing terminal

The image data processing terminal uses the three-dimensional panoramic technique to process the original image data acquired by the panoramic image collector. The original image data is first subjected to image preprocessing, mainly to complete the initial positioning of the image and smooth sharpening work. After the completion of preprocessing, the image registration is performed. Image registration is the core process of image stitching. In this paper, SIFT algorithm is used to perform image registration. After the registration is completed, the image fusion work will turn a number of images into a panoramic image, and through the projection conversion to produce three-dimensional and spatial integrity in panoramic images. This paper selects the projection transformation method for the spherical projection, more in line with the visual effects of the human eye, and the 3D feel of the panoramic image will be stronger after projection.

2.3 Information display platform

The panoramic information display platform can display the panoramic image generated by the image data processing terminal. At the same time, the user can annotate and describe the facilities and areas of interest on the panoramic image. These annotations and descriptions will form additional layers by rendering on the panorama image so that these can be edited and edited by interactive application. Data management is the administrator to manage the input, storage and output of the data such as text data, multimedia data and so on. System data including panoramic image data, navigation data, map data and attribute data. Logical service is the process of processing the input data, and mainly divided in two parts mathematical processing and rendering services. Mathematical processing includes projection transformation, coordinate transformation, rotation, etc. Rendering services includes scene rendering, animation rendering, layer rendering and so on. Interactive application services to meet user roaming, mobile scale, scene changes, demand of virtual operation and so on.

3 The Achievements of HDS-3DP

3.1 The functional modules of HDS-3DP

The functional module layer has five functional modules, including mine personnel management module, tailings pond panoramic scene module, culvert potential danger detection module, interface menu navigation module and material information management module. It can help safety inspectors to detect and investigate potential safety hazards in flood drainage culverts, which would strengthen the safe operation of tailings dam and maintain the safe and sustainable production of mines.

The image data are input to the image data processing terminal for processing which are collected by the panoramic image collector in the tailings dam flood drainage culvert. Image data processing terminal turn the original image into a broad perspective and high-definition panoramic image by using three-dimensional panoramic technology, through image preprocessing, image registration, image fusion and other processes. The 3D panoramic information display platform combines the image data processing terminal to display the panorama image on the web page. The monitoring staff can use the panoramic information display platform to discover the present situation of the tailings and the potential failure. Through the platform the monitoring staff can label the areas or facilities which have potential failure or disease, so that technical staff can solve timely. The panorama information platform includes the following features (Figure 3).

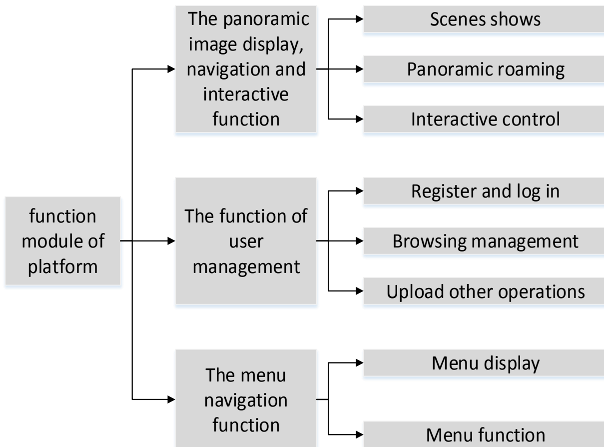


Figure 3 Function module of the panoramic information display platform

3.2 The application of HDS-3DP

The tailings dam has been redesigned for drainage facilities with a height above 435m above sea level, as well as for accumulation dams. The final design elevation reached 492.0m, the effective storage capacity of the tailings reservoir reached 7900104 m^3, and the total storage capacity reached 8700.104 m^3, to meet the tailings storage requirement of 22.66 years for the mine concentrator. After the design is finalized, the tailings dam belongs to the valley type. The outer slope ratio of the tailing dam is 1:4.0, and the drainage system is a well-hole combination.

The geographical climate of the area where the tailings reservoir is located is in a marine monsoon climate. The average annual temperature in the area is 5.34 °C, of which the minimum temperature in winter can be as low as -32 °C, and the maximum temperature in summer can rise to 36.3 °C. The average annual rainfall in the area is generally within the range of 600-800mm. The maximum annual rainfall is 855.2mm, and the minimum annual rainfall is 365.4mm. July and August each year is the main rainfall season, with frequent heavy rains. There is a freezing period in the winter in the region, and the time is generally from November of the year to March of the second year. The maximum amount of snow that can be reached in winter is 800mm, and the maximum depth of frozen soil is 1.55m.

The tunnel surrounding rocks are mainly Paleozoic sedimentary metamorphic rock series. Because of the influence of tectonic and weathering, the rock masses at the two ends of the tunnel are strongly weathered, the average value of the rock integrity coefficient is 0.20, and the integrity of rock mass is broken. Strongly weathered rock mass; with the exception of veins and fracture zones in the middle, the weathering of rocks is relatively weak and moderate weathering. The tailings dam location and basic information is displayed in Figure 4.

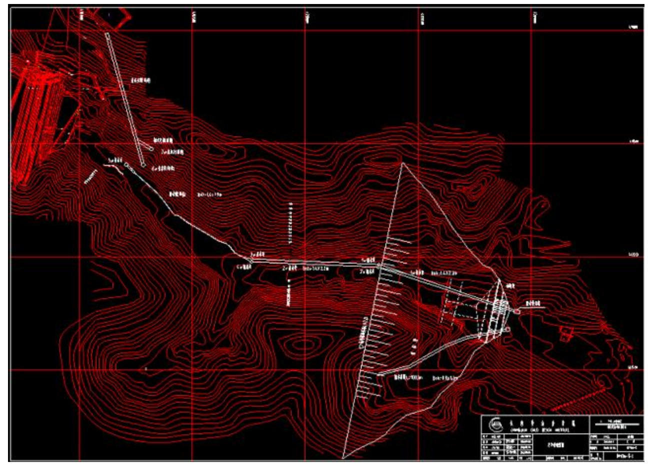


Figure 4 The tailings dam location and basic information

First, use the data collection device for flood culvert to collect the initial image data from the main hole of the tailings dump. The collection work was conducted at a fixed point, and a point was determined every 20 meters. The image collection of the main drainage environment in the point drainage hole was performed at the point, and a total of 3 sets of acquisition were performed. The raw images data is shown in Figure 5.

The raw image data collected by the collector is the RAW Bayer format. The Gamma correction is used to adjust the color, and the raw image data of the RAW format is converted into RGB format data. Gamma is also known as gamma. The reason Gamma correction is because the perception of brightness in human eye imaging changes exponentially and the camera changes linearly. Therefore, the purpose of gamma correction is to change the gamma value so that the output image gray value and the input image gray value exponential relationship, reduce color error, significantly enhance the image contrast when the low gray value, so that the camera imaging is more suitable for human eye identification habits. After gamma correction, projection processing is performed on each RGB image data. Taking the tailing gallery image data as an example, the projected images are further spliced in sequence, and each image is one of the components of the entire three-dimensional space panoramic image.

For the raw image captured by each camera of the collector, due to the image distortion generated by the camera lens, a distortion correction problem is involved and the flood culvert data collector is calibrated to preliminarily capture the image of the calibration plate, as shown in Figure 6 below. Then, the image is calibrated according to the obtained image, and related parameters such as camera parameters and distortion coefficients are obtained to perform image distortion correction. The calibration plate has black and white squares, multiple pictures are taken from the calibration plate from different angles, the corner information of the squares is extracted, and the homography matrix is solved (the projection mapping of one plane to another plane is represented by a matrix). Each perspective corresponds to a

Figure 5 The raw images data of tailings dam drainage tunnel

homography matrix, and the camera internal parameter matrix and external parameter matrix are obtained through homography matrices of multiple perspectives. Finally, according to the camera's internal parameters and external parameters to correct the distortion. Image matching feature points of tailings dam drainage tunnel is shown in Figure 6.

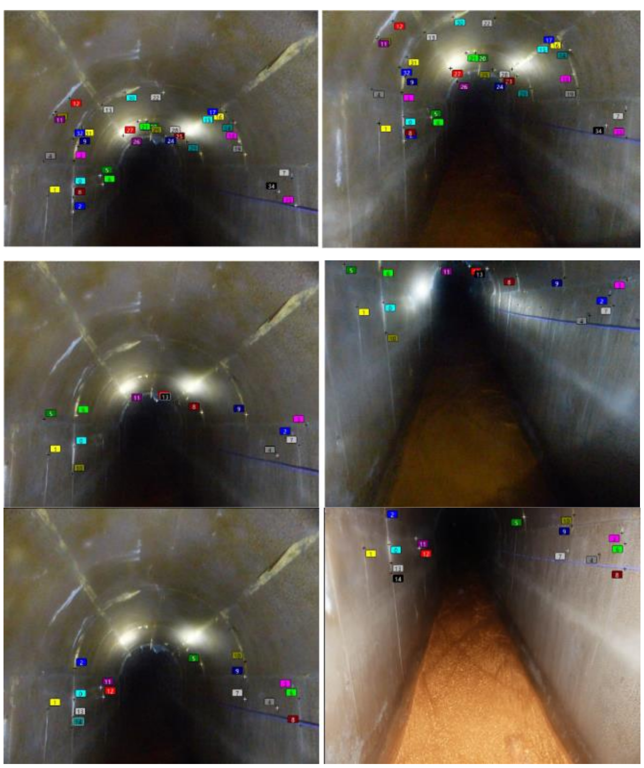


Figure 6 Image matching feature points of tailings dam drainage tunnel

The flood culvert data collector also corrects for camera instability, bracket support rotation, lens shift, etc. This kind of situation will mainly cause the image to appear parallax within a certain range, produce the shadow effect, and influence the picture mosaic. For this type of situation, the flood culvert data collector solves the above problems by adopting feature point matching on adjacent images. For 14 side wide-angle camera lenses, feature matching is performed between the images captured by each group of adjacent cameras. For feature matching between two adjacent images, the corresponding feature points need to be found first. As shown in Figures 4 and 5, taking the image of the top of the tailings gallery as an example, there is a similar area between two adjacent images. In the similar area, the image is based on the pixel features, shape features, and texture features. Edges, corners, pixel areas, etc. are used as feature points.

Select a group of data with better performance among the three groups of point data, and stitch the images of this group of images to generate a panoramic image of the flood culvert. Through the feature matching method, the image of the collected flood culvert image is searched. The correlation between adjacent images, in the form of feature points, the images are stitched together to generate corresponding flood discharge culvert panoramic images as shown in Figure 7.

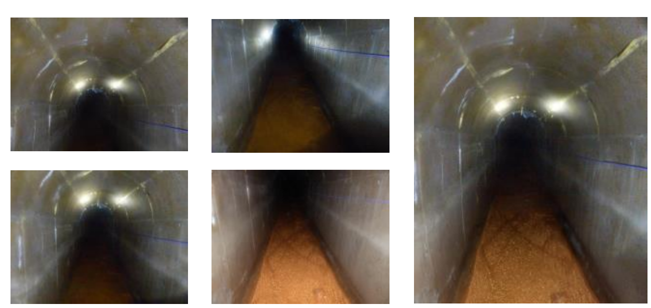


Figure 7 Flood culvert 3D panoramic image of tailings dam drainage tunnel

The panorama display platform is used to publish the panoramic image of the drainage main tunnel. After the release of the panoramic image of the flood culvert, a panoramic view of the webpage can be made through the platform. At the same time, users of the platform can remotely log in to the panoramic display platform through the cloud to experience the experience of the drainage main tunnel panoramic scene, and use the powerful panoramic editing function of the platform to customize the panorama of the main drainage tunnel as shown in Figure 8.

Figure 8 3D panoramic image of tailings dam drainage tunnel

When the mine staff uses the platform to view the panoramic view of the flood culvert, the related image of the flood culvert image that has been uploaded can be detected based on the panorama. Through the platform's own potential danger detection function module, relevant information such as adding text interactive hotspots is added after discovering potential points, and the potential content can be noted. This can be viewed through interaction with text hotspots, making it easier for other mine workers to understand the type of potential danger and specific the situation is conducive to the next step in the investigation of potential hazards in flood culverts. At the same time, a scene switching hot spot is added to the panoramic view of the flood discharge culvert, and the worker switches the hot spot by clicking on the scene to realize the movement of the scene, that is, the panoramic scene becomes the other panoramic scene. , After clicking the “Drainage Culvert” entrance scene to switch hot spots, the panoramic scene screen will be switched to show the panoramic image of the flood discharge culvert entrance as shown in Figure 9.

For the specific content of potential hazards points in flood culverts, edit them when adding text hotspots. After the mine staff clicks on potential hazards points in the panoramic view of the flood culvert, the exposure of the panoramic screen is reduced, a new layer appears on the interface, and the text information stored in the text hot spot is displayed on the layer. Corresponding to the text information in the potential points of the flood culvert, the potential content related information is added in the text hotspot.

4 Conclusions

Mainly aiming at the safety risks existing in the potential

Figure 9 3D panoramic image of flood culvert entrance

troubles of the mine tailings reservoir flood culverts, using virtual reality technology to reduce the time for personnel to carry out potential investigations in the flood culverts, and through the flood culvert data collector to the tailings dump culvert Three-dimensional space environment for rapid image data acquisition, combined with three-dimensional panoramic technology to achieve the true environment of the flood culvert in the remote computer port to restore accurate, easy for personnel to carry out potential investigations, reduce flood culvert in the corrosion, landslide, oxygen concentration is insufficient Occurrence probability of damage caused by mine workers and other diseases and potential dangers, better detection of potential dangers in mine tailings reservoir flood culverts, strengthening of safe operation of tailings ponds, maintenance of safe and continuous production of mines, and harmonious social and regional stability Has positive significance.

3D panorama data acquisition collector for flood culverts was developed. The structure of the collector consists of an upper cover, a lower cover, 14 wide-angle lenses on the side, a fisheye lens on the top, 2 fisheye lenses on the bottom, a lens sleeve, and a support rod. The collector can be carried by the personnel into the tailings dump flood culvert to achieve rapid collection of image data of the flood culvert. For the collected image data of flood culvert, the collector can work on the image splicing through the principle of feature matching and optical flow method to generate a high-quality, high-resolution panoramic image. During the process of using the platform, the mine staff will display a panoramic view of the tailings dump flood culvert through the panoramic display platform, which is convenient for the staff to find possible diseases and potential troubles. For potential risks discovered, editing and remarking using the potential danger detection function module is conducive to the investigation of the potential dangers of flood culverts.

This system can help safety inspectors to detect and investigate potential safety hazards in flood drainage culverts, which would strengthen the safe operation of tailings dam and maintain the safe and sustainable production of mines. This system has been applied to the tailings dam of a mine to collect 3D environmental image data of the flood drainage culvert. The panoramic image is spliced to generate a panoramic view through the cloud platform. The results show that this system can be used in mine drainage culvert safety hazards detection.

Acknowledgement

This research project is made possible through the financial support from National Key R&D Program of China (2017YFC0805100, 2016YFC0801305).

References

Luo, C., 2013. Explore the hidden trouble of drainage tunnel of tailings pond and discussion on countermeasures. Science Mosaic, (**11**): 222 - 227.

Mei, G.D. and Z.Z. Wu, 2012. Research on the dam-break hazard vulnerability assessment index system and methods of tailings pond. Applied Mechanics and Materials, **204**: 3450 - 3456.

Rico, M., G. Benito and A. Díez-Herrero, 2008. Floods from tailings dam failures. Journal of Hazardous Materials, **154**(**1**-**3**): 79 - 87.

Xie, X., W. Tian, Y. Wang and X. Zhang, 2009. The safety analysis of current situation and management countermeasure on tailing reservoir in China. Journal of Safety Science and Technology, **5**(**2**): 5 - 9. (in Chinese)

Zhang, X., E. Sun and Z. Li, 2011. Experimental study on evolution law of tailings dam flood overtopping. China Safety Science Journal, **21**(**7**): 118 - 124. (in Chinese)

Zhou, Y. and J. Hu, 2012. Digital mine roaming system based on 3D panorama technology. Metal Mine, **05**: 116 - 120. (in Chinese)

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 127-132
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Mining of the Waterberg - a Unique Deposit Requiring Innovative Solutions

Chabedi Kelello[1*], Mhlongo Sifiso[2]
[1] Department School of Mining Engineering, University of the Witwatersrand, Johannesburg, South Africa
[2] Exxaro Grootegeluk Coal Mine, Lephalale Limpopo, South Africa

Abstract: The Waterberg coalfield is a resource for the future contribution of energy in South Africa and has been marginally exploited to date. The coal deposit is technically unique and challenging. The carbonaceous nature of the overburden, interburden, the coal intercalations and discard makes it prone to spontaneous combustion. The coal has a high percentage of ash and low yields after beneficiation. Another unique feature of this coalfield is that it is a multi-seam coal deposit with a total of 13 benches occurring over a total thickness of 110m. Only one large open pit mine is currently in operation at the Grootegeluk Colliery despite the size of the resource. The mine has innovatively exploited the coal deposit profitability despite these challenges. Grootegeluk Colliery produces about 86 million tonnes ex-pit. The ROM produced in 2015 was about 54 million tonnes per annum (Mtpa) and the total waste produced was about 32 Mtpa making it one of the largest open pits in the history of South Africa. The paper discusses the state of the current mining and beneficiation techniques being used at the mine to exploit this vast reserve of the Waterberg coalfield which is the future coal supply of South Africa.

Keywords: Waterberg coalfield, Grootegeluk, open pit, spontaneous combustion, coal

1 Introduction

This paper discusses the innovative mining of the Waterberg coalfield at the Grootegeluk open-pit mine. Specifically the mining of the waste and coal using thirteen different benches at Grootegeluk is discussed with an emphasis on the separate mining of the Upper and Middle Ecca benches. The emphasis is on the quantity and quality of the coal produced and the different markets supplied in order to make the mine profitable, low cost and sustainable. The latter part of the paper focuses on the equipment used and the eight beneficiation plants unique to the Grootegeluk complex. Finally, spontaneous combustion problems and how to combat those problems in an open-pit environment where there is carbonaceous coal and shale is briefly discussed.

2 Current Mining in the Waterberg

Grootegeluk coal mine is the only operating mine in the Waterberg, and is an open- pit mine situated in the shallow, western part of the Waterberg Coalfield. The mine was commissioned in 1980 to supply coal to ESKOM's Matimba and lately the Medupi power stations and a blend coking coal to ISCOR now (Mittal Steel) as a bi-product. Matimba and Medupi are the largest direct dry-cooling power station in the world and have declared reserves of more than 20 years minimum. The annual send-out power of the Matimba power station is approximately 24 000 gigawatt hours (ESKOM 2013) and is expected to generate 4000MW while Medupi power station is designed to generate 4800 MW (ESKOM 2014). The blended coking coal is mined mostly from the bright coal of the Upper Ecca (Benches 2 to 4). The intercalated nature of coal and shales in the Upper Zones prevent any form of selective mining. The only feasible and economic way of mining the Grootegeluk Formation is through opencast benches. The benches are designed in such a way that they allow the entire seam in the selected zone to be mined according to geological markings (Dreyer 1994).

Figure 1 indicates how mining of overburden, interburden and coal is carried out on different benches for saleable product and waste. There are a total of 13 benches defined at the mine. Of the 13 benches three are sub-divided into A and B units. These are benches 1, 7 and 9. Bench 1A, 1B and 7A are waste units, while Bench 7B, 9A and 9B are coal units. 9 of the 13 benches are mining coal and the remainder are mining waste.

Four benches numbered 2 to 5 mine coal in the Upper Ecca or Grootegeluk formation. These benches correspond to Zones 5 to 11 numbered from 11 at the top and 5 at the bottom. The coal from Benches 2 to 4 contains bright coking coal with high vitrinite content.

The yield of this bright coal is between 8 to15 per cent because of the large proportions of shale intercalations. The shale intercalations are typically as high as 60 per cent because of non - selective mining. The rest of the coal is middlings for the power station at a yield of 30 to 40 per

* Corresponding Author: Chabedi Kelello, Email: kelello.chabedi@wits.ac.za, phone: +27 83 699 1869

DOI: 10.15273/ijge.2018.03.021

cent. Due to the high proportion of deleterious shale in the coal from the Upper Ecca, it requires a high density de - stoning step to remove the bulk of the non-carbonaceous material (De Korte 2010).

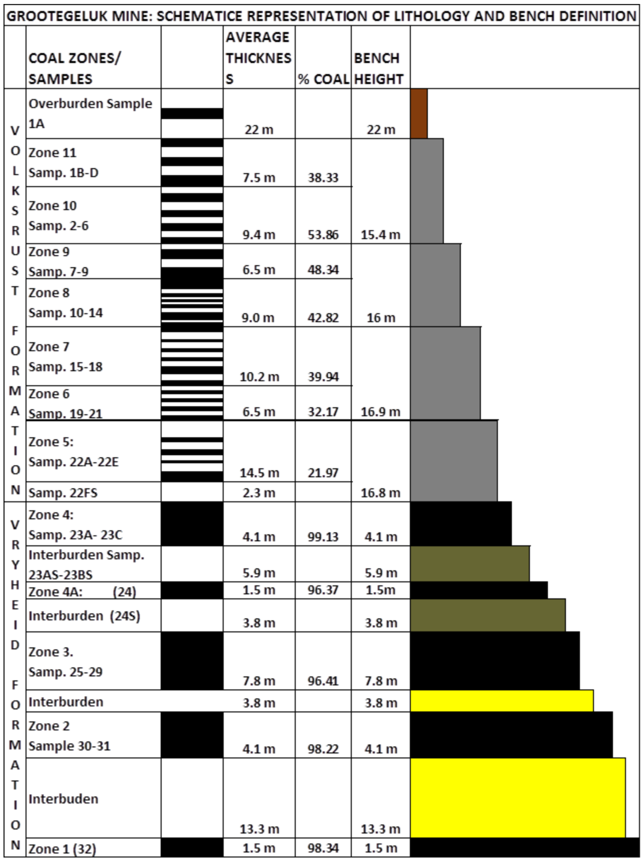


Figure 1 A schematic diagram of the lithology and bench definitions of the Upper and Middle Ecca at Grootegeluk (Adapted from EXXARO Resources Ltd 2015)

The geological structure of the Upper Zone formation, is less complicated and the coal is generally acceptable for blend coking coal characteristics. Although, bench 5 is part of the Upper Ecca formation no mining of coking coal takes place on this bench because of high phosphorous content. Instead the coal from this bench is currently mined to yield a product suitable for combustion by ESKOM (De Korte 1994).

The lower benches numbered 6 to 13 (i.e. 6, 7B, 9, 10, 11 and 13) are used to mine coal and benches 7A, 8, 10 and 12 are used to mine interburden. The coal in the Middle Ecca is mostly dull and of poorer quality when compared to that of the Upper Ecca. Bench 6, 7B and 9A are mined for the power station while Benches 9B and 11are exploited for power station and metallurgical coal. The coal benches are separated from each other by prominent sandstone, siltstone and shale interlayers.

The coal mined for metallurgical purposes is used as a semi coking coal, as well as to produce CHAR. CHAR is coal that is produced by a carbonization process at low temperatures resulting in a solid residue high in carbon and can also be used in the COREX process. CHAR can also be described as devolatilised coal used as a reductant in the ferro-alloy industries. COREX is a direct reduction process to make iron where non-coking coal is used to reduce iron ore to iron.

In summary, there are different approaches to beneficiating the Volksrust Formation and the Vryheid Formation. The Volksrust Formation is beneficiated for semi-soft coking coal and thermal coal while the Vryheid Formation is beneficiated mostly for thermal coal (De Korte 2010).

Bench 13 is not mined at present because of a thick interburden Bench 12 which must be removed to access it. Furthermore the coal in this bench is thin and therefore uneconomic. The thickness of the coal is about 1.5 metres. The sandstone above bench 13 is about 13 m thick as shown in Figure 1. The geological contacts of the coal zones coincide with the zone boundaries and make the benches to be between 15 and 17 m in height in benches 2 to 5. Thickness in the Vryheid formation vary between 1.5 m and 7.8 m. The bench heights make it possible to mine the zones easily with opencast machines such as trucks and shovels (Dreyer 1994).

3 Mining of the Different Benches

The mining of all the benches is described in detail below in order to give an understanding of how the thick coal zones of 110m package of the Waterberg stratigraphy are presently exploited by open pit mining. First, it is important to note that benches that correspond to coal zones are selected and that the height of these benches range from 1.5 m at the lowest to a maximum of about 16 m. The height of the benches also takes into account the size of available mining machinery. The benches start from the top to the bottom as opposed to the coal zones that start from the bottom upwards. In general the top benches (1-5) are mined with a combination of a rope shovel and bigger trucks as explained later on in Tables 1 and 2 respectively.

The first bench (Bench 1) is an overburden bench. It is estimated to be about 1.5m at the lowest to a maximum of - 20 m high in the western part of the coalfield and the overburden has a density of about 2.5 tonnes per cubic metre (t/m^3). At this depth the stripping ratio is low and acceptable for open-pit mining. One can expect a lot of waste stripping and topsoil stripping on this bench as is typical of any surface mine.

The second bench (Bench 2) corresponds to Zones 11 and 10 and it is the first coaling bench which is estimated to be about 13.5 m high and has an average coal density of roughly 1.74 t/m^3.

The next benches are also coaling benches i.e. benches 3 and 4. These benches are about 16m in height and have a coal density of about 1.86 t/m^3. Bench 3 corresponds to zones 9 and 8. Bench 4 corresponds to zones 7 and 6.

Bench 5 corresponds to Zone 5 and is also a coaling bench which is about 16.7 m high with a density of 1.88t/m^3. The first five benches discussed are found in the Upper Ecca and therefore have a mixture of bright coal with high vitrinite content by South African standards. The layers of bright coal are interbedded with carbonaceous mudstone (De Korte 1994).

In general the lower benches (6-13) are mined with a combination of front end loaders, hydraulic shovels and smaller trucks as explained in detail in Tables 1 and 2 respectively. The benches that follow form part of the Middle Ecca or the Vryheid Formation which is composed mostly of dull coal, sandstone and carbonaceous shale. Bench 6 corresponds to Zone 4 and is a coaling bench that is about 4 m high with a density of 1.65 t/m^3. The coaling benches of the Middle Ecca have an average thickness above 4m except Bench 7B which is less than 2m.

Bench 7 is divided into a waste and a coaling bench. Consequently, Bench 7A is an interburden bench which is about 4.3m with a density of 2.21 t/m^3 and Bench 7B corresponds to Zone 4A and is a coaling bench where the seam is about 1.5 m thick and has a density of 1.80 t/m^3.

Bench 8 is a waste bench which is about 4.3m high with a density of 2.45 t/m^3 and Bench 9 corresponds to Zone 3 and is a coaling bench which is about 7.82 m high. This coaling zone is mined in two benches i.e. Bench 9A and 9B with densities of 1.64 t/m^3 and 1.53 t/m^3.

Bench 10 is an interburden bench, mining sandstone and is about 1.4m high with a density of 2.5 t/m^3 and Bench 11 correspond to zone 2 and is coaling bench which is on average estimated to be 3.73m with a relative density of 1.52 t/m^3.

Bench 12 is an interburden bench and is on average estimated to be 3.85m with a density of 2.5t/m^3. Bench 13 corresponds to Zone 1 and is a coaling bench which is estimated to have a seam thickness of 1.5m with a density of 1.52 t/m^3. Figure 1 gives a comprehensive summary of the benches in terms of their numbering, percentage coal in each bench or zone, lithology, bench height and density.

4 Mining Equipment at Grootegeluk Mine

Mining at Grootegeluk open pit mine is done using the truck and shovel method. In general, the overburden and inter-burden are mined by electric shovels and the coal is mined primarily by all three types of primary mining equipment (hydraulic shovel, rope shovel and front end shovels). There is a combination of Komatsu PC 4000 which are front end loaders or back hoe and Komatsu PC 5500 front end loader, Taiyuan Heavy Industry (TZ) rope shovels, CAT 994 wheel loaders and LeTourneau electric-drive wheel loader. The sizes of front end loaders and electric shovel and the tonnes per hour mined by each shovel are indicated in Table 1.

Table 1 Types of Shovels (EXXARO Resources Ltd 2015)

Type of shovel	Typical tonnes per hour
CAT 994 Wheel Loader	1200
LeTourneau Wheel Loader	3200
PC 4000 Back Hoe	2100
PC 4000 Front End Loader	2200
PC 5000 Front End Loader	2200
TZ Rope Shovel	4200

According to the information gathered during a mine visit there are over 50 haul trucks on the mine in total. The fleet is composed of Komatsu 730E's, Hitachi EH 3500's, Hitachi EH 4000's and Euclids 3500. The type of trucks and payload expected are given in Table 2.

Table 2 Types of Trucks (EXXARO Resources Ltd 2015)

Types of trucks	Typical payload
Komatsu 730E	180
Euclid EH3500	180
Euclid EH4000	220

The bigger trucks which are the Hitachi EH 4000's carry the most payload and consequently consume more diesel. However, it should be noted that the productivity of the trucks depends on the distance travelled to and from the tip and is a function of how the dispatcher allocates trucks to the different ramps. The expected productivity of the Komatsu 730E is comparable and very similar to that of the Hitachi EH 3500. All trucks are equipped with electric wheel motors. They therefore use both diesel and electricity. Main haulage roads have pantograph lines on which the trucks connect to save diesel on the uphill road to the beneficiation plants. During the travel on electricity the trucks can achieve a minimum speed of 24 km/h. Hitachi EH 4000's trucks can travel faster than the other trucks as they have AC drive motors while the rest have DC drive motors.

The current mining depth is about 130m with an average stripping ratio of 0.49 m^3/t. The stripping ratio is the ratio of the volume of the overburden or waste mined to the volume of the tonnes of coal mined in most surface mines is usually between 6 and 8 but due to the thickness of the coal in Grootegeluk mine the stripping ratio is low. Other supporting equipment include drills, dozers (rubber and tyred), graders and water tankers are provided to make mining.

5 Quality and Quantity of Coal Mined

In 2015, the mine produced 86 million tonnes ex-pit. The ROM produced was 54 million tonnes per annum (Mtpa) and the total waste produced was 32 Mtpa. The breakdown of the waste produced is 23 Mtpa overburden and 9 Mtpa of interburden. The tonnes produced by the plant after the coal was washed were about 27 Mtpa of sales and therefore 27Mtpa was discard (EXXARO Resources Ltd 2015).

The final product produced by the plant is distributed as 85% for Matimba power station, about 8.5 % for the semi - soft coking coal and 6 % for the metallurgical coal.

6 Beneficiation

There are different approaches for beneficiation of the coal for the Upper section or Volksrust and the Lower section or Vryheid Formation. The Upper section is washed mainly for coking coal and thermal coal whereas the lower section is beneficiated mainly for thermal coal. The Volkrust

Formation contains a large proportion of impurities typically approximately 60%. This necessitates beneficiation of the raw coal. The beneficiated bright coal product, by virtue of its high vitrinite content and other properties, is suitable as a blend coking coal (De Korte 1994, 2010).

The coal from the Upper Ecca requires high capacity processing plants and the coal contains high amounts of dense material. The coal requires very efficient separation process that is the dense medium process and has to be crushed to a small top size (about 15mm) to liberate the coking fraction. The coal is also very friable and generates a lot of fines during handling and crushing. Therefore effective fine coal processing techniques are required. After beneficiation of the coal there is a need to dewater the products.

The Upper section, employs two stages of preparation on benches 2, 3 and 4. A first, high density separation stage is employed to remove the impurities from the raw coal. The float product from the first-stage processing is re-treated at a lower relative density to yield a blend coking coal containing approximately 10% ash and a middling product containing approximately 35% ash. The blend coking coal is utilized by Mittal Steel in the production of metallurgical coke, while the middling fraction is used for power generation at the nearby Matimba power station (De Korte 1994).

The Lower section consists of five coal seams on Benches 6-11 with the exception of Benches 7A, 8, 10 and 12 which are interburden benches. As stated before some of the coal especially benches 9A and 11 are suited for use in the thermal market in the raw state meaning that no beneficiation takes place. This coal requires crushing and screening only. Coal from Bench 7B requires high density beneficiation to lower the ash content. Coal from Benches 9A and 11 are processed to produce a pulverized coal injection (PCI) product. Bench 13 is very thin and considered uneconomic at present.

In summary the mine produces three products, namely semi soft coking coal, power station (steam or thermal) coal and metallurgical coal. Semi soft coking coal is produced mainly from the Upper Ecca. Thermal coal is produced mainly from the Middle Ecca and Upper Ecca. Metallurgical coal i.e. PCI is produced from the Middle Ecca.

In general raw coal at Grootegeluk mine is of high ash content and as a result, large coal beneficiation plants are needed to meet the production targets for both the metallurgical and thermal markets. For this reason 10 plants have been erected since 1980 to produce the required quantities of coal (De Korte 2010).

7 Discussion of the Grootegeluk Beneficiation Plants

Coal from the Waterberg coalfield is beneficiated differently to Witbank coalfield i.e. it requires ten large, separate plants to beneficiate the coal in order to meet the customer requirements as shown in Figure 2.

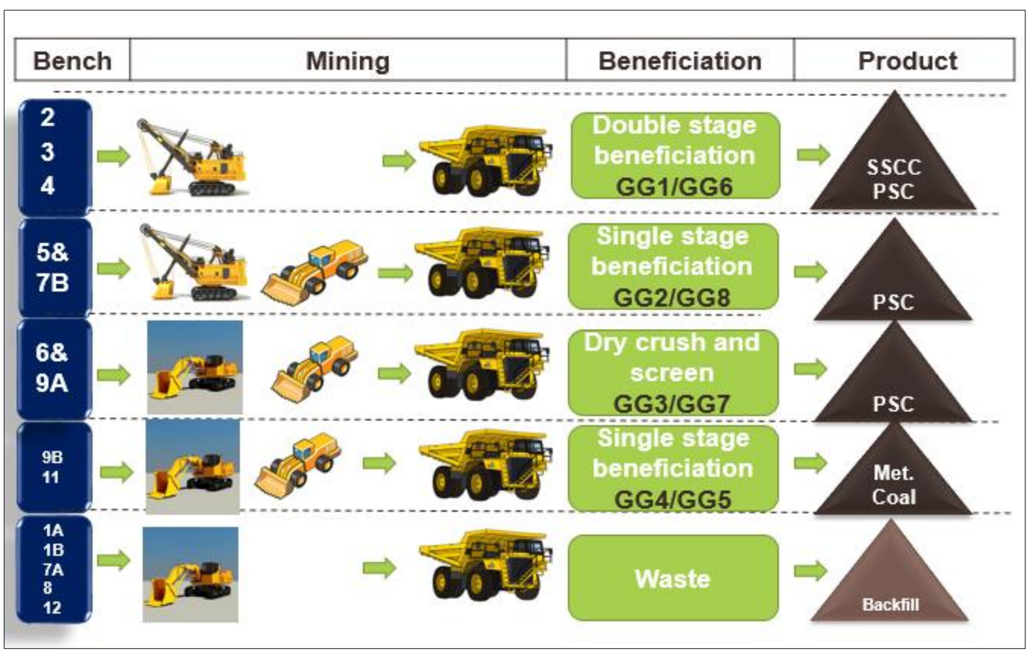


Figure 2 Material Flow and mining equipment of the different zones (EXXARO Resources Ltd 2015)

Grootegeluk 1 (GG1) produces semi - soft coking and steam coal as middlings. The plant is a two stage wash plant with low phosphorous percentages and high ROGA and swell characteristics for coking properties. The ROGA index is an indication of the caking capacity of the coal (MineSkill Australia 2010). The coal for this plant is supplied from benches two to four.

Grootegeluk 2 (GG2) is a single wash plant that produces steam coal for the power station from benches two to four at a relative density of 1.8. The coal requires high density beneficiation to lower the ash content (De Korte 2010).

Grootegeluk 3 (GG3) is a crush and screen plant which takes coal from Zone 4 or Bench 6 with a calorific value of 20.5 per cent and ash content of about 35 per cent and produce only steam coal for the Matimba Power Station. As discussed before this is dull coal but the coal is suitable to be used at the power station as raw feed thus saving on the washing costs.

Grootegeluk 4 and 5 (GG4 and GG5) produce pulverised injection (PCI) or duff with a high calorific value in the range of about 27.4 MJ per kilogram and ash of less than 17 per cent and steam coal. They also have a low phosphorous content to control emissions that are harmful to the environment. This coal produces CHAR which is used in the specialised steel industry. The coal for these two plants is mined from benches 9 and 11.

Grootegeluk 6 (GG6) is a new plant that produces semi soft coking coal and middlings for the power station also from benches 2 to 4.

Grootegeluk 7 and 8 (GG7 and GG8 are crush and screen plants that produces coal directly for Matimba and Medupi power stations.

Grootegeluk 10 (GG10) is a double stage wash plant that produces coal for the export or metallurgical purposes and midlings for the power station form benches 9A and 9B.

The beneficiation plants that handle the coal from the various mining benches are shown in Figure 2 (EXXARO Resources Ltd 2015).

8 Spontaneous Combustion

Grootegeluk Mine coal and waste material have a propensity for spontaneous combustion because of the rank of the coal amongst other factors and the carbonaceous nature of the overburden and interburden. The ROM has a yield of about 50 per cent, implying that half of the production that the mine produces ends up as discard after the beneficiation process. The plant discards have a high propensity for spontaneous combustion. The inter-burden material is also prone to spontaneous combustion due to its carbonaceous nature. The problem associated with this large quantity of waste is safe storage and disposal in a way that will prevent the occurrences of fires in the pit (Adamski 2003). The discard materials that need to be handled are mixtures of discards from various plants and waste from benches with unknown properties. Thorough knowledge of the chemical and physical properties of all the different materials and mixtures was considered to be a pre-requisite for the design of safe waste dumps/heaps (Adamski 2003). Through research it was discovered that the Grootegeluk Mine plant discards are coarse, burn easily and are very reactive. The most dangerous combination of these was a mixture of coarse and fine materials which represented Grootegeluk Mine pit waste (interburden from Benches 7 and 8).

According to Adamski in his PhD thesis (Adamski 2003), some of the above findings were recommended by Professor Glasser, a chemical engineer and one of the experts in the field of spontaneous combustion. Glasser recommended crushing and segregating material before stacking which will result in placing finer material on top of coarse material (Glasser 1983). This will effectively allow the thin, low permeable material to block air transportation. He further recommended that to minimise permeability that the dumps surface and slopes be compacted at Grootegeluk. Finally, Glasser recommended that a thin layer of middlings be stacked over the whole dump. However, the harsh climate of sun, rain and wind made for a very maintenance intensive process to ensure oxygen did not gain entry through cracks in the surface, compacted layer. Research and application of the above research by Adamski at Grootegeluk led to the conclusion that the thin layer of middlings, due to high reactivity and low permeability, if compacted, will be able to prevent oxygen from entering into the waste dumps due to two reasons.

Firstly, the thin, low permeable layer of middlings would absorb oxygen and secondly due to low permeability it would restrict the airflow into the dumps (Adamski 2003). Grootegeluk mine needed a safe method of disposing and storing the discard material from the plant i.e. middlings and the waste material produced form the pit. After much research and experimentation by Adamski - a backfill method that involves stacking the material in the pit into – prebuilt and sealed compartments was found to be a solution for the Grootegeluk spontaneous combustion problem. This method took into account aspects such as the critical time (8 weeks for slopes and 3 months for surface areas) that reactive material can be exposed to air. The critical time determined the stacking rate as well as the dimensions of the backfilling compartments. To maintain the constant stacking rate the compartments width had to be fixed.

The 110m deep pit was to backfilled to the natural ground level. The backfilling was done using four levels. The first level will contain interburden material. The second and third levels contained plant discards while the fourth-sealing level contained material with a layer of about 1m thick top-rehabilitated topsoil. The heights of the various levels were subsequently changed due to changes in production rates, to allow a safe stacking rate. The effect of backfilling in the pit was not only to place discards from the plants but also to use inert material and pit waste that would otherwise need to be hauled out of the pit (Adamski 2003).

9 Conclusions

The Waterberg coalfield is a technically challenging coal deposit to exploit because of its multi-seam nature, propensity for spontaneous combustion and coal quality characterised by high ash content. However, Grootegeluk Colliery has managed to overcome these challenges and is one of the biggest open-pits in the world and mines about 86 million tonnes of coal and 32 million tonnes of waste from the pit to meet the production requirements at a low cost. The Run of Mine coal produced in 2015 was about 54 Million tonnes per annum for the Medupi and Matimba power stations. About 50% of the ROM is produced as waste which is prone to spontaneous combustion and has to be managed carefully in the pit. The mine operates a large fleet of haul trucks and a combination of shovels and front end loaders to produce coal and waste including discards. In order to meet their production requirements coal and waste from the 13 benches has to be mined meticulously. Grootegeluk has ten one of the largest plants in South Africa producing three types of products i.e. semi-soft coking coal, steam coal and metallurgical coal in order to offset the mining costs and meet the customer requirements. The mine has experienced and successfully solved the problem of spontaneous combustion which is a major problem for surface coal mines in South Africa.

Acknowledgement

This research project is made possible through the support of Exxaro Resources Limited and the School of Mining Engineering at Wits University. We want to thank Exxaro Resources for providing material for this publication and the School of Mining for their financial support.

References

Adamski, S.A., 2003. The prevention of spontaneous combustion in backfilled waste material at Grootgeluk coal mine. Project Report, University of the Witwatersrand, Johannesburg.

De Korte, J., 1994. The Utilization Potential of Coal from the Waterberg Coalfield: Aspects of Utilization, Department of Mineral and Energy Affairs, Pretoria.

De Korte, J., 2010. Beneficiation of Waterberg Coal, Johannesburg: Unpublished.

Dreyer, C., 1994. Total utilization of the coal resource: the Grootegeluk experience. In: C. Anhaeusser, ed. Proceedings XVth CMMI Congress. South African Institute of Mining and Metallurgy, Johannesburg, South Africa, pp 153 - 164.

ESKOM, 2013. Matimba power station. [Online] Available at http://www.eskom.co.za/c/article/41/matimba-power-station/ [Accessed 04 March 2013].

ESKOM, 2014. Medupi power station. [Online] Available at http://www.eskom.co.za/Whatweredoing/NewBuild/MedupiPowerStation/Documents/NB_0002MedupiFactSheetSept2013.pdf [Accessed 28 March 2018].

EXXARO Resources Ltd, 2015. The Role of Geology at Grootegeluk Mine. Limpopo: Unpublished.

Glasser, D., 1983. Spontaneous combustion of coal. University of the Witwatersrand, Johannesburg.

MineSkill Australia, 2010. Understanding Coal Quality. 5th ed. MineSkill Australia, New South Wales.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca
IJGE 2018 **4**(**3**): 133-140
Available at http://ojs.library.dal.ca/ijge
Research and Development and Industry

Investigation of Effects of Nanobubbles on Phosphate Ore Flotation

Dongping Tao[1]*, Maoming Fan[2], Zhongxia Wu[1], Xuyu Zhang[1], Qianshuai Wang[1], Zekang Li[1]
[1] School of Mining Engineering, University of Science and Technology Liaoning, Anshan, Liaoning, China
[2] Canadian Process Technologies, Inc., Eriez Manufacturing Company, Erie, Pennsylvania, USA

Abstract: Phosphorous is vital for life, including plants, animals, and human beings and it is an essential component in agricultural fertilizers and phosphorous-based chemicals. Phosphate ores, mainly in the form of apatite and collophanite, are non-renewable natural resources of phosphorus. Froth flotation has been used in the phosphate industry for more than half a century as the primary technique for upgrading phosphate. Nevertheless, flotation does not produce satisfactory performance for phosphate beneficiation in many cases, especially for very fine and coarse phosphate particles. This study was performed with an aim to develop a nanobubble enhanced flotation process to enhance phosphate flotation efficiency. A specially designed flotation column featured with a nanobubble generator and a conventional bubble generator was employed to assess the effects of nanobubbles on the phosphate ore flotation performance under different operating conditions. Flotation process parameters investigated include feed flow rate, dosage of collector, dosage of frother, flotation time, etc. The flotation results have shown that use of nanobubbles increased P_2O_5 recovery by up to 30% for a given Acid Insoluble (A.I.) rejection, depending on phosphate concentrate grade. Nanobubbles reduced the collector and frother dosage by about 50% and also increased flotation kinetics. The improved flotation performance can be attributed to increased collection efficiency and surface hydrophobicity in the presence of nanobubbles.

Keywords: attachment, bubble size, cavitation, collision, nanobubble, phosphate

1 Introduction

Phosphate rock often exists in the form of apatite and collophanite and represents a vital non-renewable resource of phosphorous which is vital for life, including plants, animals, and human beings. It is a commodity which is neither substitutable nor recyclable in agricultural applications. The demand for phosphorous must be met through mining, beneficiation, and chemical processing of naturally derived phosphate deposits. China, Morocco, Russia and the United States of America are four leading producers of phosphate rock in the world and their outputs account for 72% of the total annual production of 160 million tons (Van Kauwenbergh 2010). The increased need for world food production assures the long-term growth in world phosphate rock demand. Nevertheless, the run-of-mine phosphate ore is low in P_2O_5 grade, contains high concentrations of impurities such as quartz, chert, clay, feldspar, mica, calcite, and dolomite and thus cannot be used directly to produce commercial products. It requires upgrading or beneficiation to reduce the content of gangue minerals to meet given specifications. For example, in the fertilizer industry the phosphate concentrate must satisfy these required criteria: 1) P_2O_5 content larger than 30%, 2) CaO/P_2O_5 ratio smaller than 1.6, and 3) MgO content less than 1%.

Froth flotation is the most widely used process for phosphate beneficiation where fatty acids are often used as collectors (Sis and Chander 2003). In this process hydrophobic phosphate particles are captured by air bubbles, ascend to the top of the pulp zone, and eventually report to the froth product whereas hydrophilic gangue minerals such as silicates, carbonates, and clays remain in the pulp and are discharged as tailings. Although the most recent studies (Priha et al 2014, Mendes et al 2014, Calle-Castañeda et al 2018) have shown that biological processes may be used for upgrading low grade phosphates, the vast majority of world's marketable phosphate is produced by froth flotation. However, the high separation efficiency of froth flotation is limited to a very narrow particle size range, which is usually 10-100 μm. In fact, one of the most difficult technical challenges facing the mineral processing industry is the recovery of fine (<37 μm) and ultrafine (<8–13 μm) mineral particles by flotation (Calgaroto et al 2015). It is generally believed that the low flotation efficiency of fine particles is primarily due to the low probability of bubble-particle collision while the main reason for poor flotation recovery of coarse particles is the high probability of detachment of particles from bubble surface (Ralston and Dukhin 1999, Yoon 2000, Tao 2004).

Tremendous efforts have been made to improve flotation recovery of phosphate particles. Davis and Hood

* Corresponding Author: Dongping Tao, Email: dptao@qq.com, phone: +86 138 1346 7505

DOI: 10.15273/ijge.2018.03.022

(1993) found that optimized conditioning process improves the recovery. Moudgil (1992) reported that the recovery of phosphate particles can be enhanced by means of collector emulsification, and use of more effective frother, etc. Maksimov et al (1993) reported that weak agitation combined with sufficiently high ascending pulp flow in a mechanic flotation cell substantially increased the flotation recovery of coarse mineral particles. Rodrigues et al (2001) observed that the flotation recovery of coarse particles is strongly affected by hydrodynamic conditions and maximum flotation recovery was achieved when the hydrodynamic parameters were in a certain range. They attributed the low flotation recovery of coarse particles under too quiescent conditions to particle settling and that under too turbulent conditions to disruption of particle/bubble aggregates. Teague and Lollback (2012) developed a rougher, cleaner, scavenger flotation scheme based on Jameson cells for beneficiation of phosphate ore feed slurry with up to 80 wt% particles finer than 20 μm to recover at least 80% phosphorus at a grade of 32% P_2O_5 or greater. However, their process requires slurry conditioning with reagents at high wt% solids (at least 70 wt%), use of guar gum as depressant and deionized water in addition to regular reagents such as soda ash, tall oil fatty acid and diesel and therefore the process may not be economically feasible. Liu et al (2017) found that saponified gutter oil fatty acid is an effective collector for reverse flotation of apatite from dolomite in collophaite ore. Zhou et al (2017) demonstrated in micro-flotation tests that use of reactive oily bubble can effectively enhance collophane flotation to produce superior separation performance. However, a practical and cost effective flotation approach has not been developed to increase the flotation recovery and reduce the flotation reagent consumption at the same time.

It is known that tiny nanobubbles or gas nuclei of less than 1 μm naturally exist in liquids such as seawater, distilled water, and blood (Johnson and Cooke 1981). It has been found (Schubert 2005, Hampton and Nguyen 2009) that nanobubbles accumulate preferentially at the hydrophobic solid–water interface, which has been confirmed by the atomic force microscopy (AFM) (Attard 2003, Mishchuk and Ralston 2006, Hampton and Nguyen 2010, Fan et al 2013, Li and Zhao 2014, Azevedo et al 2016, Knupfer et al 2017). Tiny nanobubbles attach more readily to particles than large bubbles due to their unique characteristics such as huge specific surface area, lower ascending velocity in water and rebound velocity from the surface, higher surface free energy to be satisfied, greater contact angle on solid surface, etc (Ducker 2009, Liu et al 2013, Calgaroto et al 2014, Azevedo et al 2016). Nanobubbles on particle surface activate flotation by promoting the attachment of larger bubbles since the attachment between nanobubbles and conventional sized bubbles is more favored than bubble/solid attachment. In other words, nanobubbles act as a secondary collector for particles, reducing flotation collector dosage, enhancing particle attachment probability and reducing the detachment probability. This leads to substantial improvement in flotation recovery of poorly floating phosphate particles and reduced reagent cost (Tao et al 2006, Fan and Tao 2008), which is one of the largest operating costs in commercial phosphate flotation plants. Application of nanobubbles to coal flotation resulted in an increase in flotation yield up to 15 wt%, a frother dose reduction of 10%, and a collector dose reduction of 90% (Attalla et al 2000). Similar results were obtained by Fan et al (2013). Calgaroto et al (2015) reported that use of nanobubbles (200 - 720 nm) improved the flotation recoveries of quartz fines and ultrafines by up to 20–30% and the higher contact angles and quartz fine aggregation in the presence of nanobubbles are claimed to be the most important mechanisms involved. Peng and Xiong (2015a, 2015b) confirmed that nanobubbles significantly increased coal flotation recovery.

This study was carried out to demonstrate the technical viability of the nanobubble flotation technology for the beneficiation of a plant phosphate flotation feed using a 5 cm in diameter flotation column featured with a static mixer to generate microbubbles and a cavitation tube to produce nanobubbles. Operating parameter examined in the study included feed flow rate, dosage of collector, dosage of frother, flotation time, etc.

2 Experimental

2.1 Flotation feed samples

The phosphate sample was collected from the conditioner feed streams in a Mosaic phosphate beneficiation plant in Florida, USA and placed in sealed containers. The phosphate samples were thoroughly mixed and split into small lots for storage in the lab. Representative samples were taken for size distribution analysis and chemical analysis.

2.2 Chemical analysis

XRD analyses of the phosphate flotation feed sample were conducted using Bruker D-8 Discover X-2 Advanced Diffraction Cabinet System equipped with Pelteir detector with stationary sample stage to identify principal elements. The XRD apparatus uses CuKa radiation source. The chemical composition of the phosphate samples was analyzed with the S4 PIONEER - wavelength dispersive X-ray fluorescence spectrometer (WDXRF). Up to 10 primary beam filters, 4 collimators, and 8 crystals can be utilized, which provides great analytical flexibility. The integrated standardless evaluation for all kind of samples like rocks, minerals, metals, hydrocarbons and industrial products allows the fast and easy determination of element concentrations from 100% down to the ppm-level without performing a calibration.

2.3 P_2O_5 content analysis

The P_2O_5 content analysis of phosphate sample was performed according to the standard procedure described by Zhang and Bogan (1994). About 1 gm of the dried and ground representative sample was digested in 50 ml of boiling aqua regia (a mixture of nitric and hydrochloric acids) on a hotplate until the reaction was complete. After cooling, this solution was filtered through a Whatman 42 filter paper into a 1000 ml volumetric flask. The filter paper and residue were then washed at least five times to remove all traces of dissolved salts and acid. The filtrate was diluted with distilled water and thoroughly mixed. The concentrations were analyzed using an Inductively Coupled Plasma (ICP) emission spectrometer.

2.4 Acid insoluble analysis

Acid soluble components and acid insoluble components were analyzed using the industry's standard method described by Zhang and Bogan (1994). Acid-insoluble material was measured as an aqua-regia-insoluble material. Insoluble analysis was performed using the gravimetric method. Using a clean, tarred crucible, the filter paper and residue obtained from the digestion step was ignited at 900°C. After the crucible cooled, the acid insoluble in the sample was calculated.

2.5 Bubble size measurement

A Cillas 1064 laser particle size analyzer was used to measure the cavitation tube generated nanobubbles and the static mixer generated conventional sized bubbles. Details are provided elsewhere (Fan et al 2010).

2.6 Flotation reagents

The collector employed in the present study was a mixture of a fatty acid (FA-18G) and fuel oil at the ratio of 3:2 by weight. A glycol frother (F-507) was used to reduce water surface tension. Both frother and collector were obtained from the phosphate company. The collector dosage and frother dosage were fixed at 0.9 kg/ton and 10 ppm respectively. Soda ash was used as the pH modifier for the feed sample.

2.7 Laboratory flotation with phosphate samples

The specially designed flotation column shown in Figure 1 was used to perform flotation tests with phosphate samples. The column was made of Plexiglas of 5 cm in diameter and 1.8 m in height. The cavitation tube and the static mixer were used to generate nanobubbles and conventional sized bubbles, respectively.

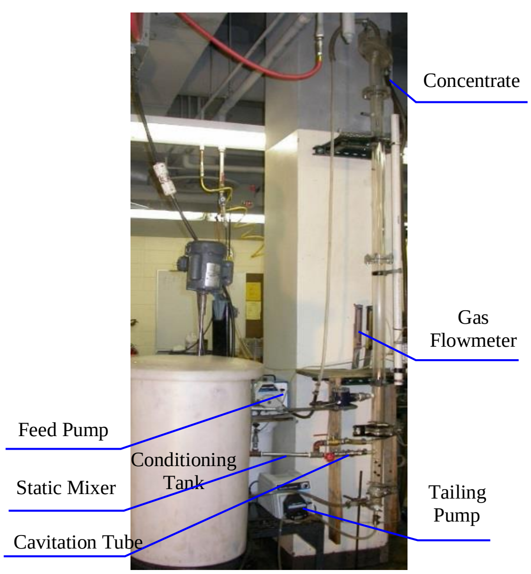


Figure 1 Specially designed flotation column

The flotation procedure is briefly described as follows: 2 kg phosphate sample was employed to make flotation feed slurry for each run. Sodium hydroxide was used to adjust the pH between 9.1 and 9.5. The flotation feed was conditioned with the collector for 3 minutes at a predetermined solids concentration (75% solids unless otherwise specified) using a mechanical agitator. The conditioned phosphate sample was diluted to 25% solids content by weight and fed tangentially into the flotation column through a peristaltic pump, which allowed a consistent underflow stream. Phosphate slurry feed rate was 800 ml/min. A glycol frother (F-507) was used for the phosphate flotation tests. The total recycling flow rate for nanobubble and conventional sized bubble generation was maintained at 8.0 l/min.

3 Results and Discussion

Figure 2 shows the XRD intensity (cps, counts per second) versus XRD 2θ of the Mosaic phosphate sample. The amplitudes for specific XRD peaks indicate that the major mineral composition of the phosphates samples were quartz (SiO_2) and apatite ($Ca_5F(PO_4)_3$). The peak amplitudes for other minerals such as dolomite ($CaMg(CO_3)_2$), wavellite ($(AlOH)_3(PO_4)_2{\bullet}5H_2O$), Crandallite ($Ca_{0.7}Sr_{0.3}Al_3(PO_4)_2(OH)_5H_2O$), and K feldspar ($KALSi_3O_8$) etc. were very small, indicating that contents of these minerals in the phosphate samples are very low.

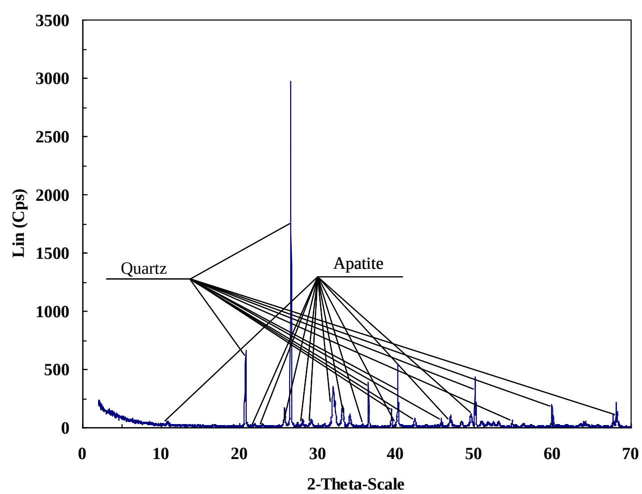


Figure 2 Mosaic phosphate XRD intensity cps versus 2θ

The particle size distribution results of the +100 mesh (>0.15 mm) phosphate plant flotation feed sample are shown in Figure 3. It was wet screened into eight size fractions. The curve of cumulative undersize against particle size shows that the median size of the phosphate sample was about 0.4 mm. Most particles or about 80% were coarser than 50 mesh or 0.3 mm. Less than 2% particles were smaller than 100 mesh or 0.15 mm and less than 1% particles were larger than 16 mesh or 1.18 mm. It should be noted that the flotation feed was the phosphate sample deslimed at 100 mesh to remove high concentrations of clays, which is the standard practice in the Florida phosphate industry. In other words, the lab flotation feed sample was the same as the plant flotation feed sample. The phosphate sample contained 15.6% moisture, 10.16% P_2O_5, and 67.23% Acid Insoluble (A.I.).

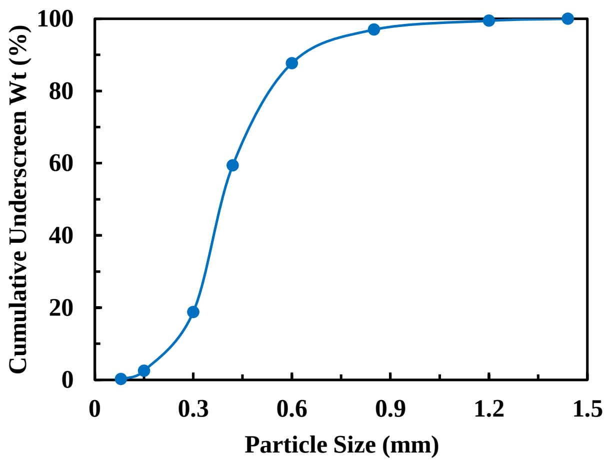


Figure 3 Phosphate particle size distribution

Figure 4 shows the size distribution of bubbles generated by the cavitation tube and static mixer at a frother dosage of 10 ppm. There are two major distribution peaks observed on the population frequency curve. They represent nanobubbles with a d_{50} of approximately 830 nm and micro-size bubbles with an average of about 70 µm generated by the cavitation tube and the static mixer, respectively. Obviously, the nanobubbles are approximately two orders of magnitude smaller than microbubbles and this result is consistent with other studies (Peng and Xiong 2015a, 2015b). Oliveira et al (2018) reported that even smaller nanobubbles (230-280 nm) can be generated with a cavitation tube and the size of nanobubbles depends on liquid surface tension, air/liquid ratio, etc. Etchepare et al (2017) used a multiphase pump and a needle valve to generate 150-220 nm nanobubbles with a concentration of up to 4×10^9 nanobubbles ml^{-1}. They found that nanobubbles were highly stable and resistant to shearing caused by pump impellers and to high operating pressures (up to 5 bar).

Figure 5 shows the effect of feed rate on concentrate grade and flotation recovery without nanobubbles. It can be observed from Figure 5 that the P_2O_5 recovery decreased from about 87% to 57% as the feed rate increased from 120 g/min to 600 g/min. This was a result of decreased flotation time with feed rate increasing. The P_2O_5 content in the concentrate increased slightly from about 26.5% to 27.5% as the feed rate increased whereas A.I. content decreased from 22.8% to 19.1%.

Figure 6 shows the effect of feed rate on flotation recovery and concentrate grade with nanobubbles. It can be observed that the P_2O_5 recovery decreased only slightly from 98% to about 96.5% as the feed rate increased from 120 g/min to 360 g/min. When the feed rate increased from 360 g/min to 600 g/min, the P_2O_5 recovery decreased to 77%. The P_2O_5 in the concentrate increased from 28.5% to 29.0% as the feed rate increased. Comparing Figure 6 with Figure 5 clearly indicates that use of nanobubbles not only increased P_2O_5 recovery but also improved concentrate grade, suggesting flotation separation efficiency was remarkably enhanced in the presence of nanobubbles.

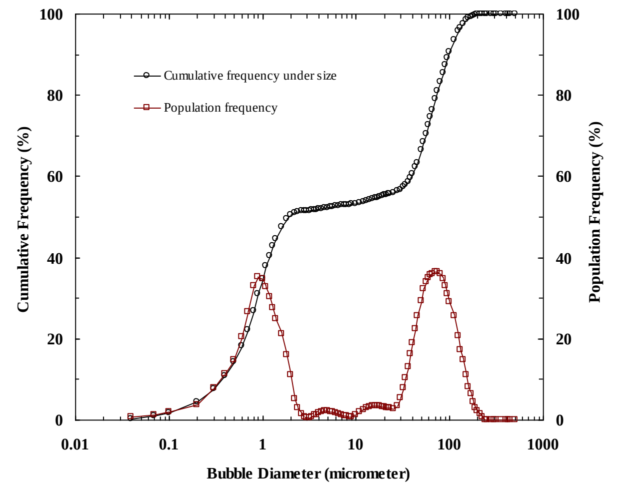


Figure 4 Size distribution of cavitation tube and static mixer generated bubbles

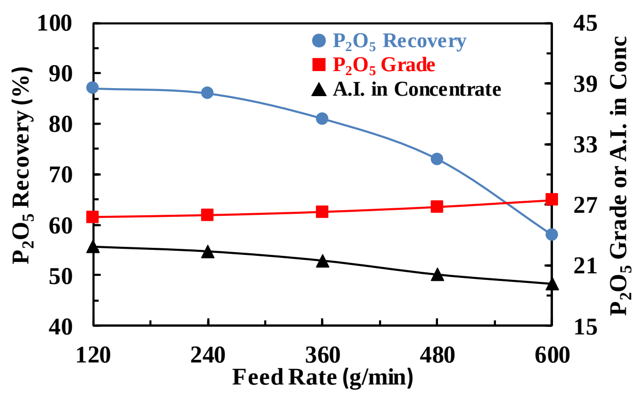


Figure 5 Effect of feed rate on concentrate grade and recovery without nanobubbles

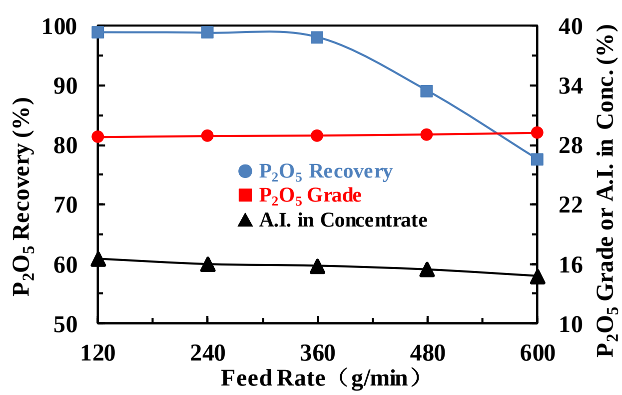


Figure 6 Effect of feed rate on concentrate grade and recovery with nanobubbles

Figure 7 shows the flotation separation efficiency curve based on the relationship between the A.I. rejection and P_2O_5 recovery obtained under the different feed rates with and without nanobubbles. The remarkable differences in two separation curves clearly indicate that the use of nanobubbles significantly enhanced the separation efficiency of froth flotation. Nanobubbles always produced a higher P_2O_5 recovery at a given A.I. rejection. For example, P_2O_5 recovery was about 30% higher at an A.I. rejection of 80%. The improvement in flotation separation efficiency by nanobubbles can be attributed to the selectivity of nanobubbles for hydrophobic particles previously demonstrated by other investigators (Hampton and Nguyen 2010, Fan et al 2013, Sobhy and Tao 2013a, Li and Zhao 2014, Azevedo et al 2016, Knupfer et al 2017). Similar flotation efficiency improvements by nanobubbles with other minerals have been reported by others (Sobhy and Tao 2013a, 2013b, Calgaroto et al 2015, Peng and Xiong 2015a, 2015b).

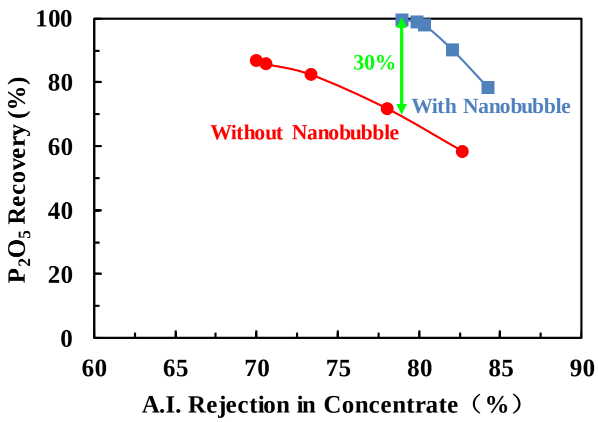


Figure 7 Effects of nanobubbles on separation efficiency curve

Figure 8 shows the effects of nanobubbles on flotation concentrate P_2O_5 recovery and grade at different collector dosages varying from 0.3 kg/ton to 2.1 kg/ton. It should be pointed out that there were no noticeable differences in the product grade with or without nanobubbles and therefore only one grade curve is shown in Figure 8. In these tests, the flotation feed rate, superficial air velocity, and frother dosage were fixed constant at 240 g/min, 1.0 cm/s, and 10 ppm, respectively. The curves in the figure indicate that the P_2O_5 flotation recovery increased remarkably as the collector dosage increased from a dosage of 0.3 kg/ton to 0.9 kg/ton with or without nanobubbles. The P_2O_5 recovery increased slightly in the absence of nanobubbles while the P_2O_5 recovery remained essentially constant in the presence of nanobubbles as the collector dosage increased from 0.9 kg/ton to 2.1 kg/ton. The maximum flotation recovery of approximately 98% and a concentrate grade of 28.8% were achieved at a collector dosage of 0.9 kg/t in the presence of nanobubbles. In contrast, the maximum flotation recovery of less than 94% was achieved at a collector dosage of 2.1 kg/t in the absence of nanobubbles. In other words, a higher maximum recovery was achieved with less collector in the presence of nanobubbles, suggesting use of nanobubbles increased P_2O_5 recovery and reduced required collector dosage. In this particular case, the required collector dosage was reduced from 2.1 kg/t to 0.9 kg/t by the introduction of nanobubbles, representing a collector cost saving of more than 50%.

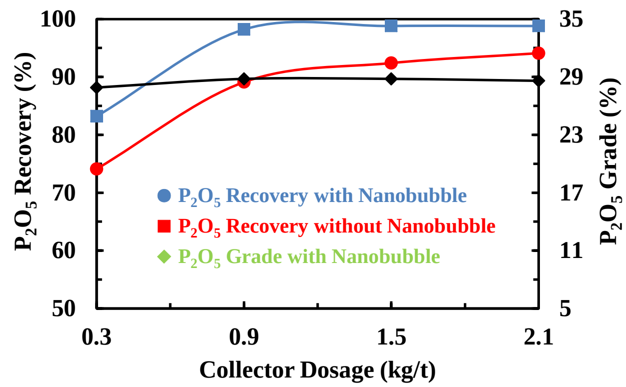


Figure 8 Effects of nanobubbles on P_2O_5 recovery and grade at different collector dosages

Figure 9 shows the effects of nanobubbles on flotation P_2O_5 recovery at varying frother dosages from 0 to 20 ppm. There were no noticeable differences in the product grade (P_2O_5% or A.I.%) in the presence and absence of nanobubbles and thus the grade data is not shown in Figure 9 for the purpose of clarity. The curves indicate that nanobubbles improved P_2O_5 recovery at lower frother dosage more significantly than at higher frother dosages. The flotation P_2O_5 recovery increased remarkably as the frother dosage increased from a dosage of 0 to 10 ppm. The flotation P_2O_5 recovery increased slightly in the absence of nanobubbles while the flotation P_2O_5 recovery remained essentially constant in the presence of nanobubbles as the frother dosage increased from a dosage of 10 ppm to 20 ppm. The flotation recovery of more than 98% and a concentrate grade of 28.8% were achieved at a frother dosage of 10 ppm in the presence of nanobubbles. By comparison, the maximum flotation recovery was 96% in the absence of nanobubbles, which was achieved at a frother dosage of 20 ppm.

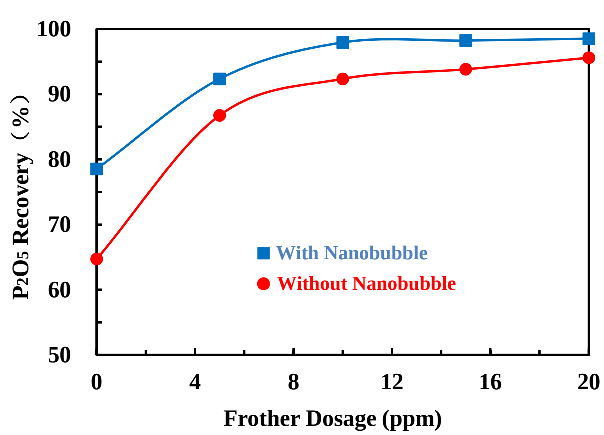


Figure 9 Effects of nanobubbles on P_2O_5 recovery at different frother dosages

The results shown in Figure 9 clearly indicate that use of nanobubbles reduced the required frother dosage by 50% and increased flotation recovery at the same time. It should be noted that reagent expense is one of the biggest cost items for a mineral processing plant and a reduction of 50% in both the collector and frother dosage represents a major economic benefit.

Figure 10 shows the effect of nanobubbles on flotation kinetics expressed as the P_2O_5 recovery vs. flotation time curve for the +0.425-1.18 mm particle size fraction. The differences in curves with and without nanobubbles suggest that the P_2O_5 recovery in the presence of nanobubbles was significantly higher at a given flotation than in the absence of nanobubbles. For example, when the flotation time was 1 minute, the P_2O_5 recovery in the presence of nanobubbles was about 21% higher than in the absence of nanobubbles. The results reveal that the presence of nanobubbles improved flotation kinetics. Based on the flotation recovery in the first minute it can be approximated that the first order flotation rate constant k is 1.89 min^{-1} and 1.01 min^{-1} with and without nanobubbles, respectively. It should be pointed out that similar improvements in flotation kinetics were observed with all other size fractions such as 0.425-0.60 mm, 0.6-0.85 mm, 0.85-1.18 mm fractions. The improvement in flotation kinetics observed in this study is consistent with previous findings (Hampton and Nguyen 2010, Calgaroto et al 2014, Calgaroto et al 2015, Ahmadi et al 2014, Zhou et al 2016) that nanobubbles are formed and attached more selectively and strongly on hydrophobic particles than conventional sized bubbles and also act as secondary collector to enhance surface hydrophobicity of mineral particles.

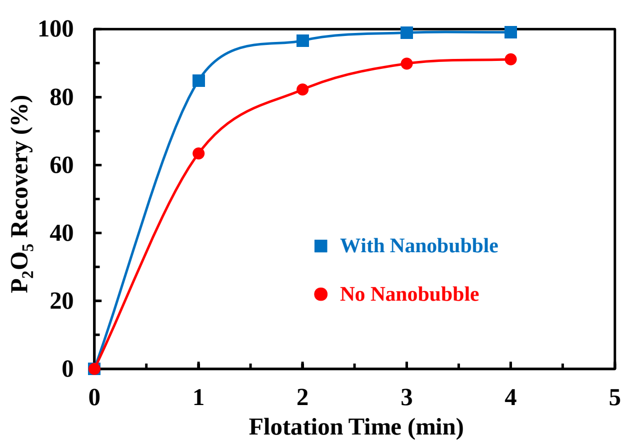


Figure 10 P_2O_5 Recovery as a function of flotation time for +0.425-1.18 mm size fraction of phosphate

4 Results and Discussion

Based on the above data and discussion, the following conclusions can be drawn:

(1) The median size of cavitation tube generated nanobubbles was about 830 nm, which was approximately two orders of magnitude smaller than microbubbles generated by the static mixer.

(2) Laboratory column flotation results show that use of nanobubbles significantly improved phosphate flotation performance. The separation performance curves obtained at different feed rates indicate that phosphate recovery can be increased by as much as 30% at a given concentrate grade.

(3) The flotation recovery of 98% was achieved at a collector dosage of 0.9 kg/t in the presence of nanobubbles at a concentrate grade of 28.79% P_2O_5. In contrast, the maximum flotation recovery of 94% was obtained at a collector dosage of 2.1 kg/t in the absence of nanobubbles. In other words, nanobubbles increased P_2O_5 recovery by 4% and reduced collector dosage by more than 50% at the same time. Similar results were observed with frother dosage which was reduced by 50% in the presence of nanobubbles.

(4) Size-by-size flotation test results indicated that nanobubbles improved the first order flotation rate constant k from 1.01 min^{-1} to 1.89 min^{-1} for the +0.425-1.18 mm size fraction of phosphate particles. Similar improvements were observed with all particle size fractions.

(5) The improvement in phosphate flotation performance can be attributed to the enhanced collection efficiency and increased surface hydrophobicity of phosphate particles as a result of unique characteristics of nanobubbles.

Acknowledgement

The authors would sincerely acknowledge the financial support provided by the Florida Industrial and Phosphate Research (FIPR) Institute through a project numbered FIPR 05-02-172R which made this work possible. The project manager Dr. Patrick Zhang's valuable advice and professional guidance is deeply appreciated.

References

Ahmadi, R., D.A. Khodadadi, M. Abdollahy and M. Fan, 2014. Nano-microbubble flotation of fine and ultrafine chalcopyrite particles. International Journal of Mining Science and Technology, **24**: 559 - 566.

Attard, P., 2003. Nanobubbles and the hydrophobic attraction. Advanced Colloid Interface Science, **104** (**1-3**): 75 - 95.

Azevedo, A., R. Etchepare, S. Calgaroto and J. Rubio, 2016. Aqueous dispersions of nanobubbles: generation, properties and features. Minerals Engineering, **94**: 29 - 37.

Calgaroto, S., K.Q. Wilberg and J. Rubio, 2014. On the nanobubbles interfacial properties and future applications in flotation. Minerals Engineering, **60**: 33 - 40.

Calgaroto, S., A. Azevedo and J. Rubio, 2015. Flotation of quartz particles assisted by nanobubbles. International Journal of Mineral Processing, **137**: 64 - 70.

Calle-Castañeda, S.M., M.A. Márquez-Godoya and J.P. Hernández-Ortiza, 2018. Phosphorus recovery from high concentrations of low-grade phosphate rocks using the biogenic acid produced by the acidophilic bacteria Acidithiobacillus thiooxidans. Minerals Engineering, **115**: 97 - 105.

Davis, B.E. and G.D. Hood, 1993. Improved recovery of coarse Florida phosphate. Mining Engineering, **45**(**6**): 596 - 599.

Ducker, W.A., 2009. Contact angle and stability of interfacial nanobubbles. Langmuir, **25**(**16**): 8907 - 8910.

Etchepare, R., H. Oliveira, M. Nicknig, A. Azevedo and J. Rubio, 2017. Nanobubbles generation using a multiphase pump, properties and features in flotation. Minerals Engineering, **112**: 19 - 26.

Fan, M. and D. Tao, 2008. Effect of picobubbles by hydrodynamic cavitation on coarse phosphate froth flotation. XXIV International Mineral Processing Congress, Beijing, China. (in Chinese)

Fan, M., D. Tao and Z. Luo, 2010. Nanobubble generation and its application in froth flotation (part I): nanobubble generation and its effects on properties of microbubble and millimeter scale bubble solutions. Mining Science and Technology, **20**(**1**): 1 - 19.

Fan, M., D. Tao, Y. Zhao and R. Honaker, 2013. Effect of nanobubbles on the flotation of different sizes of coal particle. Minerals and Metallurgical Processing. **30**(**3**): 157 - 161.

Hampton, M.A. and A.V. Nguyen, 2009. Accumulation of dissolved gases at hydrophobic surfaces in water and sodium chloride solutions: implications for coal flotation. Minerals Engineering, **22** (**9-10**): 786 - 792.

Hampton, M.A. and A.V. Nguyen, 2010. Nanobubbles and the nanobubble bridging capillary force. Advanced Colloid Interface Science, **154** (**1/2**): 30 - 55.

Johnson, B.D. and R.C. Cooke, 1981. Generation of stabilized microbubbles in seawater. Science, **213**: 209 - 211.

Knupfer, P., L. Ditscherlein and U.A. Peuker, 2017. Nanobubble enhanced agglomeration of hydrophobic powders. Colloids and Surfaces A, **530**: 117 - 123.

Li, D. and X. Zhao, 2014. Micro and nano bubbles on polystyrene film/water interface. Colloids and Surfaces A: Physicochemical and Engineering Aspects, **459**: 128 - 135.

Liu, S., Y. Kawagoe, Y. Makino and S. Oshita, 2013. Effects of nanobubbles on the physicochemical properties of water: the basis for peculiar properties of water containing nanobubbles. Chemical Engineering Science, **93**: 250 - 256.

Liu, X., C. Li, H. Luo, R. Cheng and F. Liu, 2017. Selective reverse flotation of apatite from dolomite in collophanite ore using saponified gutter oil fatty acid as a collector. International Journal of Mineral Processing, **165**: 20 - 27.

Maksimov, I.I., L.A. Otrozhdennova, A.D. Borkin, M.F. Yemelyanov and L.A. Nechay, 1993. An investigation to increase the efficiency of coarse and fine particle flotation in ore processing of non-ferrous metals. In: Proceedings of XVIII International Mineral Processing Congress, pp. 685 - 687.

Mendes, G., A.M. de Freitas, O.L. Pereira, I. Silva, N. Vassilev and M.D. Costa, 2014. Mechanisms of phosphate solubilization by fungal isolates when exposed to different P sources. Annuals of Microbiology, **64**(**1**): 239 - 249.

Mishchuk, N. and J. Ralston, 2006. Influence of very small bubbles on particle/bubble heterocoagulation. Journal of Colloid and Interface Science, **30**(**1**): 168 - 175.

Moudgil, B.M., 1992. Enhanced recovery of coarse particles during phosphate flotation. Final Report to Florida Institute of Phosphate Research, No. 02-067-099.

Oliveira, H., A. Azevedo and J. Rubio, 2018. Nanobubbles generation in a high-rate hydrodynamic cavitation tube. Minerals Engineering, **116**: 32 - 34.

Peng, F.F. and Y. Xiong, 2015a. Pico-nano bubble column flotation using static mixer-venturi tube for Pittsburgh No. 8 coal seam. International Journal of Mining Science and Technology, **25**(**3**): 347 - 354.

Peng, F.F. and Y. Xiong, 2015b. Optimization of cavitation venturi tube design for pico and nano bubbles generation. International Journal of Mining Science and Technology, **25**(**4**): 523 - 529.

Priha, O., T. Sarlin, P. Blomberg, L. Wendling, J. Mäkinen, M. Arnold and P. Kinnunen, 2014. Bioleaching phosphorus from fluorapatites with acidophilic bacteria. Hydrometallurgy, **150**: 269 - 275.

Ralston, J. and S.S. Dukhin, 1999. The interaction between particles and bubbles. Colloids and Surfaces, **151**: 3 - 14.

Rodrigues, W.J., L.S. Leal Filho and E.A. Masini, 2001. Hydrodynamic dimensionless parameters and their influence on flotation performance of coarse particles. Minerals Engineering, **14**(**9**): 1047 - 1054.

Schubert, H., 2005. Nanobubbles, hydrophobic effect, heterocoagulation and hydrodynamics in flotation. International Journal of Mineral Processing, **78**: 11 - 21.

Sis, H. and S. Chander, 2003. Reagents used in the flotation of phosphate ores: a critical review. Minerals Engineering, **16**: 577 - 585.

Sobhy, A. and D. Tao, 2013a. Nanobubble column flotation of fine coal particles and associated fundamentals. International Journal of Mineral Processing, **124**: 109 - 116.

Sobhy, A. and D. Tao, 2013b. High-efficiency nanobubble coal flotation. International Journal of Coal Preparation and Utilization, **33**(**5**): 242 - 256.

Tao, D., 2004. Role of bubble size in flotation of coarse and fine particles—A Review. Separation Science and Technology, **39**(**4**): 741 - 760.

Tao, D., M. Fan and B.K. Parekh, 2006. Picobubble enhanced flotation of coarse phosphate particles. Proceedings, XXIII International Mineral Processing Congress, Istanbul, Turkey.

Teague, A.J. and M.C. Lollback, 2012. The beneficiation of ultrafine phosphate. Minerals Engineering, **27-28**: 52 - 59.

Van Kauwenbergh, S., 2010. World phosphate reserves and resources. Fertilizer Outlook and Technology Conference. International Fertilizers Development Center (IFDC). Muscle Shoals. Al 35662 USA.

Yoon, R.H., 2000. The role of hydrodynamic and surface forces in bubble-particle interaction. International Journal of Mineral Processing, **58**: 128 - 143.

Zhang, P. and M. Bogan, 1994. Recovery of phosphate from Florida beneficiation slimes. Minerals Engineering, **8**: 523 - 34.

Zhou, W., L. Ou, Q. Shi and H. Chen, 2016. Aggregation of ultra-fine scheelite particles induced by hydrodynamic cavitation. International Journal of Mineral Processing, **157**: 236 - 240.

Zhou, F., L. Wang, Z. Xu, Y. Ruan and R. Chi, 2017. A study on novel reactive oily bubble technology enhanced collophane flotation. International Journal of Mineral Processing, **169**: 85 - 90.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca
IJGE 2018 **4**(**3**): 141-146
Available at http://ojs.library.dal.ca/ijge
Research and Development and Industry

Application of Aeromagnetic, Remote Sensing and Geological Data in the Delineation of the Geological Structures

Rinae Netshithuthuni[1*], Fhatuwani Sengani[2], Tawanda Zvarivadza[2]
[1] School of Mining and Environmental Geology, University of Venda, Thohoyandou, South Africa
[2] School of Mining Engineering, the University of the Witwatersrand, Johannesburg, South Africa

Abstract: Siloam village is well known for its hot springs that geologically lie in the Nzhelele Formation of the Soutpansberg Group rocks. About 1800 million years ago, the Soutpansberg depositional basin was formed as an east-west trending asymmetrical rift. These Soutpansberg group rocks were severely faulted which resulted in a number of major faults, like the Siloam fault. Faults provide channels through which the hydrothermal fluids can flow. These fluids are heat sources for the hot springs. With no evidence of recent volcanic activities in the Limpopo province, it is assumed that all the hot springs are of meteoric origin and the heating of the hot springs is due to the deep circulation along fault zones. The main objective of the study is to delineate the faults that are potential recharge zones of the hot springs above the ground at Siloam village using remote sensing, geological maps and aeromagnetic data. LANDSAT 8 (OLI, November 2015), scenes P69, R76 (path 69 and row 76) free of cloud cover were downloaded from the USGS website page. The data was reduced to remove excess noise. A number of processing techniques were done to further enhance the visibility of the image and locate the faults by the use of ERDAS IMAGINE software. The aeromagnetic data was used to locate the faults using the magnetic susceptibility of the rocks. Aeromagnetic data was acquired from the Council of Geoscience of South Africa, which collected it using a proton precession magnetometer mounted on a low plane flight at an average height of 150m. The traverses were oriented in the E-W direction, and the traverse separation was 1 km. The aeromagnetic data reduction was applied during the processing in order to produce a colour map using Geosoft Oasis Montaj. The geological data was obtained through digitizing and georeferencing of an existing geological map acquired from the Council of Geoscience of South Africa. The GPS was used to locate the hot springs at the Siloam village for correlation with the lineaments. The lineaments were interpreted from the remote sensing. The aeromagnetic data was correlated with the faults on the geological map. The main faults associated with the known hot springs were delineated along with the minor faults which were potential zones carrying hot water at the Siloam village. The results show that the two sets of data are capable of extracting lineaments in inaccessible areas and they can complement each other in locating faults. The results showed that the three known hot springs are associated with the major faults. Geologically the other faults are also playing a part in recharging the hot springs.

Keywords: aeromagnetic, remote sensing, geological data, geological structures, hot springs, faults

1 Introduction / Background

1.1 Background

The Siloam village is located north of Makhado in the Limpopo Province in South Africa and it is famous for its hot springs. A spring is described as a concentrated discharge of groundwater that appears at the surface as a current of flowing water (Todd 1980). Springs that discharge water at a temperature above that of the normal local groundwater are called thermal springs (Todd 1980).

There are geothermal hot springs in many locations all over the crust of the earth. While some of these springs contain water that is of suitable temperatures for bathing, others are so hot that immersion can result in injury or death (Kent 1969).

The known geothermal occurrence indicators in South Africa include approximately 74 hot springs spread almost over the whole country. There has been no recent volcanic activity in South Africa, and therefore all thermal springs are considered to be of meteoric origin and the heating of the water is believed to be due to deep circulation along main fault zones (Kent 1969).

Thermal springs are not confined to any specific type of geology. They are mainly located in the parts of the country receiving high to intermediate rainfall and where deep crustal faulting occurs. Geothermal hot springs occur where the earth's heat is carried upward by a convective circulation of naturally occurring water. Some high temperature convective hydrothermal resources result from deep circulation of water along the fractures of the rocks (Olivier et al 2011).

* Corresponding Author: Rinae Netshithuthuni, Email: rinaebanzo@gmail.com, Phone: +279 7922 171

DOI: 10.15273/ijge.2018.03.023

Hot springs are primarily found above areas in the crust where magma or molten rock has risen to a shallow depth beneath the surface. In such instances, the magma may exist in a chamber or reservoir 5 to 10 kilometres beneath Earth's surface.

They are heated by the earth's interior which is known as a hot spot. A long, slim column called a plume feeds a hot spot. A plume takes debris from the mantle, and sends it up to the hot spot just below the earth's crust. The hot spot is a pocket just below volcanoes and hot springs where the hot debris from the mantle sits, heating the earth above it, in this case, the hot springs. The hot ground heats the water to a high temperature and this is how the hot springs become hot.

At some point, steam or vapour may appear on the surface. This is due to the boiling of the water at depth which is unable to pass through to the surface due to the low permeability of the rocks (Olivier et al 2011).

A fault may play different roles in fluid migration. A fault may act as a barrier (or seal), a conduit or a combination of both. A fault is a seal or a barrier when fluids are unable to flow laterally across it due to an impermeable layer along the fault plane (Olivier et al 2011).

A fault acts as a conduit when fluid passes vertically along the fault plane. A fault acts as a barrier and a conduit when fluid can pass partially across and partially along the fault at the same time (Olivier et al 2011). The parameters which result in a fault acting as a seal include, fault orientation, burial depth, fault displacement, net sand connectivity and age of faulting (Olivier et al 2011).

There are thousands of known thermal springs on Earth, with the most abundant located in volcanic areas. (Walter and DesMarais 1993, Bryan 2000). In geothermal systems, faults, fractures, or contacts between intrusive and surrounding rocks may become conduits for thermal water.

The use of remote sensing techniques has given a boost to the analysis of various geomorphic units, lineaments or linear features quite easily, because of its synoptic view and availability of data in different spectral bands (NASA 2000). Satellite images give an excellent visual presentation of various geological structures like faults, folds, lineaments and fractures, because of its synoptivity and multispectral nature. Remote sensing techniques have been employed for geological, structural and lineament mapping by many workers (Ramasamy and Balaji 1995).

1.2 Problem statement

The known geothermal indicators in South Africa include approximately 74 hot springs almost all over the country. With no evidence of recent volcanic activities in South Africa, it is assumed that all the hot springs are of meteoric origin and the heating at the hot springs due to the deep circulation along main fault zones. The known hot springs need to be correlated with the known faults using aeromagnetic data, remote sensing data and geological structures from geological maps.

1.3 Justification of study

This study was aiming at delineating the main faults associated with the known hot springs and the minor fault zones that could be potential fault zones carrying hot water at Siloam village. The number of minor faults plus the known faults could be an indicator of the size of the potential geothermal occurrence at Siloam.

1.3 Objectives

The main objective of the study is to delineate the faults that are potential recharge zones of the hot springs above the ground at Siloam village using remote sensing, geology and aeromagnetic data. The specific objectives of the study are to; use magnetic, remote sensing and geological mapping data in delineating the faults; determine the orientation of the faults in the area; integrate the aeromagnetic data, remotely sensed data and geological data along with the base map of the hot springs to delineate faults associated with known hot springs at Siloam and produce a map with new faults delineated from remotely sensed and aeromagnetic data.

2 Research Approach

Three sets of data were collected. These sets of data were: remote sensing data, aeromagnetic data and geological data. Each set of data was processed separately for data integration during analysis. LANDSAT 8 (OLI, November 2015), scenes P69, R76 (path 69 and row 76) free of cloud cover were downloaded from the USGS website. The ASTER images for the same area were also downloaded from the USGS website. The geological data was obtained through digitizing and georeferencing of an already existing geological map acquired from the Council for Geoscience, South Africa. Before the aeromagnetic data was collected, the survey parameters were selected. These parameters include flight elevation, traverse line spacing, traverse line orientation or direction, and the type of a magnetometer to be used. There were a number of considerations considered during the setting of the parameters. For this study, the data was acquired from the Council of Geoscience of South Africa, which had collected it using a proton precession magnetometer. The proton precession magnetometer was mounted on a flight which was at an average height of 150 m. The traverses were oriented in the East-West (E–W) direction, and the traverse separation was about 1 km.

3 Results of the Study

The results of the study outline detailed results on the geological map of the area, remote sensing data interpretation, False Colour Combination (FCC), index evaluation in identifying lineaments, magnetic colour map and occurrence of hot spring in the area.

3.1 Geological map

There is a widespread agreement that geothermal springs in extensional geothermal systems are concentrated at fault tips and fault interaction zones where porosity and permeability are dynamically maintained (Curewitz and Karson 1997). It is clear that faults and fractures play a major role in the localisation and evolution of hydrothermal flows on several scales (Ramasamy and Balaji 1995).

A geological map for the study area, acquired from the Council of Geosciences of South Africa, was digitized and georeferenced for use as a base map to reference both the aerial images and magnetic images. The data of interest in the geological map was the geology and the fault systems of the area. In the analysis, the layer of faults was superimposed on the magnetic and remote sensing images for interpretation. Figure 1 shows the geological map with different lithologies along with their contacts and the faults within the lithologies. The results of the study have shown that the study area was dominated by the North East – South West (NE– SW) faults with a few faults trending in the North West – South East (NW–SE) direction. The faults in the NW–SE direction were in the same direction as the Siloam fault.

Further results of the study have indicated that Dopeni and Mphephu thermal springs are underlain by the Wylliespoort and Nzhelele Formations of the Soutpansberg group. These lithologies mainly comprise of sandstone and quartzite. Owing to that, it was also observed that the Siloam thermal spring was underlain by the basaltic lava of the Sibasa Formation. However, these observations were also supported by the previous study conducted by Oliver et al (2011), which indicated that the lava of Sibasa formation occurred through a basaltic process which had been noted to have occurred several years back.

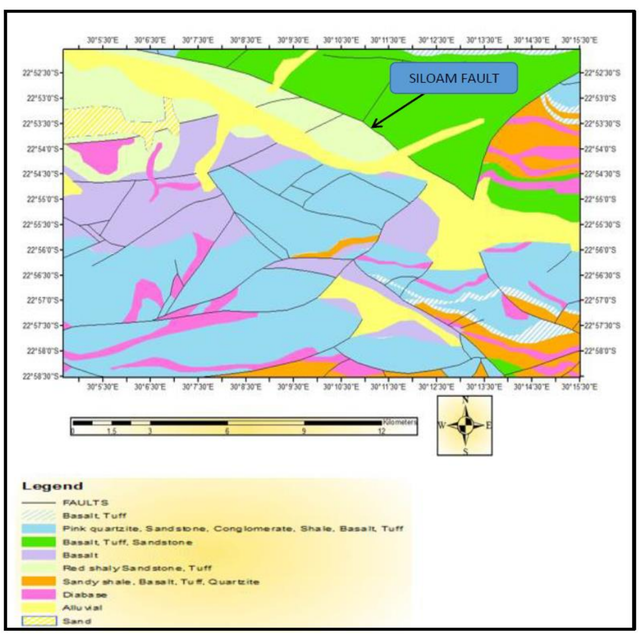


Figure 1 Map showing lithology and faults at Siloam village

3.2 Remote sensing data interpretation

In order to provide meaningful results concerning remote sensing analysis, the processed remotely sensed images were interpreted visually with the aid of two techniques, which are, FCC and NDVI. They were used to enhance the colour and tonal differences in the images.

Faults were identified as lineaments. Lineaments can be joints, fractures, dyke systems or a straight course of streams or vegetation patterns. In hard rock, lineaments represent zones of dykes, and a series of or fold aligned hills. In this study, the true colour composite images with RGB ratio of 3:2:1 (where R=Red, G=Green and B=Blue bands, and the 3:2:1 is the ratio of the bands of colours whereby 3, 2 and 1 are for Red, Green and Blue, respectively) of the Landsat 8 multi-spectral image were used.

Based on the results of the study multiple faults were observed from the original satellite image, these faults were noted as lineaments (see Figure 2).

Figure 2 A LANDSAT image with an original RGB combination

3.2.1 False Colour Combination (FCC)

In the interpretation of the lineaments using false colour representation, a combination of RGB 7:5:1 was used. Lineaments observed from the image were indicated by linear reddish colouration (see Figure 3). For clear representation of the lineaments, a colour ramp and gamma stretching were also used to improve the colour differences between the lineaments and areas with no lineaments. In Figure 3, the enhancement introduced made the lineaments more visible compared to the one with a true colour composite. The lineaments observed on the FCC image had a reddish colour. Generally the lineaments had two sets of striking direction. These striking directions are NE–SW and NW–SE (see Figure 3).

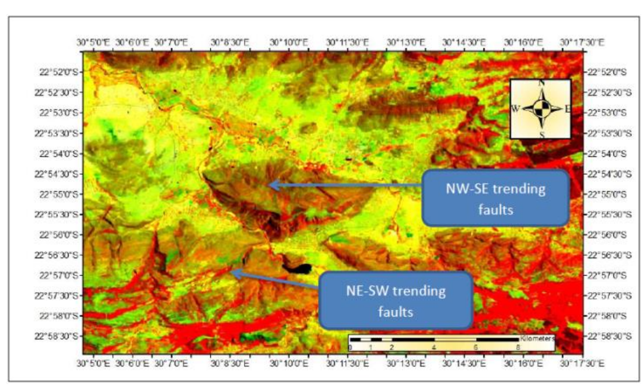


Figure 3 A false colour combination of 7:5:1 of the study

To eliminate the non-geological elements such as paths, roads, power cables and field boundaries in the study area, geographical map and field checking were undertaken by the method suggested by Yassaghi (2006).

The lineaments or faults observed on remotely sensed images were traced and then digitized using Quantum GIS. This was done in order to be able to compare with the faults observed from the geological map by superimposing the digitized faults from the geological map on the remote sensing image. It was noted that there were additional faults which were not discovered when using a geological map. Most of the faults from the geological map and the lineaments from the remote sensing image coincide, however, in some areas they were not exactly in the same position but had similar orientations and lengths. In Figure 4, the faults from the geological map are represented by black lines while the lineaments traced from the remote sensing image are represented by a blue colour (see Figure 4).

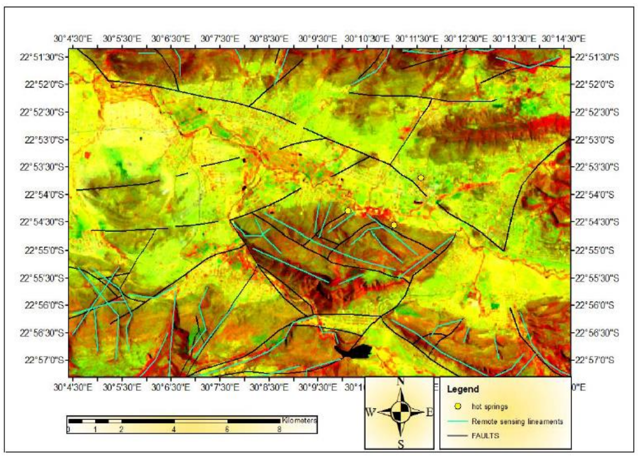


Figure 4 A false colour combination of 7:5:1 showing remote sensing lineaments and geological faults

3.2.2 Index evaluation in identifying lineaments

The Normalised Difference Vegetation Index (NDVI) method was used for the identification and mapping of geological linear features (Lineament) in hard rock terrain. This was based on tone, colour and textural pattern; as well as on a previous study conducted by Boyer and McQueen (1964). When using an NDVI method, an NDVI image is created by ARCMAP and assigned different colours based on the amount of vegetation on the ground. However, since NDVI is an indicator that uses visible and near-infrared bands of the electromagnetic spectrum, it was mainly used to assess the vegetation cover of the area.

An NDVI image created from this study shows the lineaments on the image with most of them having the same orientation of the fault line on the geological map. A related study by Boyer and McQueen 1964 indicated that in similar geological terrain the usefulness of NDVI is revealed by detecting fractures and faults that could affect the occurrence of vegetation associated with proximity of groundwater. Boyer and McQueen (1964) concluded that remotely sensed linear features are a reflection of rock fractures, emphasized by vegetation and topography. They interpreted the NDVI images and areas with denser and active vegetation defining linear features. Areas with light tones showed active vegetation along fractures. The high vegetation areas can be observed by the blue and purple colour (see Figure 5), whereas the low vegetation areas were identified by the yellow and orange colour. The striking directions of the faults had two sets of directions which are the NE–SW and the NW–SE. The image with the NDVI lineaments was overlain by the digitized faults from the geological map to see the resemblance. .

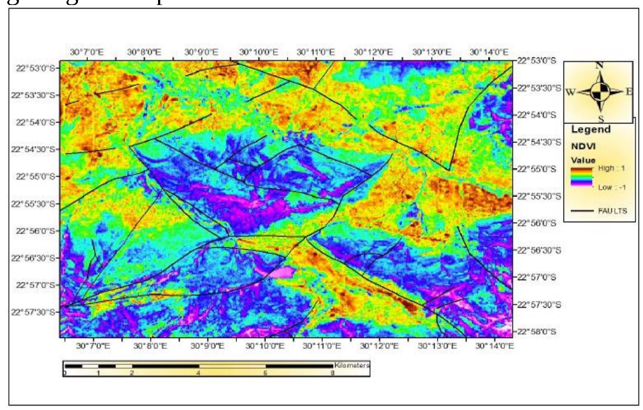


Figure 5 An NDVI image with faults

3.3 Magnetic colour map

The magnetic colour map of the total magnetic intensity was processed in the Geosoft Oasis Montaj software. The magnetic colour map (see Figure 6) shows low magnetic intensities are represented by a blue colour while high intensities by a red colour. The magnetic anomaly map from the study area showed high and low magnetic anomalies being fairly distributed within the study area (see Figure 6). These were indicative of the presence of magnetic rocks, non-magnetic rocks and discontinuities or geological structures covering the study area. The change in the magnetic intensities on the map represent a change in the lithology. The magnetic data with high and low magnetic anomalies next to each other were interpreted as contacts between the rocks. The faults on the magnetic colour map had two sets of striking directions which are NE–SW and NW–SE. There was a clear dominance of the NE–SW trending lineaments. To study the lineaments from the magnetic anomalies, the magnetic map was overlaid with digitized faults from the geological map. The faults identified on the magnetic colour map had the same orientation to the geological faults. Similar results have been observed by the study conducted by Mattsson and GeoVista (2010), which showed that low magnetic intensities coincided with known existing faults. Mattsson and GeoVista (2010), Nordiana et al (2014) and Adagunodo and Sunmonu (2012), conducted similar studies and in their studies they concluded that the low magnetic values are due to the presence of structural features such as faults or fractures, and that the high magnetic values are also due to a fault which was infilled by materials with more magnetism than the surrounding rocks. High magnetic anomalies could also be due to shallow basement and low magnetic intensities could be associated with relatively deep sources (Amigun 2013).

Mattsson and GeoVista (2010) did work in a similar environment at Sagole's hot spring and interpreted the Reduced-To-Pole (RTP) data as an area swarmed with North East trending dykes and East to West and North West geological structures using the magnetic anomalies. Mattsson and GeoVista (2010) also determined the heat source depth for the Soutpansberg basin from filtering the magnetic data. The magnetic source at depths of approximately 2 km can be attributed to shallow volcanic dykes and sills.

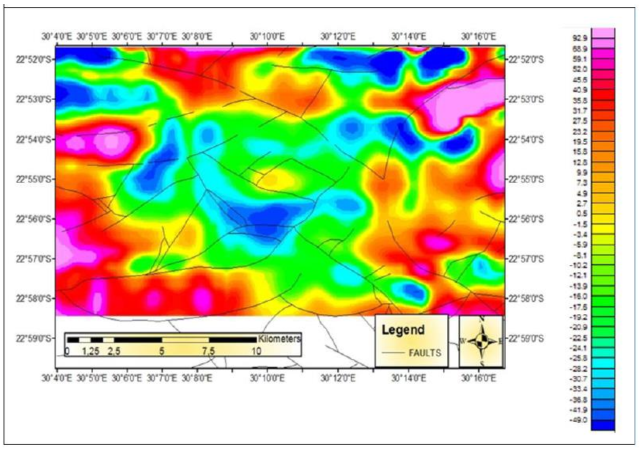


Figure 6 A magnetic anomaly map

3.4 Occurrence of hot spring in Siloam village

Geothermal hot springs occur where the earth's heat is carried upward by a convective circulation of naturally occurring hot water. Some high temperature convective hydrothermal resources result from deep circulation of water along the fractures of the rocks (Olivier et al 2011). A fault may act as a conduit where fluid passes vertically along the fault plane.

There are three hot springs in the study area namely; Siloam, Mphephu and Dopeni hot springs. To determine the relationship between the faults, hot springs and the lineaments from the remotely sensed and magnetic data, the three layers were overlaid on top of each other (see Figure 7). In Figure 7, it was observed that each hot spring was associated with a fault. The hot springs HS1, HS2 and HS3 were the Siloam, Mphephu and Dopeni hot springs, respectively. The Siloam hot spring is located on the Siloam fault which is the longest fault oriented in the in the NW–SE direction, which was named F1 in Figure 7. The Mphephu hot spring is located on a fault oriented in the NE–SW direction, the fault was named F2. The last hot spring is the Dopeni hot spring which is located very close to a NW–SE trending fault which has the same orientation as the Siloam fault. This fault was named F3 (see Figure 7). However it was noted that these faults might be the ones recharging the above mentioned hot springs.

However, it must be acknowledged that within the study area, there are some faults which are not associated with surface hot springs (see Figure 8). Scientifically, almost all faults within the vicinity of the hot spring might be channelling water to the faults which then exposes the thermal springs to the surface. It was then concluded that these faults might interact and link the hydrothermal outflow which then channels water to a single exit spring on the surface.

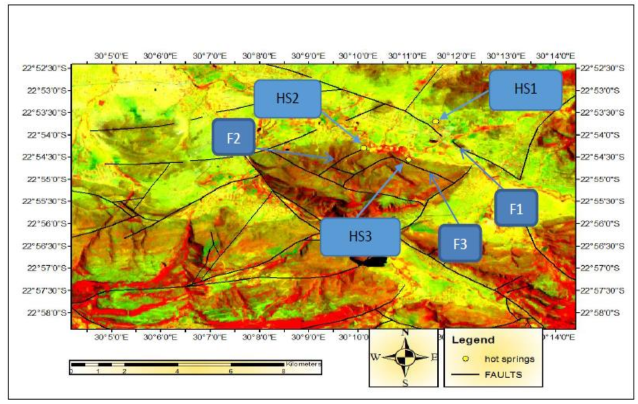


Figure 7 A remotely sensed image with faults and location of hot springs (HS1, HS2, HS3 for Siloam, Mphephu and Dopeni respectively)

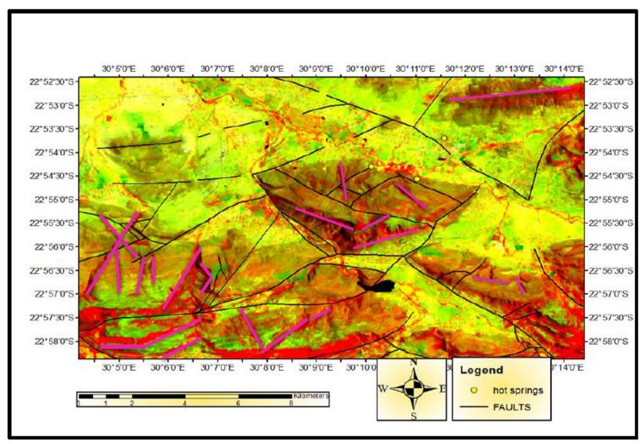


Figure 8 The lineaments that were only identified from the remotely sensed image overlaid with the geological faults

4 Conclusion

The remotely sensed, magnetic and geological mapping data delineated the faults that recharge the three hot springs in this study area as well as other faults that could have the potential for hot springs. The delineated lineaments from the remotely sensed data correlated with most of the faults on the geological map. The magnetic data also showed that the faults could be interpreted from the magnetic anomaly map. Most of the faults were located on the high magnetic areas with a few on the low magnetic areas.

The results from the study show that the remote sensing data, magnetic data and geological data were capable of extracting lineament trends in inaccessible areas. It can be concluded that remote sensing, magnetic and geological data complement each other in locating faults.

References

Adagunodo, A.T. and L.A. Sunmonu, 2012. Ground magnetic survey to investigate on the fault pattern of industrial estate Ogbomoso, South-western Nigeria. Pelagia Research Library, pp3142 - 3149.

Boyer, R. and J. McQueen, 1964. Comparison of mapped rock fractures and air photo linear features. Photogrammetric Engineering and Remote Sensing, **30**: 630 - 635.

Bryan, T.S., 2000. The geyser fields of the world. Yellowstone Interpretive Training Presentation, **12**: 65.

Curewitz, D. and A.J. Karson, 1997. Structural settings of hydothermal outflow: fracture permeability maintained by fault propagation and interaction. Journal of Volcanology and Geothermal Research, **79(3-4)**: 149-168.

Kent L.E., 1969. The thermal waters in the Republic of South Africa. In: Proc. of Symposium II on Mineral and Thermal Waters of the World, B - Overseas Countries, Vol **19**, Report of the 23rd Session of the International Geological Conference, Academia, Prague, pp143 - 164.

Mattsson, H. and A.B. GeoVista, 2010. Geological survey of Sweden and Wahlgren C-H. Interpretation of Detailed Ground Magnetic data, Resistivity and Topographic data from Äspö. SKB, Svensk Kärnbränslehantering AB, pp10 - 49.

NASA, 2000. NASA remote sensing tutorial web page. http://rst.gsfc. nasa.gov/.

Nordiana, M.M., M. Syukri, R. Saad, Marwan and N.A. Kamaruddin, 2014. The identification of fault zones in Krueng Raya, Aceh Besar (Indonesia) using magnetic method. Electronic Journal of Geotechnical Engineering, **19**: 1 - 9.

Olivier, J., J.S. Venter and C.Z. Jonker, 2011. Thermal and chemical characteristics of hot water springs in the northern part of the Limpopo Province, South Africa. Water SA, **37**(**4**): 427 - 436.

Ramasamy, S.M. and S. Balaji, 1995. Remote sensing and Pleistocene tectonics of Southern Indian Peinsula. International Journal of Remote Sensing, **16**(**13**): 2375 - 2391.

Todd, D.K. and L.W. Mays, 1980. Groundwater hydrology. Wiley, **50**(**2**): 2 - 5.

Walter, M.R. and D.J. Des Marais, 1993. Preservation of biological information in thermal spring deposits: Developing strategy for the search of fossil life on Mars. Icarus, **101**(**1**): 129 - 143.

Yassaghi, A., 2006, Integration of landsat imagery interpretation and geomagnetic data on verification of deep-seated transverse fault lineaments in SE Zagrosa, Iran. International Journal of Remote Sensing, **27**(**20**): 4529 - 4544.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 147-152
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Pore Characteristics Analysis of Shale from Sichuan Basin, China

Ke Hu*, Helmut Mischo
Institute of Mining and Special Civil Engineering, TU Bergakademie Freiberg, Sachsen, Germany

Abstract: Pore characteristics are significant for shale gas exploration and production. In this paper, the method of field emission scanning electron Microscopes (FE-SEM) was applied to qualitatively describe minerals and pore structures of shale samples. Low pressure nitrogen adsorption-desorption and carbon dioxide adsorption were applied to analyse meso-pores and micro-pores respectively. Inter-particle pores are always associated with rigid mineral grains and intra-particle pores are mainly located in unstable minerals. The BET (Brunauer–Emmett–Teller) surface area of Longmaxi Formation (LMX) is 5.47m^2/gr and 16.33m^2/gr of Wufeng Formation (WF). N_2 and CO_2 adsorption shows that the diameter of micro-pores in the LMX and WF formation is approximately 1nm. Most meso-pores in WF formations range from 2nm - 20nm, while meso-pores existing in LMX formations range from 2nm - 30nm.

Keywords: gas shale, pore characteristics, Sichuan Basin

1 Introduction

Being characterised as a most promising unconventional type of gas and due to the evolution of horizontal drilling and hydraulic fracturing technology, shale gas has already attracted much attention, especially in the U.S. The production in the United States was 469.56 billion cubic meter (BCM) in 2016, representing 50% of the total gas production in the country (EIA). Meanwhile, Canada, China, Poland, Brazil among others have also started exploring for and producing shale gas. To reduce the extent of import reliance on energy, the Chinese government has carried out some exploration and production programs as well, in Sichuan Basin (Zou et al 2010).

Sichuan Basin that is located in the southeast side of China, has already started producing shale gas since 2009 as a pioneer. The Upper-Ordovician Wufeng Formations and Lower Silurian Longmaxi Formations marine shale consist the main shale gas reservoirs.

Compared to conventional gas reservoirs, shale gas can be found in reservoirs in three states: free and compressed gas in pores and fractures, adsorbed gas on the surface of organic matter and minerals, dissolved gas in water and organic matter (Ross and Bustin 2009).

Other than in conventional hydrocarbon reservoirs, shale gas can also be found as adsorbed gas (20-80%) (Ambrose et al 2012). Pores and micro fractures are the main adsorptive sites for adsorbed gas and channels for gas flow. Therefore, geometrical morphology and pore size distribution (PSD) are key factors for gas in place (GIP) prediction and production. In addition, pore characteristics are also significant for gas migration and application of depleted wells, such as in carbon dioxide sequestration. A better understanding of pore characteristics of the shale in Sichuan basin can provide more effective information for shale gas occurrence, stored capacity and transportation mechanisms.

Compared to conventional reservoir, sedimentary environments and the diagenetic process of gas shale are much more complicated. Accordingly, this leads to a more complicated pore structure and pore geometry. In recent years, researchers applied various kinds of methods to characterise the pore system of shale, including image analysis, intrusive and non-intrusive methods. Image analysis methods are widely applied for qualitative and quantitative analysis of pore geometry, based on techniques such as; field emission scanning electron microscopy (FE-SEM) (Houben et al 2016), focus iron beam scanning electron microscopy (FIB-SEM) (Bernard et al 2013, Kelly et al 2016), transmission electron microscopy (TEM) (Bernard et al 2013), atomic force microscopy (AMF) (Javadpour et al 2012) and focused ion beam-Helium ion microscopy (FIB-HIM) (Wu et al 2017). Such methods can provide directly visual images with high resolution to observe the nano-pores. Combined with serial slices and reconstruction software, these images can represent porosity and connectivity.

Intrusive methods include mercury injection (MIP), low pressure nitrogen adsorption, low pressure argon adsorption and low pressure CO_2 adsorption. Different methods have different detectable ranges, though limited by molecular. Generally, MIP and low pressure gas adsorption are combined to determine the wide range of pore size distribution. The International Union of Pure and Applied Chemistry (IUPAC 1994) classified pores as micro-pores

* Corresponding Author: Ke Hu, Email: huke1@mailserver.tu-freiberg.de, phone: +49 3731/393033

DOI: 10.15273/ijge.2018.03.024

(smaller than 2nm), meso-pores (2-50nm) and macro-pores (larger than 50nm) in diameter, respectively.

Non-intrusive methods involve nuclear magnetic resonance (NMR) (Li et al 2015), micro CT (Tiwari et al 2013) and ultra/small angle neutron scattering (USANS/SANS) (Yang et al 2017) to determine pore size distribution without any destructive contact with shale samples.

To make a better understanding of pore characteristics of shale from Sichuan Basin, in this paper, a range of multi scale approaches including CO_2 adsorption, N_2 adsorption and field emission scanning electron microscopy (FE-SEM) are used to analyse the Wufeng formation and Longmaxi Formation shale.

2 Geological Setting and Methodology

All the samples were collected from the Wufeng Formation and Longmaxi Formation in Ordovician and Silurian, which are marine resources in Sichuan Basin in southern China. At the moment of writing this paper, Weiyuan, Changning and Jiaoshiba shale gas pilots have already been activated in Sichuan Basin. The newer samples were drilled without water and were stored with dry preservation.

2.1 FE-SEM

To observe the pore structure, minerals and micro cracks, samples from both pilots were analysed with the use of FE-SEM. The device is a FEI Quanta 650 with energy dispersive X-ray spectroscopy (EDS). The accelerating voltage of the electron beam is set at 10KV and the detector is concentric higher energy electron detector (CBS). Before scanning them, the samples were cut by saws, polished, and then coated with carbon to increase their electrical conductivity.

2.2 Low pressure N_2 and CO_2 adsorption

Low pressure N_2 and CO_2 gas adsorption tests were launched on the Micromeritics 3 Flex. Samples were grounded and sieved to 1 - 3.5mm. Subsequently, they were deaerated at 300 degrees for 3 hours to remove the residual gas and free water. The equilibrium interval time selected was 30s for N_2 and 15s for CO_2, respectively. The relative pressure (p/p_0) was 0.005 - 0.995 for N_2 adsorption and 0.00006 - 0.013 for CO_2 adsorption. During the adsorption tests, the free spaces of the device were tested separately and the input was done manually. The N_2 and CO_2 adsorption isotherms were automatically measured by the device. The surface area, pore volume, and PSDs were then calculated based on various adsorption theories.

Brunauer et al (1938) proposed the BET method which is the most widely used for representing the surface area of porous media and powders:

$$\frac{1}{Q\left(\frac{p_0}{p}-1\right)}=\left(\frac{1}{v_mC}+\frac{C-1}{v_mC}\right)\frac{p}{p_0} \qquad (1)$$

where Q is the specific adsorption quantity at relative pressure p/p_0, v_m is the monolayer adsorption capacity. C is a parameter about the adsorption heat. Generally, the BET equation is valid for low pressure N_2 adsorption within the p/p_0 of 0.05 - 0.3.

Lippens and de Boer (1965) proposed the t-plot method, which qualifies the determination of micro-pore volume, specific surface area and average pore size. It takes a reference t-plot from a number of non-porous with a C parameter similar to BET. Harkins and Jura statistical thickness equations are applied for the t plot method within a relative pressure of p/p_0 0.05 - 0.15. Through the graphical analysis of adsorption quantity versus average thickness of the statistical thickness of adsorption film t, we can obtain the t-plot.

The BJH method (Barrett et al 1951) takes the modified Kelvin method to calculate the pore size distribution of meso−pores and macro−pores. This method is based on the assumption that the pores are rigid, no micro pores exist and when the relative pressure is equal to 1, all pores are filled and suffused.

3 Results and Discussion

3.1 FE-SEM analysis

Generally, three kinds of pores can be found in shale reservoirs, including organic pores, intra-particle, and inter-particle pores, respectively (Loucks et al 2012). Figure 1a, b, c and d are taken from the WF shale sample, while 1d & e are taken from LMX sample. Figure 1b represents a partial enlarged view of Figure1a. FE-SEM images show that the organic matter (OM) and quartz are abundant in both WF and LMX formations. The widespread presence of quartz in shale gives a reasonable brittleness, making the shale fragile enough to be easily broken under hydraulic fracture.

Pyrite framboids with organic matter and intra-particle pores are widely distributed as illustrated in Figure 1a and d. Grid quartz mineral is commonly distributed around the organic matter and due to the squeezing and stretching during diagenesis, micro fractures appear at the boundary of quartz (Figure 1b and c). Pores in organic matter are significant for adsorbed gas and dissolved gas, and seem to be well developed (Figure 1d) with various geometric shapes such as cleat, honeycomb, cavernous, and irregular sphere. Organic pores are produced during the burial and maturation of diagenetic process. Organic matter exhibited in Figure 1f is formed with sliced clay minerals, suggesting that shale LMX formation suffered squeezing and that the OM migrated simultaneously with the mineral.

In Figure 1a, c, d and e, we can find a mass of inter-particle pores between rigid minerals with polygonal and elongated shapes. Inter-particle pores produced by flocculation, as a kind of original pores, are not evenly distributed in the shale formation. Dissolution of dolomite can also occur in shale formation and formed inter-particle pores (Figure 1e). Within a range hundreds of nanometers to microns, inter-particles can improve the connectivity (Figure 1a and e) and become an empty space to be filled with free gas.

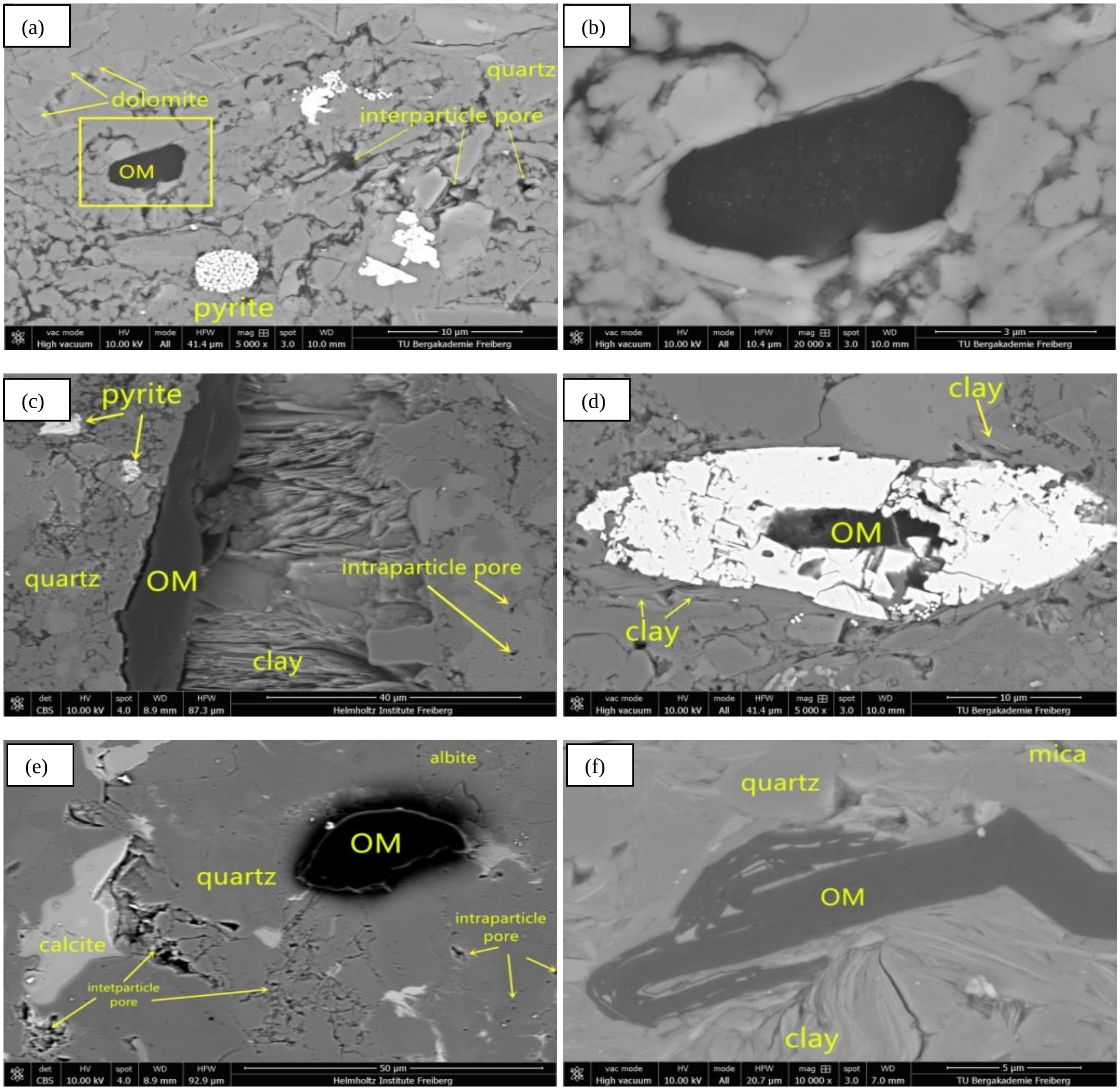


Figure 1 FE-SEM images for LMX and WF formation

In Figure 1c and e, we can observe irregular pores in mineral particles. Dissolution of dolomite and cleavage in mica consist the main sediment genesis of the intra-particle pores for LMX and WF formations. As a chemically unstable mineral, smectite generates a vast number of intra-particle pores during its transformation to an illite/smectite formation. Meanwhile, in Figure 1b, e and f, there are almost no pores in the organic matter. This may be due to the limited resolution of the FE-SEM or maybe the kerogen is immature.

3.2 Low pressure N_2 and CO_2 adsorption

Nitrogen isotherms for adsorption and desorption at 77K for the LMX and WF shale samples are presented in Figures 2 and 3, respectively. The highest quantity adsorbed at a relative pressure close to 1 is 6.66 cm^3/gr for the LMX shale and 10.81 cm^3/gr for the WF shale respectively. The adsorbed capacity always shows positive correlation with TOC (Cancino et al 2017).

At a low relative pressure, adsorption capacity demonstrates a gradual increase (type I isotherms from IUPAC) and reveals micro pores in shale samples. At a higher relative pressure, the isotherms belong to type Ⅱ isotherms from IUPAC classification. The shale sample as shown in FE-SEM images contain micro fracture and macro pores, and thus the horizontal plateau at relative pressure close to 1 is not present.

Obviously, both isotherms show adsorption hysteresis, meaning, the shale samples desorbed less gas than the adsorption process at the same pressure. This implies that both samples contain meso-pores. Theoretically, the desorption isotherm should always be above the adsorption isotherm. It can be noted that the data regarding the adsorption isotherm for the LMX sample and a given relative pressure of 0.86 - 1 are not sufficient to show such a pattern. Both desorption branches demonstrate a lower closure point at any given relative pressure of or above 0.42. This can be described as a 'Tensile Strength Effect (TSE)' and is a consequence of stability limitation of the hemispherical meniscus during desorption in pores with critical diameters (approximately 4 nm) (Groen et al 2003). This effect of TSE always leads to artificial discrepancy for PSD calculated from nitrogen desorption branch using the BJH method at 4nm. According to the classification of IUPAC for adsorption hysteresis, both isotherms show H4 hysteresis, which is often associated with narrow slit pores (Sing and Williams 2004).

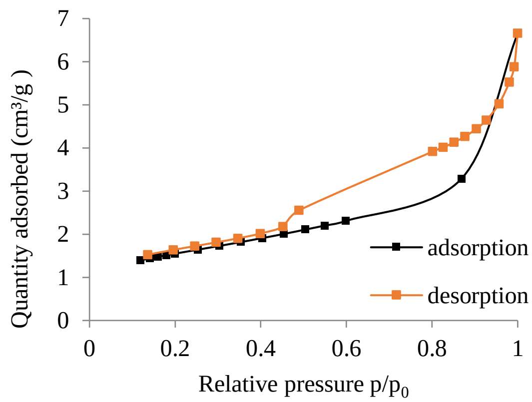


Figure 2 Adsorption-desorption isotherm of LMX shale

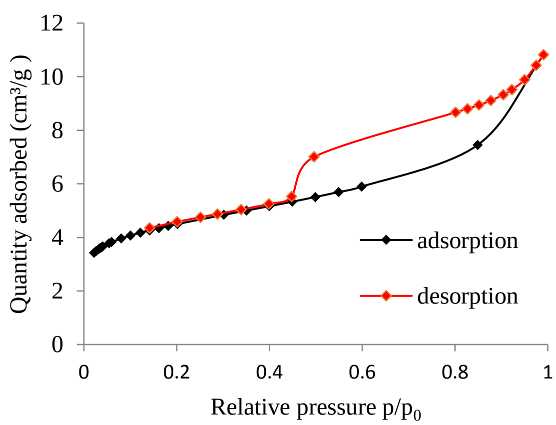


Figure 3 Adsorption-desorption isotherm of WF shale

The quadrupole moment of nitrogen molecules leads to interaction with adsorbent surface functional groups. This characteristic not only affects the orientation of adsorbed nitrogen molecules, but also influences the pressure for filling of micro-pores. For instance, initial stage of equilibrium relative pressure should be set as low as 10^{-7}. Under the ultimate low pressure, it is difficult to reach equilibrium with an extremely slow diffusion of nitrogen molecules in pores with a short time. Even worse, the pre adsorption of nitrogen can block the narrow throat. Resultantly, the filling pressure cannot quantificationally reflect the pore size of micro-pores.

Carbon dioxide with a kinetic diameter of 0.33nm can access smaller pores with rapid diffusion. Furthermore, the saturated vapor pressure of carbon dioxide is 3.5 MPa, meaning that we can get high resolution of micro-pores information during the medium pressure. The carbon dioxide isotherms for adsorption at 273K for the LMX and WF shale samples are depicted in Figure 4.

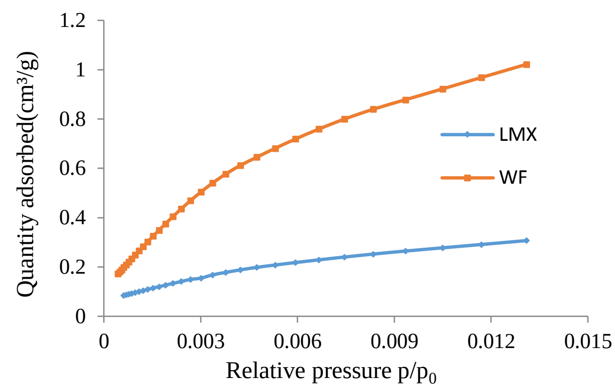


Figure 4 Carbon dioxide isotherms for adsorption at 273K

3.3 Specific surface area analysis

Specific surface areas from nitrogen and carbon dioxide isotherms are listed in Table 1. It should be noted at this point that nitrogen can access pores larger than 0.614nm, while the range of measurement of carbon dioxide is limited from 0.305 to1.475nm, at least theoretically.

Therefore, the S_{BET} value obtained from the BET method determines the total surface area of pores the diameter of which is larger than 0.614nm, while the S_{BJH} provides the information for pores within a range of 1.7-300nm. The S_{mic} derived from t-plot by nitrogen isotherms shows the specific surface area of micro pores ranging from 0.6nm to 2nm. Additionally, the S_{ext} value shows the specific surface area of pores with diameter larger than 2nm. Meanwhile, S_{co2} from isotherms of carbon dioxide reveals the specific surface area for micro pores from about 0.3 to 1.5 nm in diameter. The S_{co2} is calculated via the D-A method and is slightly higher than the S_{mic} value derived from the t-plot method, which in turn indicates that the micro pores (especially within a diameter of 0.3-1.5nm) in both shale samples are abundant.

The total specific surface areas calculated via the BET method (S_{BET}) for the LMX and WF shale samples are 5.47 m^2/gr and 16.33cm^2/gr, respectively. The S_{BJH} surface areas derived from the application of the BJH method (4.69m^2/gr, 8.72 m^2/gr, respectively) are slightly lower than the BET figures. This is due to the fact that the probed pore range (0.614 nm to 300 nm) in the BET method is greater than the analysis range (1.7 nm to 300 nm) of the BJH method. We can roughly estimate the specific surface area (given a pore size diameter from 0.6nm to 1.7nm) for the LMX and WF formations at 0.78m^2/g and 7.61m^2/gr, respectively, based on the assumption that the macro-pores make negligible contribution to the total surface area.

Table 1 Specific surface area from different method

Method	BET	t-plot		BJH	D-R
$S(m^2/gr)$	S_{BET}	S_{mic}	S_{ext}	S_{BJH}	S_{co2}
Range (nm)	0.6-300	0.6-2	2-300	1.7-300	0.3-1.5
LMX	5.47	1.26	4.21	4.69	3.29
WF	16.33	7.78	9.54	8.72	11.97

3.4 Pore volume and pore size distribution analysis

The pore volumes calculated with the t-plot method (micro pores range 0.6-2nm), BJH method (meso-macro pores range 2-300nm) and D-A method (micro pores from carbon dioxide range 0.3-1.5nm) are illustrated in Table 2.

In the LMX formation, the adsorption capacities of nitrogen and carbon dioxide are quite lower than in the WF formation. The indications for the specific surface area and pore volume show clearly that the pores in the LMX formation are not so abundant as in the WF formation. The meso−pores and macro−pores are the major contributors to the pore volumes for the samples in both formations.

Table 2 Pore volume of LMX and WF formation

Method	T-plot V_{mic}/cm^3	BJH $V_{mes-mac}/cm^3$	D-A V_{mic}/cm^3
Range (nm)	0.6-2	2-300	0.3-1.5
LMX	5.81	6.932	4.014
WF	2.833	10.766	6.068

The pore size distribution for both samples regarding N_2 and CO_2 are illustrated in Figures 5 - 8. Being an immature gas shale, the LMX formation holds less micro−pores than the WF formation, as shown in the qualitative analysis conducted using the FE-SEM. The distribution of micro−pores is merely about 1nm in diameter for both formations' samples. For meso−pores, the WF formation has a range smaller than 20nm, while meso−pores in the LMX formation range from 2nm to 30nm. The LMX formation holds a wide range of pore sizes, but with less pores volume and surface area than in the WF formation.

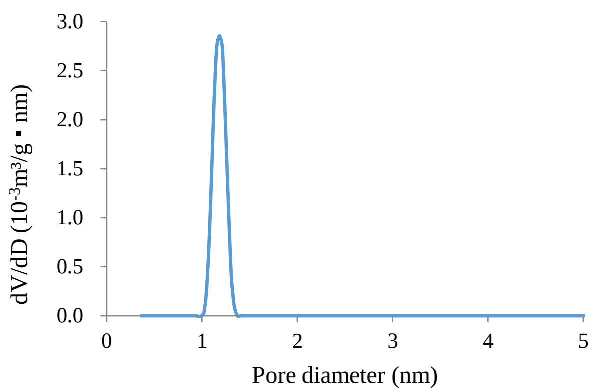


Figure 5 Pore size distribution of CO_2 for LMX sample

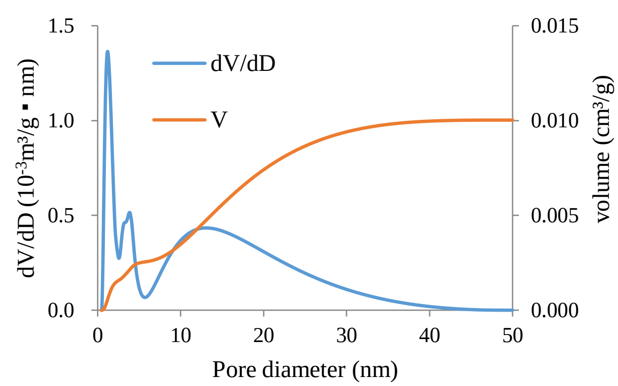


Figure 6 Pore size distribution of N_2 for LMX sample

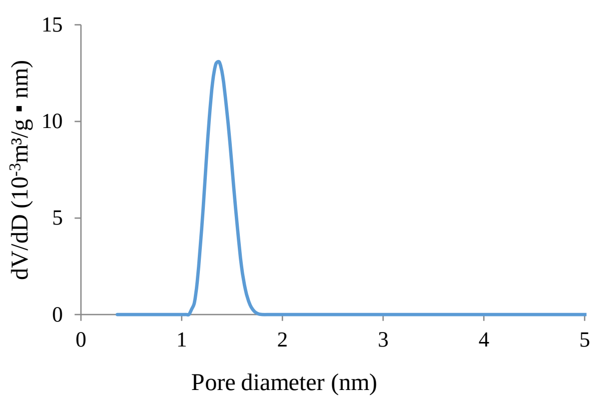


Figure 7 Pore size distribution of CO_2 for WF sample

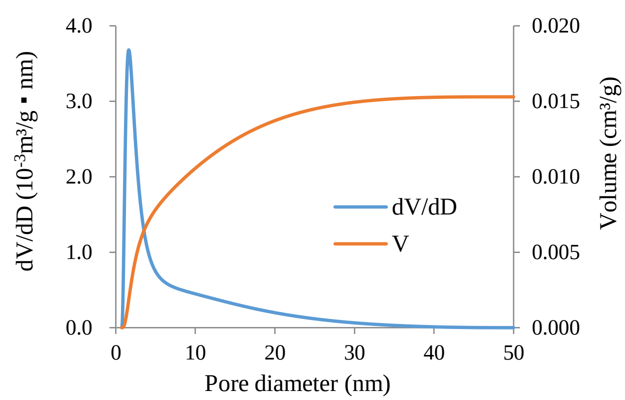


Figure 8 Pore size distribution of N_2 for LMX sample

4 Conclusions

FE-SEM and low pressure nitrogen and carbon dioxide adsorption were applied to reveal pore characteristics of Longmaxi and Wufeng shale formations. FE-SEM images show that both samples contain inorganic pores, though organic pores in LMX samples are absent. Low pressure nitrogen and carbon dioxide analysis showed that the pore size distribution for the LMX formation ranges from 1nm to 30nm. For the WF formation, the pore size distribution varies between1nm - 20nm and most pores are smaller than 10nm. Micro-pores are a major contributor to the specific surface area, while the meso-and macro-pores compose volumes for both samples.

Acknowledgement

The authors gratefully acknowledge the financial support from China Scholarship Council.

Reference

Ambrose R.J., R.C. Hartman, M. Diaz-Campos, I.Y. Akkutlu and C.H. Sondergeld, 2012. Shale gas-in-place calculations Part I: New pore-scale considerations. SPE Journal, **17**(**1**): 219 - 229.

Brunauer S., P.H. Emmett and E. Teller, 1938. Adsorption of gases in multimolecular layers. Journal of the American Chemical Society, **60**(**2**): 309 - 319.

Bernard S., L. Brown, R. Wirth and A. Schreiber, 2013. 7 FIB-SEM and TEM investigations of an organic-rich shale maturation series from the lower toarcian posidonia shale, Germany: Nanoscale Pore System and Fluid-rock Interactions. AAPG. **102**: 53 - 66.

Barrett E. P., L.G. Joyner and P.P. Halenda, 1951. The determination of pore volume and area distributions in porous substances. I. Computations from Nitrogen Isotherms. Journal of the American Chemical Society, **73**(**1**): 373 - 380.

Cancino O. P. O., D. P. Mancilla, M. Pozo, E. PErez and D. Bessieres, 2017. Effect of organic matter and thermal maturity on methane adsorption capacity on shales from the Middle Magdalena Valley Basin in Colombia. Energy & Fuels, **31** (**11**): 11698 - 11709.

Groen J.C., L.A.A. Peffer and J. Pérez-RamíRez, 2003. Pore size determination in modified micro- and mesoporous materials. Pitfalls and limitations in gas adsorption data analysis. Microporous & Mesoporous Materials, **60**(**1**): 1 - 17.

Houben M.E., A. Barnhoorn, L. Wasch, J. Trabucho-Alexandre, C.J. Peach and M.R. Drury, 2016. Microstructures of early Jurassic (Toarcian) shales of Northern Europe. International Journal of Coal Geology, **165**: 76 - 89.

Javadpour, F., M. M. Farshi and M. Amrein, 2012. Atomic-force microscopy: A new tool for gas-shale characterization. Journal of Canadian Petroleum Technology, **51**(**04**): 236 - 243.

Kelly S., H. El-Sobky, C. Torres-Verdín and M.T. Balhoff, 2016. Assessing the utility of FIB-SEM images for shale digital rock physics. Advances in Water Resources, **95**: 302 - 316.

Li J., J. Yin, Y. Zhang, S. Lu, W. Wang, J. Li, F. Chen and Y. Meng, 2015. A comparison of experimental methods for describing shale pore features - A case study in the Bohai Bay Basin of eastern China. International Journal of Coal Geology, **152**: 39 - 49.

Lippens B. C. and J. H. de Boer, 1965. Studies on pore systems in catalysts: V. The *t* method. Journal of Catalysis, **4**(**3**): 319 - 323.

Loucks R.G., R.M. Reed and S.C. Ruppel, 2012. Spectrum of pore types and networks in mud rocks and a descriptive classification for matrix-related mud rock pores. AAPG Bulletin, **96**(**6**): 1071 - 1098.

Sing K.S.W. and R.T. Williams, 2004. Physisorption hysteresis loops and the characterization of nanoporous materials. Adsorption Science and Technology, **22**: 773 - 781.

Wu, T., X. Li, J. Zhao and D. Zhang, 2017. Multiscale pore structure and its effect on gas transport in organic-rich shale. Water Resources Research., **53**(**7**):5438 - 5450.

Yang R., S. He, Q. Hu and J. Yi, 2017. Applying SANS technique to characterize nano-scale pore structure of Longmaxi shale, Sichuan Basin (China). Fuel, **197**: 91 - 99.

Zou C., D. Dong, S. Wang, J. Li, X. Li, Y. Wang, D. Li and K. Cheng, 2010. Geological characteristics, formation mechanism and resource potential of shale gas in China. Petroleum Exploration and Development, **37**(**6**): 641 - 653.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 153-162
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

A Framework of a 3D DCPCS Based on UWB Positioning in Underground Mining

Haoyu Wang[1,2], Enji Sun[1*], Feifei Wang[1,2], Shuangyue Liu[2]
[1] China Academy of Safety Science and Technology, Beijing, China, 100012
[2] University of Science and Technology Beijing, Beijing, China, 100083

Abstract: The real-time positioning and information feedback of the underground workers and equipment play a key role to achieve the safety digital mine because of the complex work scenario of non-coal mining in China, especially the injuries and collisions caused by the alternate operation between operators and vehicle equipment in underground mining. There are relevant requirements in the safety hazard called "six systems" which includes the personnel positioning, communication links, monitoring and controls, but the results are not prominent after investment and construction for its ambiguous definition of the scope of the standard and reasonable defects. This paper aims to study the application of Ultra-Wide Band (UWB) in underground personnel positioning, by comparing and analyzing traditional underground positioning technology. Combined with 3D scanning three-dimensional modeling technology, the UWB signal can also be used to construct 3D digital interactive underground map to enhance the accuracy of positioning information and the intuitiveness of monitoring perspective in control center. The framework of a 3D dynamic comprehensive prevention and control system (hereinafter referred to as 3D-DCPCS) based on UWB positioning in non-coal mining is proposed, depending on the supports of these technologies. Among them, UWB is a non-carrier communication technology. Its signal has strong anti-jamming performance and high transmission rate, which can improve the accuracy of real-time underground positioning. And the interactive 3D modeling technology is a new type of media, which can enhance the user's sense of reality through the transformation of pilot and perspective view. This framework of 3D-DCPCS is designed to have some specific modules, including user identity management module, underground three-dimensional map module, 3D interactive monitoring window module, underground risk assessment module, anti-collision module of personnel and vehicle, safety information statistical management module and other functional modules. This system can achieve the functions of different users' identity role management, underground safety risk identification and grade assessment, map of underground risk area, precise positioning and dynamic control of underground operators' vehicles, remote control and communication of underground equipment and personnel and 3D dynamic monitoring of underground operation scenarios. Meanwhile, these functions can be targeted to update through a period of security information statistical feedback. The system can be applied to comprehensive prevention and control monitoring of correlative complicated operating environment, by relating to the mentioned framework and specific situation of non-coal mine. It would be of practical values to improve the safety of underground personnel, standard safe operation of mechanical equipment and man-machine orderly cooperation in underground non-coal mine if it would be built and put into application.

Keywords: digital mine, 3D dynamic map, UWB positioning, comprehensive prevention and control system

1 Introduction / Background

China is a country of rich mineral resources (Zhang 2015). At present, there are 173 kinds of exploited minerals in China and China is the third most productive country in the world after the United States and Russia (Wang 2013). According to national statistics, with its huge mining industry, 94,753 non-coal mines have been discovered in China by the end of 2007 (Xie 2009). China has a large number of non-coal mines. However, they are widely distributed, which is a disadvantage to safety management, especially underground mining operations. In the event of an accident, the rescue difficulty and casualties are usually large. And even in standard operations, accidents involving personnel and vehicle equipment occur quite frequently due to the harsh underground environment, such as darkness and dampness, high dust concentration, high noise etc. Also, the problem of comprehensive control of underground personnel demand prompt solution. The "13th five-year" plan proposed new demands for the construction of high technology based on intelligent mines and the development of the supporting technology for unmanned working face (He et al 2015). In addition, according to the development route of the deep integration of information technology and manufacturing industry proposed in "made in China 2025" (Zhou 2015), a number of emerging technologies such as 3D digital media and the Internet of Things would be continuously applied to the mining industry, in order to

* Corresponding Author: Enji Sun, Email: enjisun@gmail.com, phone: +86 10 8491 6155

DOI: 10.15273/ijge.2018.03.025

improve the security capacity of underground production. In 2010, China issued a series of related documents and saw the construction of "six major systems" of non-coal mines launch. However, the following results could not meet the original expectation mainly due to the problems such as ambiguous scoping caused by a system with extensive covering range and the unrealistic standard regarding personnel positioning and communication. The ideal solution is to establish an informationized and digitalized multi-model mines based on mine multidisciplinary information including science and technology, information science and artificial intelligence. This also answers to the national " 13th Five-Year" plan as well as meet the future development trend of mining, (Liu 2011) The key to achieving this goal is to ensure the working staffs and devices is located accurately and achieving real-time feedback by introducing advanced technology and experience in other fields.

In related fields, Liang Bosen et al. propose that the trend of in the field of mine monitoring is accurate positioning, 3D visualization, multi-system integration, Internet of Things and multi-data mining, which provides a direction for the design of this article (Liang 2017). Xu Hualong, Yin Dafa and others put forward the mine 3D visualization monitoring system design ideas and related applications using 3D GIS technology and virtual simulation technology. The system can provide 3D underground real-time monitoring (Xu and Ying 2016), but there is a lack of corresponding solutions in the control of personnel and vehicle irregularity and the risk in different areas in the mine. Li Chunmin et al. constructed the 3D visualization framework model of "digital mine", through data manipulation, mapping and drawing (Li et al 2006), which is worthy of reference in 3D modeling. On the basis of this research, this paper focuses on the two core technologies of personnel positioning and 3D visualization. Firstly, we analyzed the current positioning technologies and designed the construction scheme of the positioning subsystem by choosing the UWB and the corresponding algorithm. After that, the 3D scene construction scheme was designed with the help of 3D modeling technology. With the support of two core technologies, the framework of 3D-DCPCS was proposed. This paper researched on the construction of the framework and analyzed specifically some key functions of it including 3D interactive monitoring window, security risk assessment and anti-collision module for personnel and vehicle.

2 Key Technology of System

2.1 Positioning technology

At present, GPRS is different from GPS, which the satellite is the receiver (Sun et al 2010a). GPRS accounts for a large market, and its clients use mobile phone to send signals to the communication base station. (Zhang 2014) Consequently, the positioning accuracy of GPRS depends heavily on both the intensity of the signal and the number of base stations. The challenges for positioning technology are even bigger because of the harsh conditions in the well. Nowadays the commonly used under-well positioning technologies are ultrasonic, Bluetooth, Wi-Fi, RFID, ZigBee and UWB, etc. The positioning methods can be roughly divided into range-based measurement and range-free measurement, and the related positioning algorithms are AOA algorithm, TOA algorithm, TDOA algorithm, RSSI algorithm and fingerprint location algorithm (Lazos and Poovendran 2006)

2.1.1 Choosing the proper positioning technology

(1) Wi-Fi positioning technology

Wi-Fi positioning technology is the most popular and a promising technology among under-well positioning technologies. The establishment of Wi-Fi position system is feasible and low-cost, but with unsecured accuracy. The users with the mobile intelligent terminal enters the underground operation area of the base station (router). On receiving the results of data processing from the clients, the server can then calculate the location. The more signals the smart terminals receive, the more accuracy the system will achieve. The demonstrative diagram of the Wi-Fi positioning system is presented in Figure 1.

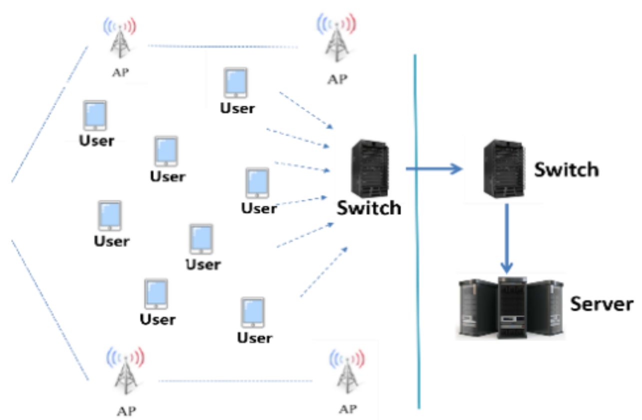


Figure 1 The diagram of Wi-Fi positioning system

(2) Radio frequency identification technology (RFID)

RFID is an high-speed recognitive, non-contact automatic wireless communication technology (Ahuja and Potti 2006) It uses radio frequency to recognize and distinguish the relative data of the target so it's capable of fast reaction and strong resistance to interference. Typical RFID system consists of Antenna, Reader, Tag (also called radio frequency recognition card), middleware and software based on RFID technology (Zeng and Zhao 2010) When people or vehicles carrying an electronic tag enter the transmitting area, the tag will send a signal which contains the information to the reader. The reader will decode and transmit it to data management system and the location information can be calculated afterwards. FRID technology is convenient to set up, but the positioning accuracy is not promising. In practice, it is commonly used for the attendance check in actual underground work. The illustrative diagram of positioning system is shown in Figure 2.

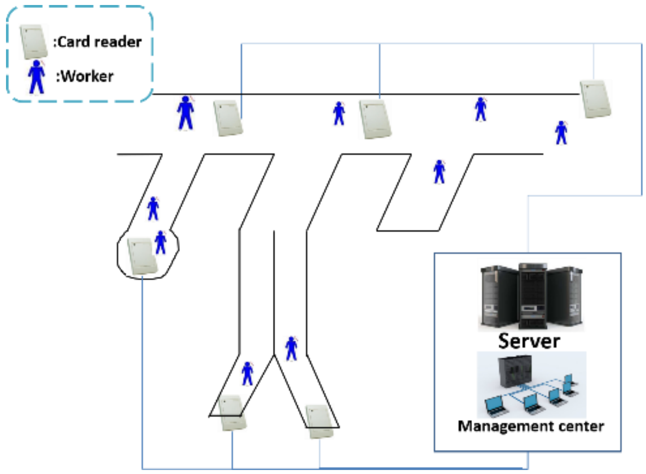


Figure 2 The diagram of FRID positioning system

(3) Zigbee communication technology

Zigbee technology is an emerging short-range wireless communication technology (Gu and Zhang 2005) It has the characteristics of low complexity and short bidirectional communication distance. It is a highly adaptive wireless network composed of many nodes. Its schematic diagram is introduced in Figure 3. As we can see in the picture, in the entire wireless network, by using frequency-hopping spread spectrum (FHSS), communication can still hold even when one node fails within the network. Zigbee communication technology is also used as location technology because of the wireless communication function. The function principle of the system is similar to that of the RFID positioning system. The biggest advantage of this technology lies in the low establishment cost, high security, despite the drawback of low positioning accuracy.

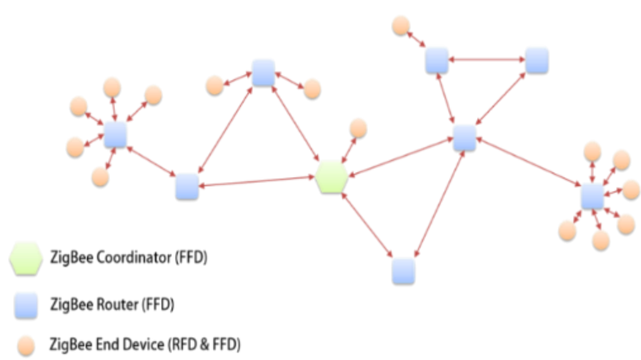


Figure 3 The diagram of Zigbee positioning system

(4) UWB positioning technology

UWB technology is also known as ultra-wideband wireless technology with bandwidth over 1GHz. The signal has strong anti-interference performance and high transmission rate (Shen et al 2005) UWB positioning system is mainly composed of software platform, wireless sensor and the active positioning labels, the working principle of which is shown in Figure 4. When personnel or vehicles enter the operation area, the active positioning tag that they wear will Send UWB pulse signal. The pulse signal will be received by the base station. The location of the target is calculated by positioning algorithm and transmitted to server terminal via Ethernet. UWB positioning technology is one of the most advanced positioning technologies with advantages of simple structure, low power consumption and high transmission efficiency etc.

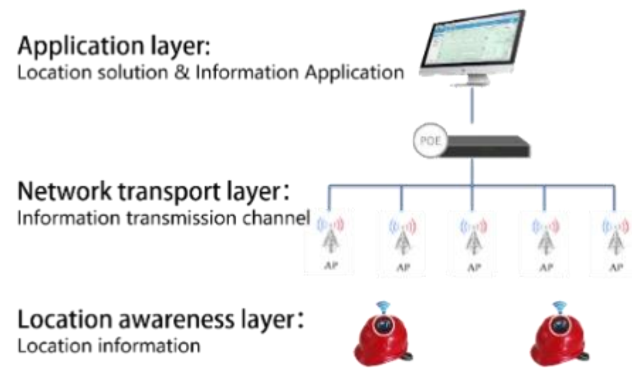


Figure 4 The diagram of Zigbee positioning system

(5) Bluetooth positioning technology

Bluetooth is a short-distance wireless communication technology mainly used to enable the communication among wireless devices. It was first developed by Ericsson in 1994 (Chen and Zheng 2003) The working principle of Bluetooth positioning technology based on the received signal intensity. Bluetooth chip is small so that it has low power consumption, But the positioning range can also be very limited.

According to the above mentioned positioning technologies , in terms of working condition—non-colliery underground well and by comparing the technologies in Table 1,we could conclude that UWB positioning technology is more suitable for underground well site because it has fast transmitting rate, simple structure, superior safety, low power consumption, better signal penetrability, stronger anti-interference ability and better positioning accuracy, all of which can contribute largely to a successful underground well positioning.

Table 1 Comparison table of positioning technology

	Frequency	Precision	Speed
Wi-Fi	2.4GHz	⩽10m	54Mpbs
FRID	LF:125KHz; HF:13.54MHz	10~30m 3~10m	12Mpbs
Zigbee	868~915MHz 2.4GHz	10~75m	10～250Kbps
UWB	3.1~10.6GHz	5~30cm	40～600Mbps
Bluetooth	2.4GHz	15m	1Mbps

2.1.2 Positioning algorithm

Currently, the algorithms related to UWB localization technology fall into two broad categories: range-free localization algorithm and range-based algorithm. And fingerprint localization algorithm is the most typical range-free measurement algorithm. The localization procedure is illustrated in Figure 5. The radio waves emitted by wireless AP node leave important multipath signal, which is named the "fingerprint of position", when they undergo refraction, diffraction, etc. while passing through its surroundings. (Rong and Yang 2010) The algorithm of this method is to first extract the characteristic parameters of radio signals; then compare them with the modules in the database via certain coupling algorithm; finally locate the most similar group or several groups of data and lock the position. However, fingerprint algorithm is prone to fail the instantaneity and accuracy of the positioning, so range-based measurement would be a better candidate.

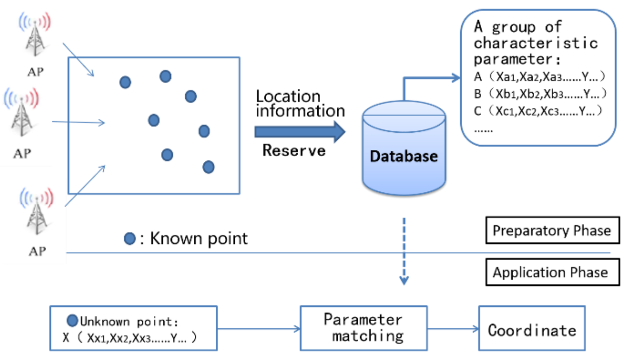


Figure 5 The localization procedure of fingerprint localization

Commonly used range-based localization algorithm are AOA algorithms, TOA, TDOA algorithm and RSSI algorithm. AOA measurement is based on the arrival angle of the signal while TOA and TDOA use the signal arrival time to calculate the distance. RSSI uses the extent of the signal decay to calculate the location. According to the characteristics of these algorithms listed in Table 2, it could be concluded that TDOA triangulation method is more suitable in the working condition of this paper.

Table 2 Comparison table of positioning algorithm

Positioning algorithm	AOA	DOA	TDOA	RSSI
advantage	Simple in structure, higher precision	Higher precision	High precision	Low cost, easily realized
defect	Susceptible, higher equipment	higher equipment	More equip-ment	Lower precisi-on

Based on TDOA algorithm, it needs at least three coordinates of AP node to locate the coordinate of the unknown point. At certain moment, the distances between positioning point and different AP nodes are different. As the transmitting velocity of the signal is known, the distance difference can be calculated using formula $d = v(T_1 - T_2)$. Analogously, the distance difference d can be drawn by multiple hyperbolas, as shown in Figure 6.

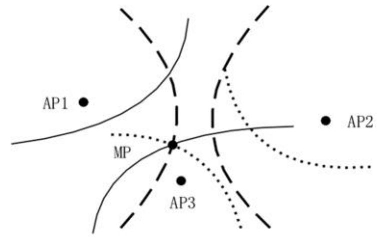


Figure 6 The positioning algorithm of TDOA

Combining the geometric model in Figures 2 and 3 with the lag time of different target-and-AP node-pairs calculated in the TDOA, it could be inferred that the positioning terminal lies in the hyperbola which uses the two AP-node coordinates as its focuses. Two hyperbola formulas could be conducted by three known AP nodes and the intersections of these hyperbolas are the position of the terminal. The coordinates of the terminals could in turn be obtained by solving the hyperbola formulas. However, in practical applications, there are many occasions when there is no overlap between the two intersections of the hyperbola, so the method of triangle centroid is needed to determine the anchor coordinates.

2.2 3D visualization technology

With the development of computer technology, two-dimensions figures cannot satisfy the requirements of users. Instead, three-dimensions technology have been applied to video production, which allow users to have a more vivid experience while enhancing level of lifelikeness of real people and objects.

2.2.1 3D scanning

3D scanning is an advance technology integrating light, machine, electricity and computer technology. It can obtain the space coordinates of the object surface by scanning object space shape, structure and color. 3D scanning can convert the stereoscopic information of underground tunnels, working environment and related equipment into digital point cloud information that can be processed by a computer, which can achieve the digitization of the underground scene. The 3D scanning technology can realize the non-contact measurement in the mine and has the advantages of fast measurement and high precision. The measurement results can be directly connected with various software interfaces.

Non-contact 3D scanners conclude raster 3d scanners (also known as photo-type 3d tracers) and laser scanners.

Photo-type 3D scanner adopts a composite 3D non-contact measurement technology, which combines structure light technology, phase measurement technology and computer vision technology. The scanner can adjust the scanning range according to the condition of the underground. It is suitable for large equipment and the overall scanning of the specific area, which can guarantee the scanning integrity and efficiency. The photo-type scanning principle is shown in Figure 7. The measuring instrument uses similar principle of the camera to obtain the

3D information of the object. In non-coal mines, underground photo-type 3D scanner can adjust the position and angle according to the site, carrying out omni-directional measurement; or implement real-time automatic merging, carrying out the partition measurement.

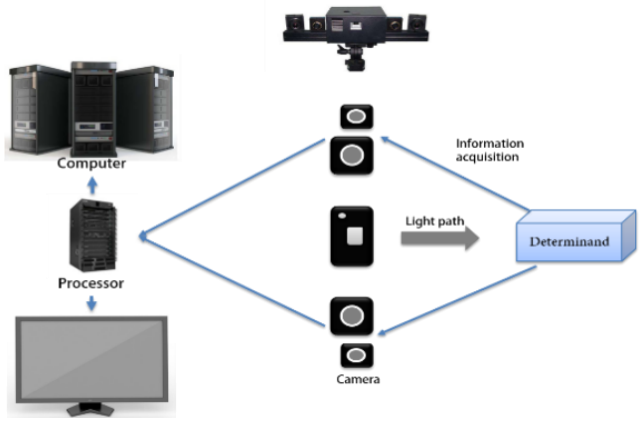


Figure 7 The sketch map of photo-type 3D scanner

Line laser handheld 3D scanner is suitable for scanning small workpiece. Before use, calibration is needed. When working, the laser line irradiates the object, which allows two cameras capture the 3D scan data of that instant. Due to the curvature of the surface of the object, the light is reflected and refracted before these information is converted to 3D images by third-party software. The hand-held 3D scanner is designed on the basis of the photo-type 3D scanner. Scanning the point cloud image on the surface of the object, these points can be used to interpolate the surface shape of the object. The accuracy of the model is in line with the density of the point cloud, which contributes to the quality of 3D reconstruction.

2.2.2 3D scene construction

(1) Technical analysis of 3-Dmodling

There are several frequently-used foreign 3D modeling software such as 3ds Max, Maya, SketchUp, etc. And the frequently-used 3D model scene displays software, are ArcGlobe, SkyLine, GeoGlobe, etc. As for domestic software, VRMap created by Beijing Lingtu Software Technology Co., Ltd and IMAGIS made by Supresoft Inc are leading the pack.

We can see the modeling software's function and advantages from the Table 3. In all, 3ds Max is superior to other software in terms of operational convenience and possibilities and will be used as main 3D modeling software in this system.

(2) Creating 3d scene of underground well

The actual effect of the underground monitoring display window depends largely on the previous 3D scene construction. The core work of the underground scene modeling is to analyze and process the point cloud information, mine drawings and topographic information of the 3D scanning. Through the 3D modeling software, a model is established for the tunnel working face, equipment, vehicles and workers in the mine. Finally, 3D restores the real scene into, 3D scene files for later use in related process steps. The concrete underground 3d scene construction is divided into three parts, including data collection, data processing and model integration. The concrete building process will be introduced in the following page.

Table 3 Comparison table of modeling software

Name	Advantage	Defect
3ds Max	Complete function,	Complex texture
Sketch Up	Rapid modeling	Insufficient information
SkyLine	Lots of 3D data scenarios.	Differential monomer modeling
Maya	All-round CG function	Focus on film

3 Studies of System Framework

3.1 System construction

Combining the actual situation of non-coal mines, this paper focus on constructing non-coal mine comprehensive monitoring and controlling system applying above mentioned two technologies. The establishment of the system is the core issue to be solved and discussed in this paper. Upon completion, the system should be equipped with functions including identity authority management of different users, underground safety risk identification and grade assessment, downhole risk area map, precise positioning and dynamic control of downhole workers' vehicles, remote control and communication of downhole personnel equipment and 3D dynamic monitoring of downhole operation scenarios. In the process of establishing the system, many issues including technology, personnel and procedures should be taken into consideration. The following section is a research on the establishment of overall system and specific steps.

3.1.1 The global perspective of system

The establishment of system in the overall perspective can be divided into four steps: 3D map construction of downhole, downhole risk identification and assessment, downhole positioning subsystem construction, system operation and monitoring, as shown in Figure 8. Every step operates with the support of Software programming, model building, background maintenance and other technologies. 3D map building Downhole is the foundation of the system framework, which provides a platform for the establishment of positioning and monitoring subsystems and system-related services. Downhole risk identification and assessment is a core content of underground safety work, which provides corresponding basis for the routine operation and maintenance of system. The construction of positioning system aims to solve the locating problem of downhole personnel and equipment, which incorporates positioning information into the 3D underground map, realizing the dynamic map (i.e. the three-dimensional monitoring of downhole operation). Finally, the system enters the actual operation and monitoring phase, in which the system will be improved according to the actual situation.

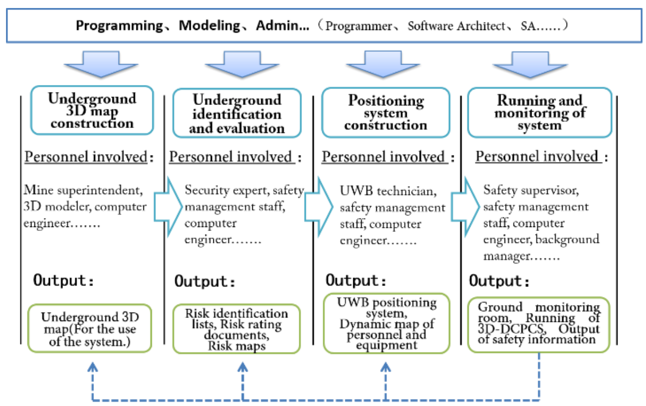


Figure 8 Overall system construction

3.1.2 The step of construction

The following section researches on the construction of 3D underground map, underground mine risk identification and assessment, underground positioning subsystem construction and system operation and monitoring.

(1) 3D map construction of downhole

As shown in Figure 9, we start with the collection of mining data, which includes the specific types of mines, types of minerals, geological conditions of mines, depth of mines and the progress of mining. After acquiring the basic information of the mine, the site survey of working environment is carried out. The underground personnel vehicles and roadways are scanned by 3D scanning technology. Then, with the drawings and photos and other information, all regions of mine and personnel vehicles are modeled with 3D modeling. The three-dimensional models of different regions are spliced to form a downhole three-dimensional model of all dimensions, i.e. 3D underground map.

Three-dimensional scene modeling of downhole is the key to the system construction, influencing the post-performance of 3D monitoring of system and the fidelity of picture presented. For underground non-coal mines, the flow chart of specific three-dimensional modeling construction shown in Figure 10 includes three major steps: The collected data includes point cloud data obtained by 3D scanning, mine drawings and other information. Data collection should be as detailed as possible to restore the scene in a truer manner in the modeling process. Data processing is a procedure to process the data by the existing corresponding data processing and modeling software, in order to formulate the 3D model of the local scene. The final model integrates the existing three-dimensional scene model to form a whole three-dimensional model and a model for each working face. And after adding the underground equipment, vehicles and personnel models, it can obtain the 3D scene display of the real underground scene.

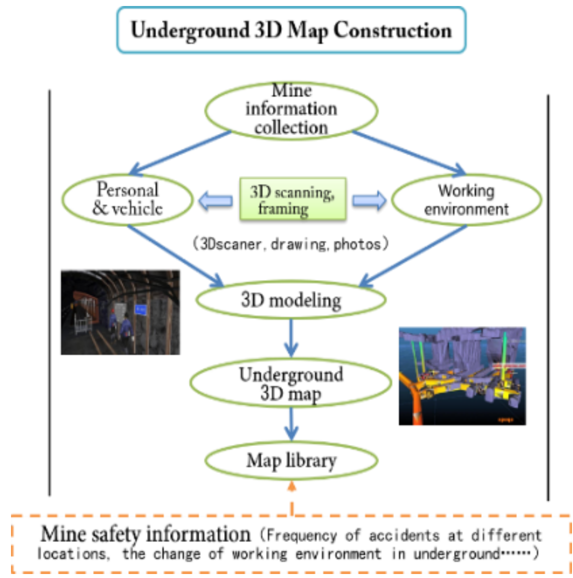


Figure 9 Underground 3d map construction

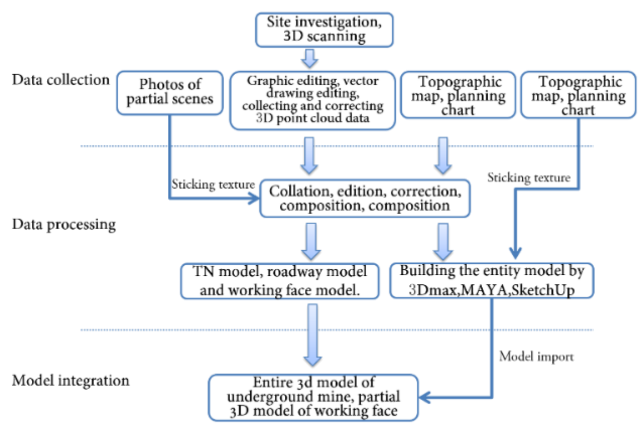


Figure 10 Underground 3D modeling

We transform the files of 3D scene model of downhole in a variety of formats, in order to facilitate the function modules of the system. By writing a system program, we build a detailed underground map library. The map library includes the whole underground, each face, as well as each key area of the three-dimensional model. The mine safety information is generated by the fourth part of the system's safety information management module. Through the feedback of safety information, the three-dimensional model in the map library is evaluated, and the three-dimensional model that does not match the real scene is modified or re-modeled.

(2) Underground risk identification and assessment

Downhole risk identification and assessment of business and business safety work is directly related to the risk identification. Risk identification and risk rating information play the role of guidance for the design and upgrade of function of system. The flow diagrams of downhole risk identification and assessment are shown in

Figure 11. Firstly, according to the basic information of the mine, combined with the relevant industry standards of non-coal mines, we developed the original version of the risk identification documents, and initially identified the non-coal mine underground danger source. Afterwards, having a knowledge of the enterprise and the status quo of production safety, we carry out the underground investigation to statistically analyse the past accidents of the enterprises. And by doing so, we improved the quality of the enterprise's risk identification documents. And then through expert assessment, model calculation and other means of hazard classification, we finished underground risk classification files, finally forming downhole risk map. Underground risk map is a presentation of risk rating, which combines the grading results with the downhole map and shows different colors on the map according to the number and level of the dangerous sources. And it achieves a more intuitive observation of the dangerous situation in each area. The mine safety information will be fed back to the three outputs, namely, downhole risk identification documents, downhole risk classification documents and downhole risk maps for updating and modification.

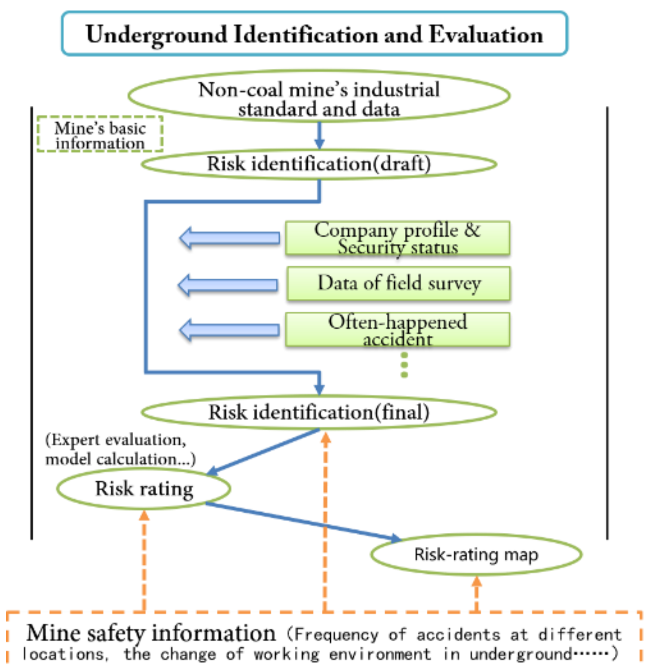


Figure 11 Underground risk identification and assessment

(3) Construction of underground position system

The sub-system of underground positioning can be illustrated in Figure 12. Before the establishment, detailed exploration of the mine should be carried out for comprehensive situation of the mine, including the location of the base station and the wires. The placement of base station should be based on the regional risk level because the data precision can be improved by increased base station number. As a result, the region with higher risk level should be equipped with more base stations to ensure the practical efficiency. When the establishment of base stations and wires is finished, the server can be added and related software can be programmed. According to the different identification of the users, different labels can be utilized in the positioning system. And the related functions in the sub-system are started up. Ultimately, the sub-system, underground 3D map and the models of people and equipment are combined together to realize the 3D demonstration of positioning information of underground people and devices, which is the underground 3D dynamic map. According the practical operation results, the location of the base stations and wires can be modified based on the feedback of the prior design.

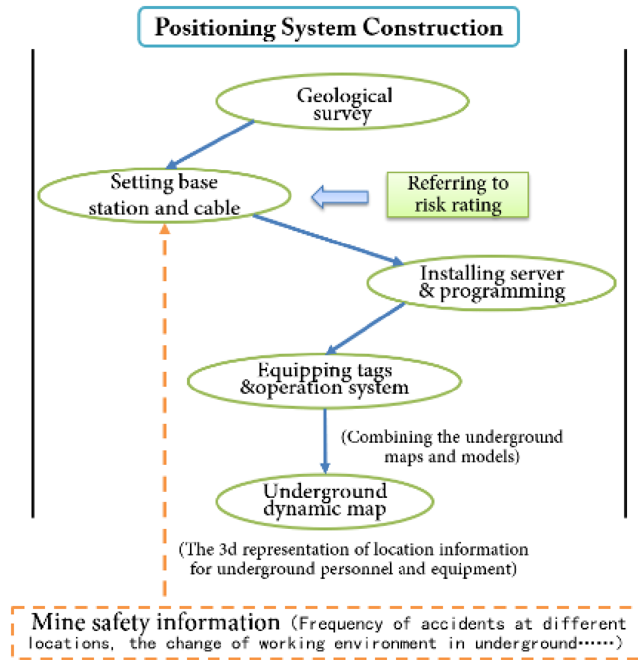


Figure 12 Underground risk identification and assessment

(4) Running and monitoring the system

The operation and monitoring of the system can be illustrated in Figure 13. According to the aforementioned results, the following steps should be carried out for operation of the system: 1) establishment of the surface monitoring room related devices; 2) programming the system and software of comprehensive monitoring and controlling; 3) administration of the original setting in the system background, including systematic prior settings, identification and authority of the users and division of the underground zone. When the system is operated, there are six main functional modules in the process: administration of the identification and authority of the users, 3D interactive monitoring, database of the 3D underground map, underground risk level ranking and prevention of underground crashing and supervision of the security information. The feedback from module of supervision of the security information can be provided to the other modules.

3.2 Achieve the system function with various modules

The whole system is mainly composed of user identity and permission management module, three-dimensional (3D) interactive monitoring window module, underground 3D map library module, underground risk rating module, underground collision avoidance module, security information management module. After the construction of the system, these modules will be triggered by different ways to achieve the function of the entire comprehensive monitoring and control system. Analysis and interpretation of these modules and its functions are as follows.

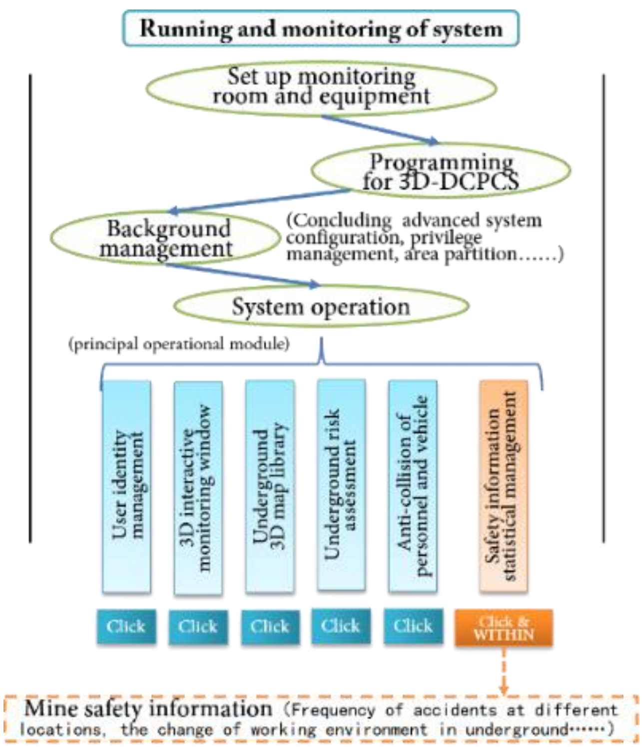


Figure 13 Running and monitoring the system

3.2.1 User identity and permission management module

As an auxiliary module, user identity and permission management module mainly contribute to the management of various users including addition and deletion of users, setting and modification of user's data, usage record of the system and so on (Figure 14). With the help of this module, employees would be managed more efficiently by personnel classification management. In addition, more detailed and concrete information of miner and their job information can be obtained.

3.2.2 3D interactive monitoring window module

The 3D interactive monitoring window is the core function module of the system (Figure 15). Generally, monitoring is the normal interface of the module. In the three-dimensional scene, the visual image reflects the position information of the underground equipment, vehicles and miners. The interactive monitoring means that the monitoring personnel can achieve changes in perspective and zoom into and out of the images, as well as provide real and efficient management information in monitoring personnel by viewing the relevant information of specific person and equipment.

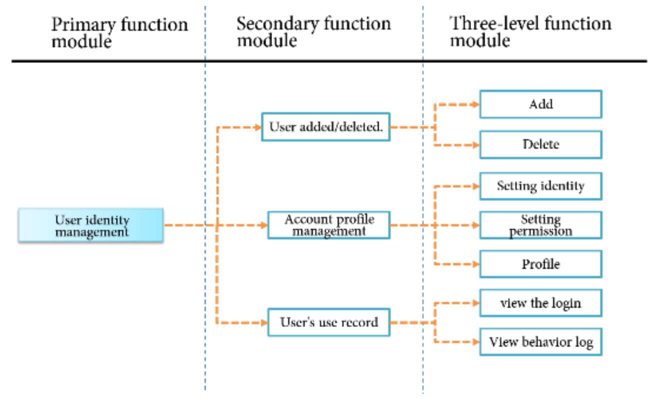


Figure 14 The function classification of user management module

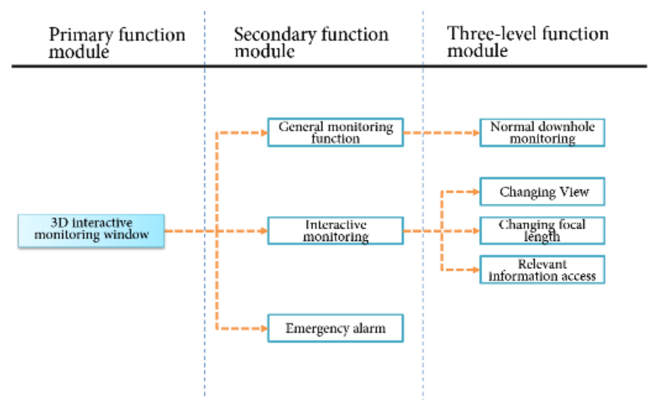


Figure 15 The function classification of the 3D interactive monitoring window

3.2.3 Underground 3D map library module

Underground 3D map library (Figure 16) is the basic module of the system, not only can it provide users with a way to view underground operating environment and to achieve the inspection and modification of 3D model which covers the whole underground area, each working face and key area, but can also to provide job scene model for those core modules, such as interactive monitoring window and risk map.

3.2.4 Underground risk rating module

Underground risk rating module is the innovation module of mine security control work, which provides users with relevant data files about underground risk identification and classification, as well as the risk map and risk map, the combination of data and 3D underground scene model. As shown as in Figure 17, the users will have more intuitive understanding of underground risk distribution and risk level so as to carry out the underground danger zone partition.

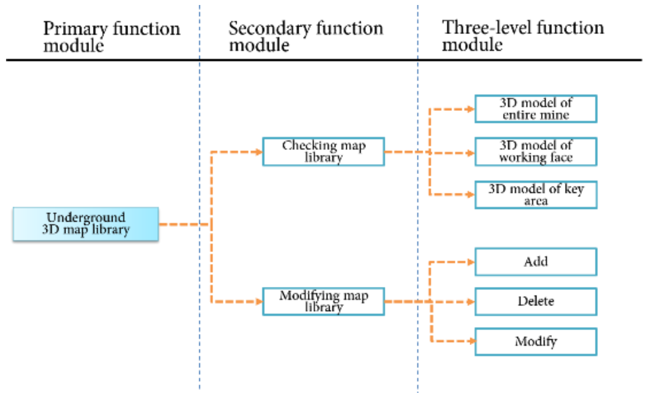


Figure 16 The function classification of underground 3D map library module

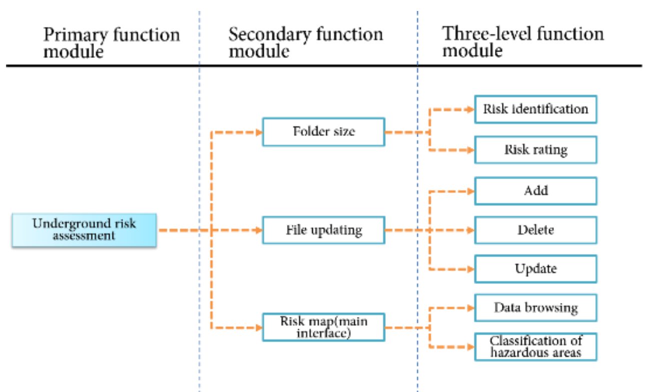


Figure 17 The function classification of underground risk rating module

3.2.5 Underground collision avoidance module

Underground collision avoidance (Figure 18) is a real-time module, which is the main function part under the normal operation of the system. The system will alert related personnel when they are in improper alternate operation or enter the hazardous area. Based on assisted driving system and route guidance functions, it helps users manage and control underground miners and vehicles to prevent collisions and accidental entry in dangerous areas (Sun et al 2010b).

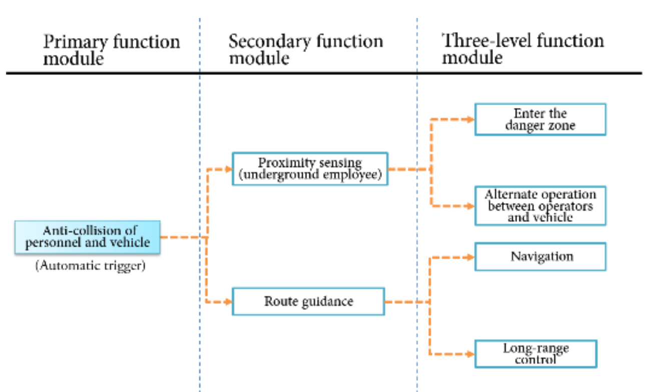


Figure 18 The function classification of underground collision avoidance module

3.2.6 Security information management module

Security information management consists of data processing and storage feedback functions, which records various types of real-time information generated during the operation of the system. As shown as in Figure 19, after mine security information being collected by means of analysing these information, the corresponding feedback will be shared to other related functional modules to upgrade and improve the system. In addition, as a browsing module, it can also be used as a tool for inspector to check whether the underground workers complete the work according to the criteria.

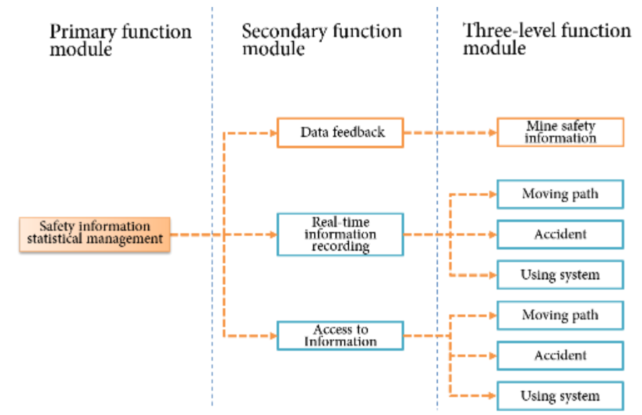


Figure 19 The function classification of security information management module

4 Conclusion

In this paper, two key technologies applied in non-coal mine shaft are discussed. And the question of how to construct the 3D dynamic control framework based on UWB positioning and the functional business modules are analyzed. Through the gradual implementation of the system construction, combined with the specific situation of the mines, the construction of the system could be finally completed and put into practice. This system can not only be applied to the underground operation of non-coal mines, but also provide comprehensive control and monitoring services for other complex operating environments. By running six business function modules, the system can intuitively understand the underground operation conditions, which improves manageability, and it can also promptly alarm the miners and equipment about the possible dangers and, prevent the occurrence of an accident. Therefore, it has practical application value on improving non-coal miners' safety, as well as ensuring the standard operation of mechanical equipment and the orderly human-machine coordination.

Acknowledgement

This research project is made possible through the financial support from National Key R&D Program of China (2017YFC0805100, 2016YFC0801305).

References

Ahuja, S. and P. Potti, 2006. An introduction to RFID technology. (radio frequency identification) (Report). IEEE Pervasive Computing, **5**(**1**): 25 - 33.

Chen, J. and Z. Zheng, 2003. Introduction of ericsson bluetooth chip ROK101007. Electronic Design Engineering, (**6**): 36 - 39.

Gu, R.H. and H.K. Zhang, 2005. Wireless network technology and its application based on ZigBee. Application of Electronic Technique, **31**(**6**): 1 - 3. (in Chinese)

Lazos, L. and R. Poovendran, 2006. HiRLoc: high-resolution robust localization for wireless sensor networks. IEEE Journal on Selected Areas in Communications, **24**(**2**): 233 - 246.

Li, C.M., Z.X. Li and Y.H. Wang, 2006. Research on 3d visualization of “digital mine”. Journal of System Simulation, **18**(**s2**): 515 - 518. (in Chinese)

Liu, L., 2011. New trends in modern mines: Automation and intelligence. Mining Equipment, **(7)**: 34 - 37. (in Chinese)

Liang, B.S., 2017. Current situation and development trend of coal mine safety monitoring and monitoring. Inner Mongolia Coal Economy, (**12**): 71 - 72. (in Chinese)

Rong, X.F. and N. Yang, 2010. Localization error analysis and simulation of RSSI position fingerprint. Journal of Xi'an Technological University, **30**(**6**): 574 - 578. (in Chinese)

Shen, X., W. Zhuang, H. Jiang and J. Cai, 2005. Medium access control in ultra-wideband wireless networks. IEEE Transactions on Vehicular Technology, **54**(**5**): 1663 - 1677.

Sun, E.J., A. Nieto and Z.X. Li, 2010a. GPS and Google Earth based 3D assisted driving system for trucks in surface mines. Mining Science and Technology, **20**(**01**): 138 - 142.

Sun, E.J., A. Nieto, Z.X. Li, and V. Kecojevic, 2010b. An integrated information technology assisted driving system to improve mine trucks-related safety. Safety Science, **48**(**10**): 1490 - 1497.

Wang, G.F., 2013. Safe and efficient mining technology and equipment of kilometer deep well in Innovative coal mine. Technology for mining the deep well of coal mines in China. (in Chinese)

Xie, K.N., 2009. Analysis on safety production management of non-coal mine mountain enterprises. Work Safety & Supervision, (**2**): 26 - 27. (in Chinese)

Xu, H.L. and D.F. Ying, 2016. Design and realization of 3d visualization monitoring system in mine. Coal Mine Safety, **47**(**7**): 136 - 139. (in Chinese)

Zeng, W.B. and J. Zhao, 2010. A design of electronic tag antenna based on RIFD technology mine safety tracking system. Mine Safety, **41**(**9**): 74 - 77. (in Chinese)

Zhang, J.W., 2014. Comparison and summary of the characteristics of BEIDOU positioning system and GPS system. Electronic Technology and Software Engineering, **(7)**: 65 - 66. (in Chinese)

Zhang, H.T., 2015. Situation of mineral resources in China. Zhejiang geological society 2015 academic annual meeting. (in Chinese)

Zhou, J., 2015. Intelligent manufacturing--Main direction of “Made in China 2025”. China Mechanical Engineering， **17**(**001**): 2273 - 2284． (in Chinese)

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 163-168
Available at http://ojs.library.dal.ca/ijge

Research and Development and Industry

Evaluating the Strength and Performance of Backfill Support in Deep Level Gold Mines

Fhatuwani Sengani[1*], Tawanda Zvarivadza[1], Rinae Netshithuthuni[2]
[1] School of Mining Engineering, The University of the Witwatersrand, Johannesburg, South Africa
[2] School of Mining and Environmental Geology, University of Venda, Thohoyandou, South Africa

Abstract: The backfill operations at the deep level gold mine consist of a Cyclone Classified Tailings (CCT) Plant as well as a Full Plant Tailings (FPT) Plant with both producing cemented backfill. Due to the high demand of backfill at the mine, including a backlog of voids that need to be filled, both the CCT and FPT Plants are being operated at the moment. The mine will require an increased capacity of backfill going forward, with monthly throughputs in the order of 200 000 to 250 000 tonnes being required. The current mining methods includes destress cuts, long hole stoping as well as drift and fill mining with cemented backfill as a support medium. These concerns have led to the review of the entire backfill operations of the mine with a need for optimising, reducing costs and reducing operational complexity going forward. The research provides strength test work (solids density, particle size distribution, slurry pH, temperature, conductivity, freely settled bed packing concentration, permeability, particle micrographs, water quality, mineralogy, boger slump tests, cement mortar tests (ISO bars), and unconfined compressive strength (UCS) tests) and audit the current backfill operations at the mine. The data showed that both materials had similar top particle sizes of approximately 500 µm. The CCT has a d30 and d10 of 63.4 and 18.2 µm, respectively, compared to the FPT with a d30 and d10 of 13.1 and 3.1, respectively, which is significantly finer. The freely settled bed packing concentration by volume was calculated from the volume of the freely settled bed formed by a known volume of solids. A slurry sample was allowed to settle for 24 hours in a measuring flask. The actual solids volume was determined from the dry mass of material and the solids density. The results were as follows: CCT 45.2 %v (69.1 %m) and FPT 40.0 %v (63.8 %m).

Keywords: CCT, FPT, UCS, backfill, deep level gold mines, support

1 Introduction / Background

South African gold mines are considered to be generating a significant amount of waste; the most important of the waste are waste rocks and tailings (Amaratunga 1991, Aubertin et al 2002). This waste material is usually stored in surface facilities. By so doing, the waste material often leads to environmental problems such as acid mine drainage. Owing to that, one way of managing the mine waste is through cemented backfill, which is a mixture of tailings, water and cement or binding agents (Grice 1998, Benzaazoua et al 1999, 2002, 2004, Belem et al 2000, Aubertin et al 2002, Yilmaz et al 2009, Abdul–Hussain & Fall 2011, Tariq & Yanful 2014, Mashoene & Zvarivadza 2016). The primary role of paste backfill is it assists in ground control (Benzaazoua et al 1999, Belem et al 2002, De Souza et al 2003, Belem & Benzaazoua 2008, Belem et al 2005, Yilmaz et al 2014) by playing the role of secondary mine support. The secondary role of underground paste backfill is to reduce the environmental impacts of mining activities by reducing the number of tailings to be stored in tailings storage facilities (Grice and Street 1998, Aubertin et al 2002, Benzaazoua et al 2002, Yilmaz et al 2009, Abdul-Hussain & Fall 2011, Tariq & Yanful, 2014).

The test results of backfill material properties have been reported by many researchers, such as Aubertin et al (2002). Previous studies have shown that the variation of backfill material properties is quite large even with the same cement content. Furthermore, studies have indicated that the variation is due to several factors that influence backfill stability, such as the grading of aggregate, the mixing process, the method of fill placement, cement content and water contents, etc. Backfill material properties are essential to numerical studies of backfill stability because these parameters are used in numerical models for the prediction of backfill behaviour. Therefore, due to the high variability of properties from one type of backfill to another, testing is still required for any study, even though there are many test results on backfill material properties that have been published. Before the implementation of backfill in the mine, it is of paramount importance to understand the properties and performance of backfill material to be used in different conditions. The main objective of this paper is to present the mechanical characteristics of cemented FPT and FPT un-

* Corresponding Author: Fhatuwani Sengani, Email: fhatugeorge@gmail.com, Phone: +2772 4430 982

DOI: 10.15273/ijge.2018.03.026

cemented. The FPT un-cemented type of backfill is composed of a mixture of tailings, water and a binding agent.

2 Research Methodology

In order to achieve the objectives of the study, several research methods were implemented. These include; material property and bench top test (solids density, particle size distribution, slurry pH, temperature, conductivity, freely settled bed packing concentration, permeability, particle micrographs of the material, water quality within the backfill types, mineralogy of the material and boger slump), cement mortar tests (ISO bars) and unconfined compressive strength (UCS) tests.

2.1 Samples used for tests

The sizes and quantity of the material used for the tests are presented in the Table 1.

Table 1 Sample used for the study with their description

Sample type	Quantity
Full Plant Tailings (FPT)	1 x 200 litre drum
Cyclone Classified Tailings (CCT)	1 x 200 litre drum
Re-mined tailings	1 x 200 litre drum
Process water	1 x 200 litre drum
Conbex	1 x 200 litre drum
Cement (CEM I)	3 x 50 kg bags
Ground Granulated Blast-furnace Slag (GGBS)	5 x 25 kg bags
Pozzfill	5 x 25 litre drums
Conbex F	5 x 25 litre drums

2.2 Samples preparation

The supernatant water from each of the CCT and FPT slurries were decanted and stored as process water. The content of each drum was thoroughly mixed up on a plastic sheet to ensure that uniform samples are used. The tailings, binder and process water were mixed together to the consistency or density required for each of the mixtures for the CCT and FPT.

2.3 Binders used for the project

The following binders were supplied and used for the project:
(1) CEM I
(2) Conbex
(3) Conbex F
In addition to the binders supplied as listed above, the constituted binders were used:
(1) CEM II 70:30% CEM I: Pozzfill
(2) CEM III 50:50% CEM I: GGBS
(3) CEM V 50:30:20% CEM I: GGBS: Pozzfill

2.4 Binder addition

The mass of binder added to the tailings was calculated using the following formula (see equation 1):

$$\%\ \text{Binder} = \frac{\text{Mass of dry binder}}{\text{Mass of dry binder} + \text{Mass of dry tailings}} \qquad (1)$$

In order to perform variations on the water to binder ratio, binders of 6%, 8% and 10% were added to tailings and water separately.

3 Results of the Study

The results of the study include the following sections; solids density, particle size distribution, slurry pH, temperature, conductivity, freely settled bed packing concentration, permeability, particle micrographs of the material, water quality within the backfill types, mineralogy of the material and boger slump, cement mortar tests (ISO bars) and unconfined compressive strength (UCS) tests results.

3.1 Solids density, ρs

The solids density of the materials and binders were determined using a helium pycnometer, which determines the skeletal solids density of the particles. Table 2 presents the solids density results. Based on the results of the study it was found that the density the material was ranging was from a minimum of 2123 kg/m^3 to a maximum of 3091 kg/m^3.

Table 2 Solids Densities

Material	Solids density (kg/m^3)
Full Plant Tailings (FPT)	2646
Cyclone Classified Tailings (CCT)	2708
Conbex	2874
Cement (CEM I)	3091
Ground Granulated Blast-furnace Slag (GGBS)	2855
Pozzfill fly ash	2123
Conbex F	2461

3.2 Particle size distribution

The particle size distribution was determined by a combination of wet sieving (+25 µm fraction) and laser diffraction (-25 µm fraction). Figure 1 presents the particle size distribution for the FPT and CCT material. The data shows that both materials have similar top particle sizes of approximately 500 µm. The CCT has a d30 and d10 of 63.4 and 18.2 µm, respectively, compared to the FPT with a d30 and d10 of 13.1 and 3.1, respectively, which is significantly finer.

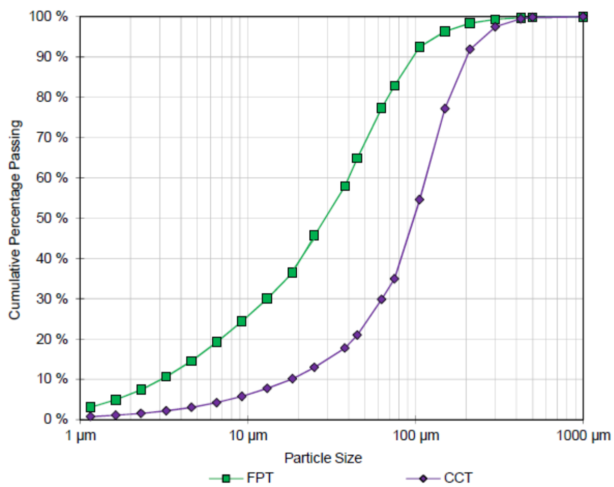


Figure 1 Particle size distribution

3.3 Slurry pH, temperature and conductivity

The pH, temperature and conductivity of the slurry are measured by using a handheld meter. The pH data for the CCT before and after binder addition was 7.0 and greater than 12.0, respectively, with the conductivity increasing from 2.1 to a magnitude greater than 4.0 ms/cm after the addition of the binder. The pH data for the FPT before and after binder addition was 7.6 and greater than 12.0, respectively, with the conductivity increasing from 1.9 to greater than 3.0 ms/cm after the addition of the binder.

3.4 Freely settled bed packing concentration, C_{bfree}

The freely settled bed packing concentration by volume is calculated from the volume of the freely settled bed formed by a known volume of solids. A slurry sample was allowed to settle for 24 hours in a measuring flask. The actual solids volume were determined from the dry mass of material and the solids density. The results were as follows:

(1) CCT 45.2 %v (69.1 %m)
(2) FPT 40.0 %v (63.8 %m)

3.5 Maximum settled bed packing concentration, C_{bmax}

The maximum bed packing concentration was determined from the volume of a compressed bed of solids formed by a known mass of solids. The bed was compressed by applying a hydraulic pressure of over 400 kPa across the settled bed with the water being allowed to drain through the solids bed. The actual volume of the solid sample was determined from the dry mass of the sample and the solids density. The maximum packing concentration was calculated from the volume of the compressed bed and the known volume of solids. No values could be recorded for the FPT tailings since the material was too fine. The maximum settled bed packing concentration for the CCT was 53.5 %v (75.7 %m).

3.6 Permeability

The permeability of the samples was determined using a falling head permeability rig as shown in Figure 2. The test involved the flow of water through a relatively short sample connected to a standpipe. The coefficient of permeability was determined by filling the standpipe with water and allowing it to flow through the soil sample while simultaneously measuring the head loss in the standpipe as well as the volume of water passing through the sample in a given time. After the falling head permeability test was completed the soil sample was dried to determine the void ratio and porosity.

The permeability for the FPT was measured for un-cemented material only, whereas the permeability for the CCT was measured for both un-cemented and a cemented mixture using 6% Conbex over a period of 13 days. Figure 2 shows the permeability measured over time for a cemented CCT sample with 6% Conbex. The data indicates that as the cement cures, the permeability decreases. The initial sharp decrease in the permeability occurs within the first 4 days of curing with very little change seen from 4 days to 13 days.

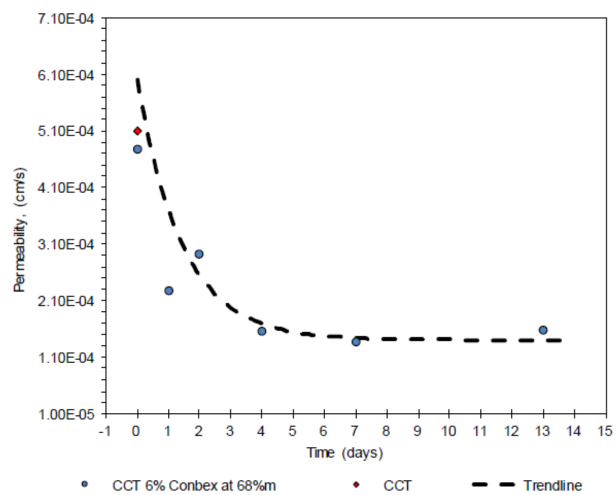


Figure 2 Permeability versus time for the cemented CCT

3.7 Water quality

The water results have shown that there were significant amounts of sulfate ions present in the process water. These sulfates were readily available for reactions with the binders and could form undesirable reaction compounds. Sodium and calcium ions were also available and to a lesser extent potassium and magnesium ions. These ions would also participate in the early hydration reactions, potentially accelerating setting compared to potable water.

3.8 Mineralogy

The CCT were composed mainly of quartz (crystalline silica) at 97% with some minor constituents such as pyrite at 1.6% and clay mineral components such as chlorite and mica. The FPT were composed mainly of quartz at 84% and mica (muscovite) at 12%, with various additional minor components. Quartz is an unreactive crystalline mineral that would not participate in any cementitious reactions. The mineralogy tests has shown that mica was the main component which was removed in the cyclone classification. Mica has a deleterious effect on concrete and backfill and reduces strengths; however due to the very fine aggregates in backfill the physical influence was decreased. As mica is an aluminosilicate mineral, it has the potential to form geopolymers if exposed to alkali activation and the right conditions.

3.9 Particle micrographs

Figure 3 shows the particle micrographs at low and high magnifications for the CCT and FPT respectively.

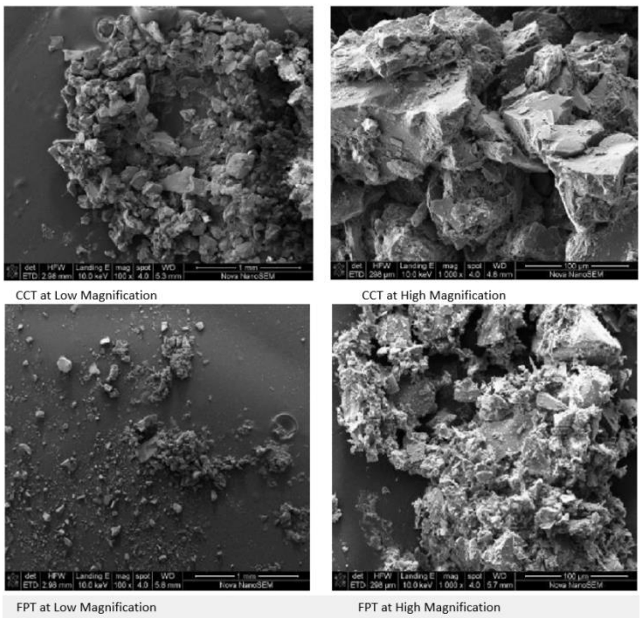


Figure 3 Particle micrographs of both CCT and FPT

3.10 Boger slump tests

The slump test measures the consistency or "stiffness" of the slurry and is a quality control measure for paste. The variation in slump as a function of solids concentration is a visual indication of the stiffness of the material. A standard 75 mm by 75 mm boger slump cylinder was used for all the tests. The slump is the distance between the top of the cylinder and the top of the slurry expressed as a percentage of the slump cylinder height. No slumps were measured for the CCT since the mixtures were too diluted. The boger slumps ranging from 51% to 60% were measured on the FPT for different binders.

3.11 Cement mortar tests

The cement mortar (ISO bar) tests confirms the strength of the cement after a fixed curing time. Samples were made up using 66.7 %m (3 parts) neutral silica sand and 22.2 %m (1 part) cement, mixed with 11.1 %m (½ part) water to obtain a water: binder ratio of 0.5. The cement mortar test data showed that the CEM V, Conbex and Conbex F do not meet the 28 days compression strength requirements (greater than 32.5).

3.12 CCT test results

Figure 4 to Figure 6 show the 7, 14 and 28 days test results for the CCT. The early strength gain (7 days) of the Conbex F was better when compared to the Conbex with the Conbex yielding significantly better in the 14 and 28 days results. The 28 days data showed that the CEM I and CEM III yield in a similar manner for the compressive strength data for the same water: binder ratios. These two binders were also the best performing compared to the other binders tested.

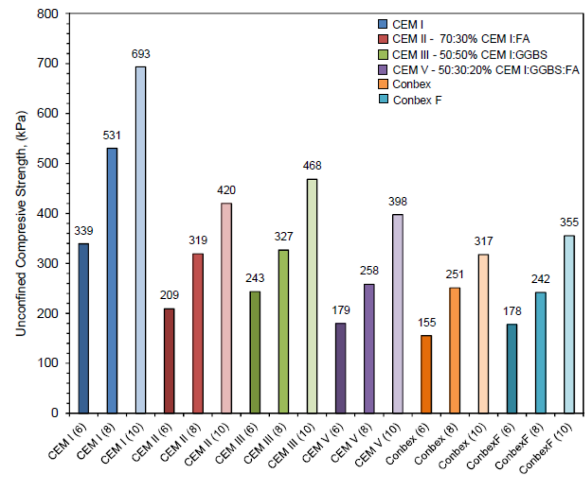


Figure 4 7 days strength results for CCT

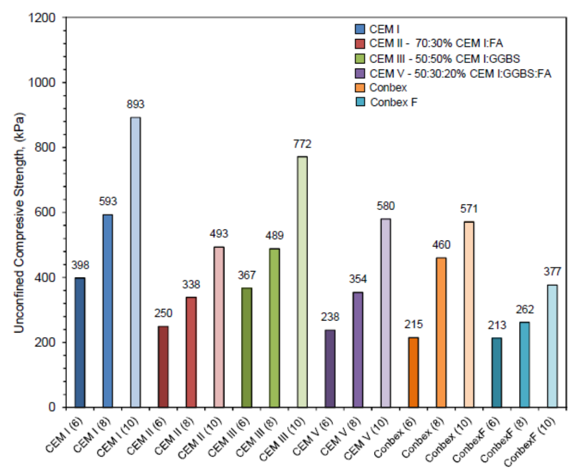


Figure 5 14 days strength results for CCT

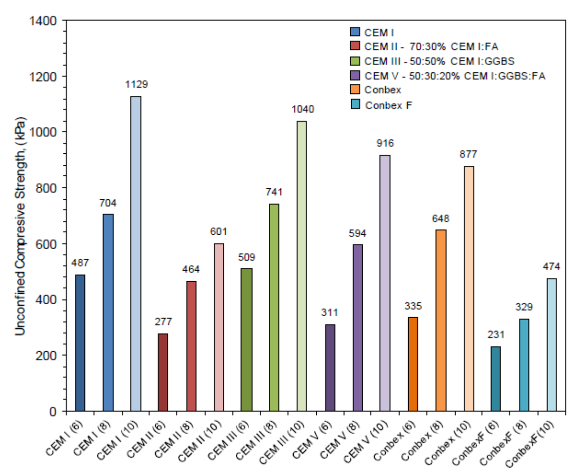


Figure 6 28 days strength results for CCT

3.13 FPT test results

Conbex F Results

In general, it was expected that, as the binder cures, the compressive strength increases over time. However, the results for Conbex F after 14 days showed a decrease in strength, which was uncommon. The Conbex F material was recast and observed similar results. Figure 7 and Figure 8 show the strength versus time graphs for the 1st and 2nd castings. The data for the 6% and 8% binder additions show similar trends with the 14 days strengths lower than the 7 days strengths. There was an increase in strength from 14 to 28 days with the 28 days strengths being comparable to the initial 7 days strengths. The data for the Conbex F with 10% binder showed a similar trend, but with the 28 days strength being stronger than the 7 and 14 days recorded strengths.

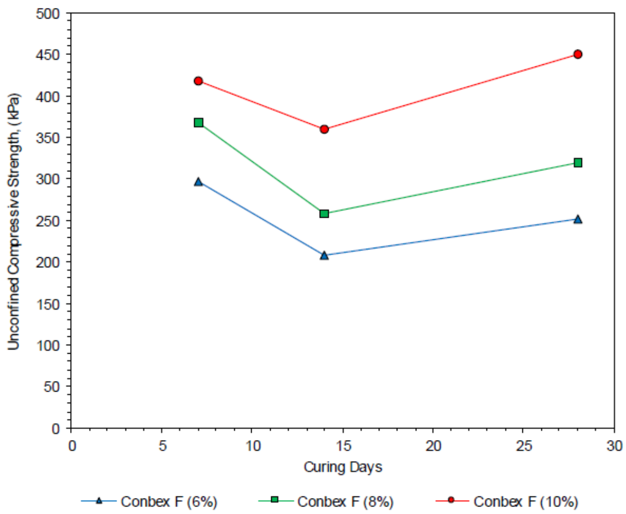


Figure 7 Conbex F – 1st Castings

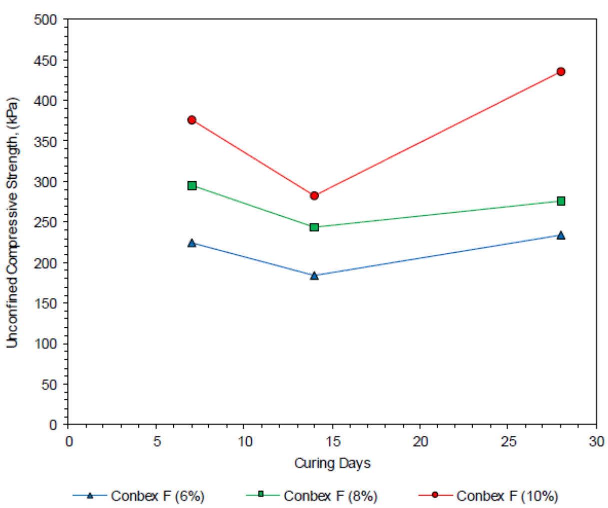


Figure 8 Conbex F – 2nd Castings

The reason for the loss in compressive strength was due to both calcium sulfate formation as well as delayed ettringite formation. The process water results show that a high sulfate concentration was present. The sulfates would react with calcium hydroxide to form calcium sulfate, which was an expensive product. These secondary reactions would induce micro-cracks in the matrix due to expansion, which would in turn lead to reduction in strength. In this case a supplementary cementitious material would be beneficial to prevent strength loss due to the sulfates present in the water. However, the calcium hydroxide addition for the Conbex F, which was added to accelerate the pozzolanic reactions of the fly ash, would have the opposite effect. The additional strength development observed after the 14 days results was due to the supplementary cementitious reactions that start to take precedence, as well as the depletion of the sulfates.

The effect could also be observed in the CCT mixes where the strength gain flattens out. However, the CCT had its own residual strength and could accommodate micro-cracking better as it was a coarser material. In addition, more of the sulfates could drain from the material as it had a higher permeability.

Figure 9 to Figure 11 present the 7, 14 and 28 days test results for the FPT. The behaviour of the Conbex F was similar to that observed with the CCT samples, with the Conbex F yielding better early strength results. The Conbex was outperforming the Conbex F after 14 and 28 days. The CEM I and CEM III binder again yields the best strength results after 28 days, with the CEM III being the best performing binder of all tested.

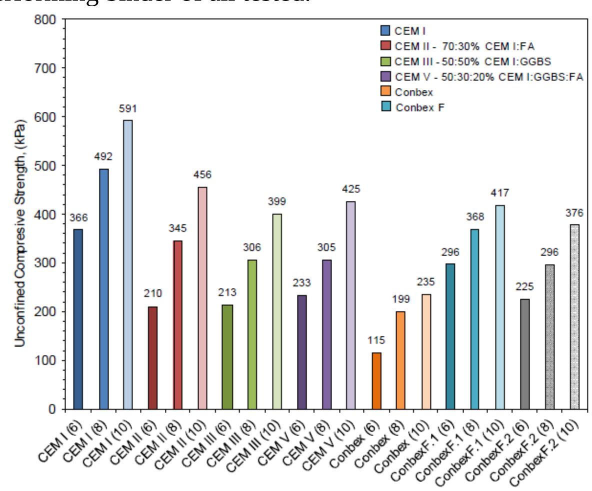


Figure 9 7 days strength results FPT

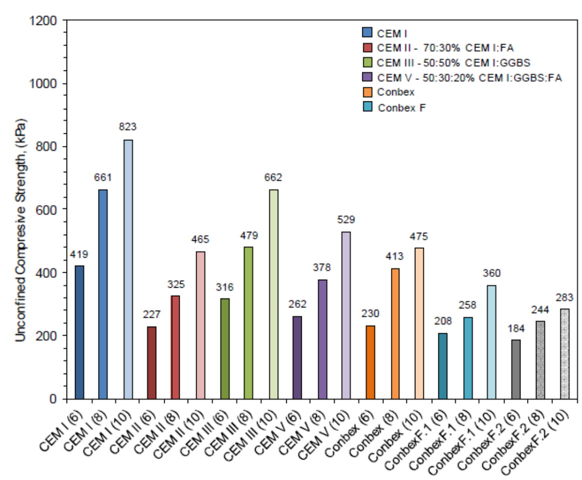


Figure 10 14 days strength results FPT

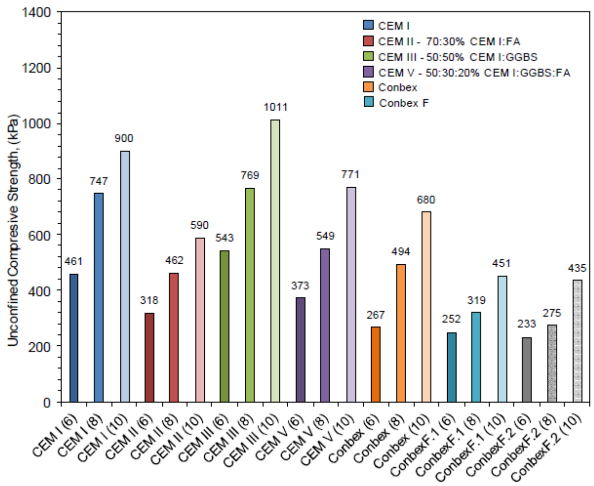


Figure 11 28 days strength results FPT

4 Conclusions

Based on the results of the study, the CCT and FPT had solids densities of 2708 and 2646 kg/m^3 respectively. Owing to that, the particle size distributions has shown that the CCT was significantly coarser with a d30 of 63.4 µm compared to a d30 of 13.1 µm for the FPT. Further results on pH data for the CCT before and after binder addition was 7.0 and greater than 12.0 respectively, with the conductivity increasing from 2.1 to greater than 4.0 ms/cm after the addition of the binder. The pH data for the FPT before and after binder addition was 7.6 and greater 12.0 respectively, with the conductivity increasing from 1.9 to a magnitude greater than 3.0 ms/cm after the addition of the binder. The long term permeability test results for the cemented CCT showed a decrease in permeability of 67 % within the first 4 days due to the cement hydration where after it stabilises.

Water process results has indicated that sulfate ions were present in the process water which may have led to deleterious secondary reactions for certain binders. The cement mortar test data showed that the CEM V, Conbex and Conbex F do not meet the 28 days compression strength requirements (greater than 32.5). The 28 days CCT strength results with CEM I and CEM III were the best performing binders and yielded similar compressive strength results at the same water: binder ratio. The 28 days FPT strength results with CEM I and CEM III yielded the best strength results, with the CEM III being slightly better. The Conbex F yielded better early (7 days) strengths when compared to the Conbex. However, due to deleterious reactions caused by the sulfates, the Conbex F experienced limited strength gain after 7 days. The effect was less pronounced in the CCT mixes as it was composed of coarser material.

References

Abdul-Hussain, N. and M. Fall, 2011. Unsaturated hydraulic properties of cemented tailings backfill that contains sodium silicate. Engineering Geology, **123**(**4**): 288 - 301.

Amaratunga, L.M., 1991. Experimental evaluation of a novel concept of utilization and disposal of fine mill tailings as aggregates by agglomeration. Minerals Engineering, **4**(**s 7**-**11**): 1081 - 1090.

Aubertin, M., B. Bussière and L. Bernier, 2002. Environnement et gestion des rejets miniers: manual sur cédérom, Presses International Polytechnique.

Belem, T., M. Fall, M. Aubertin and L. Li, 2005. Développement d'une méthode intégrée d'analyse de stabilité des chantiers miniers remblayés. Preliminary Report, IRSST project, pp**28**.

Belem, T. and M. Benzaazoua, 2008. Design and application of underground mine paste backfill technology, Geotechnical & Geological Engineering, **26**(**2**): 175.

Belem, T., M. Benzaazoua, B. Bussière and A.M. Dagenais, 2002. Effects of settlement and drainage on strength development within mine paste backfill. Proceedings of Tailings and Mine Waste, **2**: 139 - 148.

Benzaazoua, M., T. Belem and B. Bussière, 2002. Chemical factors that influence the performance of mine sulphidic paste backfill. Cement and Concrete Research, **32**(**7**): 1133 - 1144.

Benzaazoua, M., M. Fall and T. Belem, 2004. A contribution to understanding the hardening process of cemented paste fill. Minerals Engineering, **17**(**2**): 141 - 152.

Benzaazoua, M., J. Ouellet, S. Servant, P. Newman and R. Verburg, 1999. Cementitious backfill with high sulfur content physical, chemical, and mineralogical characterization. Cement & Concrete Research, **29**(**5**): 719 - 725.

De Souza, E., J.F. Archibald and A.P.E. Dirige, 2003. Economics and perspectives of underground backfill practices in Canadian mining. Proceedings of the 105th Annual General Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum, Canadian Institute of Mining, Metallurgy and Petroleum, Westmount, 15p.

Grice, T., 1998, Underground mining with backfill. Proceedings of 2nd Annual Summit—Mine Tailings Disposal Systems, Australasian Institute of Mining and Metallurgy, Brisbane, pp24 - 25.

Mashoene, K. and T. Zvarivadza, 2016. Backfill composition effects on backfill optimisation in massive mining. 50th US Rock Mechanics/Geomechanics Symposium. 26 - 29 June, Houston, United States of America. pp1 - 8.

Tariq, A. and E. K. Yanful, 2014. A review of binders used in cemented paste tailings for underground and surface disposal practices. Journal of Environmental Management, **45**(**4**): 138 - 149.

Yilmaz, E., T. Belem and M. Benzaazoua, 2014. Effects of curing and stress conditions on hydromechanical, geotechnical and geochemical properties of cemented paste backfill. Engineering Geology, **168**(**2**): 23 - 37.

Yilmaz, E., M. Benzaazoua, T. Belem and B. Bussière, 2009. Effect of curing under pressure on compressive strength development of cemented paste backfill. Minerals Engineering, **22**(**9**-**10**): 772 - 785.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 169-173
Available at http://ojs.library.dal.ca/ijge

Members Development

Changing the Culture and Attitude: Supporting Women Studying Mining Engineering

Andrea Brickey[1*], Kelli McCormick[1], Paula Jensen[2], Michael West[3]
[1] Department of Mining Engineering and Management, South Dakota School of Mines and Technology, Rapid City, SD, USA
[2] Department of Industrial Engineering, South Dakota School of Mines and Technology, Rapid City, SD, USA
[3] Department of Materials and Metallurgical Engineering, South Dakota School of Mines and Technology, Rapid City, SD, USA

Abstract: Attracting and retaining women studying STEM fields can be difficult, but even more so in very male-dominated industries such as mechanical engineering, metallurgical engineering, and mining engineering. South Dakota School of Mines and Technology is an engineering and science research university located in the state of South Dakota, United States of America. Researchers at the university have developed a program, funded by a NSF S-STEM grant, which provides financial support, mentoring, and programmatic activities to approximately 30 female students. In this paper, we will discuss curriculum changes, e.g., classroom environment, project-based learning, made by the program's mining engineering faculty. We will also present lessons learned and ideas for future curriculum modifications.

Keywords: mining engineering, curriculum, undergraduate education, culture and attitude

1 Introduction

In 2015, the Department of Mining Engineering and Management (MEM) at the South Dakota School of Mines and Technology (SD Mines) was invited to participate in a National Science Foundation S-STEM grant, called Culture and Attitude (C&A), with the purpose of recruiting and retaining women studying various engineering disciplines with low female enrollment. The goal of the program is to retain and support academically talented women, with financial need, seeking degrees in five STEM fields; civil, industrial, mechanical, metallurgical, and mining engineering. The program has been active at SD Mines since 2010, and originally focused on three disciplines, industrial, mechanical and metallurgical engineering. Mining and civil engineering were added to the program in 2015 and this paper is intended to review the ideas implemented and curriculum changes made in the mining department as part of this program and to discuss some of rewards and challenges.

According to the 2015-2016 report, *Engineering by the Numbers* (Yoder 2012), there were 308 mining engineering bachelor's degrees awarded in the United States that academic year, the lowest number of the reported disciplines. Of the 308 mining engineering graduates, only 14.3% (44) were women.

As of April 2018, the MEM department at SD Mines has 83 undergraduate students. Of those students, 12 are female or 14.5%. This sample size makes it extremely difficult to provide accurate measurements of the S-STEM program's effectiveness, but the authors believe that over the life of the C&A program, the long-term impacts will become more evident and quantifiable. This paper will discuss the Culture and Attitude program, curriculum changes being made in the MEM department, and other efforts being made to increase matriculation of women studying mining engineering at SD Mines.

2 Culture and Attitude Program

The primary goal of the Culture & Attitude program is to increase the number of women graduating with engineering degrees. The C&A program aims to achieve that goal by providing financial support, mentoring, and technical and professional development activities for the scholars. Students have access to a faculty member for one-on-one mentoring in addition to monthly group activities. These activities provide an opportunity for networking and social interactions. Monthly activities include 3-D printing, industry tours, and professional development topics, among others.

All C&A students are required to meet with a mentor once a semester, but mentoring is available on a more frequent basis if desired by the student. Many of the scholars are also active in the Women in Science and Engineering (WiSE) program, which provides numerous outreach and social activities for students.

* Corresponding Author: Andrea Brickey, Email: andrea.brickey@sdsmt.edu, phone: +01 605 394 1275

DOI: 10.15273/ijge.2018.03.027

In addition to faculty and staff support, industry has shown substantial support for the program. For example, in 2017, students went on an overnight trip to dine with senior management of a large surface coal mine and tour the mine and maintenance operations (Figure 1). These activities serve to provide student exposure to industry and to illustrate the importance of engineering and the rewarding nature of problem solving.

Figure 1 Photo of students, including many Culture and Attitude scholars at a large surface coal mine in Gillette, Wyoming, USA. (Photo by Paula Jensen)

In determining how to effectively change the culture at SD Mines to appreciate different thinking styles, an analysis was conducted to better understand the typology of engineering students (Karlin & Kellogg 2009). The results of this analysis showed that women, on average, have different thinking styles when compared to their male counterparts. This analysis used the Herrmann Brain Dominance Inventory (HDBI) which classifies thinking styles into four categories; analytical, practical, relational, and experimental. The typical engineering curriculum caters to the analytical thinking style, which fits most students graduating with STEM degrees. While female students tend to fall more broadly into the four quadrants prior to graduation, those falling outside of the analytical quadrant are less likely to graduate with a STEM degree. A primary focus of the C&A program (Kellar et al 2015) is to create classroom environments and curriculum modifications that expand beyond the analytical thinking style, which is in line with expected industry needs as described in The Engineer of 2020 (Clough 2004).

Another standard that has been of significant benefit when building curriculums and planning class activities are the twelve best practice factors identified by Burke & Mattis (2007). These factors enable faculty to provide support to women and minorities in STEM. Of the twelve factors Burke identified, the C&A program focuses on six of these (bold below).

(1) Create a classroom environment that makes it easy to ask questions;

(2) Use group projects that foster cooperative learning;

(3) Show how STEM knowledge is used in industry;

(4) Communicate the use of STEM to broader life and social issues;

(5) Choose projects that make applications clear and that build on the student's previous experiences;

(6) Use various teaching methods to appeal to different learning styles;

(7) Offer remedial classes;

(8) Use inclusive language and examples;

(9) Address teachers' sexist beliefs and stereotypes;

(10) Grade assignments blind to the identity of students.

(11) Use information such as web documents to encourage students to take STEM courses;

(12) Offer summer school courses to help talented pre-college students to overcome deficiencies in their backgrounds and build confidence in their skills in STEM.

3 Curriculum Modifications

Faculty in the MEM department began by evaluating the classroom environment and course curriculum to identify several focus areas based on the Burke factors. With a focus on improving discussion and developing more free-form dialogue, the faculty asked students, when posed a question, to consult another student before responding to the question. This gave the students an opportunity to think about the question, to build their confidence, and to encourage more participation. As the students practiced this during the first few classes, faculty emphasis on this process was less necessary as the students began to feel more comfortable and dialogue became more natural. In another class, the faculty established quizzes that allowed for group discussion to solve the problem.

Many of the upper level courses already included project-based learning, so the faculty focused on moving the projects from a strictly analytical approach to incorporating more creative problem solving. An example of this was implemented in the explosives engineering course, where students were given a general set of parameters and then asked to make reasonable assumptions in the context of a 'story'. Then the assumptions were explained as the solution was presented. For example, the student might assume that his or her blast design problem was at a mine located in a rain forest or a desert and must compete the project using appropriate parameters. As another example, the faculty encouraged students to create a story line behind the data and analysis reported in memos for the class.

To show how STEM knowledge is used in industry, the mining faculty invited several guest speakers to the campus, but also provided many real-world examples during the instructional period. It was beneficial in this case to have several faculty with in-depth mining industry experience.

The faculty made a special effort to show how STEM knowledge and problem-solving abilities are used to benefit society. This was accomplished by bringing in current issues and topical focus items for discussion. It was especially important to help the students see beyond the obvious to the greater positive impact mining has on a local, national and global scale.

As the students increase in knowledge and ability, the projects assigned to them become more complex and require a greater ability to synthesize knowledge across disciplines. An example of this is in the Senior Capstone course where students were assigned a real-world project with actual data from an operating mine. They were asked to bring in their knowledge from their course work, such as ventilation, mine design, reclamation and rock mechanics to develop a solution that will be presented to faculty and industry representatives.

The faculty also expanded upon traditional teaching methods and implemented new technologies and approaches with excellent success. One example is 'video Friday' in explosives engineering, where short videos of various blasting techniques would be shown and then the class would provide analysis.

4 Evaluation

A survey was recently conducted to evaluate the MEM undergraduate students' preferences and perception of learning. The survey was administered in March of 2018 and was sent to the undergraduate students in the MEM department. Of the 83 students, 41 responded to the survey and of those 10 identified as female. The data is presented as a total of all students and again with only the female students. The questions were phrased to gain some insight into the students' learning style preference, along with the effectiveness of those learning styles. The survey asked the students to rate the statement from 1 to 5, representing the following responses; strongly disagree (1), disagree (2), neutral (3), agree (4), strongly agree (5). The survey consisted of the following statements;

(a) I prefer classroom discussions, group quizzes and group responses to questions versus individual quizzes and individual responses to directed questions.

(b) I learn more from classroom discussions, group quizzes and group responses to questions versus individual quizzes and individual responses to directed questions.

(c) I prefer group work versus individual projects.

(d) I learn more with group work versus individual projects.

(e) I prefer to develop my own approach to a project versus having a list of directions.

(f) I learn more when I am allowed to approach a project in my own way versus having a list of directions.

Two final questions were asked with the options of *yes*, *no*, and *most of the time, but still needs improvement*. The final questions are as follows:

(a) Do you feel that the MEM department is welcoming to your gender?

(b) Do you feel that MEM classes (classroom environment) are welcoming to your gender?

The results of the first six questions for all respondents are shown in Figures 2, 3, and 4. The results from only female respondents are shown in Figures 5, 6, and 7. When asked if they prefer classroom discussions, group quizzes and group responses, many of the respondents indicated neutral to positive agreement as shown in Figure 2. The female respondents also indicated mostly neutral to positive agreement with the statement.

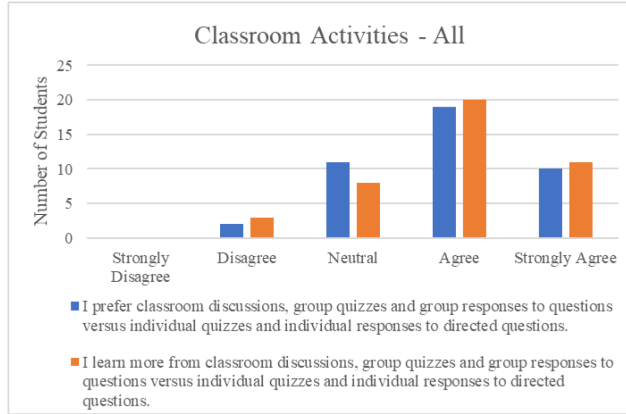


Figure 2 Survey results from all respondents to classroom activities

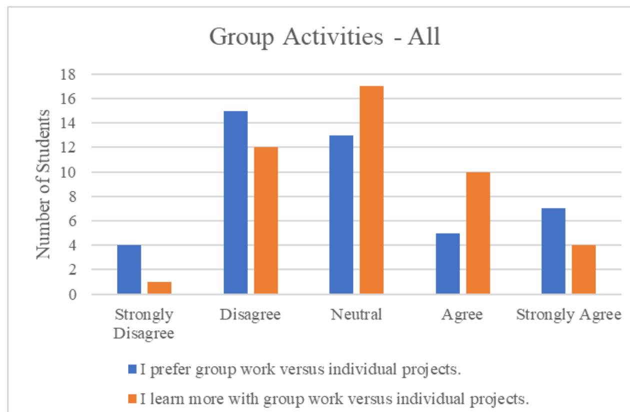


Figure 3 Survey results from all respondents to group activities

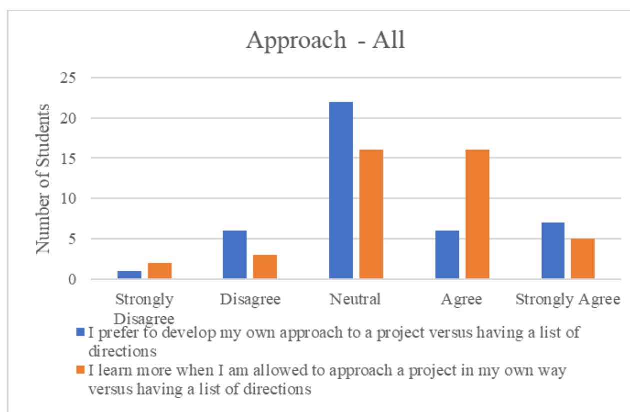


Figure 4 Survey results from all respondents to approach

Given the increasing importance of understanding social context and ability to work in teams as outlined in the Engineer of 2020, the survey results regarding whether students prefer and learn from group work versus individual work provide some interesting results. Students indicated neutral to negative when asked if they prefer group work, while they provide a neutral to positive response when asked if they learn more from group work. Although these are preliminary results, it will be interesting to assess the change in student attitudes and perceptions towards group and team assignments in the future.

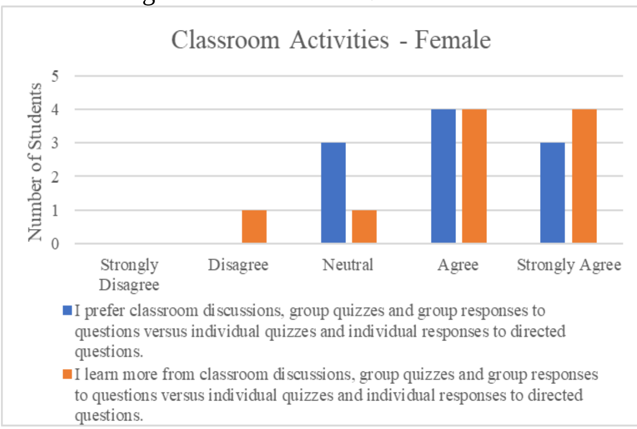


Figure 5 Survey results from female respondents to classroom activities

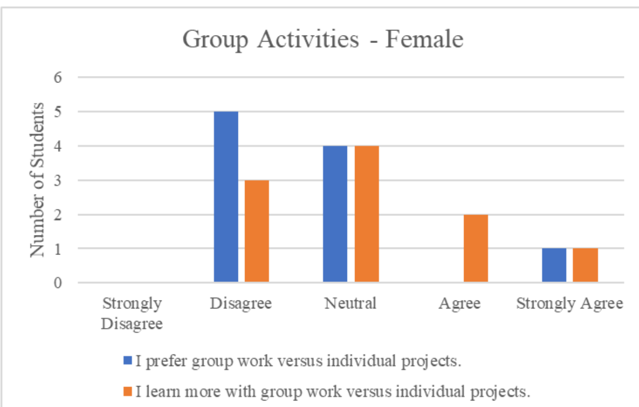


Figure 6 Survey results from female respondents to group activities

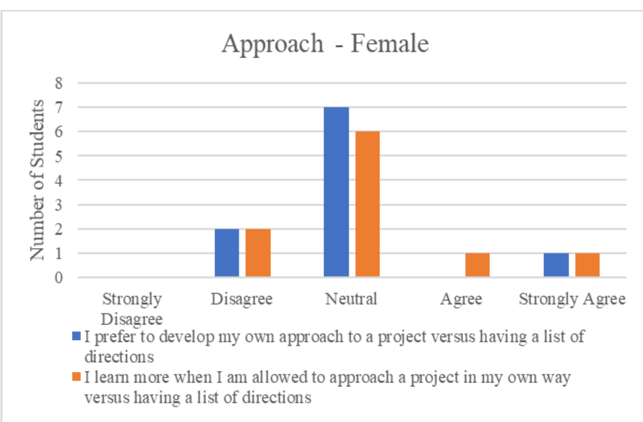


Figure 7 Survey results from female respondents to approach

With respect to projects, most students indicated that they prefer and learn more when allowed to develop their own approach to a project versus a list of directions. When isolating the female responses, the majority were neutral.

The final two questions ask the student if the MEM department was welcoming and if the classroom environment for MEM courses were welcoming to their gender. All 41 respondents answered 'yes' to the question of the MEM department being welcoming to their gender. One student, a female, did respond that the classroom environment was welcoming 'most of the time, but could use improvement' while all others responded 'yes'.

Considering the small sample size, it is difficult to make conclusive remarks on the results; however, the data gathered will be used to provide a baseline for future comparisons.

5 Conclusions

Some broad conclusions that we can draw from this survey are:

(1) most of the MEM women students are neutral or even dislike classroom or group discussions and work, but feel they learn more through this process (Figures 5 and 6). No significant difference between the MEM students, as a whole, (Figures 2 and 3) and women students only is apparent in these categories, though this may be a function of the low sample size;

(2) most of the MEM women students are neutral or somewhat dislike developing their own approach to a project or problem (Figure 7) and are neutral in feeling that they learn more through this process. Response to this question from all MEM students (Figure 4) suggests that more male MEM students feel they learn more by developing their own approach to a project than female students.

The Mining Engineering and Management Department at South Dakota School of Mines and Technology is dedicated to increasing the number of women pursuing a degree in mining engineering. The faculty are actively working to incorporate novel pedagogical methods to help retain and graduate a diverse group of mining engineers.

The survey information collected will serve as a baseline for future evaluation of the curriculum changes within the MEM department. Future work will involve developing a survey to give to students at the beginning of a course and at the end of the course to determine the impacts of the curriculum changes. The focus of future curriculum changes includes incorporating online, interactive quiz platforms, i.e., Kahoot, and soliciting industry professionals to mentor students as part of the senior capstone course.

Acknowledgement

This research project is supported by the National Science Foundation Division of Undergraduate Education S-STEM Award 1564837. The authors also extend appreciation to the South Dakota School of Mines and Technology and the Department of Mining Engineering and Management.

References

Burke, R.J. and M.C. Mattis, 2007. Women and minorities in science, technology, engineering, and matematics: Upping the numbers. Edward Elgar Publishing.

Clough, G.W., 2004. The engineer of 2020: Visions of engineering in the new century. National Academy of Engineering, Washington, DC.

Karlin, J. and S. Kellogg, 2009. Metrics and the holistic learner. Proceedings of the Research in Engineering Education Symposium, Palm Cove, QLD, pp 1-9.

Kellar, J., J. Karlin, D. Medlin and S. Kellogg, 2015. S-STEM: Culture and Attitude -- Innovative Partnerships for Success. NSF Grant Applicaiton.

Yoder, B.L., 2012. Engineering by the Numbers. American Society of Engineering Education.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 4(3): 174-179
Available at http://ojs.library.dal.ca/ijge

Capacity Building

Cooperative Program for Resources Engineering Between Kyushu University and Hokkaido University

Takashi Sasaoka[1*], Hideki Shimada[1], Koichiro Watanabe[1], Takeshi Tsuji[1], Ryo Imai[1], Hajime Miki[1], Yasuhiro Fujimitsu[1], Yuichi Sugai[1], Kotaro Yonezu[1], Naoki Hiroyoshi[2]
[1] Department of Earth Resources Engineering, Kyushu University, Fukuoka, Japan
[2] Division of Sustainable Resources Engineering, Hokkaido University, Japan

Abstract: Joint Program for Sustainable Resources Engineering was adopted as a Special Expenditure Project by the Ministry of Education, Culture, Sports, Science and Technology in Japan. In this project, in order to cultivate human resources who can contribute to Japan's resource strategies, Education and Research Departments of Resources Engineering at Kyushu University and Hokkaido University aim to jointly establish a new collaborative education program in 2017. This is the first of its kind in the resources engineering area among universities in Japan. One of the pillar of this program is "International Field Practice". For working actively and globally in the field of sustainable resources engineering, one need to (1) acquire internationally accepted knowledge and techniques in the fields, (2) be capable of utilizing the knowledge and techniques practically, and (3) understand cultures in foreign countries as well as global trends in the field. In this exercise, students work on an internship or conduct a field research in a foreign country in the field of sustainable resources engineering. Through this exercise, students learn how to develop their leadership and adaptability in the world, and to communicate scientifically and technically in English presentation, discussion, and writing. This paper describes the overview of this program and the International Filed Exercise 2017 conducted in Czech Republic.

Keywords: joint degree program, resource engineering, global leader, international field exercise

1 Introduction

The global situation surrounding mineral resources has been drastically changing since the beginning of the 21st century. As a result, resource nationalism, in which some governments use mineral resources in their own countries as trump cards of political and economic issues, has been gaining power. In order to secure stable resources, it is necessary for Japan to develop individuals with advanced expertise and international mindedness who will play a key role in resource strategies for the future.

For this reason, universities and graduate schools involved in fostering specialists need to comply with such social demands. There are, however, only a few universities and graduate schools providing comprehensive education programs for resources engineering throughout the country. In the current situation, therefore, it is difficult to fulfill such demands. Specifically, there are three problems: (1) Due to the shortage of faculty members engaged in training students in resources engineering, there are some academic fields that cannot be covered by a single university. (2) Compared to engineering education, management education is insufficient. In addition, if we see the overall picture of research and education in resources engineering in Japan, (3) the way each university uses its research and education resources (education programs and facilities) is inefficient.

As one of the methods to solve these issues, it is considered that several universities involved in education of resources engineering should work together to develop human resources. Education and research departments in resources engineering at Kyushu University and Hokkaido University (the Kyushu University Faculty of Engineering Department of Earth Resources Engineering and Hokkaido University Faculty of Engineering Division of Sustainable Resources Engineering) have been cooperating and collaborating concerning specific projects and events. In order to make their collaboration organic and full-fledged, this project establishes a collaborative graduate school education program (master's course).

This paper describes the overview of this program and the International Filed Exercise 2017 conducted in Czech Republic.

2 The Joint Program for Sustainable Resources Engineering

The collaborative graduate school education program is not only simply a combination of two existing curriculums in both universities, but also a new education program, which appropriates for fostering students in resources engineering for the 21st century as shown in Figure 1. Specifically, compared to human resources developed by each university,

* Corresponding Author: Takashi Sasaoka, Email: sasaoka@mine.kyushu-u.ac.jp, phone: +81 92 802 3333

DOI: 10.15273/ijge.2018.03.028

the project aims to develop more excellent human resources in terms of four following points: (1) to be internationally minded, (2) to be able to get an overview of the resource flow, and (3) to be capable of designing and managing. Moreover, in collaboration with the "KIZUNA (Bond) Program" promoted by JICA (4), it is also important to strengthen the bond between Japanese students in resources engineering and foreign exchange students from resource-rich countries. In accordance with these four items, we are planning to implement a collaborative education program based on the following four viewpoints: "international field surveys" to be more internationally minded, "graduate school exchange seminars" to be able to see things from broad perspectives, "resources management special seminars" to be more capable of designing and managing, and "international human resources exchange debates" to strengthen the ties between Japan and resource-rich countries.

Figure 1 Scheme of joint program for sustainable resources engineering

3 Significance and Effects

3.1 Social significance

A big feature of this project is that foreign exchange students strategically invited from resource-rich countries and Japanese students are able to study together. In this sense, this education program will reinforce human networks between Japan and those countries and also contribute to securing resources for the future of Japan. On the other hand, in this project, foreign exchange students from those countries will study the methods of resource development using environmental preservation and recovery techniques that Japan has cultivated over many years; therefore, it is expected that this project will also contribute to the prevention of environmental destruction in those countries. It is, therefore, considered that this program has great social significance for both Japan and resource-rich countries.

3.2 Effects of educational improvement

Since Kyushu University and Hokkaido University have education programs with different features, through collaborating and sharing their education resources, it will be possible to develop a high level of human resources, which neither of them would be able to realize on their own. Moreover, regarding the development of resources management education, which is essential for Japan's resources education in the future, they will be able to realize top-notch education, although it is difficult for them to do alone, by sharing the connections with business people and overseas teaching staff that they have respectively.

4 Curriculum

4.1 Human resource developed in the program

Education policies of this program are as follows:

(1) Learning the wide-ranging knowledge of resource engineering;

(2) Abilities to design and manage resources development in consideration of international politics and economics;

(3) High international perspectives;

(4) Intercultural understanding.

4.2 Curriculum for global leaders in resources fields

This Curriculum aims to develop excellent human resources in terms of the three following points:

(1) To be internationally minded;

(2) To be able to get an overview of the resource flow;

(3) To be capable of designing and managing.

The following 4 unique seminars/practices are ready for this curse.

4.2.1 Exchange seminar

In order to acquire wide-ranging knowledge of resources engineering, exchange seminar is conducted. In this system, students belong to Kyushu University will stay Hokkaido University for one quarter to take classes held in Hokkaido University and vice versa. 8 subjects on upstream sectors of resources development are provided in Kyushu University. As the same, 8 subjects on downstream sectors of resources development are provided in Hokkaido University. Then, students should take more than 10 credits of specialized "Subjects A" provided in Hokkaido University during 1 quarter as shown in Figure 2.

4.2.2 International field exercise

In order to acquire an international perspective, field exercises will be held in a foreign country for 1 to 2 weeks. The training locations will be arranged by professors in Kyushu University and Hokkaido University. The field exercise in 2017 had been held in Czech Republic and

Poland in the last year (Figure 3). The detail will be described later.

(a) Upstream sector (Mainly in KU)

(b) Downstream sector (Mainly in HU)

Figure 2 Subjects of exchange seminar

Figure 3 International field exercises

4.2.3 Resources management I/II

The education on resources management has not been sufficient in department of earth resources engineering. So, professors with broad experiences and various practical experiences will provide lectures to students in this program in order to acquire the abilities of design and management for resources development (Figure 4).

Figure 4 Class of resources management

4.2.4 Human resources exchange seminar

Human resources exchange seminar will be held in order to develop the ability of international negotiation and the international sensitivities.

4.3 Lectures provided in this Curriculum

In this Curriculum, students take the credits of Kyushu University and Hokkaido University. In Hokkaido University, 8 subjects on down stream sectors (Smelting, Recycling, Environment, and Remediation) of resources development are provided. In Kyushu University, 8 subjects on upstream sectors (Geology, Geophysics, Mining, and Processing) of recourses development are provided.

The lectures provided in this program and the schedules are shown in Figures 5 and 6, respectively.

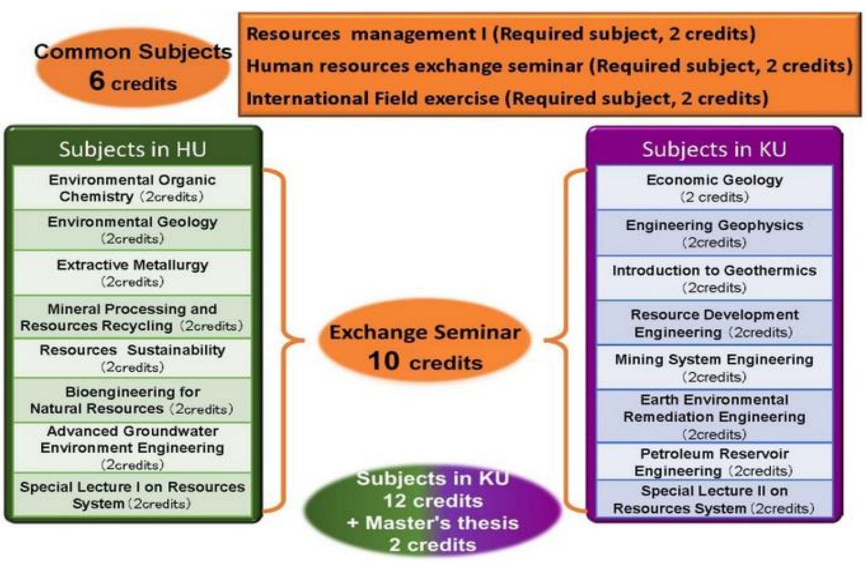


Figure 5 Lectures provided in this program

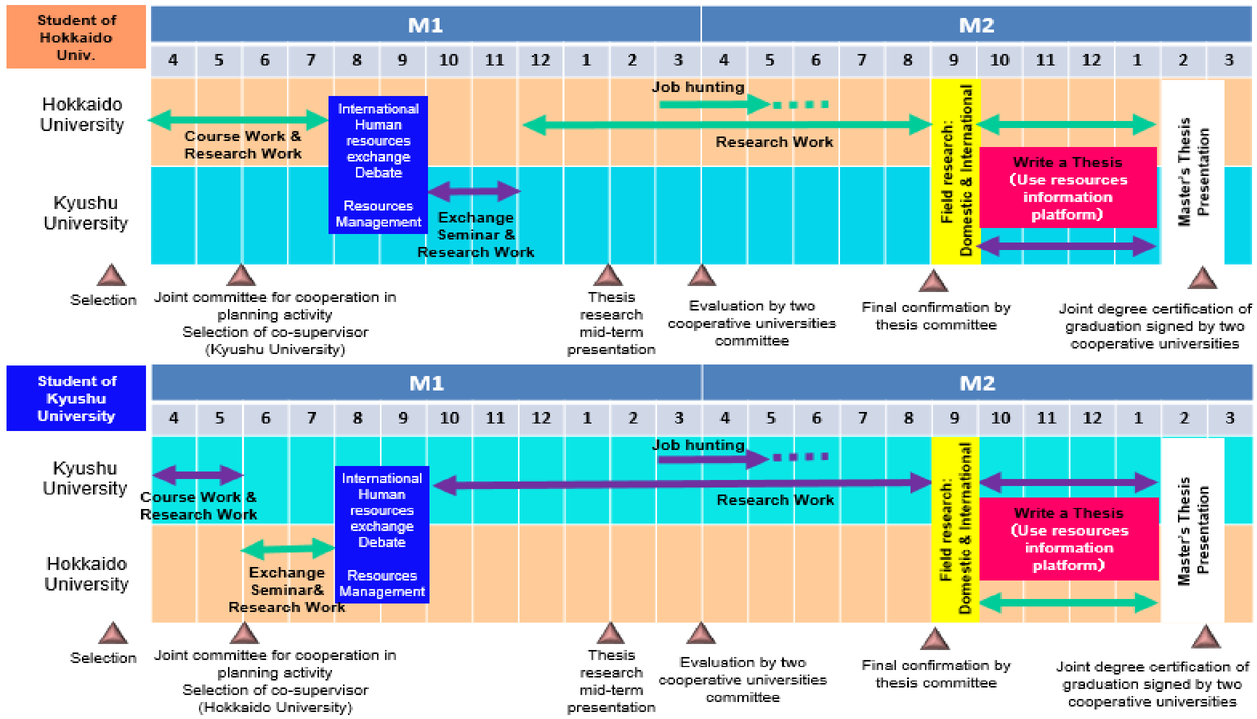


Figure 6 Joint degree's acquisition process

5 International Field Exercise in 2017

Kyushu University hold the International Field Exercise 2017 in Czech Republic supported by Technical University of Ostrava. We visited Open Pit Quarry, Underground Coal Mine, Slate Mine. Not only these places, we also visited the World Heritage like Wieliczka Salt Mine Museum.

Relationship between our department and the Faculty of Mining and Geology at Technical University of Ostrava has a long history with more than 30 years and we have signed an inter-university exchange agreement. Our colleges fully supported our International Field Exercise 2017. The reasons for the site selection are as follows:

(1) Relationship with counterpart;

(2) Long mining history (from development to closure) and ensure the mine sites to be visited;

(3) Cross-cultural understanding (difference between Europe and Asia, not only the way of thinking/concept but also geographic condition);

(4) Safety.

The number of participants is 16 including students and staffs. The schedule of International Field Exercise 2017 is listed in Table 1. The overviews of each visiting site are described as follows.

5.1 Open-pit quarry-Bohučovice

The quarry produces aggregate for concrete, contents for asphalt and coat mixes, railway beddings, rocks for dam constructions, etc. The annual production in this mine is about 3 million tons. Students learned about the whole open pit mining operation, such as the mine planning and pit design, blasting operation, transportation, crushing, and environmental issues control. Moreover, they also had an opportunity to ride on a heavy equipment (Figure 7).

Table 1 Schedule of International Field Exercise 2017

Date	Schedule
September 13th (Wed)	Fukuoka->Prague
September 14th (Thu)	Prague->Olomouc
September 15th (Fri)	**Open-pit quarry -Bohučovice**
September 16th (Sat)	Olomouc->Krakow Auschwitz Birkenau German Nazi Concentration and Extermination Camp Museum
September 17th (Sun)	**Wieliczka Salt Mine Museum (World Heritage)** Krakow -> Otrava
September 18th (Mon)	VSB-TU Ostrava (Staff meeting and lab tours) **Industrial museum- Dolní Vítkovice**
September 19th (Tue)	**OKD underground coal mine**
September 20th (Wed)	**Slate mine-Radim**
September 21st (Thu)	Ostrava -> Prague
September 22nd (Fri)	**Hieronymus mine**
September 23rd (Sat)	Depart from Prague
September 24th (Sun)	Arrive at Fukuoka

Figure 7 Open-pit slope in Bohučovice

5.2 Wieliczka salt mine museum

The Wieliczka salt mine located in the southern part of Poland close to Krakow city. This mine was commenced in 1044 to produce mainly a table salt. After almost 1,000 years' mining operation, the commercial production stopped in 1996 due to a high mining cost and severe mine water issues. The total amount of salt production is about 7.5 million tons. The total length of roadway is more than 300km and the mining depth reached 327m from the surface. During commercial operation, miners make the statues of mythology and goodness using salt rock and construct cathedrals in mined out area. This mine had been registered as UNESCO World Heritage Site in 1978. Through the visit of this mine museum, students could learn the history of underground mining systems, including mining methods, support systems, transportation systems, drainage systems, etc. Moreover, it was one of the examples to utilize a mined out area as a commercial space (Figure 8).

Figure 8 A cathedral constructed in mined out area

5.3 Discussion of student exchange and laboratory tour in Technical University of Ostrava

The Technical University of Ostrava was established in 1879. Now, there are 7 faculties and 11,000 students in total. They have many projects with EU countries. The faculties' meeting was held with our staffs, and the vice-dean and head of international affairs of Faculty of Mining and Geology, in order to discuss future collaboration, including student exchange and research. Students visited laboratories of Faculty of Mining and Geology in order to know the research topics and technologies to be developed. We also visited the University Geological Museum as shown in Figure 9.

Figure 9 Geological museum in Technical University of Ostrava

5.4 Industrial museum- Dolní Vítkovice

The Dolni Vitkovice area became in 2002 a national cultural sight. Industrial compound with high furnaces had been used for 170 years to produce iron. We could learn about the production, function of individual construction to make crude iron from iron ore and coal (Figure 10).

Figure 10 Blast furnace- Dolní Vítkovice

5.5 OKD underground coal mine

OKD is the only producer of hard coal (bituminous coal) in the Czech Republic. Its coal is mined in the southern part of the Upper-Silesian Coal Basin – in the Ostrava-Karviná coal district. OKD has three mines and the total annual coal production is about 9 million tons. All of them are deep mines (more than 1,000m underground) and coal is mined using shafts and adit systems - nowadays exclusively by means of mechanized processes. The mining method is longwall advancing with controlled caving. The coal mining is carried out by means of shearers and plows. For supporting the roof in the faces individual self-advancing hydraulic shields are used. We learned about underground coal mining system, including development of headings, longwall face, transportation, ventilation, safety measures, etc. Advanced technologies introduced in this mine for safety and management were also learned (Figure 11).

Figure 11 Main office of OKD Coal Mine

5.6 Slate mine-Radim

Originally, an extraction in the cadastral area of Svatoňovice started in 1930s. Now, a company Důl Radim a.s. prepares a new opening of the mine deposit in this territory by restoring the main crosscut. After the extraction is started, the raw material is used for the production of building stones, garden stones and crushed and milled slate products. In this mine, we could learn a compact underground mining system, small scale and sustainable operation. Moreover, it was a good opportunity to understand fundamental underground systems such as, extraction, support, transportation, ventilation, etc (Figure 12).

Figure 12 Portal of Slate mine-Radim

5.7 Hieronymus mine

The Hieronymus Mine, a cultural monument, is a unique witness of the mining culture and skills of our ancestors. The Hieronymus tin mine southwest of the former town of Čistá was registered by the mining authority in 1548. During the course of its history, the Hieronymus Mine produced approximately 500–700 tons of tin. Although mine was never as rich and renowned as other workings in the area, it has survived in its original form. With numerous interruptions and varying yields, the mine operated until the end of World War I. Currently, the mine is undergoing an extensive and costly reconstruction as a museum for understand the history of mining technology (Figure 13).

Figure 13 Hieronymus Mine

5.8 Summary

The International Field Exercises 2017 was a great opportunity to understand the mining systems in surface and underground mines. Moreover, the strategy of mine development and environmental protection, and the material flow in Europe could be learned.

6 Development in the Future

In Japan, there are only a few universities offering resources education. Among them Kyushu University and Hokkaido University have education programs with different features. They, however, have common performance of satisfactory international education and roles in “JICA KIZUNA Program” (mainly education for faculties in resource-rich countries). Therefore, there are few obstacles in collaboration between them, which enables them to promptly achieve the high-level resource education required from the society. In the future, they will experiment with the planned education program and verify its effects in order to launch a collaborative education program. Furthermore, this project aims to construct “a KIZUNA that will never be cut” with other resource-rich countries in the world by making the most of the connections formed while Japanese students and foreign exchange students from those countries study together.

Acknowledgements

The authors give grateful thanks to Dr. Pavel Stasa, Assistant Professor, Dr. Jiri Svub, Project Researcher, Technical University of Ostrava for their grate assistance and arrangement of International Field Exercises 2017 held in Czech Republic.

International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2018 **4**(**3**): 180-186
Available at http://ojs.library.dal.ca/ijge

Capacity Building

Capacity Building Initiatives in Mineral Education in Southern Africa: Opportunities for Collaboration

Godfrey Dzinomwa[1*], Harmony K. Musiyarira[1], Kawunga Nyirenda[2], Raymond Suglo[3]
[1] Department of Mining and Process Engineering, Namibia University of Science and Technology, Windhoek, Namibia
[2] Copperbelt University, Zambia
[3] Botswana International University of Science and Technology, Botswana

Abstract: Many countries in Southern Africa are generally endowed with a wealth of minerals. For example, South Africa and Zimbabwe are host to approximately 80% of the world's Platinum Group Minerals (PGMs) and chromite resources. Vast deposits of coal, both thermal and metallurgical, occur and are mined in significant quantities in Botswana, Malawi, Mozambique, South Africa, Zimbabwe and Zambia. However, the region has over the years experienced a shortfall in skilled personnel as well as well-resourced training institutions to convert the comparative advantage arising from the rich mineral endowment to a competitive advantage through efficient extraction, beneficiation and value addition. In recent years, Governments in the sub-region have responded to this unfavorable situation by opening a number of universities and other tertiary institutions focussing on educating and training a new generation of mineral professionals. This study reviewed the recent developments in the region and assessed the extent to which capacity shortfalls are being addressed in the minerals sector. The methodology included questionnaires and interviews, and the analysis was mainly qualitative. The main findings of the study were that although several mineral education institutions were being opened in the region, there is an inadequate number of professionals in the mining and minerals field in the region for teaching and research, and there are few well-equipped modern facilities for teaching and research such as laboratories and lecture rooms. This situation presents an opportunity for collaborative initiatives, not only within the region but internationally, aimed at addressing these shortfalls and ensuring that appropriate skills are developed for the mining industry and also for the academic institutions.

Keywords: capacity building, challenges, collaboration, sustainability, research

1 Introduction

Many countries in Southern Africa are generally endowed with a wealth of mineral resources. For example, South Africa and Zimbabwe are host to approximately 80% of the world's Platinum Group Minerals (PGMs) and chromite resources. Vast deposits of coal, both thermal and metallurgical, occur and are mined in significant quantities in Botswana, Malawi, Mozambique, South Africa, Zimbabwe and Zambia. Over the years, Angola, Botswana, the Democratic Republic of Congo, Lesotho, Namibia, South Africa and Zimbabwe have provided a significant share of the world's rough diamonds, and according to the Kimberly Process Certification Scheme (KPCS), these countries produced a combined 48.8% of the world's rough diamonds by volume, contributing 55.6% of the value in 2016. Base metals, especially nickel and copper, are extracted profitably in Botswana, the Democratic Republic of Congo, South Africa, Zambia and Zimbabwe. Other mineral resources which occur in large proportions in Southern African countries include aluminium, uranium, gold, iron ore, lithium, tantalite, tin, manganese, limestone and zinc.

In recent years, the region has emphasized the need for beneficiation and value addition of its minerals. However, the region has over the years experienced a shortfall in skilled personnel as well as well-resourced training institutions to convert the comparative advantage arising from the rich mineral endowment to a competitive advantage through efficient extraction, beneficiation and value addition. In the last decade, Governments in the sub-region have responded to this unfavourable situation by opening a number of universities and other tertiary institutions focusing on educating and training a new generation of mineral professionals. This study reviewed the recent developments in the region and assessed the extent to which capacity shortfalls are being addressed in the minerals sector.

Industrial growth and competitiveness hinges on technological advancement and skills development is the panacea to the lack of technological advancement of any nation or region. Training and skills development is the cornerstone of the mining industry’s ‘efficiency, effectiveness, development, growth and sustenance’ (Musiyarira et al 2013).

* Corresponding Author: Godfrey Dzinomwa, Email: gdzinomwa@nust.na, phone: +26461 207 2076

DOI: 10.15273/ijge.2018.03.029

Depressed mineral commodity prices have a significant impact on the minerals industry, particularly from a sustainability perspective (Tesh et al 2015). In this regard, tertiary institutions offering mineral education across the world face enormous sustainability challenges (Phillips 1999, Galvin et al 2001). This is a global problem that is not limited to the developing world. Most of the mineral rich countries within Southern Africa have also made it a condition that they should be in the lead in the training and skills development of their nationals as shown in Figure 1.

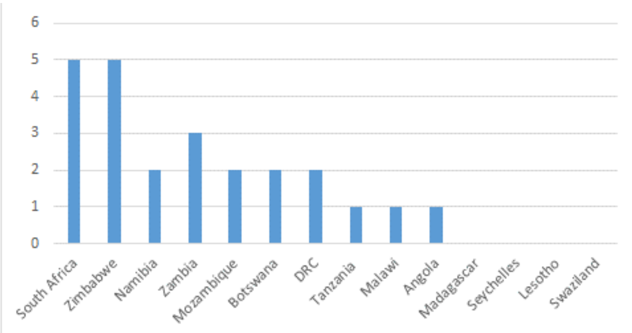


Figure 1 The Number of Mining Schools in Southern Africa (Salvador 2015)

Mining education programmes globally have traditionally seen recruitment and survival at risk during industry down cycles. For example, at the turn of 2000 many North American as well as Australian mineral education programmes were close to extinction (Scoble 2003). It is unrealistic to believe that the mineral education sector can be relevant and sustainable whilst remaining quarantined from these dramatic developments. In order to ensure a smooth supply of skills to the industry, it is necessary that collaboration be promoted between universities in different countries, the industry and governments.

2 Overview of Mineral Education in Southern Africa

Many African states have established universities and schools of mines for training in geology, mining engineering and extractive metallurgy. However, there are inadequate numbers of academics with postgraduate qualifications to teach at these new universities and to carry out research (Gudyanga 2015). This paper takes a closer look at the various training institutions in the region and the challenges being experienced, and suggests solutions, focusing on the need for greater relevance to the regional mining industry. Sections 2.1 to 2.7 present an overview of the mineral education in the region.

2.1 Namibia

In response to the mining boom, the University of Namibia (UNAM) and Namibia University of Science and Technology (NUST), formerly known as the Polytechnic of Namibia (PON), introduced Minerals Engineering degree programmes in 2008/2009 and they are in the process of developing professional and further education programmes in order to meet future mining industry skills needs and building a workforce that incorporates sustainable development into operations. The Namibia University of Science and Technology offers Bachelor of Engineering in Mining and Bachelor of Engineering in Metallurgy degrees, while the University of Namibia offers degree programmes in Geology, Mining Engineering and Metallurgical Engineering. The two mining departments were established in 2009 and their graduates have since successfully entered the professional market. The Department of Mining and Process Engineering at the Namibia University of Science and Technology has pursued an aggressive expansion programme by establishing links with various expert teaching and research professionals from renowned institutions around the world. These linkages have fostered meaningful collaboration between the University and its partners in the form of staff and student exchanges, as well as research.

2.2 Zimbabwe

Zimbabwe, in particular, has faced serious skills flight as a result of the economic slowdown spanning for almost two decades, with most of the personnel going to South Africa, New Zealand, Australia, the United Kingdom and other countries. The skills flight has been so serious that the number of graduates produced from the Zimbabwean institutions was not adequate to fill in the void that has been left. The institutions offering training and the various disciplines that are being offered by the training institutions to the Zimbabwean minerals industry are as follows:

(1) Zimbabwe School of Mines (Geology, Mining and Metallurgy up to Higher Diploma level);

(2) University of Zimbabwe (Geology, Mining and Metallurgy);

(3) Manicaland University of Applied Sciences (Mining and Metallurgy);

(4) Midlands State University (Mining and Metallurgy);

(5) Gwanda State University (Mining and Metallurgy).

As the case in the rest of the region, the institutions suffer from inadequate staff, infrastructure and other resources. The new Government has been calling on private businesses to establish various joint ventures aimed at providing infrastructure in universities. The University of Zimbabwe set up a Confucius Institute aimed at teaching the Chinese language as a means to strengthening collaboration in education, trade and other areas with China.

2.3 South Africa

The start of higher education in South Africa took place in Kimberly in 1896 with the establishment of a vocationally based School of Mines in Kimberly. This was effectively a Polytechnic whose purpose was to provide high level manpower to the developing diamond mining industry in Kimberly (Musingwini 2015). Today, more training institutions have evolved and this has led to the formation of the University of Witwatersrand, University of Pretoria, University of Venda and the University of Johannesburg. Later, the distance Education University of Southern Africa

(UNISA) was established in Pretoria. All these institutions have passionately maintained their mining related courses. A number of Technikons and colleges are being upgraded to universities of technology. While this may generally prove to be a good development, in some instances, however, it creates a gap in practical skills as the number of technicians produced has dwindled. Currently there are five universities offering minerals related programmes namely:

(1) University of Witwatersrand;
(2) University of Johannesburg;
(3) University of Pretoria;
(4) University of Venda;
(5) University of South Africa.

2.4 Mozambique

The Mozambican Minerals industry has been growing fast in recent years. The coal industry in the Tete province has experienced some rapid growth, reaching record production of 18 million tonnes in 2017 and there is a critical need for skills development to cater for the sector. At University level the province has the Polytechnic Institute of Tete while at college level there is one School - the "Instituto Médio de Geologia e Minas/ Technical College. The "Instituto Industrial e Comercial de Pemba", the "Centro de Formação Profissional INEFP de Pemba" and the "Escola Técnica Profissional de Macomia" are developing curricula for the oil and gas sector at college level. The main Universities such as Eduardo Mondlane University teach mainly (geology, exploration geology, and applied geology) while the Wunitiva University delivers a Geology and Mining Engineering degree, and they are both in Maputo. Recently the University of Lurio (UNILurio), in the North of Mozambique, and the Pedagogic University (Beira and Nampula) are offering classical geology programs. The Eduardo Mondlane University has started Master and PhD programs in Mineral Resources Management, Master in Petroleum Engineering and has established a regional (Southern and Eastern Africa) Centre of Excellency in Oil and Gas which is funded by the World Bank. The Instituto Médio de Geologia e Minas, developed curricula for the mining, geology, mineral processing, and topography at college level.

2.5 Zambia

Zambia has three mining schools namely Copperbelt University, University of Zambia and Copperstone University. The Copperbelt University has three minerals related programmes namely, Mining Engineering, Metallurgy, Geology and Survey. The Mining Department offers a number of programmes which include Diploma in Mining Engineering, Diploma in Mine Ventilation, Small Scale Mining, and a Bachelor of Engineering in Mining Engineering. The Department, through the School of Graduate Studies, also offers postgraduate programmes both by taught courses and research work (CBU 2018a). The Metallurgy Department offers the Bachelor of Engineering in Metallurgical Engineering and the Mineral Engineering, These programmes were introduced in 2001 and 2014 respectively to run concurrently with three year diploma metallurgy programmes (CBU 2018b). The Geology and Survey Department has been offering only one diploma programme in Surveying and it introduced two degree programmes in 2016. The programmes include a degree in Mining and Exploration Geology and a degree in Geomatics Engineering. The diploma programme in surveying continues to be offered by the department and there are plans to revise and rename it a Diploma in Geomatics (CBU 2018c).

The University of Zambia is the biggest state university in Zambia. The mining industry still remains the mainstay of Zambia's economy and will continue to play an important role in the development of the country (UNZA 2018). It is in the context of an acute shortage of graduate manpower for this vital industry that the School of Mines was established in 1973 as one of the Schools of the University of Zambia. The three departments of the School, namely, Geology, Mining Engineering, and Metallurgy and Mineral Processing reflect the most important disciplines involved in the search for ores, their recovery from the ground and the extraction of metals from these ores. The School of Mines offers postgraduate programmes leading to the degree of Master of Mineral Sciences. The School also offers Doctor of Philosophy (PhD) degrees in all the three mining disciplines (Besa 2015). The overall objective of the training programmes is to produce graduates with competencies in the science and technology of processing minerals and metals, process design of chemical and metallurgical operations, management of production systems, economic evaluation of engineering processes, and environmental and energy management.

2.6 Botswana

The Botswana International University of Science and Technology (BIUST) was established in the mid-2000s and offers 5 year training programmes and the graduates hold Bachelor of degrees in Mining Engineering, Geological Engineering, as well as Materials and Metallurgy Engineering. The University had its first graduates in these two programmes in February 2018. It also has postgraduate programmes in both Mining Engineering and Geological Engineering, which are 2-year MEng programmes and 3-year PhD programmes. The vision of the Department is to produce world-class professionals in the fields of mining and geological engineering.

The University of Botswana (UB) does not offer Metallurgy but offers Mineral Engineering (formerly called Mineral Processing). The University of Botswana has been offering Mining Engineering until 2017 under a 3+2 arrangement with Missouri University of Science and Technology (MUST) in the USA, where students covered the first 3 years at UB and the last 2 years at MUST. The first group of mining Engineering students to do the entire programme (5 years) at UB are expected to complete it in 2019. UB has been offering Diplomas in Mining Engineering and Mineral Engineering since 2000. However, these programmes were suspended in 2015 and Geology is being offered by the Geology department in the Faculty of Science.

3 Challenges

The survey conducted in this study established some of the challenges being experienced by most of the universities as follows:

(1) Lack of infrastructural facilities such as lecture rooms, and laboratories as well as student accommodation and transport;

(2) Difficulties in recruiting sufficient academic staff due to a wide gap between conditions of service in industry and in the universities;

(3) Lack of funding for professorial chairs to spearhead research and innovation.

In a study of the sustainability of mineral education in Namibia, (Musiyarira et al 2013) identified seven interactive factors that could affect the sustainability of mineral education. These were: (1) the funding covering the essential needs of the institutions, (2) the number of graduates matching the needs of the mining and related industries, (3) the quality and quantity of students enrolling for the programmes, (4) alliances and partnerships of the educational institutions, (5) the quality and quantity of academic staff, (6) sound infrastructures, and (7) a well-developed and dynamic curriculum. It is important to note that these factors were not only unique to the Southern African mineral education system but they were worldwide trends as noted by other researchers (Wagner 1999, Galvin et al 2001, Moudgil 2006, Cawood 2011). The only difference was that all institutions were affected differently and within their context of development.

Over the past two decades, there has been a rapid growth in the number of students in tertiary institutions in Africa. This has posed a challenge to the sustainable financing of higher education since the growth in numbers was not matched by funding levels. On an average, Africa has allocated about 0.78% of its GDP and around 20% of its current public expenditure on education over the last 15 years (World Bank Report 2010, Devarajana et al 2011). Decline in public expenditure per student is having an adverse impact on the quality of education programmes.

4 Way Forward

The main findings of the study were that although several mineral education institutions were being opened in the region, there is an inadequate number of professionals in the mining and minerals field for teaching and research, and there are few well-equipped modern facilities for teaching and research such as laboratories and lecture rooms. In some cases, student accommodation and transport is also inadequate. This is caused mainly by dwindling Government financial support, a trend which has also been observed in other universities within Africa and the western world and it has become a big constraint in attaining sustainability of education in general. The dwindling state funding has the biggest impact on new departments of universities which are trying to make their first steps to build sustainable academic programmes regarding both teaching and research.

Figure 2 and Sections 4.1 to 4.7 highlight the strategy that needs to be carried out in order to ensure the sustainability of the mineral engineering programmes in the region.

4.1 Smart partnerships

Literature studies reveal that engineers and scientists that are required to lead the minerals industry into a competitive position will emerge from innovative educational environments and from institutions that are forming smart partnerships and that understand the need to collaborate and share resources. The current fragile state of tertiary

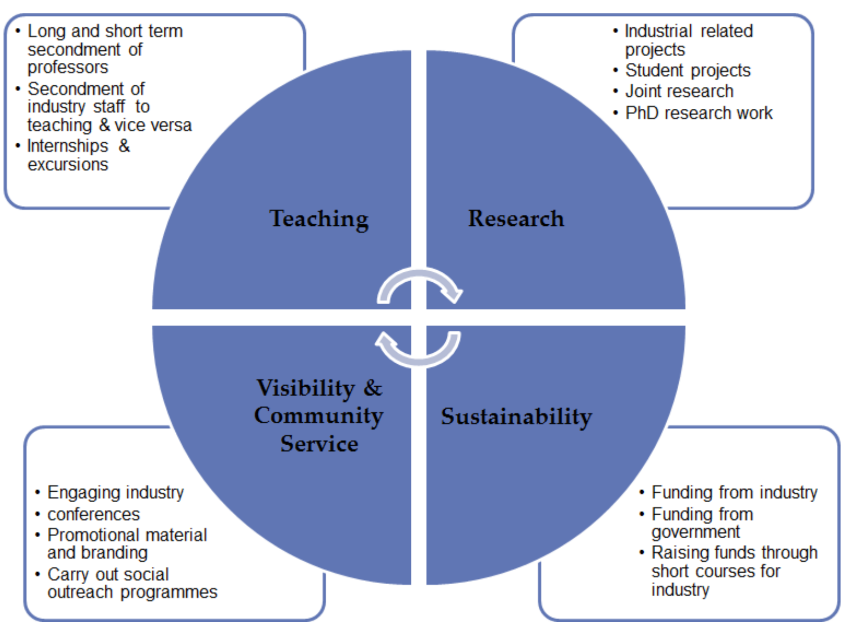


Figure 2. A collaborative strategy to ensure the sustainability of mineral education

education in the region must provide incentives for networking and collaboration rather than competition since the institutions are offering similar programmes. This situation presents an opportunity for collaborative initiatives, not only within the region but internationally, aimed at addressing the shortfalls and ensuring that appropriate skills are developed for the mining industry and also for the academic institutions. There are opportunities for joint supervision of postgraduate students. This has the added benefit where the more established universities in Zambia and South Africa can have their senior academics collaborating with the upcoming academics in other universities in postgraduate supervision and research.

4.2 Harmonisation of curricula

Universities in the region should find a common ground in the harmonisation and mutual recognition of their curricula but still maintaining a distinctive flavour or context of their environment. This harmonisation of curricula poses a strategy which will enhance the sharing of human resources either physically or through e-learning platforms that will address the staff shortages within other universities. In this regard, the universities should be encouraged to develop curricula that is relevant not only for the national industry, but also for the region to give graduates a wider range of opportunities. This will promote national and regional mobility of students and staff as well. The curricula offered should be more inclusive rather than highly specialized and restrictive ones, and it should have room for promoting entrepreneurship skills among graduates to enable them to create employment and not necessarily to look for jobs. For effective harmonization of curricula to occur, it is important that efforts be made to reduce language barriers through staff and student exchanges and the adoption of common languages across borders. The Society of Mining Professors (SOMP) provides a good platform for standard and high quality exchange of staff.

4.3 Regional forum for academics

In light of the pressing challenges facing the mineral education programmes, it will be beneficial to set up a platform for the heads of mining and related disciplines to meet and set up a vehicle for collaboration. This forum can be facilitated through the Southern African Institute of Mining and Metallurgy (SAIMM) in collaboration with the Society of Mining Professors (SOMP). This should enable the forum to have a database of teaching and research areas of the university staff and this will provide an opportunity and a platform for sharing of key human resources in terms of teaching and research. SAIMM and SOMP could play a leading role to facilitate the formation of Heads of Mining and Metallurgy Schools forum.

4.4 Retention strategies

Staff turnover is high in most of the training institutions and lessons should be learnt from the Zambian universities with regards to staff retention. Strategies for staff retention may include providing staff incentives which are competitive internationally which include:

(1) Sourcing of research grants;

(2) Improving remuneration packages so that the gap between industry and academic institutions is reduced;

(3) Defined succession and development plan for the millennials.

4.5 Elimination of duplication of programmes

The training in the region needs to be coordinated so that there is minimal duplication amongst institutions where adequate capacity does exist and each institution should have an area of excellence. This would allow staff and students along the lines of China's Double first class initiative which emphasizes the creation of world class universities and disciplines. Without adequate and continuous surveys to establish industry requirements, there is a danger of the Mining and Metallurgical Engineering programmes being oversubscribed in the industry and flooding the market. One of the challenges of the training institutions is to correctly focus on the number of graduates in order to strike a balance between the number of graduates produced and the market demand. Currently there is an imbalance in some countries between the graduates produced and the regional Minerals Industry's capacity to absorb them.

4.6 Industry and government engagement

In order to remain relevant to the development needs of their nations and to the international community in general, universities should always remain in close contact with their Industries and Governments. Networking and establishing industrial and business partners, both nationally and internationally should be encouraged by:

(1) Sourcing funding of (a) professorial chairs to spearhead applied research and innovation aimed at promoting development, and (b) scholarships for talented students who will contribute to industrial development;

(2) Involvement of industry partners in the determination of curricula of programmes so that contemporary areas of focus are addressed. This could be achieved through the appointment of industry partners to Departmental or Faculty advisory boards;

(3) Negotiating with government authorities to give investment partners tax reliefs, lower import duties and tariffs for mining and processing equipment;

(4) Providing opportunities for students to secure vacation and other industrial attachments so that they gain experience.

4.7 Exploring the One Belt One Road (OBOR) Initiative

The One Belt and One Road (OBOR) initiative was proposed by China to promote the connectivity of Asian, European and African continents and their adjacent seas to establish and strengthen partnerships among the countries along the Belt and Road, set up all-dimensional, multi-tiered and composite connectivity networks, and realize diversified, independent, balanced and sustainable development in these countries (NDRC 2015). Although Southern Africa lies outside the OBOR route, it is important that existing platforms such as the Forum on China-Africa Cooperation (FOCAC) be utilized to facilitate the inclusion of the region in the initiative. The One Belt One Road (OBOR) initiative and the Double First Class initiative present a unique opportunity for collaboration between mineral education universities in Southern Africa and mineral education universities and industries along the economic route. The goal of building world class universities and disciplines is a shared outcome for both regions, and will be realized through the promotion of extensive cultural and academic exchanges, and cooperation. According to NDRC (2015), China provides 10,000 government scholarships to the countries along the Belt and Road every year and it aims to increase cooperation in science and technology, establish joint labs (or research centers), international technology transfer centers and maritime cooperation centers, promote sci-tech personnel exchanges, cooperate in tackling key sci-tech problems, and work together to improve sci-tech innovation capability.

5 Conclusions

Most of the countries in Southern Africa are generally endowed with a wealth of minerals. These include platinum group minerals, diamonds, gold, lithium, iron ore, uranium and base metals especially copper, nickel and cobalt bearing minerals. However, the region has over the years experienced a shortfall in skilled personnel as well as well-resourced training institutions to convert the comparative advantage arising from the rich mineral endowment to a competitive advantage through efficient extraction, beneficiation and value addition. In recent years, Governments in the sub-region have responded to this unfavorable situation by opening a number of universities and other tertiary institutions focussing on educating and training a new generation of mineral professionals. This study reviewed the recent developments in the region and assessed the extent to which capacity shortfalls were being addressed in the minerals sector. The main findings of the study are that although several mineral education institutions are being opened in the region, there are inadequate numbers of professionals in the mining and minerals field in the region for teaching and research, and there are few well-equipped modern facilities for teaching and research such as laboratories and lecture rooms. This situation presents an opportunity for collaborative initiatives, not only within the region but also internationally, aimed at addressing the identified shortfalls and ensuring that appropriate skills are developed for the mining industry and for the academic institutions that develop the skills.

Acknowledgement

We would like to thank the heads of mining schools in Southern Africa for readily availing information for this study.

References

Besa, B., 2015. Strategies for addressing challenges of Mining Schools: A case study of University of Zambia, School of Mines. 3rd regional conference, Society of Mining Professors, Windhoek, Namibia, 28 September to 2 October.

Cawood, F.T., 2011. Threats to the South African minerals sector–an independent view on the investment environment for mining. Journal of the Southern African Institute of Mining and Metallurgy, **111(7):** 469 - 474.

Copperbelt University (CBU), 2018a. https://www.cbu.ac.zm/smms/. Accessed 28 March 2018.

Copperbelt University (CBU), 2018b. https://www.cbu.ac.zm/smms/mining-engineering-department/. Accessed 28 March 2018.

Copperbelt University (CBU), 2018c. https://www.cbu.ac.zm/smms/geology-survey-department/. Accessed 28 March 2018.

Devarajana, S., C. Mongab, and T. Zongoc, 2011. Making higher education finance work for Africa. Journal of African Economies, **20 (AERC Supplement 3)**: 133-154.

Galvin, J.M. and P.J. McCarthy, 2001. Mining education: driven by global impacts. Proceedings Explo 2001. Hunter Valley, NSW, pp9 -14.

Gudyanga, F., 2015. Pan-African Minerals University of Science and Technology (PAMUST). 3rd Regional Conference, Society of Mining Professors, Windhoek, Namibia, 28 September to 2 October.

Moudgil, B., 2006. Communication with SME team. Mining Engineering, pp. 1 - 5.

Musingwini, C., 2015. An overview of the Wits School of Mining Engineering, 3rd Regional Conference, Society of Mining Professors, Windhoek, Namibia, 28 September to 2 October.

Musiyarira, H., D. Tesh, and G. Dzinomwa, 2013. Challenges of promoting sustainability in the Namibian minerals education. Proceedings of the 6th International Conference on Sustainable Development in the Minerals Industry, Milos Island, Greece, 30 June - 3 July, pp. 25 -30.

National Development and Reform Commission of China (NDRC), 2015. Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road.

Phillips, H.R., 1999. Mining education in South Africa - past, present and future. CIM Bulletin, **92(1033**): 101 - 106.

Salvador, M, 2015. Strategies for addressing challenges facing mining schools, Eduardo Mondlane University of Mozambique, 3rd regional conference, Society of Mining Professors, Windhoek, , Namibia, 28 September to 2 October.

Scoble, M., 2003. The crisis in mining education. Annual Conference, Prospectors and Developers Association of Canada, Toronto.

Tesh, D., H. Musiyarira, G. Dzinomwa, and H. Mischo, 2015. Interventions for ensuring sustainability of the minerals education programmes at the Polytechnic of Namibia. Southern African Institute of Mining and Metallurgy Journal, **114 (12):** 1055-1058.

University of Zambia (UNZA), 2018. http://mines.unza.zm/?p=380. Accessed 02 March 2018

Wagner, H., 1999. How to address the crisis of mining engineering education in the western world? Mineral Resources Engineering, **8(4)**: 471 - 481.

World Bank Report, 2010. Financing Higher Education in Africa. Washington, D.C.: World Bank.