PREMIER's RESEARCH AND INDUSTRY FUND

RESEARCH CONSORTIA PROGRAM

'Unlocking Complex Resources through Lean Processing'

Final Review Report
Annual Report #7

Submitted to the Department of State Development (DSD) in July 2024

Updated with Extension Report (Appendix 13) in September 2025

Consortium Director - Professor Nigel Cook

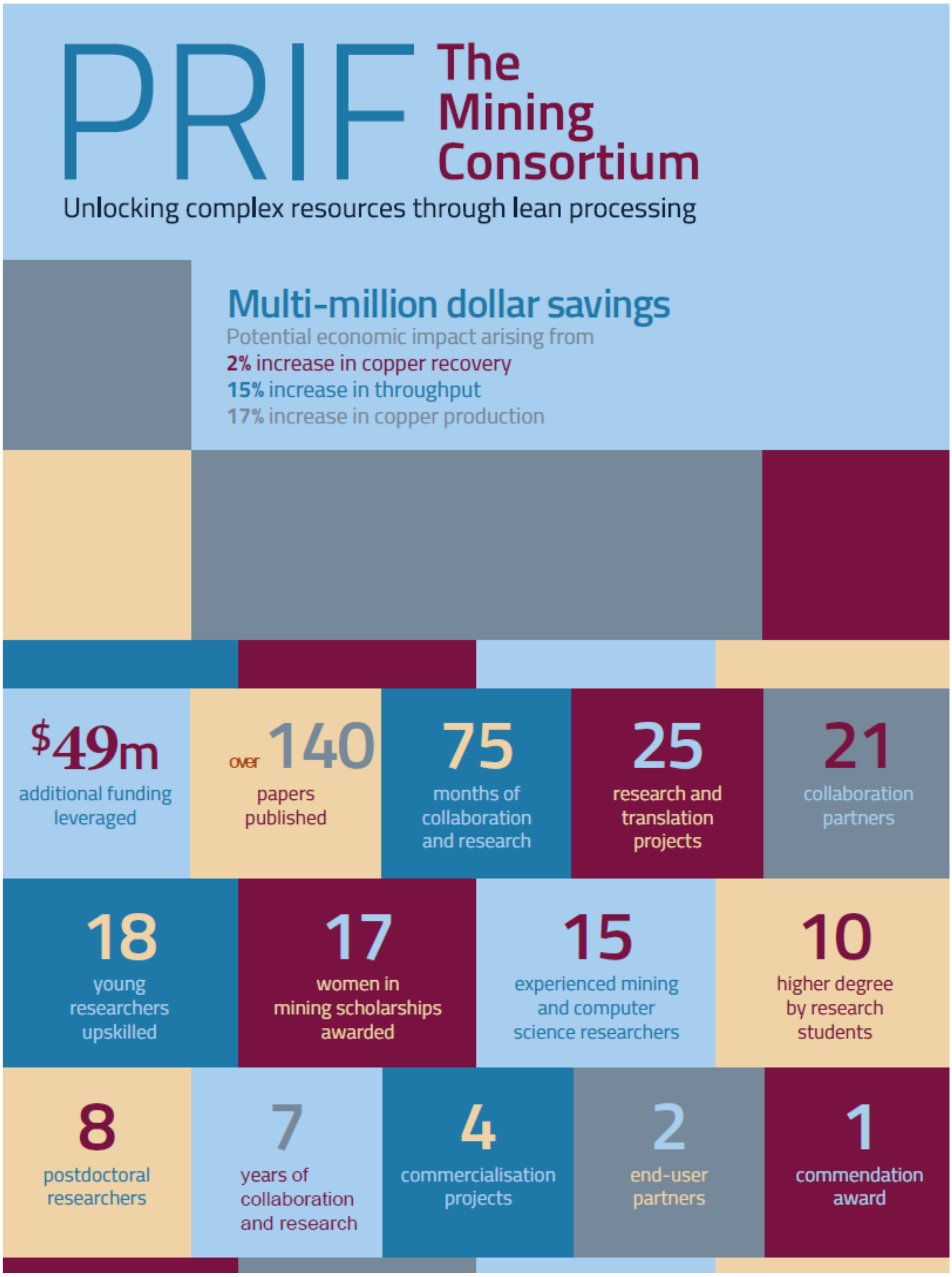
Consortium Manager - Dr Tatiana Khmeleva/ Dr Sanaz Orandi

https://www.adelaide.edu.au/imer/integrated-mining-consortium/

I. ABOUT THE PRIF MINING CONSORTIUM IN INFOGRAPHICS

The Mining Consortium is designed to develop and apply Industrial Internet of Things (IIOT), advanced sensing, data analytics and machine learning to improve mining operations, mineral processing and recovery across the entire mine value chain from in-place resources to final products. The aim is to increase the value of complex resources that are increasingly harder to mine or process through technologies that support rapid decision making, optimise productivity and enable a sustainable industry well into the future.

BENEFITS OF THE PRIF DELIVERABLES



II. COMMENDATION AWARD

The PRIF Mining Consortium team received a Commendation for Innovation & Collaboration in the Resource Sector at the 11th Annual Premier's Awards in Energy and Mining held on 8th December 2022.

III. EXECUTIVE SUMMARY

This report is the Seventh Annual Report and the Final Review Report to the Department of State Development (DSD), formerly known as the Department of Industry, Innovation and Science (DIIS), of the Premier's Research and Industry Fund (PRIF) Research Consortia Program (RCP) "Unlocking Complex Resources through Lean Processing" (the Consortium). The report covers activities of the Consortium over the period from 1st March 2023 to 30th June 2024. The report includes a summary of progress towards the Key Performance Indicators (KPIs) set by the PRIF RCP [SECTION 8].

The Funding Agreement for the Consortium was signed on the 27th October 2017, and the Collaboration Agreement on 1st June 2018. Please note, an 18-month PRIF extension was approved by DIIS with focus on commercialisation of potentially implementable projects. A Contract Variation was issued by DIIS on 24th January 2023, confirming the Consortium Program end date as 31st August 2024. Please note, that a new set of KPIs was established for the PRIF extension [SECTION 7].

The Administering Organisation is the University of Adelaide. The Partner Organisations are the University of South Australia and the Government of South Australia through the Minister for Industry, Innovation and Science. The End-User Partners are BHP Olympic Dam Corporation Pty Ltd. and OZ Minerals Limited, which became part of BHP during the extension period.

The PRIF Mining Consortium is a 7-year government initiative with total cash and in-kind support of ~ $18.4M. Please note, the overall Consortium Income has increased from the previously reported $14.1M to $18.4M due to the increase in DIIS funding of $470K for the 18-month PRIF extension, as well as in-kind contribution from the PRIF Research and Translation Partners and End-Users [SECTION 14].

The unique strength of the PRIF RCP "Unlocking Complex Resources through Lean Processing" is its combination of interdisciplinary research and collaboration with South Australian industry (METS companies and End-Users) to achieve the strategic PRIF Objectives – to develop supporting tools for optimising the entire mining value chain using machine learning, sensors and data analytics to create technology solutions that will optimise operations and make the resource industry more sustainable, while training the next generation of scientists and engineers [SECTIONS I and 3].

Please note, in 2022, **the PRIF Mining Consortium team received a Commendation for Innovation & Collaboration in the Resource Sector** at the 11th Annual Premier's Awards in Energy and Mining held on 8th December 2022. This award recognises the excellence of PRIF Mining Consortium in innovation and collaboration, showcasing vision, opportunity and/or transformational change. This is a remarkable achievement for the Consortium [SECTION II].

The Consortium has comprised 14 Research Projects and 11 Translation (industry) projects, and has involved 15 Chief Investigators experienced in mining, mineral processing and computer science, 8 postdoctoral researchers and 10 higher degree by research (HDR) students. In addition, Masters, Honours and Bachelor students from both universities are successfully working on projects relevant to the Consortium objectives. Cash and other support come from 21 industry partners and the 2 participating universities [SECTION 14].

Regular meetings occurred throughout the Consortium encouraging collaboration within and between Programs [SECTION 5]. These include:

- Fortnightly Consortium meetings for all Consortium members. Consortium researchers provided written updates for each project at fortnightly meetings to track progress against milestones and deliverables. General day-to-day operations are discussed. PRIF researchers were scheduled to give a presentation every 3-4 months representing updates of progress within their projects. In 2023 - 2024, one Tech Talk was scheduled for each meeting.

- Regular Research Group meetings were held within groups at institutions.
- Consortium participants met with End User Partners and Translation Partners when required.
- Governing Board meetings were held every 3 months.

The most recent Governing Board Meeting took place on 12th June 2024, reviewing the Consortium progress and concluding activities.

At the time of the report writing, nineteen (19) research and translation projects out of an initial twenty-five (25) have been concluded/completed. Four (4) projects were selected as potentially implementable with the intention to move them towards commercialisation during the 18-month PRIF extension [SECTION 7].

Please note that most of our PhDs and Postdocs have successfully taken up positions in different industries after completing their projects at the PRIF Mining Consortium.

Also note, that seventeen (17) Women in Mining Technology Scholarships have been awarded by the PRIF Consortium from 2019 to 2024 [SECTION 6.3].

The PRIF Mining Consortium has generated a significant body of research and has, to date, produced 154 publications, including 144 published papers. More are anticipated in the coming months [SECTION 6.2.3 and APPENDIX 11].

Facilitating knowledge exchange is a key mission of the PRIF Mining Consortium research program. The Consortium team shares its cutting-edge research findings through regular research seminars, industry workshops and conferences, collaborating effectively with end-users, research and industry partners, government and other organisations. Regarding marketing of new PRIF technologies/products, Consortium researchers participated in several national and international conferences in 2023 – 2024. Examples include the 13th International Comminution Symposium in Cape Town, South Africa; the 2023 IEEE Congress on Evolutionary Computation in Chicago, USA; the 2023 Annual Technical Meeting of Indian Institute of Metals, India; and the 2024 Digitalization in Mining Conference in Ulaanbaatar, Mongolia. The Consortium team successfully demonstrated its developed technologies in the field of sensors and process modelling by hosting booths and presenting engaging posters at Austmine 2023, Metplant 2023, SAEMC 2023 and C2TW 2024 at the Adelaide Convention Centre [SECTION 6].

The economic, social, and environmental benefits of PRIF Mining Consortium have been many. They include training of specialised personnel with a broad appreciation of disciplines across the mining value chain ready to join the workforce, and the inventions and innovations that permit mining and processing of ores with less water and chemicals, and less environmental impact. Less visible benefits of the PRIF Consortium include a demonstration of how government, industry (both METS companies and end-users), and the research community can work together towards common goals that can strengthen the sector in South Australia and across the nation.

The 2023 PRIF Mining Consortium Research Conference was successfully held in October 2023 at the National Wine Centre of Australia, Adelaide. This event was specifically designed to showcase the inventions and innovations of the PRIF Mining Consortium research teams, and celebrate the many achievements in people's research and personal lives [SECTION 6.1]

Please note, that the 2024 PRIF Final Research Conference will be held on Thursday 25th July 2024. This will be a one-day event dedicated to celebrating the successful completion of the Consortium Program and honouring the invaluable contributions from all of those involved over the past seven years: our PhD students, postdoctoral researchers, Chief Investigators, Industry Partners, Government sponsors, and Supporters. This event will showcase the successful collaboration between university researchers and the South Australian industry and demonstrate the practical applications of advanced sensing, data analytics, and machine learning to meet the real-life challenges of enhanced mining operations, optimised mineral processing, and improved copper recovery.

To accelerate legacy-related activity, a productive high-level PRIF Legacy Group (LG) was established in the first half of 2022 to help the PRIF Consortium translate research outcomes into effective industry use and to advise, make recommendations, and oversee the translation of PRIF research outcomes to Technology Readiness Level (TRLs) of at least 7 so that a major part of the PRIF endeavour can be implemented [SECTION 6.4].

Based on the TRL assessment and on recommendations from the Governing Board and Legacy Group, seven (7) projects out of 25 were identified as potentially implementable, but only four (4) projects were selected for commercialisation during the 18-month PRIF extension due to availability of original researchers: ARP3, ATP4, BRP3 and BTP9 [SECTIONS 9 and 10].

Four consortium projects are now at the commercialisation stage. Each of these targets different, yet interlinked parts of the mining-processing value chain. ARP3 leverages rapid advances in computation and machine learning to achieve more accurate modelling of geological domains essential for resource estimation. ATP4 focuses on optimised reclamation of ore stockpiles in near real-time, offering direct cost savings but also providing a competitive advantage to miners exploiting complex heterogeneous ores. BTP9 aims at maximisation of mill throughput and increased copper recovery through improved knowledge of pulp chemistry, thus reducing energy/water consumption and operational costs. BRP3 offers a revolutionary, cost-effective new approach to online measurements of particle size based on force measurement. The final reports of these projects are given in APPENDICES 1 – 5.

The impact of the translation of the selected PRIF technologies could be significant. Translation of the selected research will maximise mill throughput and increase copper recovery, reduce energy use and operational cost, provide cost-effective integration processes and improve optimisation. The selected PRIF technologies will also aid in addressing environmental, social and governance (ESG) requirements [SECTIONS 3 and 11].

The Consortium team is working hard to ensure that the legacy of the PRIF Consortium remains alive when it closes in August 2024, that PRIF's findings are efficiently communicated, and the impact on the Australian mining and copper industry maximised. We also want to ensure that there are open avenues for further work to continue and/or expand research that has potential future implementation by translation partners and/or end-users. Our dedicated researchers are preparing to apply for various grant schemes, e.g., Australia's Economic Accelerator (AEA) or Cooperative Research Centre-Project (CRC-P), etc., to support the ongoing research initiatives and legacy of the PRIF Mining Consortium [SECTION 11].

In addition, the Consortium outcomes have commercial potential for the Translation Partners and the End-users, and they have also leveraged new research opportunities for the Research Partners. The PRIF Mining Consortium leveraged funding for 7 years of the PRIF Mining Consortium is **$49,117,169** [SECTION 12].

This report also presents the report against the agreed Consortium Key Performance Indicators. To date, almost all KPIs have been achieved or exceeded [SECTION 8]. The successful achievement of the Key Performance Indicators demonstrates the PRIF team's and its industry partners' dedication and hard work towards the Consortium's strategic goals. We aim to build upon this success by applying for additional grants to drive further improvements and reach new milestones.

An update on the ARC Training Centre "Integrated Operations for Complex Resources" is included in this report. The establishment of the Training Centre was a successful outcome of the PRIF Mining

Consortium team's application for the ARC grant. The Training Centre formally commenced on 27th August 2020 and will operate for the next two years (2020 - 2026) as a lasting legacy of the PRIF. The Director of the ARC Training Centre is Professor Peter Dowd [SECTION 16].

The Financial Report for the PRIF Consortium, covering the period from 1st March 2024 – 31st August 2024 is also included in this report [SECTION 14].

The PRIF Consortium acknowledges the State Government EXCITE strategy and in its administrative structure and operation, was committed to achieving the four objectives: (i) Excellence of research and innovation outputs; (ii) Collaboration between the world's best researchers and businesses and between business and research to drive knowledge transfer; (iii) Innovation and Translation – delivery of products that are new to the world, processes and services based on R&D intensity, and the translation of innovation including through commercialisation; and (iv) An Enabled Future Workforce with the skills capability and the capacity to meet the demands of a growth in STEMM and technology-based industries across SA, different government agencies and industry sectors to deliver economic and social outputs and outcomes to support the emergence of SA as the Growth State.

In conclusion, we would like to say a big thank you to our dedicated researchers and their supervisors for their commitment to their work and passion for research and innovation.

A special thank you to our Industry Partners, End-users and the State Government for their continued support, collaboration and contributions to bridging the gap between academia and the real-world applications of research.

Thanks to the ARC Training Centre for Integrated Operations Members for their contribution and support.

We look forward to future collaborations and the opportunity to work together towards our shared goal of making a positive impact!

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IV LIST OF ABBREVIATIONS

PRIF RCP	– Premier's Research and Industry Fund Research Consortia Program (Consortium)
DIIS	- The Department for Industry, Innovation and Science (evolved as DSD)
DSD	- The Department of State Development (former DIIS)
IMER	- Institute for Mineral and Energy Resources (evolved as ISER)
ISER	- Institute for Sustainability, Energy and Resources (former IMER)
TC	- The Australian Research Council Industrial Transformation Training Centre for Integrated Operations for Complex Resources (Training Centre)
KRA	– Key Result Area
KRI	– Key Performance Indicator
CI	– Chief Investigator
HDRC	– Higher Degree Research Candidate (PhD student)
PDRF	– Post Doctoral Research Fellow (Postdoc)
RP	– Research Project
TP	– Translation Project
UoA	– The University of Adelaide
UniSA	- The University of South Australia
SCE	- School of Chemical Engineering, UoA
SEME	- School of Electrical and Mechanical Engineering, UoA
CS	– School of Computer Science, UoA
SET	- Faculty of Sciences, Engineering and Technology. UoA
FII	– Future Industries Institute, UniSA
OZM	- OZ Minerals
GB	- Governing Board
WiM	- Women in Mining Technology Scholarship
TRL	- Technology Readiness Level
PCM	- Pulp Chemistry Monitor
C&M plan	- Communication and Marketing Plan
R&D	- Research and Development
ROI	- Return on Investment
ECR	- Early-career researcher
AI	- Artificial Intelligence
COVID-19	- Coronavirus Pandemic

1. THE PRIF MINING CONSORTIUM MISSION AND ITS AIMS

The PRIF Mining Consortium was designed to provide technology solutions and tools such as advanced sensors, data analytics and Artificial Intelligence (AI), for automated, integrated and optimised mining to enhance mining operations, optimise mineral processing, and improve copper recovery, while training the next generation of scientists and engineers.

The use of sensors, models and data analytics developed by the Consortium researchers will increase certainty on mill feed to deliver predictable performance, which will reduce the energy consumption in processing, grinding and concentration in the Australian mining industry and increases efficiency and final revenue.

The specific aims of the PRIF Mining Consortium:

Address End-User Partner challenges to maximise value from complex resources and minimise environmental impacts.

Demonstrate the value of, and provide innovative tools for, integration between the resource, mining, ore delivery, processing and leaching stages.

Commercialise technological outcomes for local and global market opportunities in collaboration with the Translation Partners.

Provide research training excellence for higher degree by research students and postdoctoral researchers.

The Consortium multidisciplinary team of researchers and industry partners has expertise covering the entire mining value chain from exploration to mineral processing. Our research projects have been conducted in collaboration with our industry partners, providing our PhD students and postdocs with valuable research training with a focus on end-user commercialisation.

2. ABOUT THE PRIF MINING CONSORTIUM

The PRIF Consortium Program was designed to optimise the entire mining value chain by using machine learning, sensors and data analytics. It aims to create technological solutions that improve mining operations, optimise mineral processing, and enhance copper recovery.

Is a 7-year S.A. government initiative started in October 2017 with total cash and in-kind ~ $18.4M**.**

- The Consortium end date is 31st August 2024.
- A Contract Variation was issued by DIIS on 24th January 2023 to extend the Consortium by 18 months with intention to facilitate commercialisation of selected projects.
- The Consortium has cash and other support from 17 industry partners and 2 university partners.
- Consists of two Programs: Program A and Program B. The Program A focus is the optimisation of Upstream processes of the mining value chain, while Program B focuses on mineral processing – Downstream.
- The Consortium has 14 research projects (RP) and 11 translation projects (TP) within Programs A and B.
- Projects are aligned and focussed to the specific areas of interest of the key End-User Partners (Prominent Hill - Program A and BHP - Program B).
- The Consortium has 15 experienced researchers (CIs) in mining, mineral processing and computer science, 10 higher degree by research students (HDR), and 8 postdoctoral researchers (PDR).
- The Consortium has produced over 150 publications to date, with 144 papers published.
- 17 Women in Mining Technology Scholarships have been awarded by the PRIF Mining Consortium.
- **To date, 19 research and translation projects out of 25 have been concluded/completed.**
- To date, almost all PhDs and Postdocs have successfully taken up positions in different industries after completing their projects.
- A total of 144 research papers published.
- **Innovations from four (4) projects are regarded as particularly implementable and are now moving towards commercialisation during the 18-month Consortium extension.**
- Two Business Plans provided by Partners, and 3 Innovation Disclosures submitted.

During the extension period (1 March 2023 – 31 August 2024), the PRIF Mining Consortium focused on commercialisation of the four selected projects, while moving other active projects towards higher TRLs. The Consortium also focussed on the preservation of its work, ensuring effective communication of findings to stakeholders and the broader mining community, and maximising its impact on the Australian mining industry.

PRIF researchers demonstrated their cutting-edge technologies in the field of sensors and process modelling in captivating presentations and posters at multiple international and national conferences, and by hosting booths at many of those events.

3. ECONOMIC, SOCIAL, AND ENVIRONMENTAL BENEFITS OF THE PRIF MINING CONSORTIUM PROGRAM

DELIVERABLES

- Delivering tools to integrate and optimise the entire mining value chain by using sensors, machine learning, data-driven models and data analytics

TRAINING THE NEXT GENERATION OF SCIENTISTS, ENGINEERS AND LEADERS

- Training and upskilling 10 PhD students and 8 postdocs
- A number of Masters, Honours and Bachelor students have successfully worked on projects relevant to the Consortium objectives
- Awarded 17 Women in Mining Technology Scholarships

RESEARCH AND INDUSTRY COLLABORATION

Developed strong collaboration between Research, METS companies, End-users and Government:

- 21 industry partners and
- 2 universities,
- 14 research and 11 translation projects

CAPACITY BUILDING

- Establishing opportunities for continued research
- Securing funding and partners for future projects

PROFITABILITY

- Leveraged additional funding (cash and in-kind) through funding from Partner Organisations and competitive research grants, totalling **$49,117,169** for 7 years of the PRIF Mining Consortium

ADELAIDE AS A RESEARCH HUB

- The University of Adelaide and the University of South Australia established themselves as a national powerhouse in leading high-level integrated research that addresses optimisation of mining, comminution and mineral processing.

TRANSLATION AND COMMERCIALISATION OF CONSORTIUM TECHNOLOGIES

- Maximise mill throughput and increase copper recovery, reduce energy/water use and operational cost, provide cost-effective integration processes and improve optimisation of the Australian resources sector

COMMERCIAL POTENTILAL

- for the Translation Partners and the End-users;
- for other mining environments, and in other industries

ENVIRONMENTAL FOOTPRINT

- More sustainable mining and minimising the environmental impact of mining operations

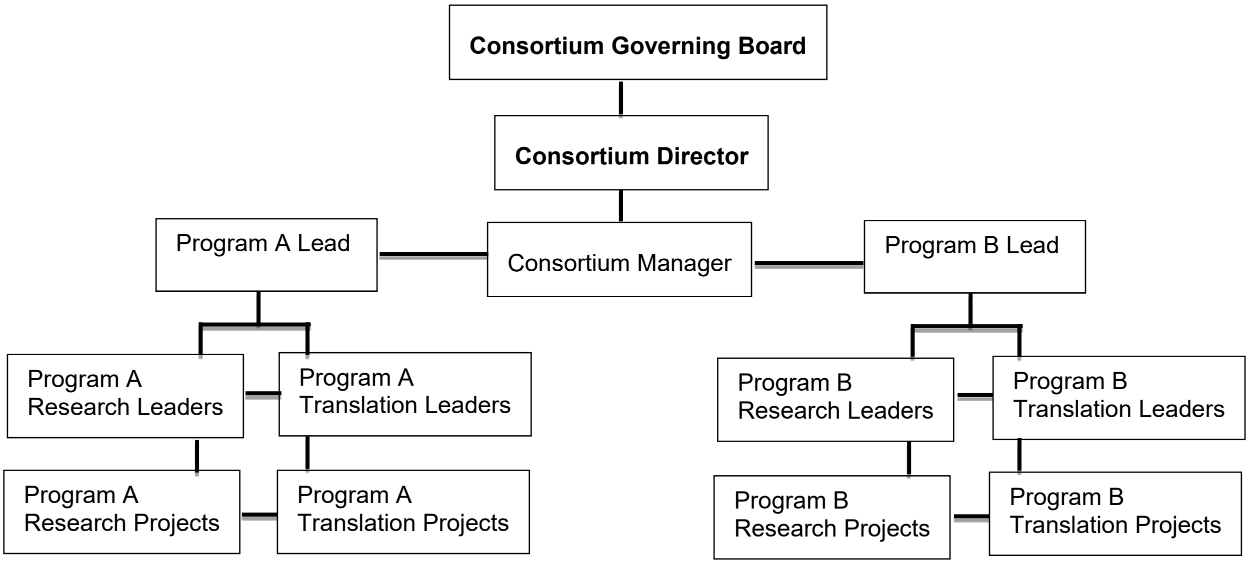
4. CONSORTIUM CALENDAR: 1st MARCH 2023 – 31st August 2024

Date	Event	Responsible	Status
21 Mar 2023	Consortium Governing Board Meeting	Chair	completed
23 Mar 2023	METS Ignited - Stranded Research Workshops	Director/ Manager	completed
April 2023	Annual Report #6	Director/ Manager	completed
8 June 2023	Legacy Group Meeting	Director/ Manager	completed
13 June 2023	Consortium Governing Board Meeting	Chair	completed
26 Sep 2023	Consortium Governing Board Meeting	Chair	completed
18 Oct 2023	2023 PRIF Mining Consortium Research Conference	Director/ Manager	completed
14 Dec 2023	Consortium Governing Board Meeting	Chair	completed
14 Mar 2024	Consortium Governing Board Meeting	Chair	completed
12 June 2024	Consortium Governing Board Meeting	Chair	completed
30 June 2024	Final Review Report –Annual Report #7	Director/ Manager	completed
18 – 19 June 2024	Copper to the World Conference 2024	Director/ Manager	completed
25 July 2024	2024 PRIF Mining Consortium Final Research Conference	Director/ Manager	
July 2024	The last DIIS tranche of $70,000 will be paid after the final report submission	DIIS	
August 2024 (TBC)	Final Consortium Governing Board Meeting	Chair	
31 Aug 2024	**End date**	All	

5. GOVERNANCE STRUCTURE

As discussed in the 2023 April Report, a Contract Variation was issued by the Department for Industry, Innovation and Science (DIIS) on 24th January 2023, confirming the change in the Consortium Governance for the extension period from 1st March 2023 until 31st August 2024. It was agreed that the PRIF Steering Committees will be removed from the Consortium Governance Structure (the Collaboration Agreement, clause 11) to provide the most efficient governance and management for the extension period. Any responsibilities critical for the delivery of KPIs performed by former PRIF Steering Committees were performed by the Consortium Governing Board.

Figure 2. Consortium Governance Structure March 2023 – August 2024



Current PRIF Governing Board

Gavin Yeates (Chair)	Gavin Yeates Consulting
Dr Ellen Schuler	Department for Industry, Innovation and Science
Prof Nigel Cook (Director)	University of Adelaide
Prof Peter Dowd (Program A Lead)	University of Adelaide
Prof William Skinner (Program B Lead)	University of South Australia
Dr Kathy Ehrig	BHP Olympic Dam
Ms Kavita Bharadwaj	BHP Olympic Dam
Mr Brett Triffett	BHP
Dr John Karageorgos	Manta Controls
Dr Ben Koch	Eka
Dr Christopher Greet	Magotteaux
Mr Simon Ratcliffe	Maptek
Dr Richmond Asamoah	University of South Australia
Dr Ley Chen	University of Adelaide
Dr Tien-Fu Lu	University of Adelaide
A/Prof Larissa Statsenko	University of South Australia
Dr Sanaz Orandi / Dr Tatiana Khmeleva	University of Adelaide

The Governing Board meetings were occurring quarterly for the extension period, as it has during 2018 – 2022.

Other regular meetings were maintained during the extension period, encouraging collaboration within and between research groups. These include:

- Fortnightly Consortium meetings for all Consortium members. General day-to-day operations are discussed. PRIF researchers are scheduled to give a presentation every 3-4 months representing updates of progress within their projects.
- Regular Research Group meetings were held within groups at institutions.
- Consortium participants meet with End User Partners and Translation Partners when required.

5.1 Changes in the Consortium Management Team

Dr Tatiana Khmeleva, the former Manager of the PRIF Mining Consortium, transitioned to a new position at the University of Adelaide on 1st March 2024. Tatiana is currently allocated 0.2 FTE to the PRIF until 30th June 2024.

Dr Sanaz Orandi has taken on the role of the PRIF Project Manager, commencing on 1st April 2024 at 0.6 FTE until 31st August 2024 with possible extension to October 2024. This is to ensure smooth operation of the PRIF during its final months and satisfactory execution of post-completion administrative tasks.

6. HIGHLIGHTS OF THE PRIF MINING CONSORTIUM 2023 – 2024

The unique strength of the PRIF RCP "Unlocking Complex Resources through Lean Processing" is its combination of interdisciplinary research and collaboration with South Australian industry (METS companies and End-Users) to achieve the Consortium Objectives. The Consortium develops tools for optimisation of the entire mining value chain using machine learning, sensors and data analytics to create technology solutions that will improve operations and make the resource industry more sustainable.

The Consortium has been progressing strongly towards the achievement of the Key Performance Indicators [SECTION 8], following the Consortium calendar [SECTION 4].

At the time of the report writing, 19 research and translation projects out of 25 have been concluded/completed [APPENDIX 10].

Four projects were selected as potentially implementable with the intention to facilitate their commercialisation during the 18-month PRIF extension [SECTIONS 7 - 10]. Two projects, ARP3 (domain modelling) and BTP9 (PCM for predictive flotation model), are expected to be completed in August 2024 achieving TRL 8 - a commercially relevant system deployed on the end-user site with a proven value proposition [APPENDICES 6 - 7]. The other two projects, ATP4 (3D stockyard modelling) and BRP3 (new sensor for particle size measurement) will be continued to the end of 2024 to achieve TRL 6 – a system model/ prototype tested on the end-user site with the refined value proposition.

The PRIF team has been actively engaged in promoting the Consortium developing technologies and sharing knowledge through a variety of activities. These have included organising research conferences for the targeted audience, presenting the PRIF outcomes at international conferences and workshops, hosting booths at industry conferences and participating in poster competitions, and collaborating with industry partners to facilitate knowledge exchange. Through these efforts, the team has successfully raised awareness of the Consortium work and fostered collaboration within the industry and a broader audience.

6.1 2023 PRIF Mining Consortium Research Conference

The 2023 PRIF Mining Consortium Research Conference was a big success. The conference was held on 18th October 2023 at the National Wine Centre of Australia, Adelaide.

This all-day event was specifically designed to showcase the inventions and innovations of the PRIF Mining Consortium and the Training Centre's research teams, and celebrate the many achievements both in research and in the lives of the people within the PRIF. It was also a celebration of the PRIF Mining Consortium research program that will conclude in August 2024, but which has proven to not only a success scientifically but also a demonstration of how government, academia from the two universities and industry can work effectively together towards shared goals. It is also worth noting how the PRIF has been exemplary in showcasing valuable synergies between the two universities (UoA and UniSA) during the ongoing process to merge the two institutions and launch Adelaide University.

2023 PRIF Mining Consortium Research Conference – Participants

2023 PRIF Mining Consortium Research Conference – Panel Discussion

The 2024 Final Research Conference will be held on Thursday 25th July 2024. This one-day conference will be dedicated to celebrating the successful completion of the Consortium Program and honouring the invaluable contributions from all of those involved over the past seven years: our PhD students, Postdoctoral researchers, Chief Investigators, industry partners, government sponsors, and supporters. Consortium researchers will showcase their innovations and inventions and demonstrate the practical benefits of their technologies for the Australian minerals industry. We also will have a lineup of great guest speakers who will deliver engaging and relevant presentations. The 2024 Final PRIF Mining Consortium event will be recorded and available on YouTube.

6.2 Knowledge exchange and marketing of PRIF technologies

Facilitating knowledge exchange is a key mission of the PRIF Mining Consortium research program. The PRIF Mining Consortium team actively engages in various knowledge exchange and marketing activities to promote its research outcomes, thus achieving significant results through the development of subsequent research projects and the translation of research findings into practical industry applications.

The Consortium is a multidisciplinary Program and has 15 Chief Investigators experienced in mining, mineral processing and computer science, 8 postdoctoral researchers and 10 higher degree by research (HDR) students from two participating universities. The Consortium team shares its cutting-edge research findings through regular research seminars, industry workshops and conferences, collaborating effectively with end-users, research and industry partners, government and other organisations. The Consortium Program provides collaboration and networking opportunities, creates a dynamic environment for stakeholders to come together, learn from each other, and drive positive change in South Australian mining sector.

In addition, the Consortium has digital platforms and social media channels to distribute information about its research projects, publications, and events, reaching a wider audience and enhancing its visibility in the industry.

6.2.1 Representing the PRIF Mining Consortium at National Conferences

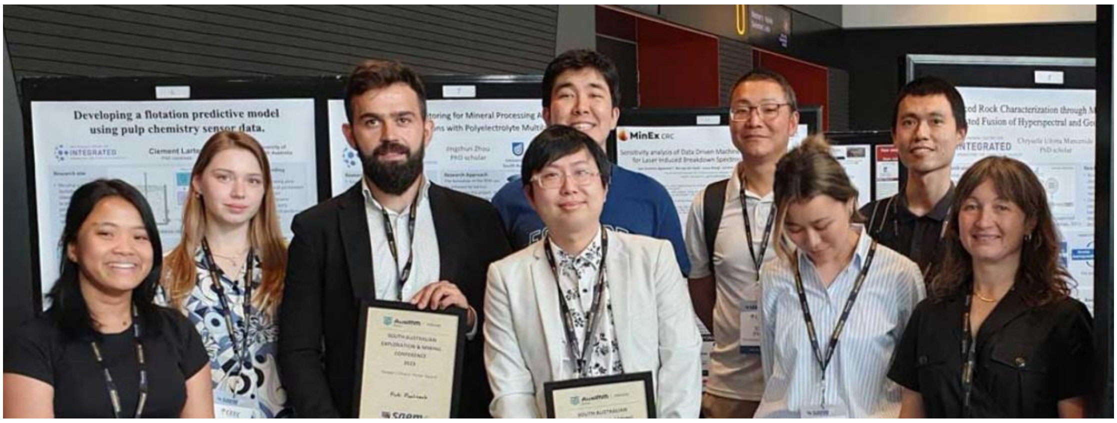
The Consortium members established valuable connections with key stakeholders and industry partners by actively participating in several national and international conferences in 2023 – 2024 promoting translation of their research outcomes and commercialisation pathways. Notable events included Austmine 2023, Metplant 2023, the South Australian Exploration and Mining Conference 2023, and Copper to the World 2024.

The Consortium successfully demonstrated its cutting-edge technologies developed by PRIF researchers in the field of sensors and process modelling by hosting booths and presenting engaging posters. This not only promoted the achievements of the PRIF Program, but also demonstrated successful collaboration between academia and industry, attracting potential end-users for the developed technologies commercialisation.

The PRIF Mining Consortium presence at these conferences established the University of Adelaide and the University of South Australia as a leading force in the mining sector, promoting connections and collaborations that will drive future success.

The PRIF Mining Consortium and the ARC Training Centre for Integrated Operations co-hosted a booth at the Austmine 2023 Conference and Exhibition, held at the Adelaide Convention Centre in May 2023. We showcased the achievements and technologies developed by the two centres, attracting a large number of conference participants. It was a fantastic networking opportunity.

The PRIF Mining Consortium and the ARC Training Centre for Integrated Operations hosted a joint booth at METPLANT 2023 in November 2023 at the Adelaide Convention Centre. The PRIF and the TC had an opportunity to display posters showcasing our achievements and upcoming technologies. The poster competition winners were Dr Richmond Asamoah from the PRIF and Clement Lartey from the TC.



The PRIF Mining Consortium and the ARC Training Centre for Integrated Operations hosted a joint booth at the South Australian Exploration and Mining Conference 2023 (SAEMC). Dr Piotr Pawliszak from the PRIF (3rd from left) won the People's Choice Poster Award and Jingchun Zhou from the TC (4th from left) won the PhD Student Poster Award.

6.2.2 Representing the PRIF Mining Consortium at International Conferences

In 2023 – 2024, the Consortium members participated in a number of International Conferences and presented their outcomes for the wider audience.

Prof Nigel Cook, Director of the PRIF Mining Consortium, was an invited speaker for the Digitalization in Mining Conference held in Ulaanbaatar, Mongolia in April 2024. Nigel talked about the success of the PRIF Program in general and about its cutting-edge technologies developed during the lifetime of the Program. It was a great opportunity to promote the Consortium internationally, especially considering that Mongolia is an emerging mining nation.

Dr Richmond Asamoah, a PRIF Chief Investigator, visited the Indian Institute of Metals in Bhubaneswar, India in November 2023 and delivered invited lectures at the Annual Technical Meeting of IIM, sharing some of the PRIF research activities with an international audience.

In July 2023, Dr Aneta Neumann, a PRIF postdoctoral researcher, presented her new paper at the international level at the IEEE Congress on Evolutionary Computation 2023 in Chicago, USA. The paper, titled 'Improving Confidence in Evolutionary Mine Scheduling via Uncertainty Discounting', is based on the results of her PRIF project in collaboration with Maptek.

Dr Yerniyaz Abildin, a PRIF postdoctoral researcher, will present his research on domain modelling in collaboration with Maptek at the International Geological Congress in Korea in August 2024.

6.2.3 PRIF Mining Consortium Publications

Table 1 below shows Consortium publications in each year of the PRIF Mining Consortium Program.

To date, the Consortium has generated a significant body of research and has 144 published papers [APPENDIX 11].

Table 1. Consortium Publications in each year of the PRIF Mining Consortium Program

Status/Year	2018	2019	2020	2021	2022	2023	2024	Total
Published	4	9	22	52	39	15	3	**144**
Accepted								
Submitted								
Under preparation							10	10
Total								**154**

6.2.4 PRIF Mining Consortium Publicity

To showcase the achievements of the PRIF Mining Consortium and promote the developed technologies to a wider audience, the following platforms were used for the PRIF Mining Consortium publicity:

- The 2023 PRIF Research Conference held on 18th October 2023 can be viewed on YouTube: https://www.youtube.com/playlist?list=PLIgDYZIzNDZJ71IPnHKHdIdorXo1k6I1J

- Maptek Forge magazine - 'Delivering value for miners' – an article dedicated to the PRIF (7/03/2023) - https://www.maptek.com/forge/march_2023/delivering-value-for-miners/

- METS Ignited website - A story on the first METS Ignited workshop for PRIF researchers -
  'METS Ignited kicks off Stranded Research Workshops' article here (30/03/2023) - https://metsignited.org/mets-ignited-kicks-off-stranded-research-workshops/

- The Collaborating for technology readiness Maptek Blog – about the PRIF and Maptek collaboration (December 2022): https://www.maptek.com/blogs/collaborating-for-technology-readiness/

- The PRIF Annual Assembly held on 22nd July 2022 can be viewed on YouTube:

  https://www.youtube.com/watch?v=YejBLIPn3qs&list=PLIgDYZIzNDZKHoTTvMPYF4HIhVAOsooQL

- PRIF Mining Consortium Promotional video for the 2022 Premier's Award in Energy and Mining (October 2022):

  https://www.youtube.com/watch?v=i8RCYJZCiQw&t=17s

- The PRIF Annual Assembly held on 1st October 2021 can be viewed on YouTube:

  https://youtube.com/playlist?list=PLIgDYZIzNDZK4Q-lUWORz8yZnfZuDjfDy

- Prof Nigel Cook – speaker presentation (YouTube):

  Professor Nigel Cook was a presenter at Amira's Global Remote Operations Automation and Robotics Day (Global ROAR), 10th October 2020. Nigel discussed 'Developing Tools to Integrate the Entire Mining Value Chain by Using Machine Learning, Sensors and Data Analytics'. The presentation is available on YouTube: https://www.youtube.com/watch?v=2H-_jjq4ve4

Overall, the knowledge exchange and marketing activities of the PRIF Mining Consortium are important for promoting collaboration, knowledge sharing, and innovation. This is leading to long-term benefits for everyone involved.

6.3 Women in Mining Technology Scholarships

As reported in the 2023 April Report, seventeen (17) Women in Mining Technology Scholarships have been awarded by the PRIF Consortium from 2019 to 2024.

The Scholarship "Women in Mining Technology" was funded by the PRIF RCP "Unlocking Complex Resources through Lean Processing" at the University of Adelaide and University of South Australia to grow the number of talented female students in engineering and technology and support female students in the completion of their educational goals. Selected students work together with high-profile academics, PDRs and HDRs to address current challenges of the mining industry.

6.4 PRIF Legacy Group

To support the effective translation of research outcomes into industry, the high-level PRIF Legacy Group was established in April 2022. The Legacy Group assisted the Consortium team in identifying specific pathways for the translation of developed technologies into effective industry use. The Legacy Group was established to advise, make recommendations, and oversee the translation of PRIF research outcomes to Technology Readiness Level (TRLs) of at least 7 (System prototype demonstrated on end-user site) and, ideally, level 8 (Commercially relevant system deployed on end-user site with proven value proposition) so that a major part of the PRIF endeavour can be implemented.

The PRIF Legacy Group consists of two staff from each of the two universities, industry end-users, and a selection of PRIF industry partners, together with independent advisors and subject matter experts who have expertise in translating research outcomes to industry use.

The Legacy Group met quarterly in 2022 - 2023. Several very constructive meetings were held with valuable discussions around the potentially implementable projects, their Tech Profiles and their potential individual commercialisation pathways.

The PRIF Mining Consortium team would like to express their gratitude to all Legacy Group members for their time and valuable/practical advice.

7. KEY PERFORMANCE INDICATORS 2023 - 2024

A new set of KPIs was established for the 18-month extension period to inspire the commercialisation activities during March 2023 – August 2024:

- One (1) Preparation of a patent application
- Two (2) Business Plans by Partners
- Two (2) Innovation Disclosures
- Attract one new industry partner (translation partner or end-user)
- Marketing: Promote the PRIF achievements with partners as necessary (e.g., METS Ignited, AMIRA), PRIF achievements in S.A., Australia and globally.
- One (1) Workshop to promote the PRIF achievements
- Progress TRL for four selected projects targeted in extension period (see table below):

Project	Title	TRL current	TRL target
B RP3	New Sensor Development for particle size measurement in Hydrocyclones	**3-4**	**6**
B TP9	MAGOPULP for improved predictive flotation model and process performance	**7**	**8-9**
A TP4	Fast ROM (Run of the Mine) Stockpile Modelling for Blending Optimisation	**4**	**6**
A RP3	Constraints and quantifying uncertainty on resource domain boundaries	**5**	**8-9**

8. REPORT AGAINST AGREED CONSORTIUM KEY PERFORMANCE INDICATORS FOR MARCH 2023 – JUNE 2024

We are pleased to report that the PRIF Mining Consortium has made significant progress in meeting and even exceeding the Key Performance Indicators (KPIs) set for this reporting period (March 2023 – June 2024). The collective effort and dedication of the Consortium team and our Industry Partners have resulted in the achievement of almost all KPIs, showcasing our commitment to excellence and collaboration.

#	KPIs	Status	Comments
1	**One (1) Preparation of a patent application**	**in progress**	At the time of this report writing, Difan Tang, a research leader on BRP3 (new PSM sensors for hydrocyclones), is working with UoA Commercialisation Services on one (1) possible patent in the future. However, more time is needed. BRP3 is extended to the end of 2024, and Difan's team is considering applying for Australia's Economic Accelerator (AEA) grants for round 4 later in 2024 to continue this highly promising and implementable research project.
2	**Two (2) Business Plans by Partners**	**completed**	**Two Business Plans provided by:** **(1) Magotteaux** - Industry Partners on BTP9: MAGOPULP for improved predictive flotation model and process performance. This Business Plan is about incorporating the data collected from the Pulp Chemistry Monitor (PCM®) installed on the mining site into a predictive flotation model developed by the TP9 team for better flotation performance. This Business Plan is confidential and includes a proposed timeline for the model validation and optimisation, a description of testing procedures, value proposition, potential challenges, and benefits etc. **(2) Maptek** - Industry Partners on ARP3: Constraints and quantifying uncertainty on resource domain boundaries. This Business Plan is about the integration of the developed geostatistical model (the framework) into commercial Maptek software DomainMCF. The scope for integration of codes developed at ARP3 into Maptek commercial software.

			This Business Plan is confidential and includes a proposed timeline for integrating the domain modelling research findings into Maptek's commercial software, a description of the development process, testing procedures, value proposition, potential challenges, and benefits.
3	**Two (2) Innovation Disclosures**	**completed and exceeded**	**Three (3) Invention Disclosures were submitted at UoA**: **(1) ARP3:** Constraints and quantifying uncertainty on resource domain boundaries. <u>Technology overview:</u> The hybrid solution uses simulations and machine learning to create a geological model with uncertainty measurements. It includes advanced noise filtering to correct errors in sample classification, making the classification more accurate and reliable. The grade simulation tool uses statistical methods to model grade variables. Machine learning is used to categorize types of rock based on the modelled grades, using data from samples. This process creates different possible models of the ore deposit, which help assess the uncertainty in defining the boundaries of the area. Waiting for UoA Commercialisation Services assessments and feedback. **(2) ATP4:** Fast ROM (Run of the Mine) Stockpile Modelling for Blending Optimisation. <u>Technology overview:</u> The technology generates near real-time 3D models for run-of-mine stockpiles using widely available mine operational data. These models are utilised to calculate quality and quality distribution within a stockpile. The calculation results are then employed to optimise the reclaiming process, aiming to minimise the time for reclamation, implicitly also using less fuel and manpower. Waiting for UoA Commercialisation Services assessments and feedback. **(3) BRP3:** New sensor development for particle size measurement in hydrocyclones <u>Technology overview:</u> The main function of this technology is to analyse particle size at hydrocyclone overflow in real time using a probe inserted into the overflow pipe. This device not only gives a

			single particle size-passing fraction number (PSPF) for target particle sizes but also provides information about the corresponding PSD. Two features of the sensing system are identified as potentially patentable.
4	**Attract one new industry partner (translation partner or end-user)**	**completed and exceeded**	**The PRIF Mining Consortium successfully attracted four (4) new industry partners** to collaborate and support the commercialisation activities of the PRIF projects during the last 18 months: (1) Reforme Group from WA supports BTP9 (MAGOPULP data for modelling) through PRIF's industry partner Magotteaux. (2) Nimble Resources from WA supports BRP3(PSM sensors). A Mutual Confidentiality Agreement was signed in Feb 2023. (3) Nova Terra from SA is the PRIF Supporting Partner. This small company evaluates the technology and identifies opportunities for research translation. An Agreement was signed in May 2023. (4) Veracio is the new Industry partner of PRIF, replacing Boart Longyear. A Deed of Novation was signed by all partners in July 2023.
5	**Marketing: Promote the PRIF achievements with partners as necessary** (e.g., METS Ignited, AMIRA), PRIF achievements in S.A., Australia and globally	**completed**	To showcase the achievements of the PRIF Mining Consortium and promote the developed technologies to a wider audience, the range of different platforms were used for the PRIF Mining Consortium publicity, i.e. PRIF Website, LinkedIn, Twitter, YouTube, Maptek Forge magazine etc. See SECTION 6.2.4 for more details. The Consortium successfully demonstrated its cutting-edge technologies developed by PRIF researchers in the field of sensors and process modelling by presenting engaging talks and posters, and hosting booths at international and national conferences: - Dr Lei Chen (CI), presented Difan Tang's work (BRP3) at the 13th International Comminution Symposium (Comminution '23) in April 2023, **Cape Town, South Africa**.

			- In July 2023, Dr Aneta Neumann, a PRIF postdoctoral researcher, presented her new paper at the international level at the IEEE Congress on Evolutionary Computation 2023 in **Chicago, USA**. The paper, titled 'Improving Confidence in Evolutionary Mine Scheduling via Uncertainty Discounting', is based on the results of her PRIF project in collaboration with Maptek. - The PRIF Research Conference 2023 is available on YouTube. An article about the event was posted on LinkedIn, Twitter, PRIF website and UoA SET newsletter. - The PRIF and the TC hosted a joint booth at METPLANT 2023 at the Adelaide Convention Centre on 5 – 8 November 2023, **Adelaide**. The PRIF and TC researchers participated in the poster competition. - The PRIF and the TC hosted a joint booth at SAEMC 2023 at the **Adelaide Convention Centre** on 1st December 2023. The PRIF and TC researchers participated in the poster competition. - Dr Richmond Asamoah delivered Invited Lectures at the Annual Technical Meeting of IIM (**Indian Institute of Metals**), sharing some of the PRIF research activities with an international audience. - David Beattie presented a poster on BRP5 (MOF sensors) at 2024 Australasian Colloid and Interface Symposium (ACIS) on 4 -7 February 2024 in Terrigal, **NSW**. The poster is a combination of Linda (PRIF, RP5) and Everette's (ITTC) work on ferric ion sensing. - 20 Members of PRIF and TC attended the AusIMM International Women's Day event on Thursday 29 February 2024 at SkyCity **Adelaide**. - Nigel Cook was an invited speaker for the Digitalization in Mining Conference **Mongolia**, held in Ulaanbaatar in April 2024. Nigel talked about the success of the PRIF Program in general and about its cutting-edge technologies developed during the lifetime of the Program.

			- 5 Researchers showcased their research outcome through a poster exhibition at the Copper to the World 2024 conference on 18 -19 Jun 2024, **Adelaide**. - The PRIF Final Research Conference 2024 will be held on 25th July 2024 at the National Wine Centre, **Adelaide**. The PRIF researchers will be showcasing the achievements of the PRIF Program and celebrating its successful completion. - Yerniyaz (ARP3) will attend and showcase his research work at the International Geological Congress which will be held in Busan, **Korea** on 25-31 August 2024.
6	**One (1) Workshop to promote the PRIF achievements**	**completed and exceeded**	**(1)** The PRIF Mining Consortium Research Conference 2023 was held on 18th October 2023 at the National Wine Centre of Australia with over 75 participants from universities, industry and government. This all-day conference was specifically designed to showcase the inventions and innovations of the PRIF Mining Consortium and the Training Centre's research teams and celebrate the many achievements both in peoples' research and in peoples' personal lives. **(2)** The 2024 Final Research Conference will be held on Thursday 25th July 2024. This one-day conference will be dedicated to celebrating the successful completion of the Consortium Program and honouring the invaluable contributions from all of those involved over the past seven years: our PhD students, Postdoctoral researchers, Chief Investigators, industry partners, government sponsors, and supporters.
7	Progress TRL for four selected projects targeted in the extension period	**completed**	See APPENDICES 6 -8 below - Technology Readiness Levels and Commercial Readiness Levels - Definitions and descriptions. See technology overviews in SECTION 10 below. See the researchers' final reports in APPENDICES 1 - 5 below.
	BRP3	completed	TRL 6 CRL 1

	New Sensor Development for particle size measurement in Hydrocyclones		BRP3 moved from TRL 4 to TRL 6. The prototype of the sensing system for particle size measurements was tested in the operating environment that closely represents the real operating environment. The tests were conducted using BHP and Nimble Resources ores.
	BTP9 MAGOPULP for improved predictive flotation model and process performance	completed	TRL 8-9 CRL 4-5 BTP9 moved from TRL 7 to TRL 8-9. The robust flotation predictive model was Incorporated in Commercial Design (PCM$^{@}$, Magotteaux): the technology has been proven to work in its final form and under expected conditions.
	ATP4 Fast ROM (Run of the Mine) Stockpile Modelling for Blending Optimisation	completed	TRL 6 CRL 1 ATP4 moved from TRL 4 to TRL 6. Prototype System Verified. The 3D stockpile models are demonstrated in Eka's operational environment. By the end of 2024, ATP4 can move to TRL 7 - 'Integrated Pilot System Demonstrated'.
	ARP3 Constraints and quantifying uncertainty on resource domain boundaries	completed	TRL 8-9 CRL 1 ARP3 moved from TRL 5 to TRL 8-9. A Hybrid Domaining Framework (HDF) - the geostatistical model, was implemented as a part of Maptek DomainMCF: the technology has been proven to work in its final form and under expected conditions. The technology is in its final form and will operate under the full range of operating conditions in August 2024.

In conclusion, the successful achievement of the Key Performance Indicators demonstrates the PRIF team's and its industry partners' dedication and hard work towards the Consortium's strategic goals. We aim to build upon this success by applying for additional grants to drive further improvements and reach new milestones.

9. PRIF MINING CONSORTIUM PROJECTS 2023 - 2024

Originally, the PRIF Mining Consortium Program had 25 research and translation projects from 2017 to 2022. Please see APPENDICES 9 and 10 for more details. Nineteen (19) projects have been completed by the end of 2022, and there are six active projects in 2023-2024.

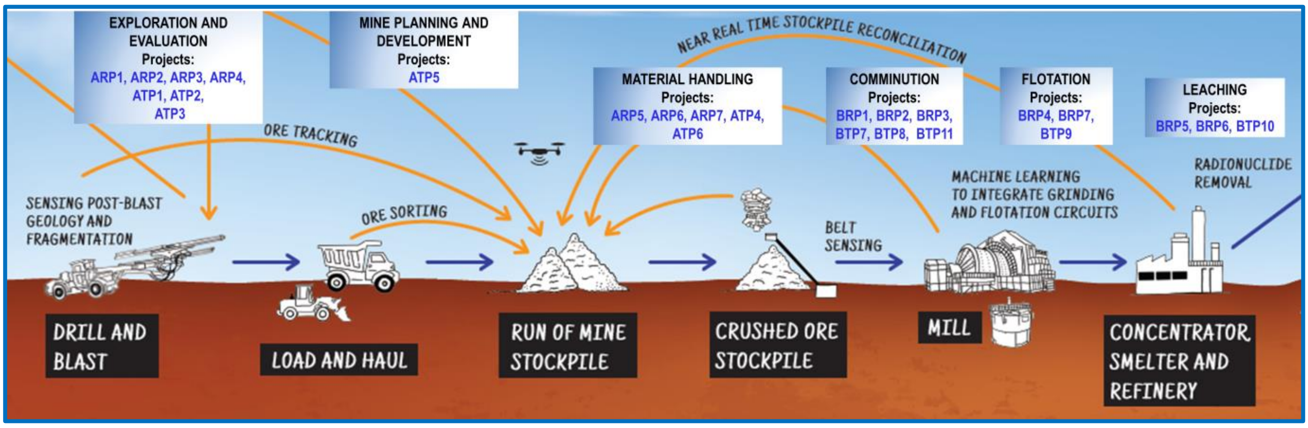
9.1. Background – PRIF projects 2017 – 2023

In 2017 – 2022, the Consortium consisted of two types of projects that were conducted under one of the two Programs (A/B). There were fourteen (14) Research Projects (RP) and eleven (11) Translation/Industry Projects (TP):

- Research Projects provide innovative solutions to generic industry-wide challenges using basic and applied research. They flag opportunities for software and technology development in Translation Projects.
- Translation Projects create field deployable prototypes from promising Research Projects, or evaluate the existing emerging technologies of industry partners, in a fast win-fast fail manner.

Figure 1. Mining Value Chain and PRIF Mining Consortium projects in 2017 – 2022

PROGRAM A (UPSTREAM)	PROGRAM B (DOWNSTREAM)
Integration between the resource, mining and ore delivery In Program A, sensors are used at several points of the upstream mining chain to enable machines to identify and monitor ore characteristics.	**Integration between the resource, processing and leaching** In Program B, grinding, flotation and tail leach circuit sensors, as well as analytics and integration are used to maximise mill feed tonnage.



At the time of the report writing, 19 research and translation projects out of 25 have been concluded/completed. Many of the Consortium projects have made significant progress over the lifetime of the Consortium. Figure 1 above shows the initial structure of the Consortium in 2017 – 2022, while APPENDIX 10 shows a list of original PRIF research and translation projects.

As was reported in the 2023 April Report, to progress towards research translation and commercialisation, the Technology Readiness Level (TRL) method has been used to assess progress in each of the 25 projects towards larger system integration and industry implementation (Annual PRIF Mining Consortium Report #6, April 2023). The Consortium management team, Chief Investigators in collaboration with Industry Partners rated all projects using the CRC-ORE TRLs scale from 1 to 9, with 9 being the most mature technology. The CRC-ORE TRLs were chosen to assess PRIF technology capabilities, as it is relevant to PRIF projects in mining and mineral processing. TRLs 1–4 represent fundamental Research, TRLs 5–7 Integration/Development, and TRLs 8–9 Demonstration/Implementation and Commercial deployment.

Most research and translation projects, 17 out of 25, were rated at level 1-4 (fundamental R&D: a formulated technology concept, established proof of concept and technology validated in laboratory environment).

Eight (8) projects were rated TRL 4-7 marking the end of fundamental research and indicating that systems have been tested and simulated in industrially relevant environment.

While it is not possible to advance all PRIF projects to higher TRLs through scaled-up on-site trials, several projects have shown notable progress within the Consortium lifetime as it was demonstrated in the 2023April report.

9.2. List of PRIF projects 2023 - 2024

As was mentioned above, the Department of Industry, Innovation, and Science (DIIS) has approved an 18-month extension of the PRIF program, with an emphasis on commercialising four potentially implementable technologies developed in projects **ARP3, ATP4, BRP3, and BTP9**. These projects were identified by PRIF CIs in collaboration with our industry partners.

Please note that while during the extension period, we were focused on the four selected projects, the PRIF has also supported the further development of two promising projects with lower Technology Readiness Levels (TRLs): **BRP2 and BRP5**. Additionally, the PRIF has provided support for two PhD candidates to submit their theses in May-June 2023.

Please see below the list of PRIF Mining Consortium Projects that were carried out during the extension period (March 2023 – August 2024):

Exploration and Evaluation

ARP3: Constraints and quantifying uncertainty on resource domain boundaries *(PhD project completed in June 2023, and this project was continued as postdoc project)*

Material Handling

ATP4: Fast ROM (Run of the Mine) Stockpile Modelling for Blending Optimisation

Comminution

BRP2: Predictive machine health monitoring for SAG/AG mills

BRP3: New sensor development for particle size measurement in hydrocyclones

Flotation

BTP9: Pulp Chemistry Monitor (PCM®) for improved predictive flotation model and process performance

Leaching

BRP5: Further development of Metal Organic Framework based fibre optic sensor

BRP6: Diffusive processes in mineral processing *(completed, PhD thesis submitted in June 2023)*

10. PROGRESS OF PRIF PROJECTS 2023 – 2024 - SUMMARIES

As stated above, four (4) projects - ARP3, ATP4, BTP9 and BRP3, are now at the commercialisation stage, each targeting different, yet interlinked parts of the mining value chain.

ARP3 leverages rapid advances in computation and machine learning to achieve more accurate modelling of geological domains essential for resource estimation.

ATP4 focuses on optimised reclamation of ore stockpiles in near real-time, offering direct cost savings but also providing a competitive advantage to miners exploiting complex heterogeneous ores.

BTP9 aims at maximisation of mill throughput and increased copper recovery through improved knowledge of pulp chemistry using robust flotation models, thus reducing energy/water consumption and operational costs.

BRP3 offers a revolutionary sensing system, a cost-effective new approach to online measurements of particle size based on force measurement.

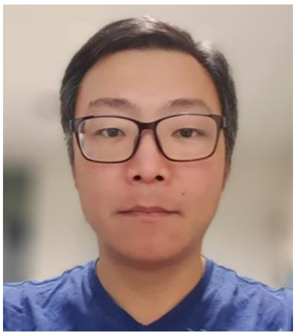
Additionally, two other projects, BRP2 and BRP5, were also supported by the PRIF to further develop and advance their TRLs. BRP5 is developing new sensors designed to detect ferric iron, which have wide-ranging commercial potential that goes beyond mining-specific areas of interest. BRP2 involves University of Adelaide Masters Students and addresses vibrational monitoring of SAG mills. Project summaries are given in SECTIONS 10.5 and 10.6, respectively.

Please note, Yerniyaz Abildin and Kirsten Louw successfully completed their theses in June 2023 and have since continued to work on the PRIF projects as postdocs in various capacities. Dr Yerniyaz Abildin is focusing on the implementation of his domain modelling project (ARP3) and Dr Kirsten Louw is providing support for BTP9 and is involved in model validation work.

The completed final researchers' reports of ATP4, ARP3, BRP3, BTP9, and BRP5 can be found in APPENDICES 1 - 5 of this report.

10.1 Summary ATP4 – Fast ROM (Run of the Mine) Stockpile Modelling for Blending Optimisation

Researcher: Dr Shi Zhao, University of Adelaide



Supporting Researchers, UoA: Dr Hirad Assimi and Victor Caquilpan Parra

Chief Investigators: Dr Tien-Fu Lu (UoA) and A/Prof Larissa Statsenko (UniSA)

Project Duration: November 2019 – December 2024

Industry Partner: Eka, BHP

TRL 6

CRL 1

"3D stockpile modelling enables optimised reclamation in near real-time."

This project utilizes a fast computer simulation technique, provided by the industry partner EKA, to generate ROM stockpile models in near real-time through widely available operational data. Additionally, this project integrates these 3D quality-embedded models with research outcomes obtained from RP5 project, creating one real-scale and one small-scale demonstration system for reclamation optimisation.

The objective is to meet the required quantity and quality with minimal violation factors, and also reduce the reclaiming time.

Project aims

- To change current selectively stacking techniques in stockpile management and quality control systems to proactively reclaiming techniques.
- To implement Eka's modelling techniques for stacking operations and analyse its performance.
- To demonstrate the optimised reclaiming sequences for multiple front-end loaders (FELs) using the mine operational data.
- To move project to a higher TRL/CRL and increase the chance of commercialization.

The short description of technology

The technology generates near real-time 3D models for run-of-mine stockpiles using widely available mine operational data. These models are utilised to calculate quality and quality distribution within a stockpile. The calculation results are then employed to optimise the reclaiming process, aiming to minimise the time for reclamation, implicitly also using less fuel and manpower.

Benefits

Near real-time, multi-layered 3D stockpile models result in accurate quality calculations, which allow various optimisation algorithms to be evaluated either for stacking, reclaiming, or both operations. The modelling process uses data sets saved in the current management system and does not introduce extra hardware costs.

Table 2 below shows ATP4 activities toward project commercialisation, and proposed deliverables at the end of this projects.

Table 2: ATP4 – Fast ROM (Run of the Mine) Stockpile Modelling for Blending Optimisation

Project, Partner	Implementation Activities 2023 - 2024	Value proposition	Deliverables
A TP4 Eka, BHP	**<u>Stage 1:</u>** Evaluating cost savings from the reclaiming system optimization using a new dataset. The evaluation result will advance the proposed technological solution to TRL5 or TRL6 and increase its CRL level. **<u>Stage 2:</u>** Creating a full-scale demonstration system using EKA stockyard management system. A full-scale demonstration system will advance the proposed technology to TRL6 or TRL7 increase its CRL level further	The integration between 3D stockpile models and optimisation algorithms will **improve the blending efficiency and reduce the operational cost.** It has been identified that stockpiled products are currently being reclaimed at approximately 50% of their potential engineering production rates. There is a tremendous opportunity to improve productive rates using such 3D stockpile models. Additionally, such integrations allow the end user to calculate the quality and quantity combinations precisely, which minimises the margin between the required and supplied quality. Also, reducing the cost.	**Current TRL 6** **CRL 1** **Software:** Develop 3D stockpile models to improve the blending efficiency, optimise the reclaiming operations and reduce the operational cost (e.g., using data provided by Prominent Hill). The translation partner, EKA, is the best vendor for this technology. Eka is currently discussing the strategy of 'plugging-in' the ATP4 model to the EKA visualisation modules for demonstrating the value to the mine site. EKA, listed two successful case studies on their website, demonstrating the use of such 3D stockpile models in bulk material handling.

Key Findings and Outcomes

- An Invention Disclosure was submitted in July 2023.

- This project has developed two demonstration systems. Both demos can display the quality embedded 3D stockpile models and can show the optimised reclaiming sequences for three front-end loaders in future (FELs).

  (1) The small-scale system using a self-developed Python program - Integrated such models with research outcomes obtained from the RP5 project, resulting in an optimisation

system that meets the required quantity and quality with minimal violation factors (higher priority), and reduces the reclaiming time (lower priority). The small-scale demo is close to completion and is accessible to the public.

(2) The real-scale system using Eka's software: Insight CM - Generated/updated 3D quality-embedded stockpile models in near real-time using operational data from a mining site. All integration tasks will be completed by December 2024.

- The project advanced from TRL 3-4 to TRL 6

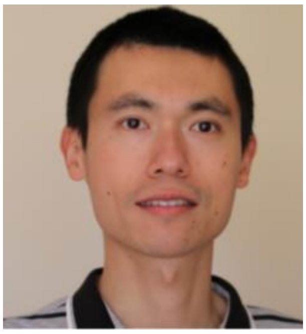
Considerable effort is needed to set up the computer simulation system, which is owned by EKA, to generate the most realistic 3D model for truck dumping (stacking) activities. Thus, the real 3D scanning models were used to demonstrate the outcome of the research. To reach TRL 7-8, it would require at least 1 year of one researcher with access to the Eka system.

Dr Shi Zhao (ATP4) is considering applying for Australia's Economic Accelerator (AEA) grants for round 4 later this year.

The completed ATP4 report can be found in APPENDIX 1.

10.2 Summary BRP3 - New sensor development for particle size measurement in hydrocyclones

Researcher: Dr Difan Tang, University of Adelaide



Supporting Researchers: Lin Yang, UoA

Chief Investigator: Dr Lei Chen, UoA

Project Duration: October 2019 – December 2024

Industry Partner: BHP, Manta Controls, Rockwell Automation, Nimble Resources, BHP

TRL 6

CRL 2

"A cost-effective method for online analysis of particle size can help deliver energy-efficient mineral processing with economic implementation."

Monitoring particle size-passing fraction (PSPF) at hydrocyclone overflow is critical to mineral processing as it not only assists gauging the quality of mill discharge and flotation feed but also significantly helps enabling closed-loop optimal control for energy-efficient comminution and downstream flotation. Further knowledge on particle size distribution (PSD) in addition to the single number of PSPF can be more beneficial. However, there has been a lack of cost-effective techniques for hydrocyclone overflow PSPF and PSD online sensing, especially when each individual hydrocyclone unit is to be monitored, given the large number of hydrocyclones typically employed on a mine site.

The primary function of the new sensing system is to monitor particle size at hydrocyclone overflow in real time through a probe inserted into the overflow pipe. It not only gives a single number of PSPF for target particle sizes but also provides information of corresponding PSD. In addition, it simultaneously offers two auxiliary measurements including mass flow rate and flow viscosity.

This study resolves the problem with a new technique based on vibration measurement. Laboratory tests using samples from an Australian Alluvial gold deposit have proven the proposed approach effective in monitoring density variation of classified concentrates stream.

The short description of technology:

The primary function of this technology is to analyse particle size at hydrocyclone overflow in real time using a probe inserted into the overflow pipe. This device not only gives a single particle size-passing fraction number (PSPF) for target particle sizes but also provides information about the corresponding PSD.

Benefits

1. Multiple measurement functions useful for grinding and classification: Particle size, Mass flow rate, Flow viscosity.
2. Easy installation, operation, and maintenance.
3. Enabling future integration of automatic control systems for automated and optimised mill and hydrocyclone operation.
4. Low-cost deployment (hardware procurement, installation, and ongoing maintenance), less than 10% of the total expenditure required by other existing solutions.

Table 3 below shows BRP3 activities toward project commercialisation, and proposed deliverables at the end of this projects.

Table 3. BRP3 – New sensor development for particle size measurement in hydrocyclones:

Project, Partner	**Implementation Activities 2023 – 2024**	**Value proposition**	**Deliverables**
B RP3 BHP, Nimble Resources	**Stage 1:** Further laboratory testing using samples form mine sites (BHP Olympic Dam, and Nimble Resources) and model refinement based on testing results. Using samples from mine site provides more realistic testing environment and will move the TRL of the technology to TRL5 and increase CRL. **Stage 2:** On-site testing for model refinement and validation. Testing the sensing technology on a mine site will move the TRL of the technology to TRL6 and increase CRL.	In the mining industry, a cost saving of over 90% is foreseeable for both translation partners and end-users given the total low cost involved in sensor procurement, installation, and maintenance, compared with using other existing technologies. The integration of automatic control using the new sensing system is predicted to enable up to 10% increase in throughput at the same particle size or up to 4.5% reduction in particle size at the same throughput. As an essential part of an automatic control system, the new sensing system will allow cost-effective integration and further benefit translation partners specialising in integrated control solutions (e.g., Manta Controls, Rockwell Automation). Upon establishing optimal grinding and hydrocyclone control, the end-users (e.g.,	Current TRL 6 CRL 2 **Hardware (sensor) and Software/Modelling:** Real-time and cost-effective **sensing method** for online hydrocyclone overflow particle size-passing fraction (PSPF) measurements. The 2-in-1 sensor monitors both the PSPF and the mass flow rate, featuring easy installation, operation, and maintenance. This technology can potentially revolutionise the accurate assessment of the quality of mill discharge and flotation feed, a parameter that is critical for mineral processing. The product could either be implemented for a single end-user or sold widely. The product could either be implemented for a single end-user or sold widely.

		BHP Olympic Dam Mine, Nimble Resources) will gain increased throughput while being able to reduce energy consumption in the meantime.	Potential vendors include translation partners and all other entities offering advanced transforming technologies for mineral processing, power plants, and powder manufacturing industries.

Key Findings and Outcomes

- An Invention Disclosure was submitted in July 2023.
- Two patentable features of the sensing system are determined.
- Working with UoA Commercialisation Services on one (1) possible patent in the future.
- The prototype of the sensing system for particle size measurements was tested in the operating environment that closely represents the real operating environment.

- Laboratory testing using samples form mine sites: BHP Olympic Dam and Nimble Resources.
- Model refinement based on real ore testing results.
- PSD assessment accuracy can be improved by a hybrid approach based on both the impact mechanics and the bluff-body hydrodynamics.
- The new sensing system is also applicable in Dry Mineral Processing to monitor the density of air/gas-conveyed particles in real-time.
- The project advanced from TRL 3-4 to TRL 6.

Dr Difan Tang (BRP3) has developed a cost-effective, real-time method for online hydrocyclone overflow particle size-passing fraction sensing by force and acceleration measurements. Although still at the testing stage, this could potentially revolutionise the accurate assessment of the quality of mill discharge and flotation feed, something which is critical for mineral processing.

Further work to optimise the sensor performance is also required. It would require at least 1-2 years of one researcher with access to lab facilities and specific equipment to bring the sensor to the next level - TRL 7.

Dr Difan Tang (B RP3) is considering applying for the Australia's Economic Accelerator (AEA) grants for round 4 later this year.

The completed BRP3 report can be found in APPENDIX 2.

10.3 Summary BTP9 – MAGOPULP for improved predictive flotation model and process performance

Researchers: Dr James Dankwah, Dr Kirsten Louw and Ms Van Tran

University of South Australia



BTP9 project is linked to the PhD project BRP4 which was caried out by Bismark Amankwaa-Kyeremeh

Chief Investigators, UniSA:	Dr Richmond Asamoah and Prof Bill Skinner,
Project Duration:	August 2019 – August 2024
Industry Partner:	Magotteaux Australia, BHP

TRL 8-9

CRL 4-5

"Integration of MagoPulp® in the flotation circuit improves copper recovery prediction and process optimisation."

Magopulp addresses the need for continuous and real time pulp chemistry measurement. Specifically, Magopulp measures key pulp chemistry variables such pH, Eh, dissolved oxygen, oxygen demand and temperature from any process stream, providing a real time mineralogy proxy. Magopulp provides a platform for the integration of new sensors in process streams.

This project aimed to develop robust flotation predictive models to achieve higher copper recovery by using real PCM data from mining sites. The focus was on model validation and optimization strategies to maximize flotation efficiency.

This research investigated the influence of pulp chemistry variables (pH, Eh, dissolved oxygen and temperature) in predicting flotation systems using a Gaussian process regression algorithm.

The model performance indicated that pulp chemistry variables are essential in predicting rougher copper recovery. The feature selection also revealed that pulp chemistry variable relevance is in the order dissolved oxygen > pH > Eh > temperature.

Benefits

This technology has very significant benefit to the minerals industry nationally and internationally. Given the increasing ESG requirements, eco-efficient methods are required, including frugal use of reagents and maximisation of returns with little input resources (e.g., energy and water). The specific benefits include:

- Improved flotation circuit optimisation and copper mineral selectivity.

- Maximized copper production and reduced waste (energy, water and value minerals), hence, lower operating cost.
- Improved downstream unit performance through consistent feed characteristics.

Table 4 below shows BTP9 activities toward project commercialisation, and proposed deliverables at the end of this projects.

Table 4: BTP9 - Pulp Chemistry Monitor (PCM®) for improved predictive flotation model and process performance

Project, Partner	**Implementation Activities 2023 - 2024**	**Value proposition**	**Deliverables**
B TP9 Magotteaux, BHP	**<u>Stage 1:</u>** Validate models developed at the industry site. This will involve restoring the Magopulp on site. Collecting useful data for good statistics. Refining models and demonstrating the value of the Magopulp to BHP Olympic Dam.. **<u>Stage 2:</u>** Develop a software tool for adoption at processing plant. Demonstrating the performance of the Magopulp through the advanced predictive models to BHP Olympic Dam will further increase the TRL and CRL whilst encouraging adoption by other mining companies. The financial benefit of the sensor will be provided.	- Develop robust flotation performance predictive models for improved optimisation; - Increase copper recovery within constraints of concentrate/product grade.	Current TRL 8-9 CRL 4-5 **Software:** Develop robust flotation predictive models for higher copper recovery and improved optimisation: (i) Install the Pulp Chemistry Monitor (PCM®), first at the rougher cells, and incorporate the data collected into a predictive flotation model for better flotation performance; (ii) Obtain PCM data; (iii) Re-training and refining the flotation models as new PCM® data on future treated ores become available.

Key Findings and Outcomes

- Magotteaux, Industry Partner, submitted the Business Plan for implementing robust flotation predictive models into Magotteaux's commercial software.
- Machine learning models that are well developed and can predict copper recovery well.
- It was proved that selected input features are critical to the model performance and robustness.
- Pulp chemistry variables improve the predictive model performance and influence the number of model-selected features.

- Model validation and interpretation has been undertaken to aid integration of machine learning techniques and MagoPulp® in process streams.

- New optimisation algorithm for maximising copper production and process performance, with MagoPulp® integration and value demonstration, has been undertaken.

- The project advanced from TRL 7 to TRL 8-9

Additional work at multiple end-user sites to further increase the TRL and/or CRL and integrate MagoPulp® is recommended. Strong engagement between technology end-users and Magotteaux is required.

The completed BTP9 report can be found in APPENDIX 3.

10.4 Summary APP3 – Constraints and quantifying uncertainty on resource domain boundaries

Researcher: Dr Yerniyaz Abildin, University of Adelaide

Chief Investigators, UoA:	A/Prof Chaoshui Xu and Prof Peter Dowd
Project Duration:	October 2019 – August 2024
Industry Partner:	Maptek, BHP

TRL 8-9

CRL 1

"The most effective geological domaining approach combines human expertise and machine learning."

This project proposes a hybrid framework of domain method (Hybrid Domaining Framework - HDF) that consists of two components: (1) Geostatistical simulations of a comprehensive set of grade variables assayed for the deposit; (2) Application of machine learning (classification algorithms) for domain classification based on simulated grade values. Additionally, the classifier is trained on the available geological logs after a noise filtering algorithm has been applied to correct misclassification errors in samples.

Project aimed:

(1) To develop the HDF based on geostatistical simulation and machine learning classification algorithms in order to quantify uncertainty on domain boundaries and thereby increase the reliability of the resource model.

(2) To implement developed HDF within a commercial product and to elevate the project to higher TRLs/CRLs

As mentioned above, this project focuses on the geological domain modelling with the associated assessment of uncertainties in the domain boundaries, using a hybrid framework based on grade simulations and machine learning (classification). A state-of-the-art noise filtering algorithm is also integrated into the classification process to resolve misclassification errors among problematic samples. This has been demonstrated to be effective pre-processing step in practice to improve the reliability of the classification algorithms.

The first component of the framework takes advantage of abundant sample grade values for reliable simulations of grade variables (e.g., Cu, Au, Fe) on a dense regular grid using geostatistical approaches. Machine learning is then applied to classify the lithological units based on the simulated grade values and referencing the limited domain samples available. In the hybrid framework, geostatistical simulations of grade variables introduce multiple equally probable realisations of the orebody, which are then used for the uncertainty assessment of the domain boundaries.

The short description of technology:

The hybrid solution uses simulations and machine learning to create a geological model with uncertainty measurements. It includes advanced noise filtering to correct errors in sample classification, making the classification more accurate and reliable. The grade simulation component applies geostatistical methods to simulate grade variables. Machine learning is then applied to classify the lithological units based on the simulated grade values, referencing the available domain samples. Geostatistical simulations of grade variables result in multiple, equally probable realisations of the orebody, which are then used for the uncertainty assessment of the domain boundaries.

Benefits

A Hybrid Domaining Framework (HDF) provides a more accurate geological domaining method, as the geostatistical simulations of grade variables are in general more reliable compared with the direct simulations of domain variables. Domaining based on different spatial statistics and machine learning algorithms relies on a data-driven approach, which can filter out subjective bias during the modelling process. In addition, the capability of quantifying the uncertainty of domain boundaries as part of the outcomes from the framework is an added benefit compared with other existing approaches.

Table 5 below shows ARP3 activities toward project commercialisation, and proposed deliverables at the end of this projects.

Table 5: ARP3 - Constraints and quantifying uncertainty on resource domain boundaries

Project, Partner	**Implementation Activities 2023 - 2024**	**Value proposition**	**Deliverables**
B RP3 Magotteaux, BHP	**<u>Stage 1:</u>** - Design of an all-purpose, generalised domaining framework: geostatistical tools and machine learning algorithms. - Validation against different cases, including geological, geometallurgical and mineralogical 3D models. **<u>Stage 2:</u>** Creating or integrating into a full-scale software product. Calibration of user interface by user experience and recommendations. Time required: 3 (three) months and 3 (three) weeks.	Key values of the proposed framework include **its accuracy and its capability of assessing the uncertainty of domain boundaries** compared with existing tools. The process can also be semi-automated so that time spent on domain modelling is shortened and manual interactions with the model are minimised, leading to an optimised workload and increased productivity for routine tasks such as grade control and domain modelling.	Current TRL 8-9 CRL 1 **Software:** A Hybrid Domaining Framework (HDF) provides a more accurate resource model and domain boundaries leading to optimisation of workload and increased productivity. The framework can be implemented as a standalone package or as an add-on package to an existing platform such as Maptek Compute Framework (DomainMCF).

			The framework has been implemented as a part of DomainMCF.

Key Findings and Outcomes

- An Invention Disclosure was submitted in July 2023.
- A business plan was developed in collaboration with Matpek (Industry partner) for implementing domain modelling research into Maptek's commercial software.
- The framework has been developed and implemented as a part of Maptek DomainMCF.
- The project advanced from TRL 5 to TRL 8-9

- Data-driven noise filtering is an effective tool against geological misclassification.
- Tree-based classification methods perform well for geological predictions.
- HDF is completely general and can be applied to any type of deposit.
- The proposed framework has been demonstrated to work effectively using a Prominent Hill dataset.

Maptek's DomainMCF is a perfect platform for the full-scale commercial implementation of the HDF. Currently, most codes are operational. However, additional work is needed to consolidate the codes and to escalate the method to the final TRL 9, so that it can be advanced towards the next CRLs.

Dr Yerniyaz Abildin (ARP3) will apply for the following research grants from the International Association for Mathematical Geosciences (IAMG) to continue the domain modelling project beyond the PRIF end date. Applications will be based on his PhD and the post-doctoral work:

• Computers & Geosciences Research Scholarships

• Founders Scholarship

The completed ARP3 report can be found in APPENDIX 4.

10.5 Summary BRP 5 – Further development of Metal Organic Framework based fibre optic sensor

Researcher: Dr Piotr Pawliszak, University of South Australia

BRP5 is based on Dr Linda Rozenberga's PhD work.

Chief Investigators, UniSA:	Prof David Beattie, Prof Marta Krasowska, Prof David Lancaster, Prof William Skinner, Anton Blencowe
Project Duration:	September 2018 – August 2024
Industry Partner:	Magotteaux Australia, BHP

TRL 4

CRL 1

"Luminescence sensor allows for accurate and wide range Fe3+ ion sensing to improve control for more efficient mineral leaching."

This project aims to develop a fast, accurate, luminescence-based sensor for iron (III) detection and measurement in mineral leaching processes.

Effective monitoring of chemical parameters in mineral processing is crucial for optimizing recovery rates. Traditional methods are costly and slow, lacking real-time measurement.

This project focuses on developing a new luminescent Fe3+ sensor by optimizing the synthesis of luminescent sensor material, encapsulating the material in a polymer matrix, and using this composite material to coat an optical fibre. Further optical set-up and sensor optimisation is necessary for practical application in the industry.

To address challenges like poor long-term stability and implementation difficulties, a composite material combining Europium metal organic frameworks (EuMTA) with Poly (2-hydroxyethyl methacrylate) (PHEMA) was developed.

Benefits

This advancement holds promise for real-time monitoring of critical parameters in mineral processing, facilitating enhanced process control and efficiency.

The new sensor will be significantly faster, will not require sample pre-treatment, will be more accurate, and will possess a wider sensing range compared to traditional methods.

Table 6 below shows BRP5 activities toward project commercialisation, and proposed deliverables at the end of this projects.

Table 6: BRP5 - Further development of Metal Organic Framework based fibre optic sensor.

Project, Partner	Implementation Activities 2023 - 2024	Value proposition	Deliverables
B TP9 Magotteaux, BHP	**<u>Stage 1:</u>** - Improve the adhesion of the MOF-polymer matrix allowing for improved robustness. • Learning synthesis of Eu-based MOF and incorporation in the polymer matrix. • Deposition of MOF-polymer film on fibre optics treated with various adhesion promoters/testing deposition conditions and testing the sensor performance. - Assessing the reliability and accuracy of MOF-based sensor against classical lab-based ferric ion testing techniques.	- Develop fluorescence based optical fibre sensor that can selectively and instantaneously measure Fe3+ ion concentration in mineral leaching and wastewater treatment processes. By accurately measuring Fe3+ levels, mineral processing operations can make informed decisions that lead to better outcomes and higher copper productivity.	Current TRL 4 CRL 1 **Hardware:** Develop a fast, accurate, luminescence-based sensor for iron (III) detection and measurement in mineral leaching processes. While the first prototype has been developed by BRP5, there is still much work to do before commercialisation.

Key Findings and Outcomes

- Validated and confirmed the synthesis of Europium Metal-Organic Framework (EuMOF), achieving a significantly improved yield of 37.6%.

- Developed a composite material that combines EuMOF with Poly(2-hydroxyethyl methacrylate) (PHEMA) and optimized the PHEMA cross-linking conditions.

- The polymer-MOF composite exhibits practical Fe^{3+} sensing capabilities, with the sensing range significantly extended from 0–4 ppm in a EuMOF suspension to 0–300 ppm in the PHEMA-EuMOF composite, demonstrating a linear dependency.

- The composite sensor also demonstrates good reusability, excellent luminescence stability, and robust mechanical properties.

- CRC-P application has been submitted, which (if successful) will provide longer term funding allowing to build a prototype of the MOF-based sensor and its implementation in the PCM.

While the first prototype was developed by BRP5 during the lifetime of the Consortium, there is still much work to do before commercialisation. The optical setup used to run the sensor needs to be optimised to be more cost-effective and practical. Sensor assembly requires precision equipment. Further work to optimise the sensor performance is also required. It would require at least 1-2 years of one researcher with access to lab facilities and specific equipment to bring the sensor to the next TRL5.

The completed BRP5 report can be found in APPENDIX 5

10.6 Summary BRP2 – Predictive Machine Health Monitoring for SAG/AG Mills

also known as 'Vibrational Monitoring for Online Machine Health Check using Internet of Things (IOT) Sensors'

Master students: Abhishek, and Romody Momoto Sogavo


Chief Investigator: Dr Lei Chen

Commenced: December 2023

Completing: December 2024

Industry partner: Manta Controls, Rockwell Automation, BHP

TRL 4

CRL 1

'Mathematical model of SAG mill shell vibrations was validated through simulation and comparison with existing literature data. Simulation demonstrates the impact of liner removal and wear on vibrational frequency changes and helps identify critical thresholds for maintenance and fault detections.'

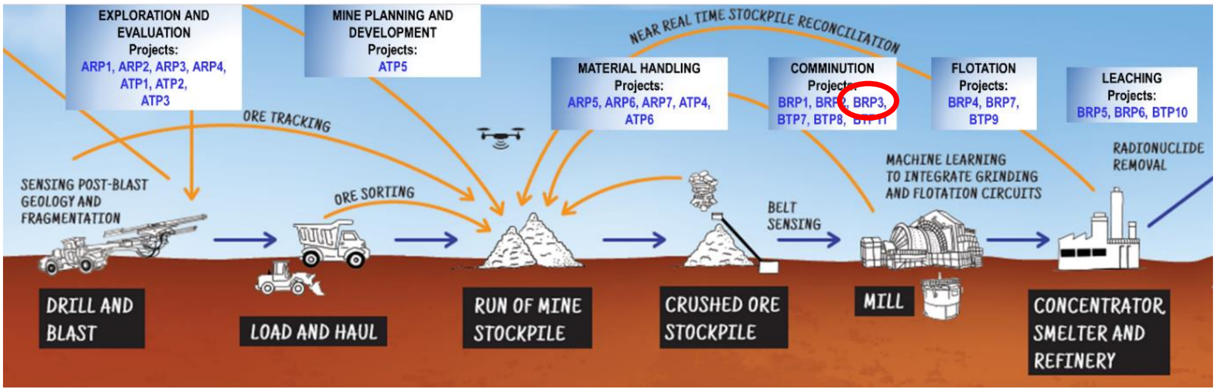


Figure 1: PRIF Mining Consortium projects.

Introduction/Background

B-RP2 is one of the COMMINUTION Projects (Figure 1). As a grinding device, SAG mills belong to a comminution circuit and play an important role in linking comminution to flotation.

Online monitoring the liners and lifters health is critical to mineral processing as it not only relates to the SAG mill throughput but also significantly helps enabling closed-loop optimal control for energy-efficient comminution and downstream flotation.

Project Objectives

- Enhances precision in monitoring and maintenance planning by isolating load-related effects.
- Enables accurate differentiation between liner wear-induced frequency variations and those caused by operational loads.

Project overview:

Autogenous Grinding/Semi-Autogenous Grinding (AG/SAG) mills are used in grinding worldwide. Two of the parts inside an AG/SAG mill, the liners and lifters, are of paramount importance. Liners transfer the energy and protect the mill shell, and lifters lift small ore particles to the next processing stage. After a period of time liners and lifters suffer from wear and tear and require replacing. In industry, liners and lifters are replaced periodically to maintain the AG/SAG mills in good health.

AG/SAG mill liners and lifters are critical to continuous efficient mining operations. However, their status of liners and lifters are related to the effectiveness of the mills and are not observable while it is running. To check the status, the mills have to be stopped, which means the mineral processing has to be interrupted. To identify the status of liners and lifters online and increase the efficiency of the mills, it is highly desirable to have a method to monitor the liners and lifters in real-time.

In this project, using advanced IoT sensing technology, an accurate model was created for the status of liners and lifters by collecting the data of wireless accelerometers placed on the shell of the mills combined with the shaft rotation angles.

Table 7 below shows BRP2 activities toward project commercialisation, and proposed deliverables at the end of this projects.

Table 7: BRP2 - Predictive Machine Health Monitoring for SAG/AG mills.

Project, Partner	**Implementation Activities 2023 - 2024**	**Value proposition**	**Deliverables**
B RP2 BHP	<u>**Stage 1:**</u> Design and build a demo system to monitor the internal structure of the rotating mill in real-time using wireless accelerometers and encoders. • Maths modelling of the simplified mill. • Simulation of the modal shapes and vibrations of the mill. • Installation of IoT sensors and measurement system. • Empty load testing.	An online health monitoring system for AG/SAG mills will be built and demonstrated on a small-scale laboratory mill. Various operating conditions will be simulated to proof the concept and approach.	Current TRL 4 CRL 1 **Hardware and software:** In this project Engineering Master's students designed and built a demo system to monitor the internal structure of the rotating mill in real-time using wireless accelerometers and encoders.

	• Testing with different load conditions. • Demonstration of the system.		

Key Findings

- Simulation demonstrated the impact of liner removal and wear on vibrational frequency changes and helped identify critical thresholds for maintenance and fault detections.
- Increasing shell thickness to replicate load provides insights into the effects of load on vibrational behaviour.

This project was successfully carried out by Engineering Master's students who studied the effect of the liner health condition on vibration signals that can be measured in real-time using wireless accelerometers. While it has been demonstrated that the performance of AG/SAG mills can be monitored using vibration signals, further work is needed to expand these findings to a larger SAG mill to advance the Technology Readiness Level (TRL) to the next level.

11. PRIF MINING CONSORTIUM LEGACY AND THE PROPOSED IMPACT OF THE TRANSLATION OF THE RESEARCH BY THE END OF THE CONSORTIUM

The Consortium team is working hard to ensure that the legacy of the PRIF Consortium remains alive when it closes on 31st August 2024, that PRIF's findings are efficiently communicated, and the impact on the Australian mining and copper industry maximized. We also want to ensure that there are open avenues for further work to continue and/or expand research that has potential future implementation by translation partners and/or end-users.

The overall impact of the translation of the Consortium research could be significant, as the PRIF consortium has generated a significant body of research and has published over 140 papers to date.

The Consortium Program was designed to create technology solutions to help boost South Australia's copper production by developing tools to integrate and optimise the entire mining value chain by using machine learning, sensors and data analytics.

The Projects of the Consortium are aligned and focussed on the specific areas of interest of BHP Olympic Dam and OZ Minerals (part of BHP now) as the key End-User Partners, whilst also demonstrating the value of integration between the resource, mining and ore delivery in Program A and between the resource, processing and leaching in Program B, as the performance of the downstream stages such as Grinding, Flotation and Tails Leach all critically depend on the feed characteristics presented to the mill.

As discussed above, based on the TRL assessment and recommendations from Industry Partners and the Legacy Group, four (4) potentially implementable projects were selected for commercialisation during the 18 months of the PRIF extension (March 2023 – August 2024):

- **BRP3:** Dr Difan Tang (BRP3) has developed a cost-effective, real-time method for online hydrocyclone overflow particle size-passing fraction sensing by force and acceleration measurements. Although still at the testing stage, this could potentially revolutionise the accurate assessment of the quality of mill discharge and flotation feed, something which is critical for mineral processing. BRP3 is sponsored by BHP.

- **BTP9:** Dr Richmond Asamoah with UniSA team in collaboration with Magotteaux installed the Pulp Chemistry Monitor in the flotation circuit at BHP Olympic Dam for collecting data for the improved predictive flotation model and process performance. This model will deliver significant benefits to the industry, i.e. improve flotation circuit optimisation and copper mineral selectivity; maximize copper production and reduce waste (energy, water and value minerals); lower operating cost; improve downstream unit performance through consistent feed characteristics. BTP9 is sponsored by Magotteaux and BHP

- **ATP4:** Dr Shi Zhao developed a near-real-time 3D stockpile model that enables fast and accurate calculations of quality and quantity distribution within and among ROM (Run of the Mine) stockpiles to improve the blending efficiency and optimise reclaiming process. ATP4 is sponsored by EKA and OZM

- **ARP3:** Yerniyaz Abildin has developed software that offers a new geological domain modelling technique combining geostatistical simulations and classification algorithms, with a pre-processing data validation step. Yerniyaz's software promises significant advantages for industry, i.e. automated data analysis, reduction of human bias and identification of potentially misinterpreted information during geological operations. ARP3 is sponsored by Maptek and OZM.

Translation of the selected technologies will maximise mill throughput and increase copper recovery, reduce energy use and operational cost, provide cost-effective integration processes and improve optimisation.

Even though the selected projects are aligned and focussed to the specific areas of interest of BHP Olympic Dam and Prominent Hill (formerly operated by OZ Minerals), some of them have the potential to be used in other mining environments, and some even in other industries.

The new PRIF technologies will also aid in addressing environmental, social and governance requirements (ESG) such as enabling more sustainable mining and reduced environmental impacts, economic growth and the creation of new jobs for South Australia.

The biggest impact of the Consortium is 18 well-trained scientists (PhDs and Postdocs) in sensors, analytics, and artificial intelligence for the Australian mining industry.

In addition, the Consortium outcomes have commercial potential for the Translation Partners and the End-users, and they have also leveraged new research opportunities for the Research Partners. Please see the PRIF Consortium initiatives as a measure of the Government investment efficiency in SECTION 12 below. The PRIF Mining Consortium leveraged funding for 7 years of PRIF Program is **$49,117,169**.

Potential additional funding to develop further Consortium projects beyond the PRIF Program:

- ATP4 (Shi Zhao) and BRP3 (Difan Tang) are considering applying for Australia's Economic Accelerator (**AEA**) grants for round 4 later this year.

- ARP3 (Yerniyaz Abildin) will apply for the following research grants from the International Association for Mathematical Geosciences (IAMG) to continue the domain modelling project beyond the PRIF end date. Applications will be based on his PhD and the post-doctoral work:

  • Computers & Geosciences Research Scholarships

  • Founders Scholarship

- The UniSA team in collaboration with Magotteaux has submitted the CRC-P application to continue BRP5, which (if successful) will provide longer term funding allowing to build a prototype of the MOF-based sensor and its implementation in the PCM.

Overall, the Consortium will leave a substantial legacy, which can be split into the following:

(1) Adelaide (and implicitly, the two participating universities) will have established itself as a national powerhouse in leading high-level integrated research that addresses optimisation of mining, comminution, and mineral processing, in which a trans-disciplinary approach has proven successful in achieving results of broad value to SA industry and with application far beyond. CIs in the two universities will continue to attract funding and students to follow research themes developed within the Consortium.

(2) The Consortium will have made a significant contribution to the training and upskilling of 18 young researchers who possess a unique set of skills in the critical areas of sensors, data analytics and artificial intelligence for complex resources and ready to enter the industry workforce. Each of these researchers will be high achievers in their own fields but have also had the benefit of the broad context and industry-related format offered by working as a team within a Consortium. We would hope that the Consortium has also engendered a culture of

teamwork, collegiality, and an ability/desire to think outside individual discipline-defined comfort zones.

(3) Whether outcomes are implemented on-site or not, the participating companies will be far more aware of the opportunities to develop and optimise their operations offered by cutting-edge research of the type carried out within the Consortium.

(4) The Consortium, together with its outputs and researchers, have received recognition across the minerals engineering community. These achievements, and the levels of trust and partnership inferred by the successful collaboration have been and will continue to be important in securing funding and partners for future projects: ARC 'Integrated Operations' Training Centre; and 'Copper for Tomorrow' CRC Bid (2023); etc., with doubtless others to follow.

$Multi-million dollar savings

Potential economic impact arising from
2% increase in copper recovery
15% increase in throughput
17% increase in copper production

$49m additional funding leveraged	over **140** papers published	**25** translation and research projects	**21** collaboration partners during lifetime of PRIF
18 young researchers upskilled	**17** women in mining scholarships awarded	**15** experienced mining, mineral processing and computer science researchers	**10** higher degree by research students
8 postdoctoral researchers	**7** years of collaboration and research	**4** commercialisation projects	**1** commendation award

12. CONSORTIUM INITIATIVES AS A MEASURE OF THE GOVERNMENT INVESTMENT EFFICIENCY

Currently, the PRIF Consortium managed to leverage additional funding (cash and in-kind) through funding from PRIF Partner Organisations and competitive research grants such as ARC Training Centres, ARC Linkages, CRC-Ps and others totalling **$49,117,169** for 7 years of the PRIF Mining Consortium operations (Tables 8 and 9).

There is a total of $4,470,000 of DIIS funding for all years (cash), including $470K for the PRIF extension [SECTION 13].

Table 8 shows a list of Consortium and other relevant initiatives in the resources area and demonstrates the indirect legacy of the PRIF Consortium, and the efficiency of the Government investments in the PRIF Consortium. The PRIF Consortium acts as springboard into other funded initiatives.

Long-term Return on Investment (ROI) difficult to estimate at this stage. It could, however, make a very significant difference if all of these initiatives are successful.

Table 8. List of Consortium and other relevant initiatives in the resources area as a measure of the Government Investment Efficiency.

N	PRIF Initiatives	Comments	Award, $
1	**ARC Training Centre "Integrated Operations for Complex Resources"**: University of Adelaide (IMER), University of South Australia and Curtin University End-Users: BHP and OZM Participants: Professor Peter Dowd etc.	The Training Centre formally commenced in 2020 with a duration of 6 years.	**$11.75M**
2	**ARC Linkage:** A Machine Learning driven flow modelling of fragmented rocks in cave mining University of Adelaide, School of Civil, Environmental and Mining Engineering/ OZ Minerals Participants: A/Prof Murat Karakus etc.	project success in 2020	**$516K**
3	**ARC Linkage:** Critical metals from complex copper ores University of Adelaide, School of Civil, Environmental and Mining Engineering/ BHP Olympic Dam Participants: Professor Nigel Cook etc.	project success in 2020	**$456K**
4	**ARC Training Centre in Critical Resources** Participants: Prof Nagel Cook etc.	project success in 2023	**$5M**

5	Funding received from **EnviroCopper Ltd:** Stage 2 - Model development for the in-situ recovery of copper minerals. Participants: Prof Peter Dowd and A/Prof Chaoshui Xu	project success in 2023	**$87K**
6	**CRC-P:** In-place recovery: Solution mining of critical minerals. Participants: Prof Peter Dowd and A/Prof Chaoshui Xu	project success in 2023	**$2,4M**
7	Funding received from **Newcrest Mining** To investigate further aspects of pyrite oxidation modelling of gold stockpiles. Participants: Prof Peter Dowd and A/Prof Chaoshui Xu	project success in 2023	**$188K**
8	**CRC-P:** Vertically integrated battery anode material development program. Participants: Prof Bill Skinner and A/Prof Max Zanin etc.	project success in 2023	**$514K**
9	**Australia's Economic Accelerator SEED Grants:** Transforming Australian regions for sustainable development: a novel approach to efficient metal recovery for cleaning contaminated sites Participants: A/Prof Larissa Statsenko and Prof Nigel Cook etc.	project success in 2023	**$298K**

Table 9. PRIF Consortium leveraged funding for 7 years of the PRIF Mining Consortium operations (2017 – 2024)

Organisation	Cash, $	In-kind, $	Total Amount, $
UoA	1,200,000	4,894,998	6,094,998
BHP	600,000	1,200,000	1,800,000
OZM	-	900,000	900,000
UniSA	400,000	1,050,000	1,450,000
PRIF Industry Partners	-	3,710,000	3,710,000
ARC Training Centre for Integrated Operations for Complex Resources	5,586,000	6,160,000	11,746,000
ARC Linkage: A Machine Learning driven flow modelling of fragmented rocks in cave mining	516,000	484,000	1,000,000
ARC Linkage: Critical metals from complex copper ores	456,000	544,000	1,000,000
ARC Training Centre in Critical Resources	5,000,000	6,250,000	11,250,000
Funding received from **EnviroCopper Ltd:** Stage 2 - Model development for the in-situ recovery of copper minerals.	87,000	174,000	261,000
CRC-P: In-place recovery: Solution mining of critical minerals.	2,415,000	3,563,578	5,978,578
Funding received from **Newcrest Mining** To investigate further aspects of pyrite oxidation modelling of gold stockpiles.	188,000	376,000	546,000
CRC-P: Vertically integrated battery anode material development program.	514,000	1,123,880	1,637,880
Australia's Economic Accelerator SEED Grants:	298,000	1,444,713	1,742,713

Transforming Australian regions for sustainable development: a novel approach to efficient metal recovery for cleaning contaminated sites.			
Total	**$17,260,000**	**$31,875,169**	**$49,117,169**

13. UPDATE ON THE AUSTRALIAN RESEARCH COUNCIL INDUSTRIAL TRANSFORMATION TRAINING CENTRE FOR INTEGRATED OPERATIONS FOR COMPLEX RESOURCES

Key Result Area 4 of the PRIF Consortium required a submission to the ARC Industrial Transformation Training Centres Programme for a Training Centre entitled Integrated Operations for Complex Resources. The intention was that the Training Centre would underpin and complement the PRIF Consortium. The Training Centre application was successful, and the formal award was made on 7th November 2019 with the Collaboration Agreement signed by all Parties and a commencement date of the 27th August 2020.

The Training Centre was originally funded to operate for four years (2020-2024), however due to delays in recruitment caused largely by COVID, the Training Centre has received a two year extension approved by the Australian Research Council with a new end date of 26th August 2026. The total project award has not changed, and is still $11.75M, comprising $3.7M in cash from the ARC; $916k in cash and $3.2M in-kind from industry partners; $970k in cash and $2.96M in-kind from the research (university) partners.

The Training Centre is led by the Director, Professor Peter Dowd and comprises:

- Three Research partners: University of Adelaide, University of South Australia and Curtin University.
- Two end-user partners: BHP and OZ Minerals. However, due to BHP acquiring OZ Minerals in 2023, BHP now owns all the mine sites that were formally associated with the Training Centre – Olympic Dam, Carrapateena and Prominent Hill. The OZ Minerals Think and Act Differently technology and resource development group has been maintained within BHP.
- Twelve Partner investigators: Veracio, Bureau Veritas, CRC ORE, Dassault Systèmes, Magotteaux, Manta Controls, Maptek, Matrix Group (Eka Software Solutions), MZ Minerals, Orica, Petra Data Science and RoqSense.
- Six Supporting partners: AMIRA, METS Ignited, Resources and Engineering Skills Alliance (RESA), Rockwell Automation, Scantech, South Australia State Government Department for Energy and Mining.
- A Business Manager, 20 academics (Mining Engineering, Mineral Processing, Geology, Computer Science, Mechanical Engineering, Chemical Engineering, Mathematics, Biology), 16 PhD students and three Postdoctoral Researchers.

The aims of the Training Centre are:

(1) to deliver the enabling tools – advanced sensors, data analytics and Artificial Intelligence – for automated, integrated and optimised mining.

(2) to train the next generation of scientists and engineers in the critical areas of sensors, data analytics and artificial intelligence for complex resources, a current knowledge priority for the mining industry.

A significant, defining feature of this Training Centre is an inter-disciplinary approach to the inter-disciplinary construct of optimising the entire mining value chain rather than independently optimising the component parts of the value chain. The emphasis is on horizontal and vertical integration of research and technology.

During the period from April 2023 to June 2024 the Training Centre has achieved the following milestones:

- An offer has been made to a candidate to fill the remaining Postdoctoral Researcher position at the University of Adelaide, he is expected to start mid-July 2024;
- A Postdoctoral Researcher left and a new Postdoctoral Researcher has started at the University of South Australia;
- All 16 PhD scholarships have been filled, the first time since the Training Centre started;
- The Executive Management Committee oversees the governance and operation of the Training Centre and has met three times in this 12-month period;
- The Advisory Committee met twice during 2023 and provided high level strategic advice to the Centre;
- There have been four Science Advisory Committee meetings during this 12-month period. Over the four meetings twelve different Training Centre Scholars provided an overview of their Projects and received positive feedback and advice from the independent international committee;
- Fortnightly Training Centre Seminars continue;
- Fortnightly Research Meetings have continued to include presentations of the research conducted by PhD Scholars and Postdoctoral Researchers;
- The Training Centre co-hosted an exhibition booth with the PRIF Consortium at METPLANT 2023, Austmine 2023 and the South Australian Exploration in Mining conference in December 2023;
- Training Centre PhD Scholars promoted their research at a number of conferences in 2023, including the 34th Australian Colloid and Surface Science Student Conference in Melbourne in January 2023, Comminution in South Africa in May 2023, CRITCON in Adelaide in May 2023, Austmine in Adelaide in May 2023, the World Mining Congress in Brisbane in June 2023, the 9th Bubble and Drop Conference in Poland in June 2023, the Australia and New Zealand Nano and Microfluidics Conference in Adelaide in July 2023, the Modelling and Simulation Conference in Darwin in July 2023, METPLANT in Adelaide in November 2023, and the South Australian Exploration and Mining Conference in Adelaide in December 2023;
- PhD industry placements have been undertaken at Petra Data Science, Orica, Manta Controls, Scantech, Magotteaux, Bureau Veritas, Veracio, the Australian Synchrotron and the National Core Library;
- The fifth and sixth Research Review Meetings were held on the 25th September 2023 and the 23rd April 2024, respectively. PhD Scholars and Postdoctoral Researchers presented their research and Project plans to Training Centre members;
- A Training Centre commercialisation group has been formed to discuss commercialisation outputs of the HDR projects. The commercialisation group consists of two people from the University of Adelaide – Peter Dowd and Francois Duvenage, and two people from the University of South Australia - William Skinner and Atif Majeed;
- On the 12th April 2024 we had an on-line meeting at which each of our Training Centre PhD Scholars presented their work to the Think and Act Differently (TAD) group who were previously embedded within OZ Minerals, and are now continuing within BHP. Five minutes were allocated for each PhD presentation followed by five minutes discussion led by TAD members. It was agreed that we would continue with similar meetings, but at a more highly focused level, in the hope of achieving different ways towards commercialisation; and

- The Training Centre successfully met its 2023 Australian Research Council KPIs and submitted the Australian Research Council Progress Report in March 2024.

14. OVERALL CONSORTIUM INCOME – CASH AND IN-KIND FOR 7 YEARS OF THE PRIF MINING CONSORTIUM

Table 10 below shows overall Consortium Income secured for research in South Australia, including internal and external cash and in-kind contributions for seven (7) Financial Years (2018 – 2024).

There is a total of $4.47 million of DIIS funding for all years and $2.2 million from BHP Olympic Dam, and the two universities, plus $11.7 million in-kind support from research and industry partners. Overall Consortium income is ~$18.4 million.

Please note, the overall Consortium Income has increased from the previously reported $14.1M to $18.4M due to the increase in DIIS funding of $470K for the 18-month PRIF extension, as well as in-kind contribution from the PRIF Research and Translation Partners and End-Users.

Table 10. Overall Consortium Income – Cash and In-Kind for 7 years of the PRIF Mining Consortium

	2017-2018 FY1 PRIF Payment 1: Oct 2017 PRIF Payment 2: Apr 2018		2018-2019 FY2 PRIF Payment 3: May 2019		2019-2020 FY3 PRIF Payment 4: June 2020		2020-2021 FY4 PRIF Payment 5: June 2021		2021-2022 FY 5 PRIF Payment 6 - Jul 2022		2022 - 2023 FY6 PRIF Payment 7: March 2023		2023-2024 FY7 PRIF Payment 8: July 2024		Total		Total cash and in-kind
	cash	in-kind	cash	in-kind	cash	in-kind	cash	in-kind	cash	in-kind	cash	in-kind	cash	in-kind	cash	in-kind	
PRIF	$500,000		$800,000		$1,000,000		$1,000,000		$200,000		$400,000		$70,000		$4,470,000		$4,470,000
PRIF	$500,000																
UoA	$300,000	$815,833	$300,000	$815,833	$300,000	$815,833	$300,000	$815,833		$815,833		$815,833			$1,200,000	$4,894,998	$6,094,998
UniSA	$100,000	$175,000	$100,000	$175,000	$100,000	$175,000	$100,000	$175,000		$175,000		$175,000			$400,000	$1,050,000	$1,450,000
BHP	$350,000	$200,000	$140,000	$200,000	$80,000	$200,000	$30,000	$200,000		$200,000		$200,000			$600,000	$1,200,000	$1,800,000
OZ Minerals		$150,000		$150,000		$150,000		$150,000		$150,000		$150,000				$900,000	$900,000
Translation Partners		$650,000		$585,000		$605,000		$700,000		$585,000		$585,000				$3,710,000	$3,710,000
Total	**$1,750,000**	**$1,990,833**	**$1,340,000**	**$1,925,833**	**$1,480,000**	**$1,945,833**	**$1,430,000**	**$2,040,833**	**$200,000**	**$1,925,833**	**$400,000**	**$1,925,833**	**$70,000**		**$6,670,000**	**$11,754,998**	**$18,424,998**
Total Cash and In-kind	**$3,740,833**		**$3,265,833**		**$3,425,833**		**$3,470,833**		**$2,125,833**		**$2,325,833**		**$70,000**		**$18,424,998**		

It should be noted that to date in-kind contribution has been provided in line with the agreement requirements.

Also note, that the last DIIS tranche of $70,000 should be paid in July 2024 after this final report submission.

15. FINANCIAL REPORT 1st MARCH 2023 – 31st AUGUST 2024

This Financial Statement was provided by the Financial and Research Accounting Services of the University of Adelaide on 26th June 2024. The report covers the period from 1st March 2024 to 31st August 2024.

Please note that the balance of funds (paid by the Minister) is -$70K as at 31st August 2024, as the remaining salaries of fixed-term staff until the end of August 2024 have been calculated and adjusted.

Overall, the Financial Report looks healthy. As mentioned above, we expect the last DSD (formerly DIIS) tranche of $70,000 in July 2024 after this report submission, it will bring the DSD/DIIS account balance to zero by the 31st of August 2024.

Financial Statement
Unlocking Complex Resources through Lean Processing
PRIF - Research Consortia Program - RCP 5 - Chief Investigator Nigel Cook

THE UNIVERSITY *of* ADELAIDE

EXPENDITURE

Reporting period - 1 March 2024 To 31 August 2024

INCOME	COMMENTS	$
Opening Balance – 1 March 2024		**148,245.78**
Funds received from the Minister for Industry, Innovation and Science		0.00
Income received from other parties:		
BHP Billiton Olympic Dam Corporation P/L		-
University of South Australia		-
The University of Adelaide		-
Interest Income		-
TOTAL INCOME FOR THE REPORTING PERIOD		**0.00**
EXPENDITURE OF FUNDS (being only the Funds paid by the Minister) (*some examples provided below, delete those which are not relevant*)		
Salary UoA	UoA	188,213.65
Salary UniSA	UniSA	0.00
Scholarships/Stipends	UoA	20,850.35
Scholarships/Stipends	UniSA	0.00
Consultant – MZ Minerals	UoA	0.00
Operating – Equipment & Maintenance	UoA	4,684.60
Operating – Equipment & Maintenance (Chemicals, Laboratory consumables, Flurophotometer)	UniSA	0.00
International Collaborators		0
Travel - Domestic	UoA	4,497.18
Travel - Domestic	UniSA	0.00
External Services (AMIRA)	UniSA	0.00
Other Expenses (please list) - *FBT Expense Payment*		0
Total Expenditure of Funds (paid by the Minister) for the reporting period		**218,245.78**
Surplus (Deficit) for the reporting period		**-218,245.78**
BALANCE OF FUNDS (paid by the Minister) AS AT 31 August 2024		**-70,000.00**

Certification by the Chief Investigator

I certify that:

All details in this Progress Report are true and complete and that this is an accurate Progress Report for the period covered.

Signed by

Name: Nigel Cook

Certification by the Recipient

This Progress Report has been verified by the Recipient Representative as accurate and a true representation by the Recipient of the use of the Funds.

Hommema.

Digitally signed by Tanya Hommema, CPA
DN: cn=Tanya Hommema, CPA, o=University of Adelaide, ou=Manager, Financial and Research Accounting, email=finresearch@adelaide.edu.au, c=AU
Date: 2024.06.25 13:38:23 +09'30'

Signed by ______________________

16. POST PROJECT MANAGEMENT

We requested retention of the Consortium name and identity for 3 years after the end of the project in August 2024 from the Department of State Development (formerly known as the Department of Industry, Innovation and Science - DIIS), for purposes of communication and marketing. The formal request was submitted by email on 28th June 2024. At the time of this report writing, **we are waiting for DSD approval.**

The Director will continue to act as a contact person, supported by professional staff within the Institute for Sustainability, Energy and Resources, ISER (formerly known as the Institute for Mineral and Energy Resources, IMER), University of Adelaide.

The Consortium website and file-sharing/archiving systems would continue to operate during this period (3 years).

PRIF projects - BRP3 and ATP4, are extended until 31st December 2024 beyond the PRIF end date. Dr Difan Tang and Dr Shi Zhao will continue their research to achieve the strategic objectives of their respective projects and move further towards commercialisation of their developed technologies.

In case of any surplus at the end of the PRIF Consortium Program in the Consortium Industry Fund, we are considering the possibility of further extending potentially implementable projects, such as BRP3 and ATP4, under their respective schools' governance.

APPENDIX 1 ATP4 - FINAL RESEARCH REPORT 2023 - 2024

ATP4: Fast ROM stockpile modelling for blending optimisation

Researcher(s): Dr Shi Zhao

Chief Investigator(s): Dr Tien-Fu Lu, A/Prof Larissa Statsenko

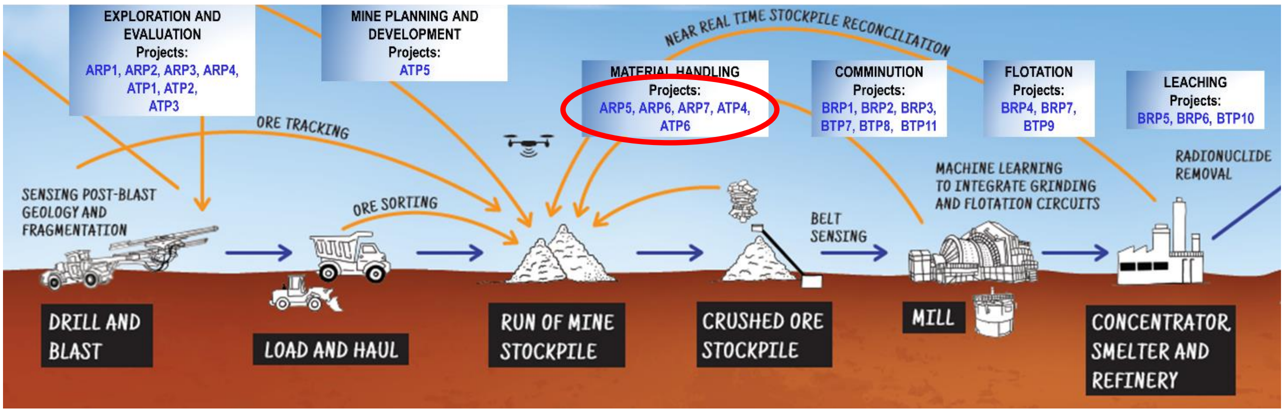
Commenced: 1st March 2023

Completing: 31st December 2024

Industry partner: Eka

TRL 6

CRL 1



This report is the final research report for the Translation Project ATP4 '3D ROM stockpile modelling' and covers activities from 1st March 2023 to 30th June 2024.

'3D stockpile modelling enables optimised reclamation in near real-time'

Introduction/Background

Iron Oxide Copper-Gold (IOCG) ores typically contain a complex range of impurities. Some of these impurities lower the value of ores because they can be detrimental to the environment and/or human health, cause equipment corrosion, and generate hazardous residues. Custom copper smelters impose substantial financial penalties to the presence of deleterious impurity elements (Lane et al., 2016). Therefore, customers use the grade and the grade consistency in price and quantity negotiations. As a result, producers are keen to control or remove penalised impurity elements from the beginning of the mining processing and maintain a low-grade variability throughout the process chain. ROM (Run Of Mine) stockpiles allow valuable ore to be stacked in different locations at stockyards based on its quality and reclaimed depending on the quality and quantity required for future processing. They play a critical role in quality control, ensuring that the ore meets the necessary standards throughout the process chain.

ROM stockpiles are widely used as buffers and blending units for quality control between mines and processing plants. They are generally located near the mine site where the raw ore is extracted. The blending function is achieved through two opposing processes. Ores with different quality parameters are stacked selectively into/onto different stockpiles. Loaders reclaim stacked ores from distinct locations within one stockpile or among multiple stockpiles. The mix of different grade ores will happen naturally during the reclaiming operations. Thus, Stockpile blending is widely recognised as an effective and primary method to reduce short term quality variations. However, it is difficult to achieve efficient and effective blending at most processing plants due to high heterogeneity of ore quality in situ and hence low accuracy of the ore quality information coming straight out of the mine. Currently, the most accurate quality assay result about the ore body carried by a haul truck is acquirable within 24 to 72 hours after receiving a sample. For this reason, the quality of the reclaimed material or mill feed is not available with the highest degree of accuracy. Once the material has been reclaimed from ROM stockpiles, it is too late to make the quality control more efficient. It must happen at stockpiles, or value will be lost from that point onwards. Solutions to this challenge do not currently exist commercially. Our modelling techniques and optimisation system minimise the negative consequences caused by lagging chemical assay results since they can serve as placeholders for the quality data.

Key Findings

Generate/update 3D quality-embedded stockpile models in near real-time using operational data from a mining site.

Integrate such models with research outcomes obtained from RP5 project, resulting an optimisation system that meets the required quantity and quality with minimal violation factors (higher priority), and reduce the reclaiming time (lower priority).

Outcomes

1. An Invention Disclosure was submitted.
2. This project has developed two demonstration systems with an aim of increasing the TRL/CRL for this project. Both demos can display the quality embedded 3D stockpile models and are able to show the optimised reclaiming sequences for three front-end loaders in future (FELs).
    a. The small-scale system using self-developed Python program - Integrated such models with research outcomes obtained from RP5 project, resulting in an optimisation system that meets the required quantity and quality with minimal violation factors

(higher priority), and reduces the reclaiming time (lower priority). The small-scale demo is close to completion and is accessible to public through this link.

b. The real-scale system using Eka's software: Insight CM - Generated/updated 3D quality-embedded stockpile models in near real-time using operational data from a mining site. All integration tasks will be completed by December 2024.

Project aims

- To change current selectively stacking techniques in stockpile management and quality control systems to proactively reclaiming techniques.
- To implement Eka's modelling techniques for stacking operations and analyse its performance.
- To demonstrate the optimised reclaiming sequences for multiple front-end loaders (FELs) using the mine operational data.
- To move project to a higher TRL/CRL and increase the chance of commercialization.

Technology overview

This project creates 3D dumping models through computer simulation in nearly real-time using widely available operational data at most mining sites. Key inputs for the modelling process include dumping locations, truck headings, tonnages, ore density, and the angle of repose. It only needs an average of 8 seconds to generate such a dump model after receiving an input. Additionally, the quality of each model is linked to the chemical assay results when they become available, resulting a multi-layered stockpile mode. Such multi-layered, quality-embedded models ensure the highest degree accuracy in calculation results for the quality and quality distribution of the stacked ore.

To optimise reclamation for FELs, a group of operational constraints, including quantity and quality, operational cost, safety and precedence, is produced automatically from 3D stockpile models and the specifications of FELs. Most importantly, stockpile models are further partitioned into nodes. These nodes have the same widths and depths, which are identical to the width of a loader bucket. Each node has a shape similar to a voxel in three-dimensional space, but its top surface is simplified to match the surface of a stockpile. The quality and quantity of each node is calculated separately because these nodes typically contain materials from different dumps. These nodes are considered as basic reclaiming units for optimisation and can be reclaimed from eight compass directions. Two different optimisation algorithms developed in PR 5 have been integrated into the stockpile models so far. We are currently working on integration of the last optimisation algorithm. The results (optimise reclaiming sequences) are demonstrated in a real-scale model through Eka's Insight CM software and in a small-scale model through self-developed Python program.

The real-scale demonstration (RSD) accepts the load-haul-dump data, provided by the end-user partner, BHP, as messages and generates a 3D model for each dumping event. The quality for each dumping model is associated with the quality assay results from the grab sample data. Fig. 1 illustrates some of these dump models and quality information about these modes. These models will be exported as point clouds and then imported into the optimisation system. The final optimised results will be sent back as messages for display purpose.

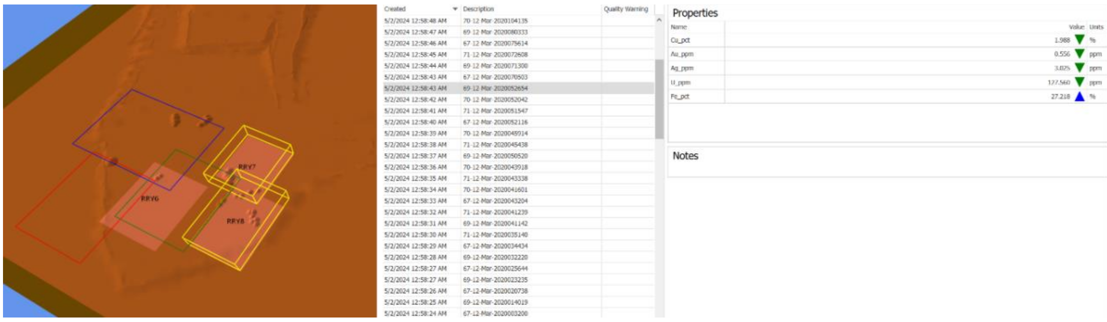


Fig. 1. 3D dumping models and their quality information showing the Insight CM

The small-scale demonstration (SSD) follows almost identical processing steps and offers same functions as the RSD. However, it uses the monthly scanning stockpile models provided by the end-user partner, BHP. Its interface is designed as a webpage. The benefits of having such a system are that the optimised reclaiming sequences can be illustrated as a table and an animation. The SSD is accessible to public through the link. Fig. 2 shows stockpile models and their nodes in SSD.

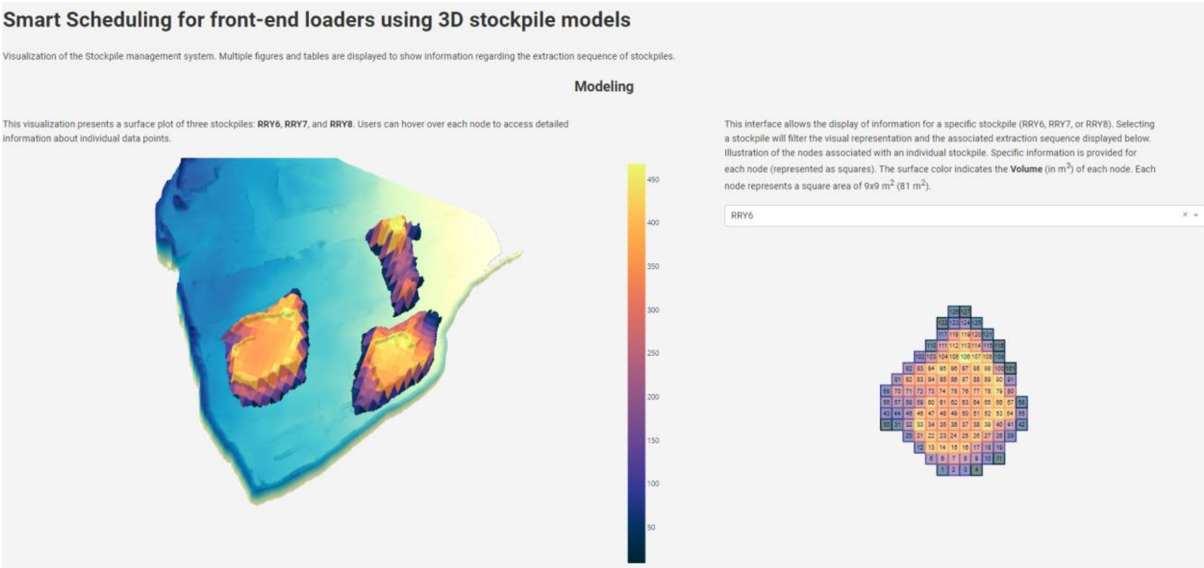


Fig. 2. 3D stockpile modes are divided into nodes and displayed in the SSD.

The optimisation system allows users to adjust required quality and quantity and apply different optimisation algorithms. By the time of submitting this report, it supports one FEL only, but its capability will be extended to accommodate three FELs by the end of this year at the latest. The optimised reclaiming sequences are exported as a csv file. Table 1 summarise one of the optimisation results for 11 reclaiming requests for one FEL. Fig. 3 shows the utility factors (time over tonnage) for these 11 requests. A utility factor denotes that the objective is to reclaim more material in a shorter time to reduce operating costs.

Table 1. A summary of reclaiming requests produced by deterministic greedy algorithm. The violation factor is calculated from the penalty function, which is formulated from the target quality. It is zero when there is no violation in the penalty function.

Target quality	Cu (pct)	U (ppm)	F (ppm)
Lower limit	0.25	0	0

Upper limit	2.5	130	12000
Job request	Each request needs 24,000 tonnes. The completion of 11 requests results in approximately 260,000 tonnes.		
Violation factors	First 8 requests: 0		
	Request 9: 3.41	Request 10: 2.31	Request 11: 7.9

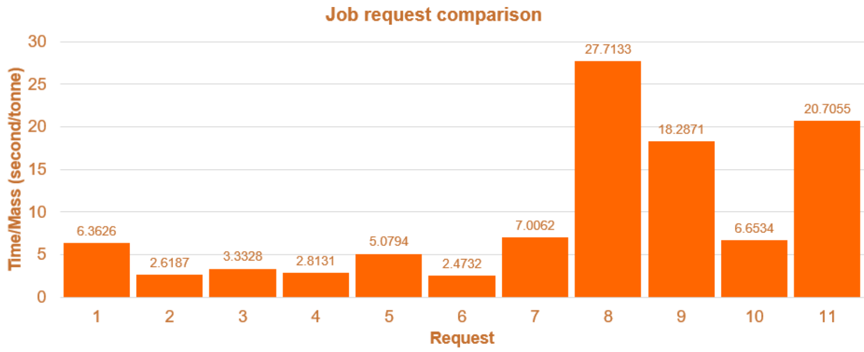


Fig. 3. Utility factors obtained for the optimised solutions

Benefits to industry and the wider community

Geologists or operation managers will gain a better insight into the quality of stacked materials and even the quality distributions within a stockpile through these quality embedded 3D stockpile models. They can apply this knowledge in on-site decision-making. For example, directing haul trucks to different dumping locations to adjust stockpile quality or instructing FELs to reclaim materials from stockpiles to meet required quantity and quality standards. Additionally, researchers can use these models as a platform and apply different optimisation algorithms to control the quality and reduce the operational costs in blending for short- or long-term purposes. This project produced a proactive solution for reclaiming operations that reduces the complexity of stockpile blending optimisation problem. Given the key contribution of this project is to meet the required quantity and quality with minimal violation and reduce the reclaiming time, it will improve blending efficiency, reduce operational cost, minimise waste, improve the grade consistency, and increase the value of exports.

Applications

IOCG ore is used as a case study to improve the quality control in blending. However, techniques developed by this project are applicable for most bulk material handling operations, such as iron ore, black coal, and bauxite. Furthermore, the integration of modelling and optimisation can be used at any ROM stockyards, processing plants, ore exporting ports, which aim to control the quality and reduce the variations through stockpiles.

Potential Value

In 2019, Australian mineral exports (excluding petroleum products) amounted to approximately $234 billion, this project can realise two aspects of enormous value. If we can improve the quality control of ore, concentrate, or metal by a conservative 1%, it would translate into approximately $2.34 billion in value to our economy. Additionally, the increased efficiency in capital expenditures (CapEx) and operating expenditures (OpEx) for the mines and processing plants could add even more value. This will increase operational margins for mines, extend the life of mines, and provide greater overall value.

If one mine alone can lose as much as $100 million per annum through inefficient stockpile management, imagine what that might translate to across our entire mining industry, worth over $400 billion per annum to Australia.

Potential Market

At the beginning of the PRIF extension period, we also explored stockpile modelling techniques using CoppeliaSim, a physics simulation engine. It can simulate the truck dumping process through generating random shaped rigid bodies to mimic the interaction between the ore bodies. The results indicated that it requires a more powerful CPU and GPU to run these simulations effectively. Considering the time and efforts needed, we did not proceed further with this technique. However, there are also many Discrete Element Method (DEM) technology companies in the market offering such physics engines and simulations. Additionally, another modelling solution is to continuously scan stockpiles using sensors such as a 3D laser scanner. This method produces more accurate models compared to simulations. Any Mining Equipment, Technology, and Services (METS) company that provides ore quality optimisation solutions for mining operators could further investigate these two options. Subsequently, the modelling and optimisation system could be developed into a standard product for their customers.

Eka is a METS company, whose goal is to "Optimise your mine-to-market value chain and maximise operational efficiency by connecting every step from ore to manufacturing for base metals, refined, steel, scraps, concentrates and more." Eka's digital stockyard management system traces the quality of material by individual sample lot as it is moved and blended throughout a terminal using near real-time 3D stockpile models. They have collaborated with the University of Adelaide for over 10 years. It is Eka's business objective is to create a digital twin through accurate 3D modelling and movement processes, which will enable more precise ore mixing. At the beginning of the PRIF extension period, with the assistance from Eka, we prepared a list of tasks to merge the project outcomes into their software. To date, Eka have completed 60% of the tasks and are willing to complete the remainder by the end of this year. There is a high chance that the modelling and optimisation system will become one of the modules in their software suite.

Future work

This project has developed two demonstration systems with an aim of increasing its TRL/CRL. Both proposed systems are scheduled to be completed by the end of 2024. The real-scale demonstration system receives the operational data sets as messages through an application programming interface (API) and produces quality embedded dumping stockpile models in nearly real-time. The remaining tasks are listed below:

1. To create truck load events from current data for reclaiming demonstration (updating stockpile shapes using the cutting surface during reclaiming);
2. To extract 3D dumping models as point cloud data to produce the input files for the optimisation system;
3. To update the In-sight CM software to support voxelised stockpile models;
4. To enable the API function to receive and display optimised reclaiming steps;

The small-scale demonstration system uses the real scanning data for modelling and displays the optimised reclaiming steps in both tabular and graphical formats. The remaining tasks are listed below:

1. To use an animation for reclaiming steps display;
2. To allow users to enter some input parameters, such as, the number of job requests, the greed factor (a local optimal factor), for optimisation;

For both systems, our aim is to optimise the reclaiming sequences for three FELs. At the moment, the program we received only supports a single FEL. We also expect the researcher for the PR 5 project to update the optimisation program to support multiple FELs.

Recommendations

The optimisation results obtained from this project are based on the assumption that there is no stacking operation during reclaiming operations and vice versa. Thus, the next critical upgrade to either or both demonstration system(s) is to enable real-time optimisation capability. For example, once a new quality-embedded model becomes available to the management system, it could be added into the optimisation module to update current reclaiming sequences or produce a new set of reclamation sequences. We are seeking research grants, i.e. AEA Seed funding, to advance this project to a higher level through two aspects: (i) upgrading the system structure to enable real-time optimisation; and (ii) using a physics simulation engine to model dump stockpiles. The completion of these two objectives will further improve the TRL/CRL for this research.

List of publications and conference participations during the lifetime of the PRIF

Journal publications

1. Zhao, S., Lu, T.-F., Statsenko, L., Koch, B. and Garcia, C. (2022), "A framework for near real-time ROM stockpile modelling to improve blending efficiency", Journal of Engineering, Design and Technology, Vol. 20 No. 2, pp. 497-515.
2. Zhao, S., Statsenko, L., Lu, T.-F., Assimi, H, Koch, B. and Garcia, C. "Short term reclamation optimisation for front end loaders (FELs) using quality embedded 3D ROM stockpile models ", Minerals Engineering, under preparation

Conference Participation and Public Presentation

- Poster presentation, The Copper to the World 2024 conference, June 2024, Adelaide
- Oral presentation, 2023 PRIF Final Research Conference, PRIF RCP “Unlocking Complex Resources through Lean Processing”, 18/10/2023.
- Poster presentation, The Austmine 2023 conference, May 2023, Adelaide
- Poster presentation, METPLANT 2023, Novembers 2023, Adelaide
- Poster presentation, The South Australian Exploration and Mining Conference 2023 (SAEMC), December 2023, Adelaide
- Oral presentation, The Copper to the World 2022 conference and PRIF Mining Consortium workshop - “Pathways to Commercialisation and Implementation”, May 2022 (Online).
- Oral presentation, 2022 Annual Assembly, PRIF RCP “Unlocking Complex Resources through Lean Processing”, 22/07/2022.
- Oral presentation, 2021 Annual Assembly, PRIF RCP “Unlocking Complex Resources through Lean Processing”, 01/10/2021.
- Oral presentation, 2020 Annual Assembly, PRIF RCP “Unlocking Complex Resources through Lean Processing”, 02/10/2020.

- Oral presentation, 2020 BHP Workshop, PRIF RCP “Unlocking Complex Resources through Lean Processing”, 21/07/2020.
- Poster presentation, 2019 Annual Assembly, PRIF RCP “Unlocking Complex Resources through Lean Processing”, 13/12/2019.

Acknowledgement

This research has been supported by the SA Government through the PRIF RCP Mining Consortium “Unlocking Complex Resources through Lean Processing.

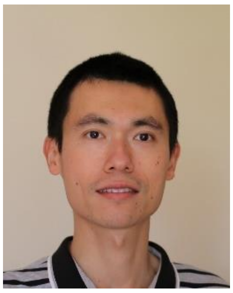
References

Lane, D. J., Cook, N. J., Grano, S. R., & Ehrig, K. (2016). Selective leaching of penalty elements from copper concentrates: A review. Minerals Engineering, 98, 110-121.

APPENDIX 2 BRP3 - FINAL RESEARCH REPORT 2023 - 2024

B-RP3: New Sensor Development for Particle Size Online Measurement at Hydrocyclones

Researcher(s): Dr Difan Tang



Chief Investigator(s): Dr Lei Chen

Commenced: December 2019

Completing: December 2024

Industry partner:

TRL 6

CRL 2

This report is a final research report for the Research Project B-RP4 'New Sensor Development for Particle Size Online Measurement at Hydrocyclones' and covers activities from 1st March 2023 to 30th June 2024.

'A cost-effective method for online analysis of particle size can help deliver energy-efficient mineral processing with economic implementation.'

Introduction/Background

B-RP3 is one of the COMMINUTION Projects (Figure 1). As a classification device, hydrocyclones belong to a comminution circuit and play an important role in linking comminution to flotation as flotation takes its feed from hydrocyclone overflow.

Monitoring particle size-passing fraction (PSPF) at hydrocyclone overflow is critical to mineral processing as it not only assists gauging the quality of mill discharge and flotation feed but also significantly helps enabling closed-loop optimal control for energy-efficient comminution and downstream flotation. Further knowledge on particle size distribution (PSD) in addition to the single number of PSPF can be more beneficial. However, there has been a lack of cost-effective techniques for hydrocyclone overflow PSPF and PSD online sensing, especially when each individual hydrocyclone unit is to be monitored, given the large number of hydrocyclones typically employed on a mine site.

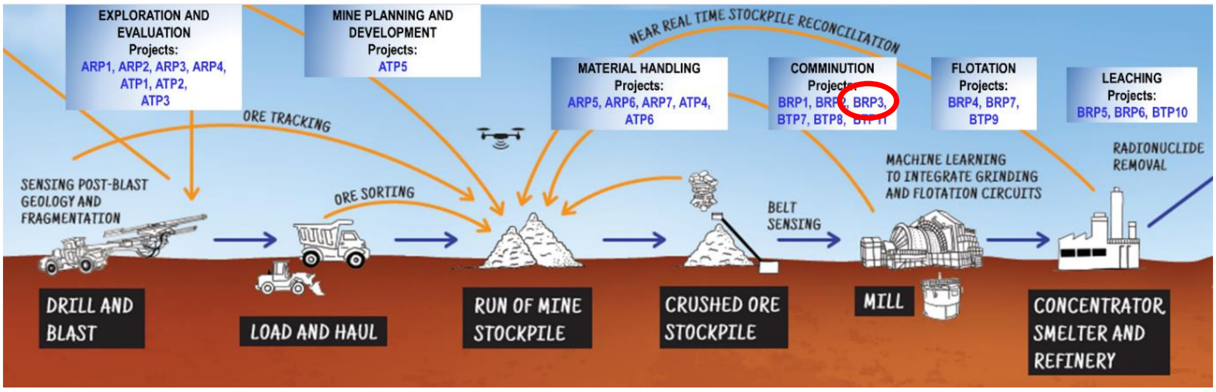


Figure 1: PRIF Mining Consortium projects.

Key Findings

- PSD assessment accuracy can be improved by a hybrid approach based on both the impact mechanics and the bluff-body hydrodynamics (Figure 2).
- The new sensing system is also applicable in Dry Mineral Processing to monitor the density of air/gas-conveyed particles in real-time (Figure 3).

Project Objectives

- Improving PSD assessment accuracy for wet applications under wide particle size ranges and minerals varieties; Installing and testing the new sensing system on industrial hydrocyclones.
- Prototyping a particle density monitor for dry applications; Installing and testing the new sensing system in air classification processes.

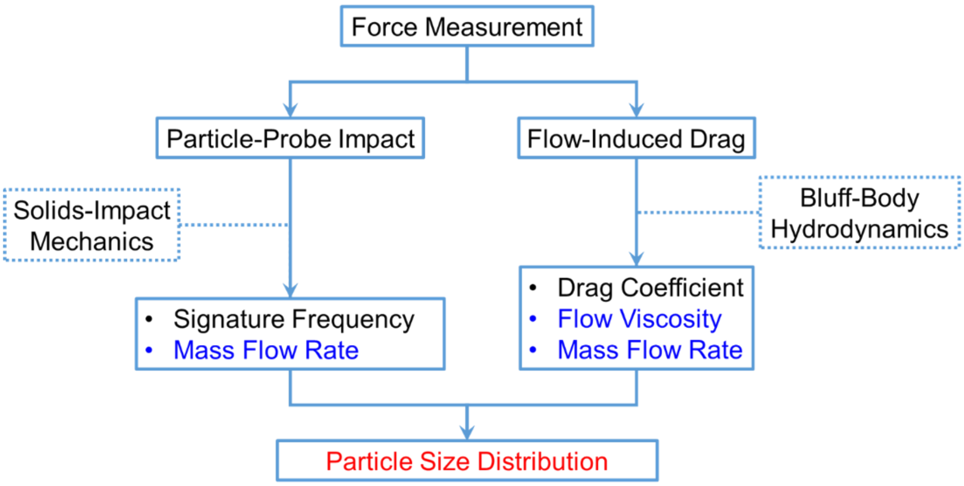


Figure 2: Measurement flow chart.

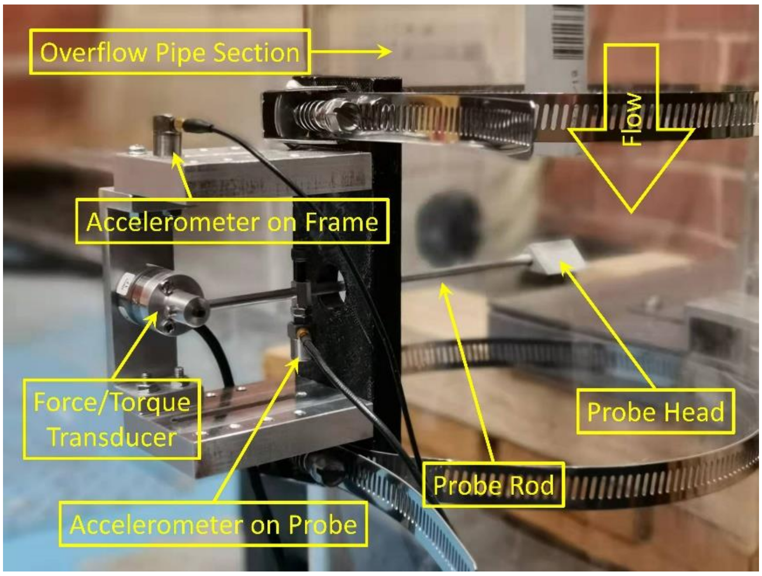


Figure 3: The new sensing system setup for particle density tests.

Technology Overview

The primary function of the new sensing system is to monitor particle size at hydrocyclone overflow in real time through a probe inserted into the overflow pipe. It not only gives a single number of PSPF for target particle sizes but also provides information of corresponding PSD. In addition, it simultaneously offers two auxiliary measurements including mass flow rate and flow viscosity. This represents a cost-effective multifunctional alternative to other existing methods that are single-function, costly and bespoke, and hence is particularly suitable for deployment on, and individual monitoring of, every hydrocyclone unit at a mineral processing plant. In addition to gauging the quality of mill discharge and flotation feed, it enables the integration of automatic control systems for optimal grinding and hydrocyclone operations, which will deliver enhanced quality control and energy-efficient comminution and flotation. Beyond hydrocyclones, the new sensing system is also applicable in Dry Mineral Processing, where particles are conveyed in air/gas systems.

Experimentation and Main Findings

Experimentation at current stage were conducted in laboratory, with wet tests setup shown in Figure 4, and dry tests setups shown in Figures 3 and 5.

Wet tests focused on improving PSD assessment accuracy using ore samples from Australian mines, under solids loading of 10%- 40%. Samples that have been tested were hematite breccia-hosted iron oxide copper ore sourced from hydrocyclone overflow. Results in Figure 6 show that:

- PSPF can be estimated through detecting particle-probe interaction dominated by coarse particles, based on impact mechanics.
- PSD can by synthesised from flow-induced drag characterised by fine particles via bluff-body hydrodynamics.
- PSD assessment accuracy can be further improved by a hybrid approach based on both the impact mechanics and the bluff-body hydrodynamics.

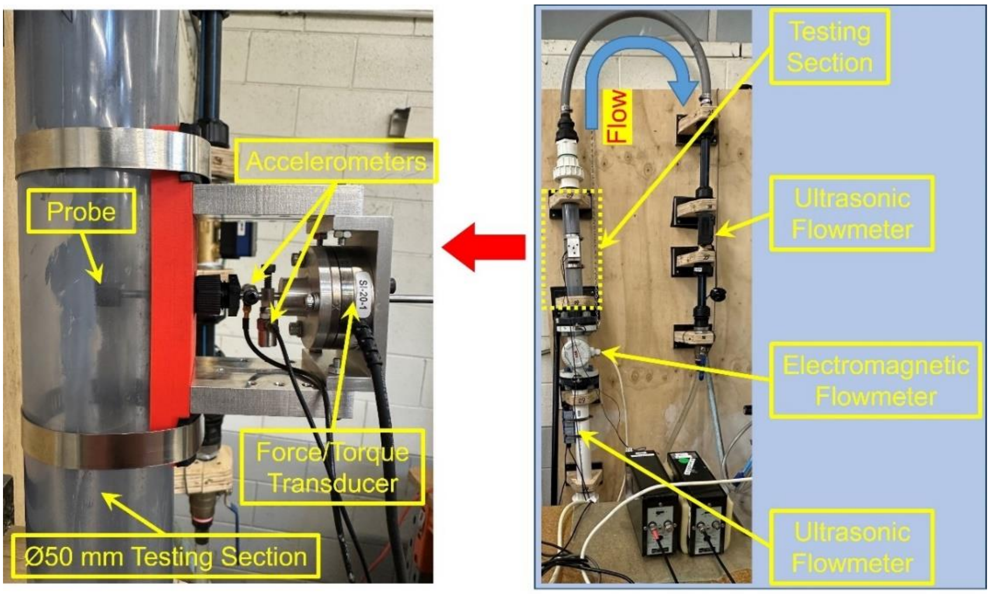


Figure 4: Wet-test setup.

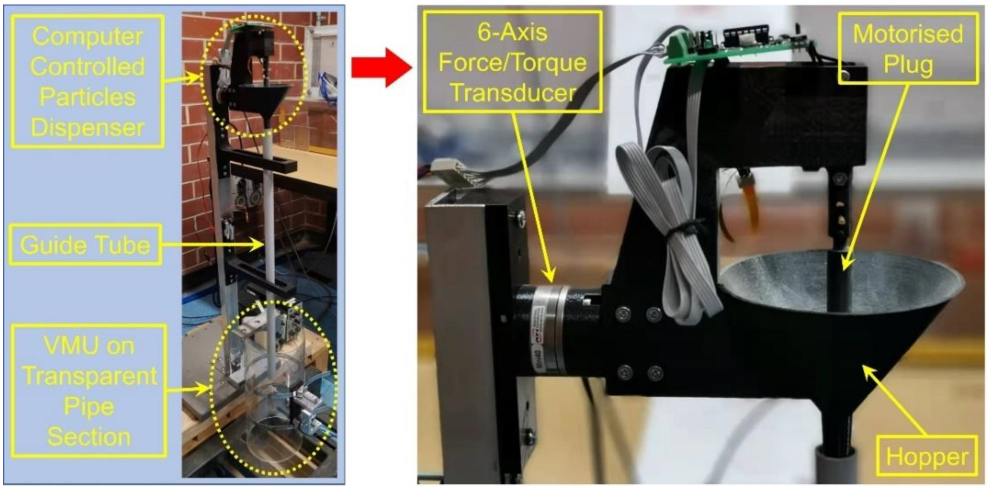


Figure 5: Dry-test setup.

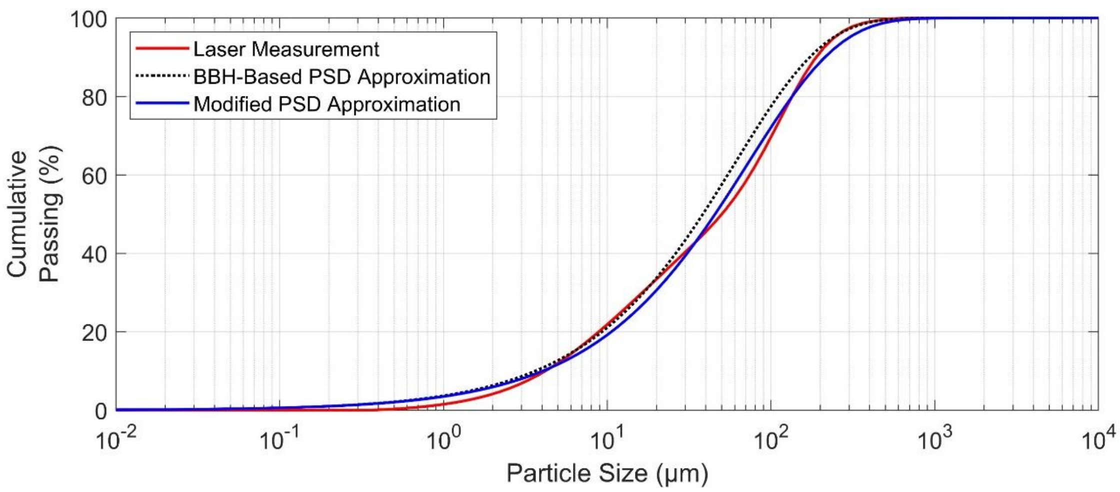


Figure 6: Modified PSD approximation based on solids impact mechanics & bluff-body hydrodynamics (BBH)

For dry tests, the aim was to dynamically monitor density change in the gold-bearing concentrates classified through Rotary Air Concentrators (RAC) developed and used by Nimble Resources in its Alluvial Gold Mining projects. The tests were successful as shown in Figure 7, which confirms that the new sensing system is also applicable in Dry Mineral Processing to monitor the density of air/gas-conveyed particles in real-time.

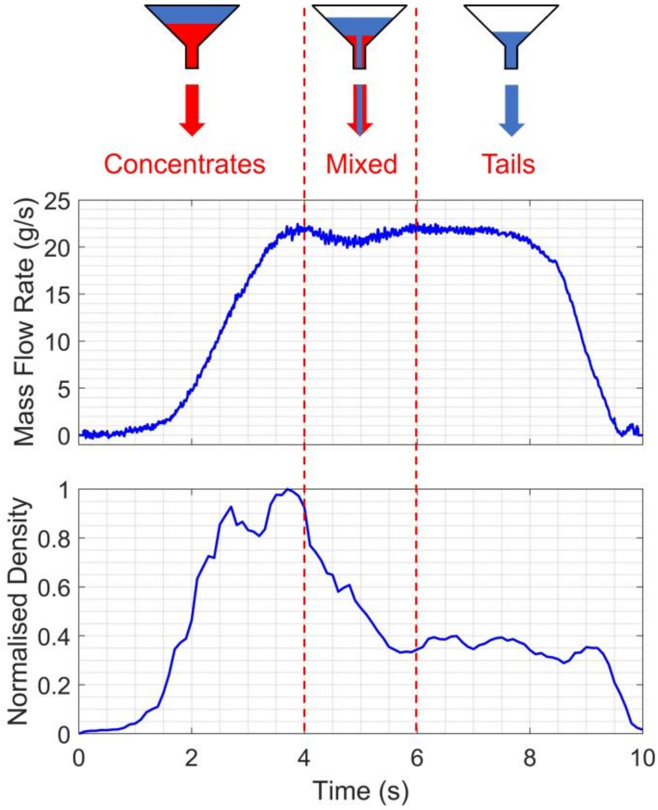


Figure 7: Monitoring density variation in real-time when particles change from concentrates to tails.

Benefits to industry and the wider community

The new sensing system, upon improvement as documented in this report, offer the following benefits to its target industry:

- Easy installation, operation, and maintenance.
- Enabling future integration of automatic control systems for automated and optimised mill and hydrocyclone operation.
- Low-cost deployment (hardware procurement, installation, and ongoing maintenance), less than 10% of the total expenditure required by other existing solutions.

Applications

Applications include both target industries and potentially applicable fields, covering:

- Particle sizing at cyclones and hydrocyclones for classification processes used in all industries.
- Particle sizing of solid-state fuels (e.g., biomass or coal) at power plants.
- Particle sizing for powder (e.g., cement, flour, infant formula, laundry powder, etc.) in powder-related manufacturing industries.

Potential Value

In the mining industry, a cost saving of over 90% is foreseeable for both translation partners and end-users given the total low cost involved in sensor procurement, installation, and maintenance, compared with using other existing technologies. The integration of automatic control using the new sensing system is predicted to enable up to 10% increase in throughput at the same particle size or up to 4.5% reduction in particle size at the same throughput. As an essential part of an automatic control system, the new sensing system will allow cost-effective integration and further benefit translation partners specialising in integrated control solutions (e.g., Manta Controls, Rockwell Automation). Upon establishing optimal grinding and hydrocyclone control, the end-users (e.g., BHP Olympic Dam Mine, Nimble Resources) will gain increased throughput while being able to reduce energy consumption in the meantime.

The product could either be implemented for a single end-user or sold widely. Potential vendors include translation partners and all other entities offering advanced transforming technologies for mineral processing, power plants, and powder manufacturing industries.

Take BHP Olympic Dam (OD) operation as a case study, with the new sensing system installed on every individual hydrocyclone, the total annual benefits is demonstrated in Figure 8. It is worth noting that the assumptions made in the case study are conservative and actual benefits can be more than the value given in Figure 8.

At BHP Olympic Dam Mine

- 2022 financial-year copper production: 138 kt
- Throughput Increase: 1%
- Prevented recovery loss due to faults (roping or plugging): 1%
- Hydrocyclones: 17 units
- Operation: 10 years

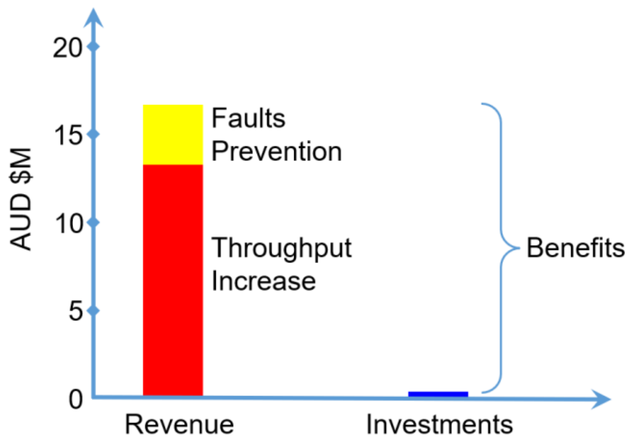


Figure 8: BHP OD case study: estimated additional revenue and sensor investments (per annum)

Similar to online PSD assessment, the density monitoring capability will benefit Alluvial gold production upon sensor integration into the existing RAC control system, enabling optimisation of its classification performance via optimal closed-loop feedback control.

Potential Market

There have been some trials of other existing technologies which on the other hand have demonstrated vast needs. However, these existing technologies under trials are unlikely to constitute any potential competition in terms of being cost-effective. Therefore, the potential market will be highly inclusive, covering companies of all sizes and all industries that require particle sizing.

Future Work/Recommendations

To facilitate laboratory tests with mineral particles from mine site(s), samples have been requested and partially obtained from BHP OD, Bureau Veritas, and Nimble Resources. More mineral samples are needed from more mine site(s) to build a sample base of a wide variety. To test samples from mine site(s) allows direct evaluation and demonstration of the new sensing system under near-reality conditions. Those mine site(s) that provide the samples will be able to develop an understanding of the capacity of the new sensing system in dealing with the minerals from their mines.

We need access to site testing which will further upgrade the technology along the commercialisation path. It not only serves as a competence test of the new sensing system but also provides an opportunity for the participating mine site(s) to witness as well as to gain first-hand experience of the effectiveness, convenience, and utility, of the new sensing system. By then, it will form a solid basis to perform detailed analysis of market size and competition.

Australia's Economic Accelerator (AEA) Seed Program will be considered as potential funding source to support commercialising the online density monitor feature of the new sensing system, targeting integration into the existing RAC control system at Nimble Resources for process optimisation.

List of Publications and Conference Participations during the Lifetime of the PRIF

Patent Application

Tang D, Yang L, Chen L and Cook N (2024, pending) An adaptive life-long probing mechanism for in-stream particle-laden flow monitoring. Patent Application. Unpublished.

Conference Participation and Public presentation

Poster presentation, "Particle density online monitoring for Dry Mineral Processing", Copper to the World (C2TW) Conference 2024, Adelaide, Australia, June 18-19, 2024.

Poster presentation, "Monitoring particle size at hydrocyclones and beyond", South Australian Exploration and Mining Conference 2023, Adelaide, Australia, December 1, 2023.

Oral presentation, "Ultrafine-particle online detection and size-distribution approximation at hydrocyclone overflow", the 13th International Comminution Symposium (MEI conference of Comminution '23), Cape Town, South Africa, April 17-20, 2023.

Poster presentation, "Next-generation online particle-size sensor for hydrocyclones", South Australian Exploration and Mining Conference 2022, Adelaide, Australia, December 2, 2023.

Oral presentation, "New sensor development for hydrocyclone overflow particle cumulative percent passing size online monitoring – A preliminary experimental investigation under dry condition", IMPC Asia-Pacific 2022, Melbourne, Australia, August 21-23, 2022.

Oral presentation, "A new approach for hydrocyclone overflow online monitoring for energy-efficient comminution", the 7th International Symposium on Sustainable Minerals (MEI conference of Sustainable Minerals '22), July 11-13, 2022 (Online).

Oral presentation, "A new method for online estimation of particle size distribution in the overflow of hydrocyclones: A preliminary investigation", the 12th International Comminution Symposium, (MEI conference of Comminution '21), April 19-22, 2021 (Online).

Oral presentation, The Copper to the World 2022 conference and PRIF Mining Consortium workshop - "Pathways to Commercialisation and Implementation", May 2022 (Online).

Poster presentation, The Austmine 2023 conference, May 2023, Adelaide

Poster presentation, METPLANT 2023, Novembers 2023, Adelaide

Poster presentation, The South Australian Exploration and Mining Conference 2023 (SAEMC), December 2023, Adelaide

Poster presentation, The Copper to the World 2024 conference, June 2024, Adelaide

Oral presentation, 2023 PRIF Final Research Conference, PRIF RCP "Unlocking Complex Resources through Lean Processing", 18/10/2023.

Oral presentation, 2022 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 22/07/2022.

Oral presentation, 2021 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 01/10/2021.

Oral presentation, 2021 BHP Workshop, PRIF RCP "Unlocking Complex Resources through Lean Processing", 14/05/2021.

Oral presentation, 2020 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 02/10/2020.

Oral presentation, 2020 BHP Workshop, PRIF RCP "Unlocking Complex Resources through Lean Processing", 21/07/2020.

Oral presentation, 2019 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 13/12/2019.

Journal and Conference Publications

Difan Tang, Lei Chen, and Chunhua Shen (2021), A new method for online estimation of particle size distribution in the overflow of hydrocyclones: A preliminary investigation MEI Conference: Comminution '21, Online, April 19-22, 2021

Lin Yang, Difan Tang, and Lei Chen (2021), A new flotation feeds size strategy: narrowing passing size band and increasing coarser particle throughput, MEI Conference: Flotation '21 (The 10th International Flotation Conference), November 8-11, 2021, Online

Difan Tang, Lei Chen, Lin Yang, and Eric Hu, A new approach for hydrocyclone overflow online monitoring for energy-efficient comminution (2022), MEI Conference: Sustainable Minerals '22 (The 7th International Symposium on Sustainable Minerals), July 11-13, 2022, Online.

Tang, D, Chen, L, Yang, L, & Hu, E (2022) New sensor development for hydrocyclone overflow particle cumulative percent passing size online monitoring – A preliminary experimental investigation under dry condition. In: Proceedings of the IMPC Asia Pacific 2022, Melbourne, Australia, 22-24 August 2022, Vol. 5/2022, pp. 625–631. Melbourne, Australia + Online: The Australian Institute of Mining and Metallurgy.

Difan Tang, Lei Chen, Lin Yang, and Eric Hu (2023), Ultrafine-particle online detection and size-distribution approximation at hydrocyclone overflow, MEI Conference: Comminution '23 (The 13th International Comminution Symposium), April 17-20, 2023, Cape Town, South Africa.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Online particle-size monitoring for hydrocyclone overflow: Where is the beacon? *Minerals Engineering*. Manuscript under review.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Size estimation of gas-conveyed particles via solid-impact mechanics based on accelerometer measurement. *Minerals Engineering.* Manuscript under review.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Hydrocyclone roping prediction versus detection: Could prediction be possible? *Minerals*. Manuscript under review.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Online mass-flow-rate measurement of high-intensity gas-conveyed particle flow using force transducer. *Powder Technology*. Manuscript under review.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Online particle size distribution and P80 monitoring via force-measurement based vibration sensing. *Minerals Engineering*. Manuscript under review.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Online estimation of particle size distribution in the overflow of hydrocyclones via force measurement: Theory and preliminary investigation. *Minerals Engineering*. Manuscript in preparation.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Hydrocyclone overflow particle-size estimation: Size passing fraction P80 detection via solids impact mechanics. *Minerals Engineering*. Manuscript in preparation.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Hydrocyclone overflow particle-size estimation: Particle size distribution estimation via bluff-body hydrodynamics. *Minerals Engineering.* Manuscript in preparation.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Improving particle-size estimation at hydrocyclone overflow via data fusion. *Minerals Engineering.* Manuscript in preparation.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Online particle density measurement for rotary air concentration used in Alluvial Gold Mining. *Minerals Engineering.* Manuscript in preparation.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Experimental investigation on the correlation between hydrocyclone roping and overflow air content. *Minerals Engineering.* Manuscript in preparation.

Acknowledgement

This research has been supported by the SA Government through the PRIF RCP Mining Consortium `Unlocking Complex Resources through Lean Processing'. Special acknowledgments go to:

- Bureau Veritas: for supplying ore samples for our dry tests and coordinating site visits during the LOESCHE® Vertical Roller Mill operation.
- Nimble Resources: for their strong support throughout the AEA grant application process and their generous offer of Alluvial Gold mine samples.
- Manta Controls: for providing valuable insights into the mineral processing industry and organising hydrocyclone overflow slurry samples sourced from Australian mines.
- University of South Australia: for providing precious lab space and excellent mineral processing facilities, which significantly assisted our experimental studies.

APPENDIX 3 BTP9 - FINAL RESEARCH REPORT 2023 - 2024

BTP9: PULP CHEMISTRY MONITOR (NOW MAGOPULP®) FOR IMPROVED PREDICTIVE FLOTATION MODEL AND PROCESS PERFORMANCE

Researcher(s): Dr James Dankwah, Dr Kirsten Louw and Ms Van Tran

Chief Investigator(s): Dr Richmond Asamoah, Prof William Skinner

Commenced: 1 Feb 2023 to 30 June 2024

Completing: 30 June 2024

Industry partner: Dr Christopher Greet, Magotteaux Australia

TRL 8-9

CRL 4-5

This report is a final research report for the Research Project BTP9 'Pulp Chemistry Monitor (PCM®) for improved predictive flotation model and process performance' and covers activities from 1st Feb 2023 to 30th June 2024.

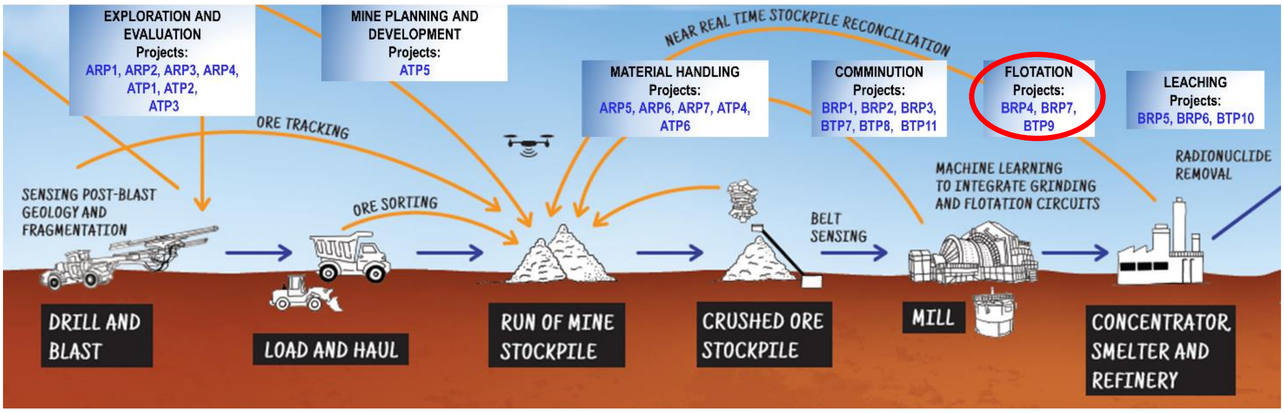
Integration of MagoPulp® in the flotation circuit improves copper recovery prediction and process optimisation.

Introduction/Background

With the ever-increasing ore variability, MagoPulp® technology improves process stability by measuring valuable pulp chemistry variables to monitor, optimise and maximise metal recovery. In particular, the MagoPulp® technology addresses the following key end-user challenges:

1. Increased ore complexity and variability, leading to less predictive flotation response;
2. Lack of efficacious real time on-line monitoring strategies during valued mineral flotation; and
3. Poor interplay between copper recovery and target product grades within process constraints.

This translation research is part of the flotation research activities of the PRIF Consortium. See below red circle in the image, indicating the flotation research activities of the PRIF Consortium.



Key Findings

1. Machine learning models that are well developed can predict copper recovery well.
2. Selected input features are critical to the model performance and robustness.
3. Pulp chemistry variables improve the predictive model performance and influence the number of model-selected features.
4. Model validation and interpretation has been undertaken to aid integration of machine learning techniques and MagoPulp® in process streams.
5. New optimisation algorithm for maximising copper production and process performance, with MagoPulp® integration and value demonstration, has been undertaken.

Project aim

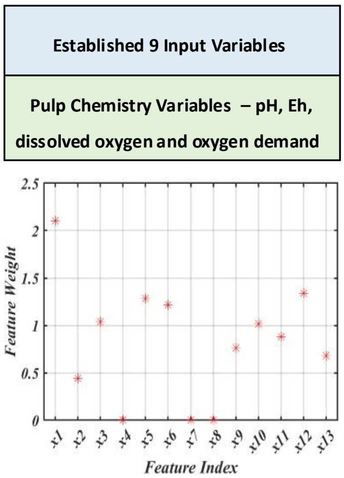
Installing the MagoPulp® (previously Pulp Chemistry Monitor) in the flotation circuit for improved predictive flotation model and process performance. Specifically, the reporting period aimed at collecting large data from the mineral processing plant (this may involve restoring the installed MagoPulp® at BHP Olympic Dam), validating the predictive models and developing an optimisation algorithm (software) to evaluate the contribution of MagoPulp® in improving the flotation process performance.

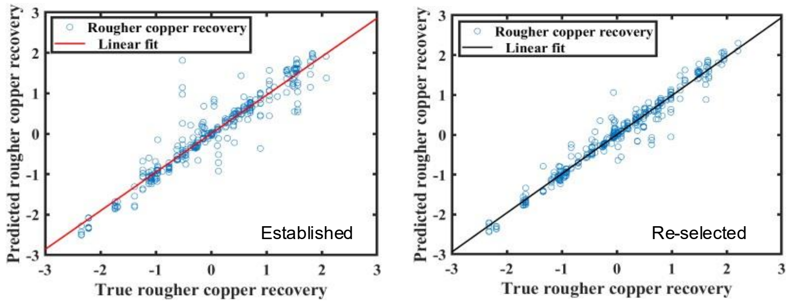
Technology overview

The MagoPulp® measures pH, Eh, oxygen demand, dissolved oxygen and temperature as proxy of mineralogy in the process stream. The unit is equipped with the required sensors for measurement. The technology's current TRL is 8.
Magotteaux's MagoPulp® will aid in the maximisation of valuable metal (e.g., Cu, Au and Ag) production whilst mitigating waste and enhancing sustainable mining operation.

Experimentation and Main Findings

Validate models developed at the industry site (Figure 1). This will involve restoring the MagoPulp® on site and collecting useful data for good statistics. Refining models and demonstrating the value of the MagoPulp® to mining operations such as BHP Olympic Dam through process optimisation studies.



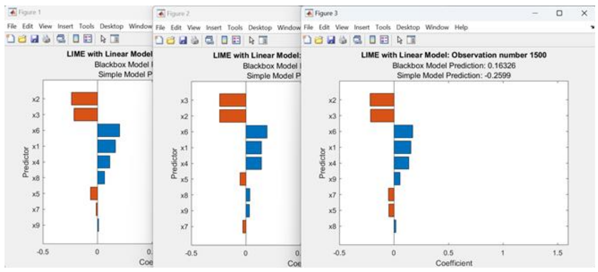


Criteria	Established	Re-selected
	Testing dataset	Testing dataset
Correlation coefficient	0.9528	0.9806
Root mean square error	0.4897	0.3122

Figure 1 Validate predictive models having pulp chemistry variables.

Demonstrating the performance of the MagoPulp® through the advanced predictive models to mining operations such as BHP Olympic Dam has further increased the TRL and CRL whilst encouraging adoption by other mining companies. Interpretation of the predictive models have been investigated (Figure 2). The financial benefit and business case for the MagoPulp® has been provided by Magotteaux Australia.

- The contribution of the variables varied for different observations at the local level.
- The contribution also varied with the different investigated scenarios.



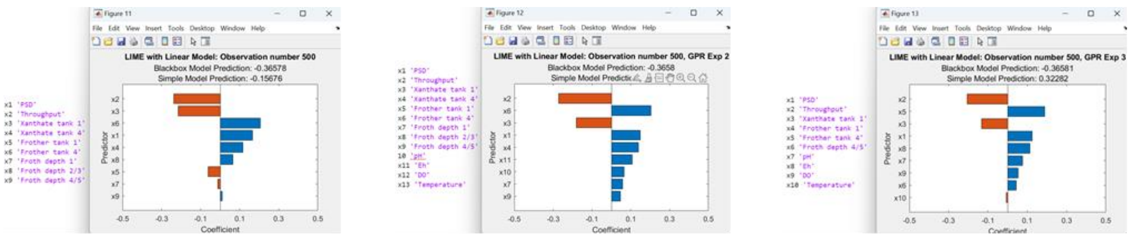


Figure 2 Interpretation of predictive models

Benefits to industry and the wider community

The benefits of the MagoPulp® include:

1. Improved flotation circuit optimisation and copper mineral selectivity.
2. Maximized copper production and reduced waste (energy, water and value minerals), hence, lower operating cost.
3. Improved downstream unit performance through consistent feed characteristics.

Applications

Minerals industry. Applications can be extended to other industries with high feed variability. Potential vendors include mining companies (e.g., BHP, OZ Minerals, Newcrest Mining, Reforme Group, AngloGold Ashanti) with operations where solution chemistry is critical to process performance.

Potential Value

The value proposition includes:

1. Develop robust flotation performance predictive models for improved optimisation; and
2. Increase copper recovery within constraints of concentrate/product grade.

Future work/Recommendations

Additional work at multiple end-user sites to further increase the TRL and/or CRL and integrate MagoPulp® is recommended. Strong engagement between technology end-users and Magotteaux is required.

List of publications and conference participations during the lifetime of the PRIF

Journal Publications

1. Amankwaa-Kyeremeh, B, McCamley, C, Zanin, M, Greet, C, Ehrig, K & Asamoah, RK 2024, 'Prediction and optimisation of copper recovery in the rougher flotation circuit', Minerals, vol. 14, no. 1, pp. 1-31.

2. Amankwaa-Kyeremeh, B, Ehrig, K, Greet, C & Asamoah, R 2023, 'Pulp chemistry variables for gaussian process prediction of rougher copper recovery', Minerals, vol. 13, no. 6, article no. 731, pp. 1-16.

3. Amankwaa-Kyeremeh, B., Zhang, J., Zanin, M., Skinner, W., Asamoah, R. K., (2021), "Feature selection and Gaussian process prediction of rougher copper recovery", *Minerals Engineering,* article no. 107041, pp. 1 - 14.

Conference Publications

4. Amankwaa-Kyeremeh, B., McCamley C., Asamoah, R. K., (2024), "Copper recovery predictive performance for selected machine learning algorithms", International Mineral Processing Congress 2024, National Harbor, Washington, DC, paper accepted.

5. Amankwaa-Kyeremeh, B., Skinner, W., Asamoah, R. K., (2021), "Comparative study on rougher copper recovery prediction using selected predictive algorithms", 5th International Future Mining Conference, Online, pp. 1 - 10.

6. Amankwaa-Kyeremeh, B., Greet, C., Skinner, W., Asamoah, R. K., (2021), "Correlating process mineralogy and pulp chemistry for quick ore variability diagnosis", 5th International Future Mining Conference, Online, pp. 1 - 10.

7. Amankwah-Kyeremeh, B., Greet, C., Skinner, W., Asamoah, R. K., (2021), "A brief review of pulp chemistry parameters in relation to flotation feed variation", International Mineral Processing Congress 2020, Cape Town, South Africa, pp. 1855 - 1863.

8. Amankwaa-Kyeremeh, B., Greet, C., Zanin, M., Skinner, W., Asamoah, R. K., (2020), "Predictability of rougher flotation copper recovery using Gaussian Process Regression Algorithm", 6th UMaT Biennial International Mining and Mineral Conference, UMaT, Tarkwa, Ghana, pp. 1 - 8.

9. Amankwaa-Kyeremeh, B., Greet, C., Zanin, M., Skinner, W., Asamoah, R. K., (2020), "Selecting key predictor parameters for regression modelling using modified Neighbourhood Component Analysis (NCA) Algorithm", 6th UMaT Biennial International Mining and Mineral Conference, UMaT, Tarkwa, Ghana, pp. 320 - 325.

Reports

10. Asamoah, R. K., Zanin, M., Skinner, W., (2022), "Pulp Chemistry Monitor (PCM®) for Improved Predictive Flotation Model and Process Performance", 2022 *Translation Project 9 Progress Report,* PRIF RCP "Unlocking Complex Resources through Lean Processing", Reporting period: 01/09/2019 to 01/11/2022, 7 p.

11. Asamoah, R. K., Zanin, M., Skinner, W., (2021), "Pulp Chemistry Monitor (PCM®) for Improved Predictive Flotation Model and Process Performance", 2021 *Translation Project 9 Progress Report,* PRIF RCP "Unlocking Complex Resources through Lean Processing", Reporting period: 01/09/2019 to 01/11/2021, 7 p.

12. Asamoah, R. K., Zanin, M., Skinner, W., (2020), "Pulp Chemistry Monitor (PCM®) for Improved Predictive Flotation Model and Process Performance", 2020 *Translation Project 9 Progress Report,* PRIF RCP "Unlocking Complex Resources through Lean Processing", Reporting period: 01/09/2019 to 15/11/2020, 6 p.

13. Greet, C., (2019), "PCM® Installation at Olympic Dam: Scope of Work", PRIF RCP "Unlocking Complex Resources through Lean Processing", Magotteaux, 28/10/2019, 17 p.

Public Presentations

14. **PRIF Final Research Conference 2023,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 18/10/2023.

15. **2022 Annual Assembly,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 22/07/2022.

16. **Workshop at Copper to the World Conference 2022,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 17/05/2022.

17. **2021 Annual Assembly,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 01/10/2021.

18. **2021 BHP Workshop,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 14/05/2021.

19. **2020 Annual Assembly,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 02/10/2020.

20. **2020 BHP Workshop,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 21/07/2020.

21. **2019 Annual Assembly,** PRIF RCP "Unlocking Complex Resources through Lean Processing", 13/12/2019.

Acknowledgement

The project research team would like to acknowledge the financial support of the South Australia Government for this translation research. Also, the support of partnering technology and end-user companies for the successful delivery of this project is greatly acknowledged.

APPENDIX 4 ARP3 - FINAL RESEARCH REPORT 2023 - 2024

ARP3: Constraints and quantifying uncertainty on resource domain boundaries

Researcher(s): Dr Yerniyaz Abildin

Chief Investigator(s): A/Prof Chaoshui Xu, Prof. Peter Dowd.

Commenced: 15 May 2024

Completing: 31 August 2024

Industry partners:

MAPTEK

Maptek DomainMCF

Machine learning assisted domain modelling

BHP

TRL 8 - 9

CRL 1

This report is a final research report for the Research Project ARP3 ‘Constraints and quantifying uncertainty on resource domain boundaries’ and covers activities from 15th May 2023 to 31st August 2024.

‘The most effective geological domaining approach combines human expertise and machine learning.

1.1 Introduction/Background

In a mining operation, geological domaining of the deposit is a critical step needed for resource/reserve estimation, mine design and mine planning, as well as the creation of the production plan for the operation. Geological domains are defined as 3D geometrical envelopes (wireframes) within which grade, geological, lithological, mineralisation and/or statistical characteristics are more or less consistent.

The proposed domaining method (hereafter, Hybrid Domaining Framework - HDF) consists of two components: 1). geostatistical simulations of a comprehensive set of grade variables assayed for the deposit; 2). application of machine learning (classification algorithms) for domain classification based on simulated grade values. The classifier is trained on the available geological logs after a noise filtering algorithm has been applied to correct misclassification errors in samples. ARP3 project lies in the main value chain's exploration and evaluation stage (Figure 1, highlighted with red).

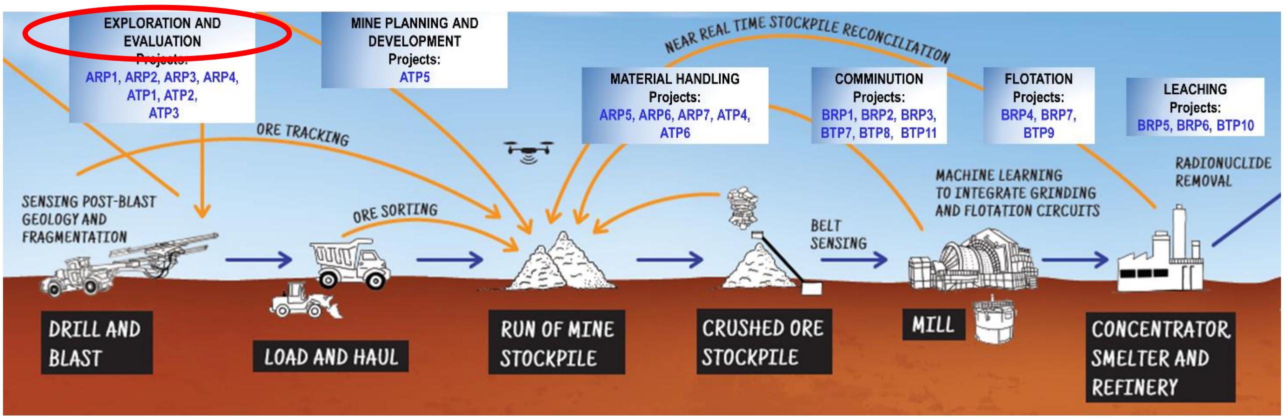


Figure 1. Mine value chain

1.2 Key Findings

1. Data-driven noise filtering is an effective tool against geological misclassification
2. Tree-based classification methods perform well for geological predictions

1.3 Project aims

- To develop the HDF based on geostatistical simulation and machine learning classification algorithms in order to quantify uncertainty on domain boundaries and thereby increase the reliability of the resource model.
- To implement developed HDF within a commercial product and to elevate the project to higher TRLs/CRLs

1.4 Technology Overview

Currently, there are three geological domaining methods used in the mining industry: explicit domaining, implicit domaining and geostatistical modelling. Explicit domaining is essentially a manual drawing method, which is labour-intensive, inefficient and prone to subjective judgement errors. The implicit domaining generates domain boundaries by using particular radial basis functions, or similar substitutions, which have difficulties in dealing with complex geological structures. The geostatistical modelling methods, including indicator kriging, sequential indicator simulation, truncated gaussian simulation and plurigaussian simulation, in general suffer from the lack of domain data, leading to low reliability of the created domain model.

Our solution is a hybrid framework based on grade simulations and machine learning (classification), resulting in a geological domain model with the associated assessment of uncertainties in the domain boundaries. A state-of-the-art noise filtering algorithm is also integrated into the classification process to resolve misclassification errors among problematic samples. This has been demonstrated to be a necessary and effective pre-processing step in practice to improve the reliability of the classification algorithms. The first component of the framework takes advantage of abundant sample grade values for reliable simulations of grade variables (e.g., Cu, Au, Fe) on a dense regular grid using geostatistical approaches. Machine learning is then applied to classify the lithological units based on the simulated grade values and referencing the limited domain samples available. In the hybrid framework, geostatistical simulations of grade variables introduce multiple equally probable realisations of the orebody, which are then used for the uncertainty assessment of the domain boundaries.

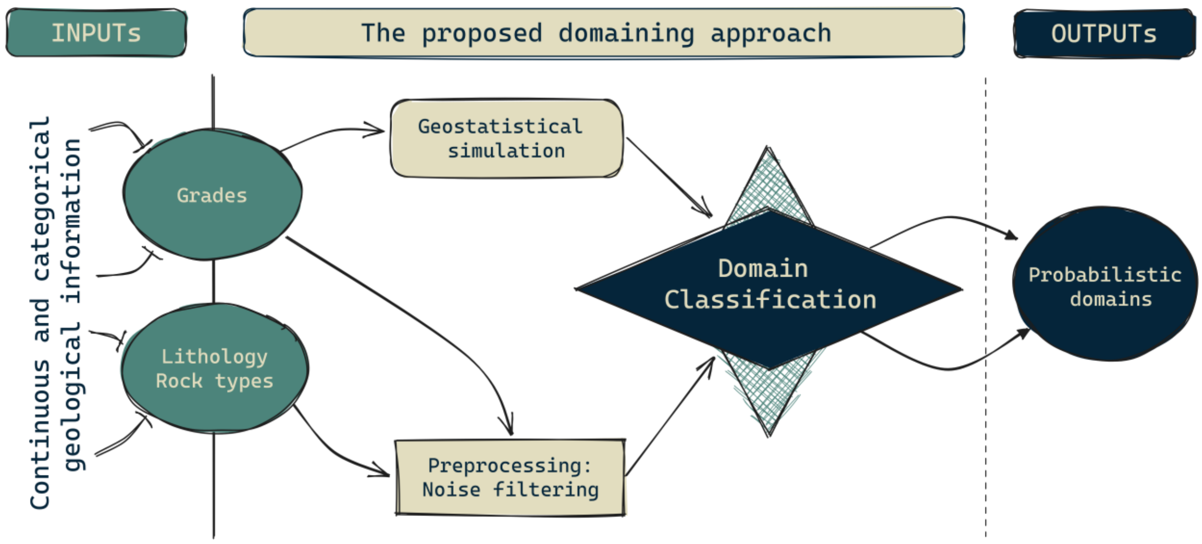


Figure 2. HDF workflow.

Currently, the evaluation of the proposed framework is in progress using real case studies. The project is at TRL8 and CRL1, which means the project output is incorporated in the commercial design (i.e., DomainMCF - Maptek's geological modelling solution).

1.5 Experimentation and Main Findings

HDF has progressed through various stages of development and testing. By the time it reaches TRL 8, the framework has been fully integrated into the operational workflows of DomainMCF and has been extensively tested in real-world geological datasets by geologists and engineers from Maptek and outside of the company.

Key Components:

1. ***Core Software***: Main parts for data input, processing, simulation, classification and uncertainty quantification.
2. ***Database Integration***: Connects to the above-mentioned cores in between each other to get inputs, intermediate results, and the final results.

3. ***User Interface***: Intuitive UI for data interaction and model visualization (3D block model etc.).
4. ***Data Processing Algorithms***: Interprets geological and geochemical data for model generation.
5. ***Interoperability Modules***: Integrates with HDF as services into Maptek Compute Framework (MCF) to operate it within DomainMCF (Figure 3).
6.

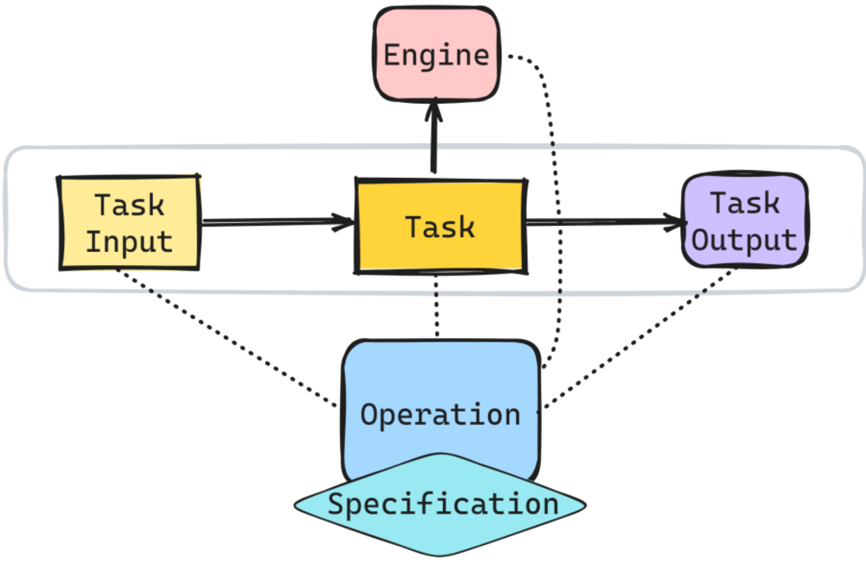


Figure 3. MCF structure

- *Engine*: User-defined binary/code package (i.e., HDF as backend) that processes the input data to get the result and output it.
- *Operation*: A specific operation that an engine can perform.
- *Specification*: It's a part of an operation. A specification file is a file that describes the inputs and outputs required for an operation, as well as some of the required configurations.

Integration Process

1. ***Development and Unit Testing***: Individual services/modules developed and tested. These services are simulation: Tuning bands simulation and classification: XGBoost algorithms.
2. ***System Integration***: Combine all modules into a cohesive MCF operation.
3. ***Database Connection***: Ensure robust data import/export functionality.
4. ***Algorithm Validation***: Test algorithms with diverse geological datasets (porphyries, veins and seams etc.).
5. ***User Interface Testing***: Ensure usability and functionality.
6. ***Interoperability***: Integrate and test with other software systems.
7. ***Collaboration Features***: Enable real-time collaboration and data consistency.
8. ***Actual Testing***: Deploy HDF in DomainMCF and refine through feedback from users.
9. ***Operational Testing***: Validate in various geological projects and settings.

Demonstration and Qualification

- ***Demonstration***: Showcase software in real-world geological projects.
- ***Qualification***: Confirm reliability and robustness through extensive testing, meeting TRL 8 requirements.

Example Scenario

DomainMCF with HDF is deployed by a mining company:

- Accurately models subsurface formations and orebodies at multiple mining sites (e.g., Figure 4).
- Seamlessly integrates with existing GIS and CAD systems through Maptek's mining-oriented solutions such as Vulcan and CoreGeology.
- Enables geologists to input field data, generate 3D models on Cloud demanding less compute power, and guide exploration.
- Facilitates team collaboration with real-time updates and shared insights.
- Validated through successful comparison with actual drilling results.

This ensures the HDF is ready for widespread deployment, marking its qualification at TRL 8-9.

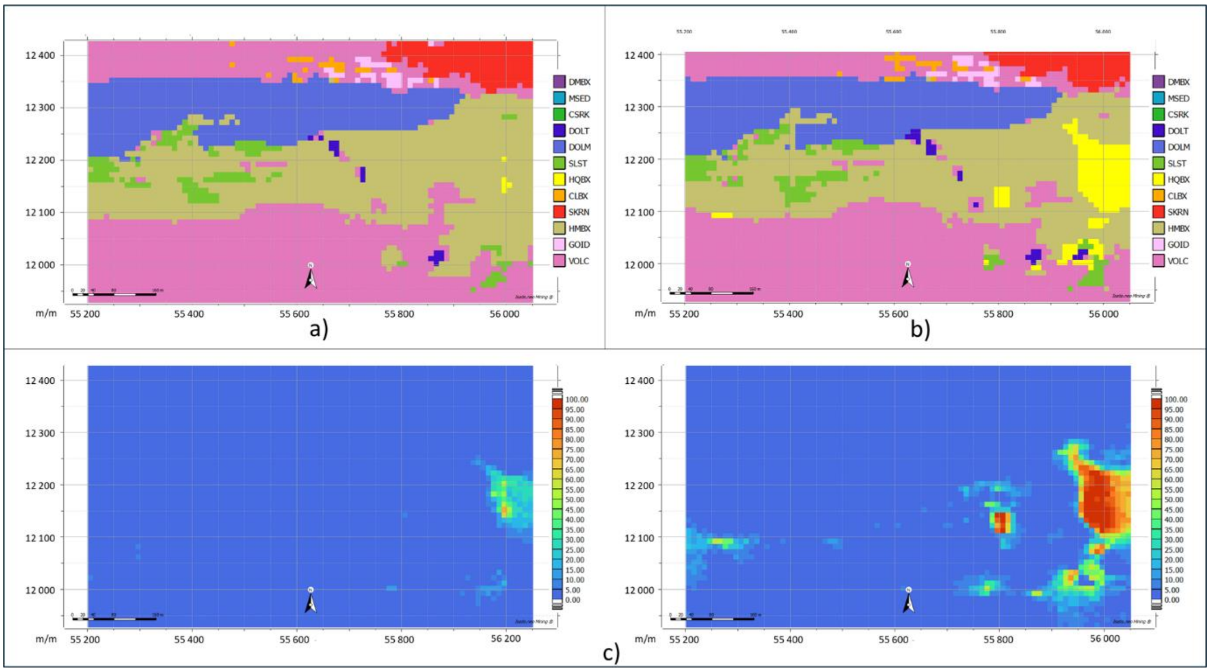


Figure 4. Example of HDF results: top view of the horizontal cross-section of the most probable lithology maps without (a) and with (b) preprocessing; c) The corresponding probability maps of the HQBX domain (in yellow color) are also shown for both cases.

1.6 Benefits to industry and the wider community

HDF provides a more accurate geological domaining method, as the geostatistical simulations of grade variables are in general more reliable compared with the direct simulations of domain variables. Domaining based on different spatial statistics and machine learning algorithms relies on a data-driven approach, which can filter out subjective bias during the modelling process. In addition, the capability of quantifying the uncertainty of domain boundaries as part of the outcomes from the framework is an added benefit compared with other existing approaches.

1.7 Applications

HDF is completely general and can be applied to any type of deposit. The technique is essentially a data-driven approach, and it requires assayed samples for grade simulations and geological log samples for training the domaining classifier. These two sets of data are normally available in any mining operation. The proposed framework has been demonstrated to work effectively using a Prominent Hill dataset.

1.8 Potential Value

Key values of the proposed framework include its accuracy and capability of uncertainty assessment of domain boundaries compared with existing tools. The process can also be semi-automated so that time spent on domain modelling is shortened and manual interactions with the model are minimised, leading to an optimised workload and increased productivity for routine tasks such as grade control and domain modelling. The framework has been implemented as a part of DomainMCF.

1.9 Potential Market

Apart from the three existing domaining methods mentioned in the technology overview, the application of machine learning in domain modelling is still very much an active research area. Currently Maptek has the DomainMCF product in this space. The inclusion of our proposed method will introduce to the company an additional capability in this space, particularly when dealing with complex domain structures.

1.10 Future work/Recommendations

Maptek's DomainMCF is a perfect platform for the full-scale commercial implementation of the HDF. Currently, most codes are operational. However, additional work is needed to consolidate the codes and to escalate the method to the final TRL 9, so that it can be advanced towards the next CRLs.

1.11 List of publications and conference participations during the lifetime of the PRIF

Journal papers:

Abildin, Y., Xu, C., Dowd, P., & Adeli, A. (2022). A hybrid framework for modelling domains using quantitative covariates. *Applied Computing and Geosciences*, *16*, 100107.

Abildin, Y., Xu, C., Dowd, P., & Adeli, A. (2023). Geometallurgical Responses on Lithological Domains Modelled by a Hybrid Domaining Framework. *Minerals*, *13*(7), 918.

Yerniyaz Abildin, Chaoshui Xu, Peter Dowd, on geo-metallurgical modelling for the International Geological Congress (August 25-31, 2024, BEXCO, Busan, Republic of Korea). This paper is under preparation.

Conference Participation and Public Presentation:

- Oral presentation, International Geological Congress 2024 – Busan, South Korea.
- Oral presentation, The Copper to the World 2022 conference and PRIF Mining Consortium workshop - "Pathways to Commercialisation and Implementation", May 2022 (Online).
- Poster presentation, The Copper to the World 2024 conference, June 2024, Adelaide.
- Poster presentation, The Austmine 2023 conference, May 2023, Adelaide.
- Poster presentation, METPLANT 2023, Novembers 2023, Adelaide.
- Poster presentation, The South Australian Exploration and Mining Conference 2023 (SAEMC), December 2023, Adelaide.
- Oral presentation, 2023 PRIF Final Research Conference, PRIF RCP "Unlocking Complex Resources through Lean Processing", 18/10/2023.
- Oral presentation, 2022 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 22/07/2022.
- Oral presentation, 2021 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 01/10/2021.
- Oral presentation, 2020 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 02/10/2020.
- Oral presentation, 2020 BHP Workshop, PRIF RCP "Unlocking Complex Resources through Lean Processing", 21/07/2020.
- Oral presentation, 2019 Annual Assembly, PRIF RCP "Unlocking Complex Resources through Lean Processing", 13/12/2019.

1.12 References and Acknowledgement

This project is supported by the South Australian Government through the PRIF Research Consortium Programme "Unlocking Complex Resources through Lean Processing".

Researcher, Yerniyaz Abildin, thanks Simon Ratcliffe from Maptek for visionary leadership and support, and dedicated PRIF members: Prof. Nigel Cook, Dr Tatiana Khmeleva and Dr Sanaz Orandi for their hard work, administrative assistance and unwavering support.

Special thanks to Prof. Peter Dowd and A/Prof. Chaoshui Xu for technical expertise and invaluable guidance, and Maptek's DomainMCF team for providing resources and support.

APPENDIX 5 BRP5 - FINAL RESEARCH REPORT 2023 – 2024

BRP5: Further development of Metal Organic Framework (MOF) based fibre optic sensor

Researcher: Dr Piotr Pawliszak

Chief Investigator(s): David Beattie, Marta Krasowska, William Skinner and Anton Blencowe

Commenced: 04 September 2023

Completing: 31 August 2024

Industry partner:

MAGOTTEAUX BHP

TRL 4

CRL 1

This report is a final research report for the Research Project BRP5: "Further development of MOF sensor" and covers activities from 04th September 2023 to 30th June 2024.

'Luminescence sensor allows for accurate and wide range Fe^{3+} ion sensing to improve control for more efficient mineral leaching".

Introduction/Background

BRP5 project lies in the main value chain's leaching stage (Figure 1, highlighted with red).

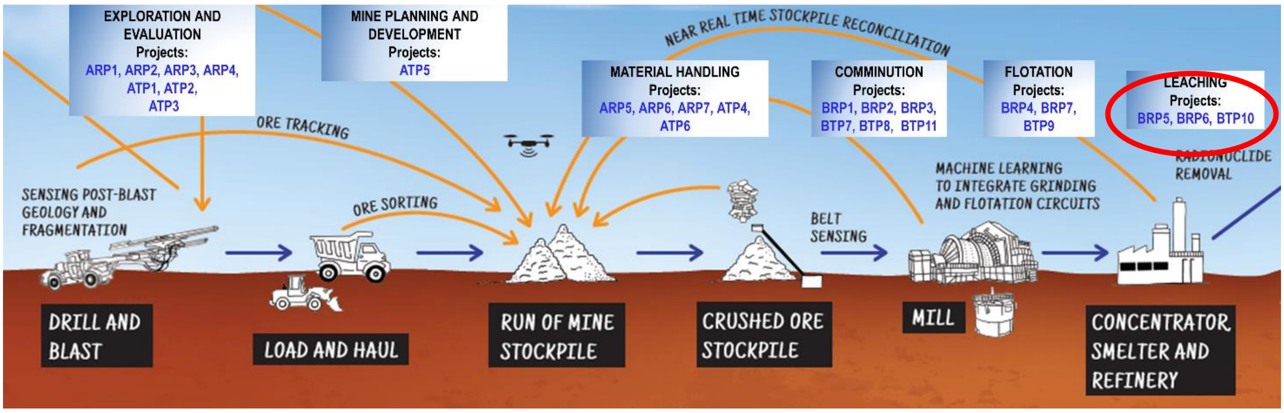


Figure 1. Mine value chain.

Key Findings

The key findings from our research are as follows (Figure 2):

- We validated and confirmed the synthesis of Europium Metal-Organic Framework (EuMOF), achieving a significantly improved yield of 37.6%.

- We developed a composite material that combines EuMOF with Poly(2-hydroxyethyl methacrylate) (PHEMA) and optimized the PHEMA cross-linking conditions.

- The polymer-MOF composite exhibits practical Fe3+ sensing capabilities, with the sensing range significantly extended from 0–4 ppm in a EuMOF suspension to 0–300 ppm in the PHEMA-EuMOF composite, demonstrating a linear dependency. The composite sensor also demonstrates good reusability, excellent luminescence stability, and robust mechanical properties.

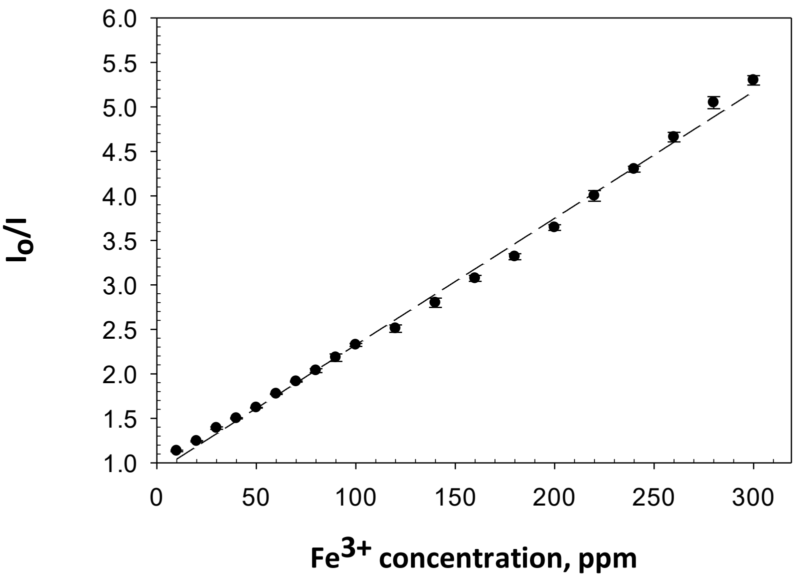


Figure 2. Sensing capabilities of Fe^{3+} by the composite. Change in relative intensity of Eu^{3+} emission band at 616 nm to the initial emission as a function of Fe^{3+} concentration. Error bars represent ± standard deviation (n = 3).

Project aims

- MOF-based sensor assessment of the reusability and accuracy for ferric ions with improvement of detection range.

- Improvement of MOF-polymer mechanical properties to ensure proper adhesion to fibre optic's surface.

- Synthesis method confirmation and analytical sensing method validation that move project towards higher TRL (TRL 4).

Technology overview

The project focused on utilising luminescent chemical sensors to detect and monitor Fe^{3+} ion concentrations, which are crucial oxidants in the leaching processes of many metals [1]. Luminescence sensors offer an alternative to conventional methods of iron ion detection due to their ability to provide accurate and precise measurements of very low ion concentrations [2]. The luminescent component is an EuMOF material, synthesized from europium nitrate. Metal-organic frameworks (MOFs) are a class of crystalline materials composed of metal ions interconnected by organic ligands [3]. Europium MOFs exhibit suitable characteristics for sensing applications, including resistance to harsh mineral processing environments, superior optical properties, and high selectivity and sensitivity. To implement the EuMOF into a measuring device, the luminescent material was incorporated within a cross-linked PHEMA matrix, allowing the sensor to be used as a polymeric slide in a cuvette or as a coating at the tip of an optical fibre.

Experimentation and Main Findings

The synthesis of EuMOF was conducted using a Teflon-lined autoclave reactor. $Eu(NO_3)_3 \cdot 5H_2O$ (4.5 g, 10.51 mmol) and 2-methoxyterephthalic acid (1.5 g, 7.65 mmol) were added to ultrapure water (750 ml), sealed in the reactor, and placed in an oven at 160°C for 3 days. The reactor mixture was then cooled to room temperature, and the resulting orange-red crystals were washed with water and methanol to remove unreacted reagents. After drying under high vacuum, the mass of EuMOF obtained was 0.8891 g, corresponding to a reaction yield of 37.6%. The structure of the obtained orange-red EuMOF crystals (Figure 2 insert) was confirmed using powder X-ray diffraction (Figure 3), as the PXRD pattern for synthesized EuMOF (blue line-dot) was in very good agreement with theoretical predictions (red line).

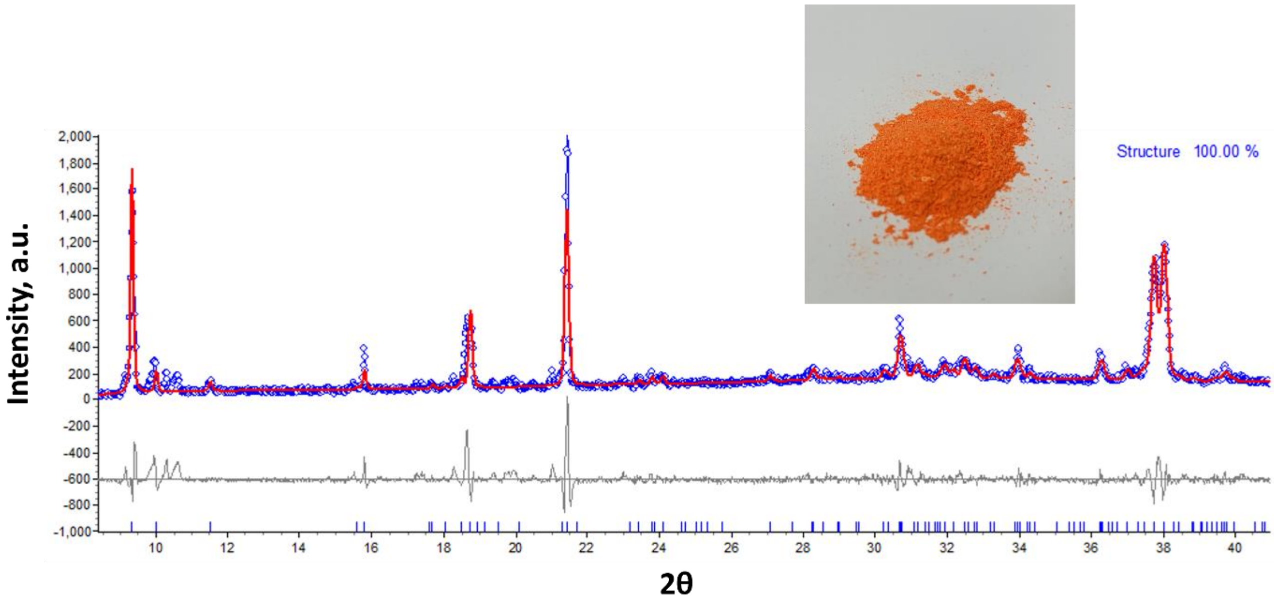


Figure 3. The theoretical PXRD pattern of the EuMOF (red line) in solvated (water) compared to synthesized EuMOF in solvated state (blue line-dot). Inset: picture of synthesised crystalline EuMOF product.

The PHEMA-EuMOF composite was prepared according to the scheme in Figure 4. The polymerization mixture was prepared by mixing 8.75 g of 2-hydroxyethyl methacrylate (HEMA), 850 mg of ethylene glycol dimethacrylate (EGDMA, cross-linker content 8 wt%), 87.5 mg of 2-hydroxy-4′-(2-hydroxyethoxy)-2-methylpropiophenone (HHMP), 1 ml of ultrapure water, and 25 mg of EuMOF (0.25 wt%). The mixture was sonicated for 90 minutes, followed by degassing using high-purity argon. The suspension was then cross-linked in 3D-printed moulds placed in a UV-Vis chamber for 40 minutes. This procedure allowed for the preparation of 5 PHEMA-EuMOF composite slides. To optimize the luminescence and mechanical properties, the composites were fabricated using coarse EuMOF powder (composite A) or finely ground EuMOF powder (composites B-D), with double the amount of cross-linker EGDMA (composite C) or double the amount of cross-linker EGDMA and initiator HHMP (composite D).

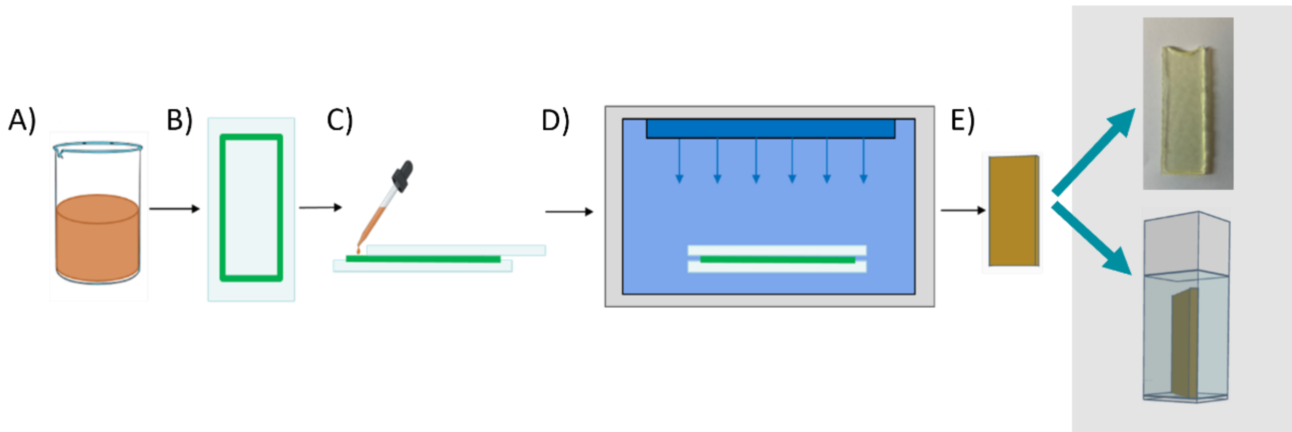


Figure 4. Preparation of the PHEMA-EuMOF composite: A) the polymerisation suspension is prepared and sonicated; B) 3D printed mould on a glass; c) the polymer suspension is transferred to the mould; D) Crosslinking in the UV chamber; e) the composite is released followed by washing.

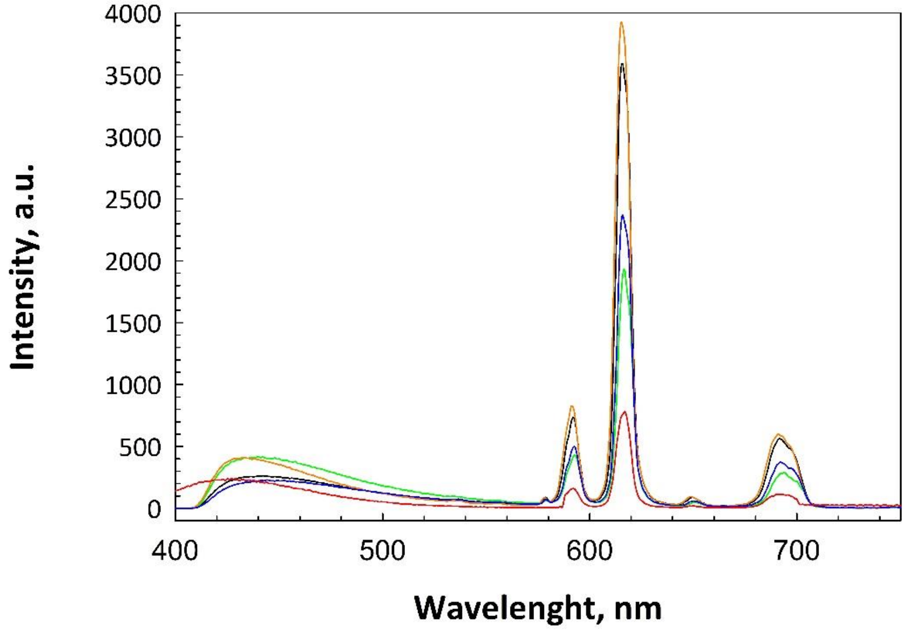


Figure 5. Luminescence emission spectra (λ_{ex} = 320 nm) of PHEMA-EuMOF composites fabricated using different parameters (Composite A- green, Composite B- orange, Composite C- black, composite D- blue) and EuMOF suspension in water (red).

The luminescence emission spectra of the EuMOF water suspension and the PHEMA-EuMOF composites were measured using a spectrofluorophotometer in the range of 335–800 nm with excitation at 320 nm. The EuMOF emission spectra consist of Eu3+ emission bands observed at 590, 616, 650, and 690 nm (Figure 5). All PHEMA-EuMOF composites exhibited an increase in the intensity of the Eu^{3+} bands at 590, 616, and 690 nm compared to the EuMOF suspension. The most intense 616 nm band was selected to assess the luminescence properties. The incorporation of EuMOF within PHEMA resulted in a luminescence-enhancing effect, with band intensity at 616 nm being 6-7 times greater when the MOF particles were cast in the polymer matrix. The composites with finely ground particles (B-D) showed increased 616 nm emission band intensity compared to the composite with coarse EuMOF particles. PHEMA is a hydrophilic polymer that swells in the presence of water, which affects its mechanical properties. Increased water content makes the polymer less stiff and more prone to detachment from the optical fibre. The polymer composite mass increase upon swelling is presented in Table 1.

Table1. The mass increase of PHEMA-EuMOF composites subgenre in water.

Composite	Mass increase 24 h	Mass increase after 7 days
A	20.4% ± 1.0%	22.4% ± 0.9%
B	19.8% ± 1.4%	21.5% ± 0.7%
C	10.2% ± 0.5%	11.0% ± 0.3%
D	9.7% ± 0.7%	10.4% ± 0.6%

Considering both luminescence and mechanical properties, composite C (crosslinker content 16 wt%) was chosen as the optimized fabrication protocol. Embedding fine EuMOF particles in the PHEMA matrix with an increased amount of crosslinker showed a significant increase in the overall intensity of the emission at 616 nm, potentially extending the sensing range, and provided a robust material sensing platform that could be incorporated into an optical device.

The sensing properties of the PHEMA-EuMOF composite were determined by measuring luminescence spectra in the presence of FeCl3 at different concentrations. The PHEMA-EuMOF composite emission spectra intensity decreased gradually with increasing Fe3+ ion concentration (Figure 6, left). The system's response to the analyte was determined using the Eu^{3+} 616 nm band, as it has the highest initial intensity (Figure 6, right). The composite showed an excellent response to ferric ions, with the relative change in luminescence intensity linearly dependent on concentration, with a coefficient of determination equal to 0.998. The detection range of the composite was 10–300 ppm, indicating a significant increase compared to the MOF suspension sensing range of 0.1–4 ppm.

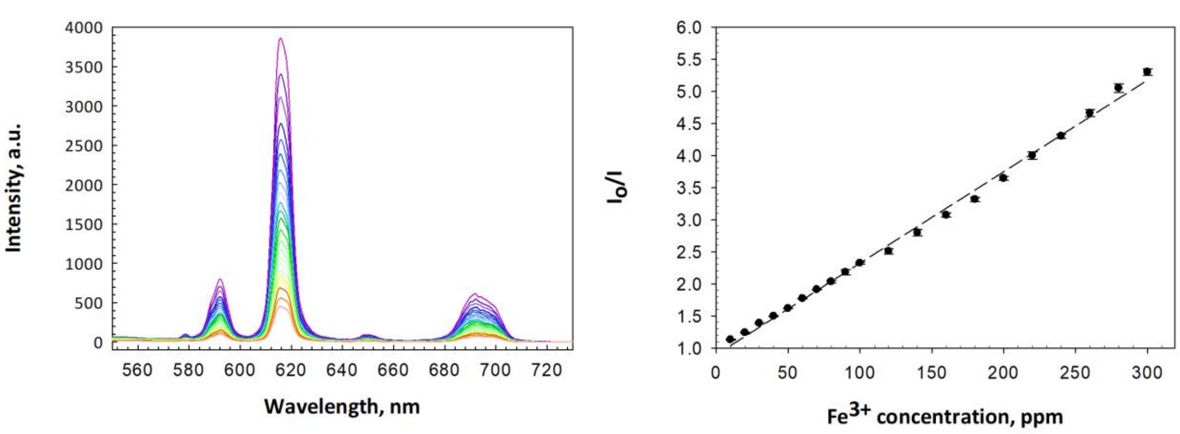


Figure 6. Ferric ions sensing by the PHEMA-EuMOF composite: Left panel: the composite luminescence emission spectra (λ_{ex} = 320 nm) in presence of Fe^{3+} aqueous solutions (0-300ppm); Right panel: Variation in the intensity of the Eu^{3+} emission band at 616 nm compared to its initial emission intensity, plotted against Fe^{3+} concentration. Error bars represent ± standard deviation (n = 3).

The PHEMA-EuMOF sensor is characterized by good reusability, which was tested by exposure to 50 ppm FeCl3, followed by rinsing with ultrapure water. The water rinse was sufficient to remove Fe3+ ions and restore the initial emission intensity within 10 sensing cycles (Figure 7, left panel). This feature indicates that the composite does not form a complex with the analysed ions, and no chemical bond is formed between them, thus requiring only a simple rinse to ensure sensor reusability. The PHEMA-EuMOF sensor shows an excellent quenching response at the 616 nm band and repeatability across three different samples for 10 measurement cycles with ferric ions.

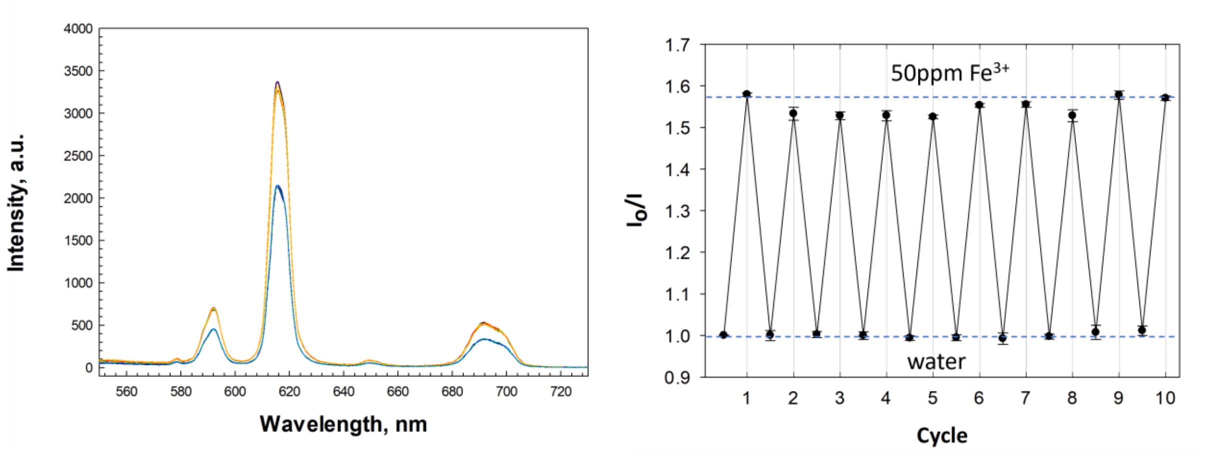


Figure 7. PHEMA-EuMTA composite response and recovery tests: Left panel composite luminescence emission spectra exposed to 50ppm Fe^{3+} solution and after rinsing with ultrapure water. Right panel: luminescence response of 616 nm Eu^{3+} emission band to analyte and water over 10 sensing cycles. Error bars indicate ± standard deviation (n = 3).

Benefits to industry and the wider community.

Iron ion concentration is an important parameter in industrial chemical processes, particularly in mineral leaching[1]. Ferric ions are oxidants used in the leaching of copper[4], uranium[5] and zinc[6], making the determination of ferric ion concentration crucial for optimizing mineral recovery rates. PHEMA-EuMOF-based composite sensors are a good alternative to conventional methods of iron ion detection due to their ability to provide sensitive, selective, precise, rapid, and economical measurements of very low ion concentrations. The PHEMA-EuMOF composite sensing platform shows potential for in-line application, providing real-time knowledge of Fe^{3+} concentrations and allowing for optimization of the mineral leaching process. Therefore, this technology brings economic benefits by improving recovery rates and environmental benefits by generating less waste through more controlled mineral leaching.

Applications

The main considered application of PHEMA-EuMOF composite is incorporation in optical fibre as a part of the Pulp Chemistry Monitor (PCM) allowing for real-time detection of ferric ions. Additionally, PHEMA-EuMOF sensor can find application in environmental sciences to detect ferric ions concentrations in aquatic environments[7] or biomedical analysis to monitor the Fe^{3+} content [8].

Potential Value

The potential value of the sensing device has not been assessed as it is not yet at the commercialisation stage.

Potential Market

Mineral processing companies employ leaching as a part of mineral separation including for cooper[4], uranium[5] and zinc[6], and including companies such as BHP or Rex Minerals.

Future work/Recommendations

- CRC-P application has been submitted, which (if successful) will provide longer term funding allowing to build a prototype of the MOF-based sensor and its implementation in the PCM.

- Optimize the deposition of the PHEMA-EuMOF composite as a thin layer at the tip of an optical fibre via direct polymerization and assess its sensing capabilities. The concept of direct PHEMA-EuMOF polymerization has been tested, and a microscopic image showing the thin composite layer in the centre of the optical fibre is presented in Figure 8.

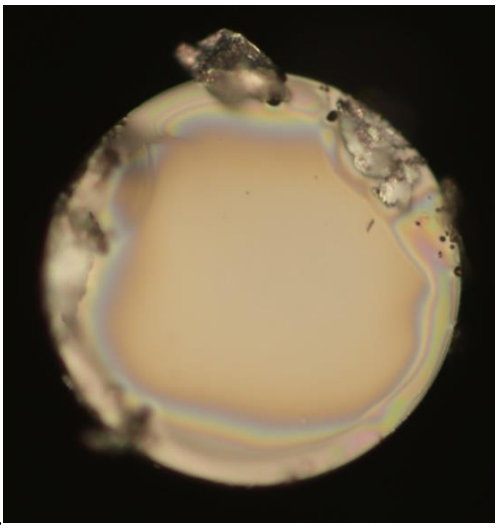


Figure 8. Microscopic image (x10) of 200 µm diameter optical fibre with centrally deposited layer of PHEMA-EuMOF.

List of publications and conference participations during the lifetime of the PRIF

Journal papers:

Piotr Pawliszak, Bronwyn Bradshaw-Hajek, Chris Greet, Bill Skinner, David Beattie, Marta Krasowska: Interfacial Tension Sensor for Low Dosage Surfactant Detection, Colloids and Interfaces, 2021, vol. 5, p9.

Piotr Pawliszak, Vamseekrishna Ulaganathan, Bronwyn H. Bradshaw-Hajek, Reinhard Miller, David A. Beattie, Marta Krasowska: Can small air bubbles probe very low frother concentration faster? Soft Matter, 2021, vol. 17, 9916.

Piotr Pawliszak, Bronwyn H. Bradshaw-Hajek, William Skinner, David A. Beattie, Marta Krasowska (2024), Frothers in flotation: A review of performance and function in the context of chemical classification. Minerals Engineering, Volume 207, February 2024.

Conference Participation and Public Presentation:

- Poster presentation, The Copper to the World 2024 conference, June 2024, Adelaide.
- Poster presentation, METPLANT 2023, Novembers 2023, Adelaide.
- Poster presentation, The South Australian Exploration and Mining Conference 2023 (SAEMC), December 2023, Adelaide.
- Oral presentation, 2023 PRIF Final Research Conference, PRIF RCP “Unlocking Complex Resources through Lean Processing”, 18/10/2023.

References and Acknowledgement

l would like to acknowledge the funding support administered by The Department of Industry, Innovation and Science, and by the SA Government through the PRIF RCP Mining Consortium ‘Unlocking Complex Resources through Lean Processing’.

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7. Marilú Barrera, O., et al., *Mobility of Heavy Metals in Aquatic Environments Impacted by Ancient Mining-Waste*, in *Water Quality*, D. Daniel, Editor. 2021, IntechOpen: Rijeka. p. Ch. 7.
8. Abbaspour, N., R. Hurrell, and R. Kelishadi, *Review on iron and its importance for human health.* J Res Med Sci, 2014. **19**(2): p. 164-74.

APPENDIX 6 TECHNOLOGY READINESS LEVELS (TRLs) of FOUR IMPLEMENTABLE PROJECTS

As was reported in the 2023 April Report, to progress towards research translation and commercialisation, the Technology Readiness Level (TRL) method has been used to assess progress in each of the PRIF projects towards larger system integration and industry implementation (see Table below). The Consortium management team and Chief Investigators in collaboration with Industry Partners rated all projects using the CRC-ORE TRLs scale from 1 to 9, with 9 being the most mature technology. The CRC-ORE TRLs were chosen to assess PRIF technology capabilities, as it is relevant to PRIF projects in mining and mineral processing. TRLs 1–4 represent fundamental Research, TRLs 5–7 Integration/Development, and TRLs 8–9 Demonstration/Implementation and Commercial deployment.

The progress of each project, as well as TRLs, were discussed at the Governing Board meetings in 2023 - 2024. Also, we discussed how to maximize the impact of the PRIF Consortium research on the Australian mining and copper industry and to find a mechanism to ensure that PRIF outcomes are known to industry partners so that they can be either implemented or allowed to be further developed.

The table below shows the estimated TRLs for 6 extended and active projects in 2023 – 2024.

Two (2) projects are rated TRL 4 marking the end of fundamental research and indicating that systems have been tested and simulated in the industrially relevant environment.

Although not all PRIF projects can be moved to higher TRLs with scaled-up trials on-site, the following implementable projects have made significant progress during the extension period (March 2023 – June 2024) and achieved their strategic objectives. TRLs of the four selected projects listed below increased as:

- ARP3: from TRL 5 to TRL 8-9
- ATP4: from TRL 4 to TRL 6
- BRP3: from TRL 3-4 to TRL 6
- BTP9: from TRL 7 to TRL 8-9

also,

- BRP5: from TRL 2 to TRL 4
- BRP2: from TRL 2 to TRL 4

Please note, the Consortium outcomes such as models, software and diverse hardware, have commercial potential for the Translation Partners and are useful for the End-users, and also could leverage new research opportunities for the Research Partners.

TRLs - TECHNOLOGY READINESS LEVELS FOR PRIF PROJECTS 2023 - 2024

#	Project/ Translation Partner(s)	Project Title	Technology Readiness Levels								
			Invention - Research				Integration - Development			Implementation	
			TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
			Basic Principles Observed/ Reported	Technology Concept &/or Application Formulated	Analytical & Experimental Proof of Concept	Component Integration Validated in Laboratory Environment & Initial Value Proposition Defined	System Tested &/or Simulated in Realistic Environment	System Model/ Prototype Tested on End User Site with Refined Value Proposition	System Prototype Demonstrated on End User Site	Commercially Relevant System Deployed on End User Site with Proven Value Proposition	Actual System Proven Reliable Through Successful Operation
1	**A RP3** Maptek	Constraints and quantifying uncertainty on resource domain boundaries								8 -	9
2	**A TP4** Eka	Fast ROM (Run of the Mine) Stockpile Modelling for Blending Optimisation						6			
3	**B TP9** Magotteaux	MAGOPULP for improved predictive flotation model and process performance								8 -	9
4	**B RP3** Manta Controls Nimble Resources	New sensor development for particle size measurement in Hydrocyclones						6			
5	**B RP5** Magotteaux	Further development of Metal Organic Framework based fibre optic sensor				4					
6	**B RP2** BHP	Predictive machine health monitoring for SAG/AG mills				4					
			Invention - Research				Integration - Development			Implementation	

APPENDIX 7 TECHNOLOGY READINESS LEVELS - DEFINITIONS AND DESCRIPTIONS

TRL 1 Definition	TRL 1 Description
Basic Research. Initial scientific research begins. Examples include studies on basic material properties. Principles are qualitatively postulated and observed.	Basic principles are observed. Focus is on fundamental understanding of a material or process.
TRL 2 Definition	**TRL 2 Description**
Applied Research. Initial practical applications are identified. Potential of material or process to satisfy a technology need is confirmed.	Once basic principles are observed, practical applications can be identified. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from basic to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
TRL 3 Definition	**TRL 3 Description**
Critical Function, i.e., Proof of Concept Established. Applied research continues and early stage development begins. Includes studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology. Examples include research on materials, components, or processes that are not yet integrated.	Analytical studies and laboratory-scale studies are designed to physically validate the predictions of separate elements of the technology. Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical components. At TRL 3 experimental work is intended to verify that the concept works as expected. Components of the technology are validated, but there is no strong attempt to integrate the components into a complete system. Modelling and simulation may be used to complement physical experiments.
TRL 4 Definition	**TRL 4 Description**
Laboratory Testing/Validation of Alpha Prototype Component/Process. Design, development and lab testing of technological components are performed. Results provide evidence that applicable component/process performance targets may be attainable based on projected or modelled systems.	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-6 represent the bridge from scientific research to engineering, from development to demonstration. TRL 4 is the first step in determining whether the individual components will work together as a system. The goal of TRL 4 should be the narrowing of possible options in the complete system.

TRL 5 Definition	**TRL 5 Description**
Laboratory Testing of Integrated/Semi-Integrated System. Component and/or process validation in relevant environment- (Beta prototype component level).	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical. Scientific risk should be retired at the end of TRL 5. Results presented should be statistically relevant.
TRL 6 Definition	**TRL 6 Description**
Prototype System Verified. System/process prototype demonstration in an operational environment- (Beta prototype system level).	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include fabrication of the device on an engineering pilot line. Supporting information includes results from the engineering scale testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the final system. The engineering pilot scale demonstration should be capable of performing all the functions that will be required of a full manufacturing system. The operating environment for the testing should closely represent the actual operating environment. Refinement of the cost model is expected at this stage based on new learning from the pilot line. The goal while in TRL 6 is to reduce engineering risk. Results presented should be statistically relevant.
TRL 7 Definition	**TRL 7 Description**
Integrated Pilot System Demonstrated. System/process prototype demonstration in an operational environment- (integrated pilot system level).	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Final design is virtually complete. The goal of this stage is to retire engineering and manufacturing risk. To credibly achieve this goal and exit TRL 7, scale is required as many significant engineering and manufacturing issues can surface during the transition between TRL 6 and 7.

TRL 8 Definition	**TRL 8 Description**
System Incorporated in Commercial Design. Actual system/process completed and qualified through test and demonstration- (Pre-commercial demonstration).	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include full scale volume manufacturing of commercial end product. True manufacturing costs will be determined and deltas to models will need to be highlighted and plans developed to address them. Product performance delta to plan needs to be highlighted and plans to close the gap will need to be developed.
TRL 9 Definition	**TRL 9 Description**
System Proven and Ready for Full Commercial Deployment. Actual system proven through successful operations in operating environment, and ready for full commercial deployment.	The technology is in its final form and operated under the full range of operating conditions. Examples include steady state 24/7 manufacturing meeting cost, yield, and output targets. Emphasis shifts toward statistical process control.

APPENDIX 8 COMMERCIAL READINESS LEVELS - DEFINITIONS AND DESCRIPTIONS

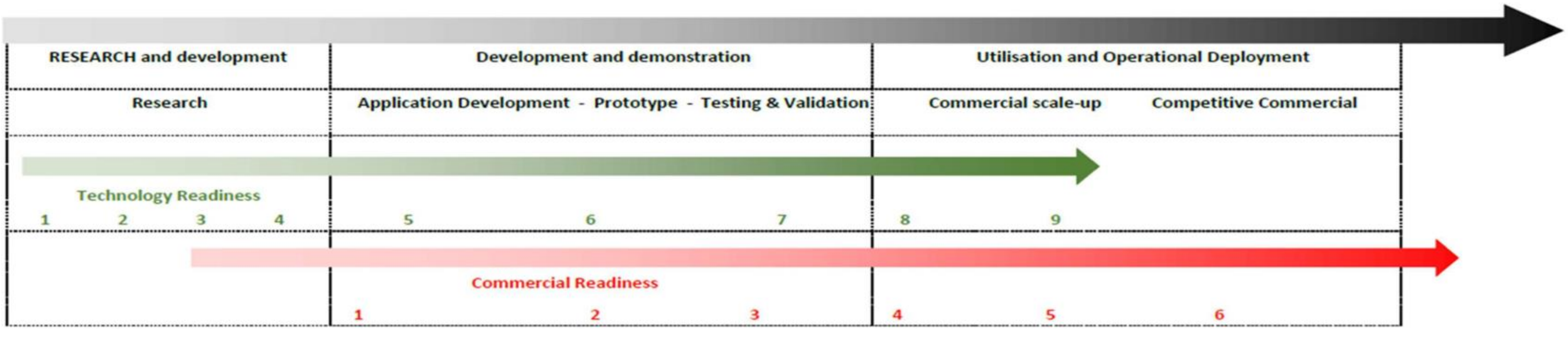
The Commercial Readiness Level is a measure on a scale of 1 to 9 of how ready a technology is to be made commercially available. Starting from the belief that a new technology could be commercially successful all the way through to:

- full regulatory compliance,
- commercial availability and
- wider acceptance within the target market.

Commercial Readiness Levels definitions.

Commercial Readiness Level	Description
CRL 1	Basic hypothesis that a new technology would be commercially viable.
CRL 2	Basic market awareness demonstrated.
CRL 3	Applications of technology found.
CRL 4	Identify support needed from supply chain, plus any certification and regulatory requirements.
CRL 5	Financial model for sales, costs and margins established.
CRL 6	Confirm exploitation routes; form partnerships across the value chain; and certification and regulatory requirements underway.
CRL 7	Financial model/commercial viability validated.
CRL 8	First commercial system built; route to market established; market assumptions updated.
CRL 9	Technology has been introduced to market.

General overlap between Technology and Commercial Readiness Levels.



APPENDIX 9 PRIF MINING CONSORTIUM PEOPLE 2019 - 2024

The PRIF Mining Consortium brings together an exceptional team of researchers:

Consortium Management Team

Director
Prof Nigel Cook
University of Adelaide

Program Manager
Dr Tatiana Khmeleva
(October 2019 – March 2024)

Project Manager
Dr Sanaz Orandi
(April – August 2024)

Chief Investigators

Prof Peter Dowd (Lead)
University of Adelaide

Prof William Skinner (Lead)
University of South Australia

A/Prof Chaoshui Xu
University of Adelaide

Prof Frank Neumann
University of Adelaide

Dr Tien-Lu -Fu
University of Adelaide

Dr Lei Chen
University of Adelaide

Prof David Lancaster
University of South Australia

Prof David Beattie
University of South Australia

Prof Marta Krasowska
University of South Australia

Adjunct A/Prof Max Zanin
University of South Australia

A/Prof Bronwyn Hajek
University of South Australia

A/Prof Larissa Statsenko
University of South Australia

A/Prof Anton Blencowe
University of South Australia

Higher Degree by Research Students

Hu Wang
University of Adelaide

Yue Xie
University of Adelaide

Hirad Assimi
University of Adelaide

Yerniyaz Abildin
University of Adelaide

Bismark Amankwaa-Kyeremeh
University of South Australia

Kwaku Boateng Owusu
University of South Australia

Linda Rozenberga
University of South Australia

Kirsten Louw
University of South Australia

Yusha Li
University of Adelaide

Kiet Wong
University of Adelaide

Postdoctoral Fellows

Dr Difan Tang
University of Adelaide

Dr Shi Zhao
University of Adelaide

Dr Richmond Asamoah
University of South Australia

Dr Amir Adeli
University of Adelaide

Dr Junjie Zhang
University of Adelaide

Dr Aneta Neumann
University of Adelaide

Dr Dale Otten
University of South Australia

Dr Todd Gillam
University of South Australia

Dr Piotr Pawliszak
University of South Australia

Please see the Consortium website for more information:

https://www.adelaide.edu.au/integrated-mining-consortium/

APPENDIX 10 PRIF PROJECTS 2019 - 2024

Exploration and Evaluation

ARP1: Optimising mining operations under different constraints with a focus on in-situ resource to stockpile

ARP2: Resource heterogeneity modelling for optimal ore extraction

ARP3: Constraints and quantifying uncertainty on resource domain boundaries

ARP4: Correlations of elemental, mineralogical, hyperspectral with sensor data for mineral identification

ATP1: Ore tracking from resource to crusher

ATP2: Performance assessment of LiDAR muckpile fragmentation measurement technique

ATP3: Active thermography as a tool for the determination of steely vs non-steely haematites in drill core samples

Mine Planning and Development

ATP5: Advanced Ore Mine Optimisation under Uncertainty

Material Handling

ARP5: Resource heterogeneity modelling from trucking to multiple stockpiles to mill feed

ARP6: Blend strategy optimisation

ARP7: Mill feed sorting to optimise throughput and energy usage

ATP4: ROM stockpile modelling

ATP6: Mill feed sorting to optimise throughput and energy usage

Comminution

BRP1: Sensing and optimisation of autogenous and semi-autogenous grinding mills

BRP2: Predictive machine health monitoring for SAG/AG mills

BRP3: New sensor development for particle size measurement in hydrocyclones

BT7: Manta Mic acoustic analyser: Increase mill throughput and reduce overgrinding

BTP8: Ultrasonic particle size distribution sensor: Improve mill energy efficiency and throughput together with optimum particle size for flotation

BTP11: Development of Laboratory AG/SAG mill: A multifunctional laboratory AG/SAG mill mimicking industrial conditions

Flotation

BRP4: Sensing and optimisation of flotation circuits and integration with grinding

BRP7: Formation of MIP particle film on substrate and successful detection of flotation frother via gravimetric detection.

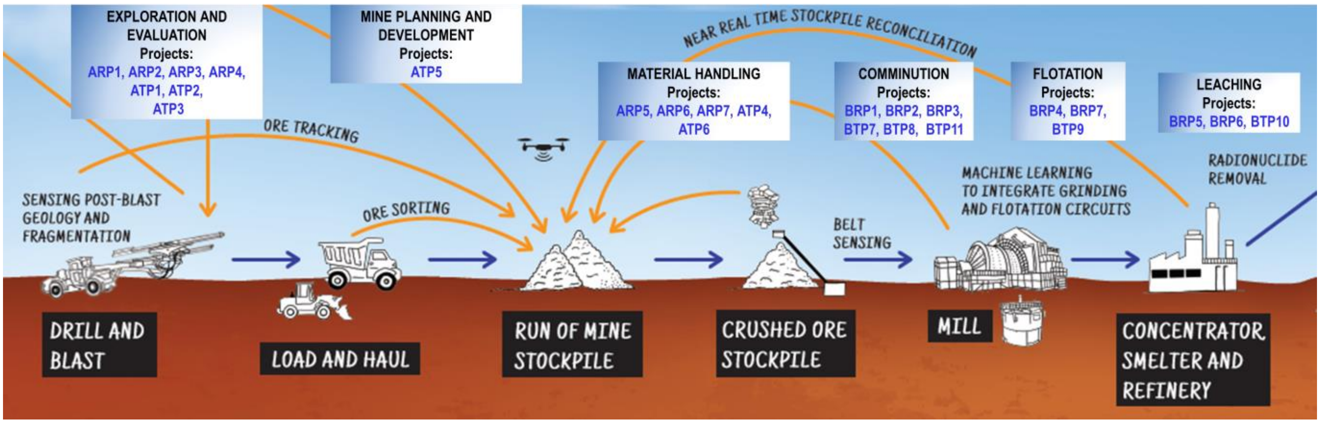
BTP9: Pulp Chemistry Monitor (PCM®): Develop robust flotation predictive models for higher copper recovery and improved optimisation

Leaching

BRP5: Metal Organic Framework based fibre optic sensors

BRP6: Diffusive processes in mineral processing

BTP10: Tails Leach Circuit/MOF sensors: Develop reliable fibre optic sensor for harsh uranium leaching environment



Please see the Consortium website for more information:

https://www.adelaide.edu.au/integrated-mining-consortium/

APPENDIX 11 PRIF MINING CONSORTIUM PUBLICATIONS AND PUBLICITY

At the time of this report writing, the PRIF Mining Consortium has 143 papers published.

Consortium Publications in each year of the PRIF Mining Consortium Program

Status/Year	2018	2019	2020	2021	2022	2023	2024	Total
Published	4	9	22	52	39	15	3	**144**
Accepted								
Submitted								
Under preparation							10	10
Total								**154**

Publicity about the PRIF Mining Consortium:

To showcase the achievements of the PRIF Mining Consortium and promote the developed technologies to a wider audience, the following platforms were used for the PRIF Mining Consortium publicity:

- The 2023 PRIF Research Conference held on 18th October 2023 can be viewed on YouTube: https://www.youtube.com/playlist?list=PLIgDYZIzNDZJ71IPnHKHdIdorXo1k6I1J

- Maptek Forge magazine - 'Delivering value for miners' – an article dedicated to the PRIF (7/03/2023) - https://www.maptek.com/forge/march_2023/delivering-value-for-miners/

- METS Ignited website - A story on the first METS Ignited workshop for PRIF researchers -
  'METS Ignited kicks off Stranded Research Workshops' article here (30/03/2023) - https://metsignited.org/mets-ignited-kicks-off-stranded-research-workshops/

- The Collaborating for technology readiness Maptek Blog – about the PRIF and Maptek collaboration (December 2022): https://www.maptek.com/blogs/collaborating-for-technology-readiness/

- The PRIF Annual Assembly held on 22nd July 2022 can be viewed on YouTube:

  https://www.youtube.com/watch?v=YejBLIPn3qs&list=PLIgDYZIzNDZKHoTTvMPYF4HIhVAOsooQL

- PRIF Mining Consortium Promotional video for the 2022 Premier's Award in Energy and Mining (October 2022):

  https://www.youtube.com/watch?v=i8RCYJZCiQw&t=17s

- The PRIF Annual Assembly held on 1st October 2021 can be viewed on YouTube: https://youtube.com/playlist?list=PLIgDYZIzNDZK4Q-lUWORz8yZnfZuDjfDy

- Prof Nigel Cook – speaker presentation (YouTube):

  Professor Nigel Cook was a presenter at Amira's Global Remote Operations Automation and Robotics Day (Global ROAR), which was held on 10th October 2020. Nigel discussed 'Developing Tools to Integrate the Entire Mining Value Chain by Using Machine Learning, Sensors and Data Analytics'. The presentation is available on YouTube: https://www.youtube.com/watch?v=2H-_jjq4ve4

List of PRIF Mining Consortium Publications

Legend: **Published in black font colour**

Accepted and addressing reviewers comments in purple font colour

Submitted in green font colour

Under Preparation in red font colour

N	Publication	Comments (e.g. published/ accepted/submitted)
	Program A	
1	Adeli, A., Emery, X. and Dowd, P.A. (2018) Geological modelling and validation of geological interpretations via simulation and classification of quantitative covariates. Minerals, 8 (7), doi:10.3390/min8010007	Published, 2018 full text available on Box
2	Sepulveda, E., Dowd, P.A. and Xu, C. (2018) Fuzzy clustering with spatial correction and its application to geometallurgical domaining. Mathematical Geosciences, 50 (8), 895-928.	Published, 2018 full text available on Box
3	Sepulveda, E., Dowd, P.A. and Xu, C. (2018) The optimisation of block caving production scheduling with geometallurgical uncertainty – a multi-objective approach. Mining Technology, 127 (3), 131-145.	Published, 2018 full text available on Box
4	Wang, H., Pardo-Igúzquiza, E., Dowd, P.A. and Yang, Y. (2018) Comparison of statistical methods for testing the hypothesis of constant global mean in spatial statistics. Spatial Statistics, 23, 143-159.	Published, 2018 full text available on Box
5	Hou, J., Xu, C., Dowd, P.A. and Li, G. (2019) Integrated optimisation of stope boundary and access layout for underground mining operations. Mining Technology, 128, (4), 193- 205.	Published, 2019 full text available on Box

6	Qiuzhu Pan (2019), Muck-pile fragmentation measurement techniques - from controlled samples to field trials, MSc thesis, the University of Adelaide *Awarded the PRIF RCP Women in Mining Technology Scholarship*	Published, 2019
7	F. Neumann, A. Sutton (2019): Runtime analysis of evolutionary algorithms for the chance-constrained knapsack problem, Proceedings of the Foundations of Genetic Algorithms XV, FOGA 2019, ACM Press, 147-153. (CORE A*)	Published, 2019 full text available on Box
8	J. Bossek, P. Kerschke, A. Neumann, M. Wagner, F. Neumann, H. Trautmann (2019): Evolving diverse TSP instances by means of novel and creative mutation operators, Foundations of Genetic Algorithms XV, FOGA 2019, ACM Press, 58-71. (CORE A*)	Published, 2019 full text available on Box
9	Yue Xie, Oscar Harper, Hirad Assimi, Aneta Neumann, and Frank Neumann (2019): Evolutionary algorithms for the chance-constrained knapsack problem, Proceedings of the Genetic and Evolutionary Computation Conference, GECCO 2019, ACM, New York, NY, USA, 338-346. DOI: https://doi.org/10.1145/3321707.3321869. (CORE A)	Published, 2019 full text available on Box
10	Lei Zhang, Wei Wei, Qiang Shen, Chunhua Shen and Anton van den Hengel (2019), Accurate Imagery Recovery Using a Multi-Observation Patch Model, Information Science 501, 724-741.	Published, 2019 full text available on Box
11	Haokui Zhang, Ying Li, Yenan Jiang, Peng Wang, Qiang Shen and Chunhua Shen (2019), Hyperspectral Classification Based on Lightweight {3D-CNN} With Transfer Learning, IEEE Transactions on Geoscience and Remote Sensing 57; 10.1109/TGRS.2019.2902568	Published, 2019 full text available on Box
12	Liang Liu, Hao Lu, Haipeng Xiong, Ke Xian, Zhiguo Cao and Chunhua Shen (2019), Counting Objects by Blockwise Classification, IEEE Transactions on Circuits and Systems for Video Technology. 10.1109/TCSVT.2019.2942970	Published, 2019 full text available on Box
13	Zifeng Wu, Chunhua Shen and Anton van den Hengel (2019), Wider or Deeper: Revisiting the {ResNet} Model for Visual Recognition, Pattern Recognition 90, 119-133.	Published, 2019
14	B. Doerr, C. Doerr, A. Neumann, F. Neumann, A. M. Sutton (2020), Optimization of chance-constrained submodular functions, Proceedings of the Thirty-Fourth AAAI Conference on Artificial Intelligence, AAAI 2020, AAAI Press 2020, ISBN 978-1-57735-823-7, (CORE A*), 1460-1467.	Published, 2020 full text available on Box
15	Wang, Z., Xu, C., Dowd, P.A., Xiong, F. and Wang, H. (2020), A Nonlinear Version of the Reynolds Equation for Flow in Rock Fractures With Complex Void Geometries. *Water Resources Research*, 56 (2), e2019WR026149. https://doi.org/ 10.1029/2019WR026149.	Published, 2020 full text available on Box
16	Jeuken, R., Xu, C. and Dowd, P.A. (2020) Improving Coal Quality Estimations with Geostatistics and Geophysical Logs. Natural Resources Research, 29, 1-18.	Published, 2020 full text available on Box

17	Pardo-Igúzquiza, E. and Dowd, P.A. (2020) Identification, delineation and morphometric analysis of closed terrain depressions on Mars. Icarus, 348. https://doi.org/10.1016/j.icarus.2020.113869	Published, 2020 full text available on Box
18	Pardo-Igúzquiza, E. and Dowd, P.A. (2020) Identification and delineation of the Earth's large-scale closed terrain depressions and their fractal size-distribution. Accepted for publication in Mathematical Geosciences. https://doi.org/10.1007/s11004-020-09888-9	Published, 2020 full text available on Box
19	Li, Y., Sepulveda, E., Xu, C., Dowd, P.A. (2020) A Rapid updating method to predict grade heterogeneity at smaller scales. Mathematical Geosciences. https://doi.org/10.1007/s11004-020-09901-1	Published, 2020 full text available on Box
20	Jorreto-Zaguirre, S., Dowd, P.A., Pardo-Igúzquiza, E., Pulido-Bosch, A. and Sanchez-Martos, F. (2020) Stochastic simulation of the heterogeneity of deltaic hydrofacies accounting for the uncertainty of facies proportions. Frontiers in Earth Sciences special edition on Stochastic Modelling in Hydrogeology. DOI: 10.3389/feart.2020.563122.	Published, 2020 full text available on Box
21	Hirad Assimi, Ben Koch, Christopher Garcia, Markus Wagner, Frank Neumann, Automatic Search Strategy for ROM Stockpile Recovery Optimisation Preconcentration Digital Conference 2020 (10-11, 17-18 November), Australia	Published, 2020 full text available on Box
22	Hirad Assimi, Ben Koch, Christopher Garcia, Markus Wagner, Frank Neumann, Automatic Search Strategy for ROM Stockpile Recovery Optimisation Preconcentration Digital Conference 2020 (10-11, 17-18 November), Australia	Published, 2020 full text available on Box
23	Hirad Assimi, Oscar Harper, Yue Xie, Aneta Neumann, and Frank Neumann: Evolutionary Bi-objective Optimization for the Dynamic Chance-Constrained Knapsack Problem Based on Tail Bound Objectives, In Proceedings of the 24th European Conference on Artificial Intelligence, ECAI 2020 Digital Conference, pp. 307-314. 2020. IOS Press.	Published, 2020 full text available on Box
24	Yue Xie, Aneta Neumann, Frank Neumann: Specific single- and multi-objective evolutionary algorithms for the chance-constrained knapsack problem, Proceedings of the Genetic and Evolutionary Computation Conference, GECCO 2020 Electronic-only Conference ACM 2020, ISBN 978-1-4503-7128-5, (CORE A), 271-279. GECCO '20, July 8–12, 2020	Published, 2020 full text available on Box
25	Yue Xie, Aneta Neumann, Frank Neumann: Specific single- and multi-objective evolutionary algorithms for the chance-constrained knapsack problem, Proceedings of the Genetic and Evolutionary Computation Conference, GECCO 2020 Electronic-only Conference ACM 2020, ISBN 978-1-4503-7128-5, (CORE A), 271-279. GECCO '20, July 8–12, 2020	Published, 2020 full text available on Box

26	Aneta Neumann and Frank Neumann: Optimising Monotone Chance-Constrained Submodular Functions Using Evolutionary Multi-Objective Algorithms, Proceedings of the 16th International Conference on Parallel Problem Solving from Nature, PPSN XVI 2020 (hybrid), (CORE A), Leiden, South Holland, Netherlands. HYBRID 5 - 9 Sep 2020	Published, 2020 the full text is available on Box
27	Hu Wang, Qi Wu, Chunhua Shen: Soft Expert Reward Learning for Vision-and-Language Navigation (accepted by ECCV 2020). The article address is https://www.ecva.net/papers/eccv_2020/papers_ECCV/papers/123540120.pdf an introductory video here: https://www.youtube.com/watch?v=mTMHju4F2UU	Published, 2020 full text available on Box
28	Hu Wang, Guansong Pang, Chunhua Shen, Congbo Ma: Unsupervised Representation Learning by Predicting Random Distances (accepted by IJCAI 2020). The article address is https://www.ijcai.org/Proceedings/2020/0408.pdf. There is a long version with appendix is at: https://arxiv.org/abs/1912.12186	Published, 2020 full text available on Box
29	Pardo-Igúzquiza, E. and Dowd, P.A. Fractal analysis of the Martian landscape: a study of kilometre-scale topographic roughness. Icarus, 372, Article 114727.	Published, 2021
30	Pardo-Igúzquiza, E. and Dowd, P.A. (2021) The mapping of closed depressions and its contribution to the geodiversity inventory. International Journal of Geoheritage and Parks, 9 (4), 480-495.	Published, 2021
31	Adeli, A., Dowd, P.A., Emery, X. and Xu, C. (2021) Using cokriging to predict metal recovery accounting for non-additivity and preferential sampling designs. Minerals Engineering, 170, 106923.	Published, 2021 full text available on Box
32	Pardo-Igúzquiza, E. and Dowd, P.A. (2021) Identification and delineation of the Earth's large-scale closed terrain depressions and their fractal size-distribution. Mathematical Geosciences, 53, 1027-1045	Published, 2021
33	Li, Y., Sepulveda, E., Xu, C., Dowd, P.A. (2021) A Rapid updating method to predict grade heterogeneity at smaller scales. Mathematical Geosciences, 53 (6), 1237-1260.	Published, 2021
34	Xu, C., Dong, S, Wang, H., Wang, Z., Xiong, F., Jiang, Q., Zeng, L., Faulkner, L., Tian, Z. and Dowd, P.A. (2021) Modelling of coupled hydro-thermo-chemical fluid flow through rock fracture networks and its applications. Geosciences, Special Issue on Quantitative Fractured Rock Hydrology, 11, 153. https://doi.org/10.3390/geosciences11040153	Published, 2021 full text available on Box
35	Wang, H., Xu, C. and Dowd, P.A. (2021) Modelling the pyrite oxidation level in a refractory gold-bearing stockpile to assess its potential for gold recovery by direct cyanide leaching. Minerals Engineering, 171, 107089	Published, 2021

36	Xu, C., Dowd, P.A., Nguyen, N. and Wang, W. (2021) Non-parametric three-dimensional discrete fracture modelling from fracture mapping data. Boletín Geológico y Minero, 131 (3): 401-422. ISSN: 0366 -0176.	Published, 2021
37	Sepulveda, E., Dowd, P.A. and Xu, C. (2021) A novel index for quantifying small-scale resource heterogeneity. Mathematical Geosciences, 54, 243-282.	Published, 2021 full text available on Box
38	Pardo-Igúzquiza, E. and Dowd, P.A. (2021) Automatic mapping and spatial analysis of high spatial resolution closed terrain depressions and mounds on Martian landscapes. Icarus, 369. Article 114632.	Published, 2021 full text available on Box
39	Wang, H., Dowd, P.A. and Xu, C. (2021) Modelling pyrite oxidation in a refractory gold ore stockpile to estimate the gold recovery via direct cyanide leaching – A case study. Minerals Engineering, 173, 107177	Published, 2021 full text available on Box
40	Yusha Li, Exequiel Sepulveda, Chaoshui Xu, Peter Dowd, A rapid updating method to predict grade heterogeneity at smaller scales. Mathematical Geosciences, 53, pages1237–1260.	Published, 2021 full text available on Box
41	Shi Zhao, Tien-Fu Lu, Larissa Statsenko, Ben Koch, Chris Garcia: A Framework for Fast ROM Stockpile Modelling to Improve Blending Efficiency, Journal of Engineering, Design and Technology (Q2) Volume 20 Issue 2, accepted April 2021, published July 2021. https://www.emerald.com/insight/1726-0531.htm	Published, 2021 full text available on Box
42	Zhao, S., Statsenko, L., Lu, T.-F., Assimi, H, Koch, B. and Garcia, C. "Short term reclamation optimisation for front end loaders (FELs) using quality embedded 3D ROM stockpile models ", Minerals Engineering, under preparation	2024 under preparation
44	Hirad Assimi, Koch, B., Garcia, C., Wagner, M., & Neumann, F. (2020): Modelling and Optimization of Run-of-Mine Stockpile Recovery, In Proceedings of the 36th Annual ACM Symposium on Applied Computing, pp. 450-458. 2021.	Published, 2021 full text available on Box
45	Aneta Neumann, William Reid, Simon Ratcliffe, Frank Neumann: Advanced Ore Mine Optimisation under Uncertainty Using Evolution IAM'21 Workshop at GECCO'21 as a full publication (The Genetic and Evolutionary Computation Conference (GECCO)) July 10-14, 2021; Online-only Conference, Lille, France	Published, 2021 full text available on Box
46	Aneta Neumann, Yue Xie, and Frank Neumann: Evolutionary Algorithms for Limiting the Effect of Uncertainty for the Knapsack Problem with Stochastic Profits. The 17th International Conference on Parallel Problem Solving from Nature PPSN 2022 (1), Vol. 13398 of Lecture Notes in Computer Science, Springer, September 10-14, 2022, Dortmund, Germany, pp. 294–307, (CORE A).	Published, 2022 full text available on Box

47	Pardo-Igúzquiza, E. and Dowd, P.A. Millennial-scale rapid climate changes during the Holocene: cycles or repetitions?	Published, 2022
48	Pardo-Igúzquiza, E., Montillet, J.-P., Dowd, P.A., Sanchez-Morales, J., Darbeheshti, N. and Rodríguez-Tovar, F.J. Terrestrial water storage variations in southern Spain using rainfall estimates and GRACE data.	Published, 2022
49	E. Pardo-Igúzquiza, P.A. Dowd, 2022: The roughness of Martian topography: A metre-scale fractal analysis of six selected areas. Published by Elsevier Inc., Available online https://doi.org/10.1016/j.icarus.2022.115109	Published, 2022 full text available on Box
50	Hang Wang, Chaoshui Xu, Peter A. Dowd, Zhihe Wang, Leon Faulkner, 2022: Modelling in-situ recovery (ISR) of copper at the Kapunda mine, Australia. Minerals Engineering, 186, 107752; Published by Elsevier Inc., Available online https://doi.org/10.1016/j.mineng.2022.107752	Published, 2022 full text available on Box
51	Eulogio Pardo-Igúzquiza, Juan J. Durán-Valsero, Peter A. Dowd, Juan A. Luque-Espinar, Javier Heredia, Pedro A. Robledo-Ardila, 2022: Geodiversity of closed depressions in a high relief karst: Geoeducation asset and geotourism resource in the "Sierra de las Nieves" National Park (Málaga Province, Southern Spain). Published by Elsevier Inc., Available online https://doi.org/10.1016/j.ijgeop.2022.04.001	Published, 2022 full text available on Box
52	Chaoshui Xu, Peter Dowd and Nathan Nguyen, 2022: Non-parametric three-dimensional fracture modelling from fracture mapping data. Boletín Geológico y Minero, 131 (3): 55-76, ISSN: 0366 -0176 DOI: 10.21701/bolgeomin.131..005	Published, 2022 full text available on Box
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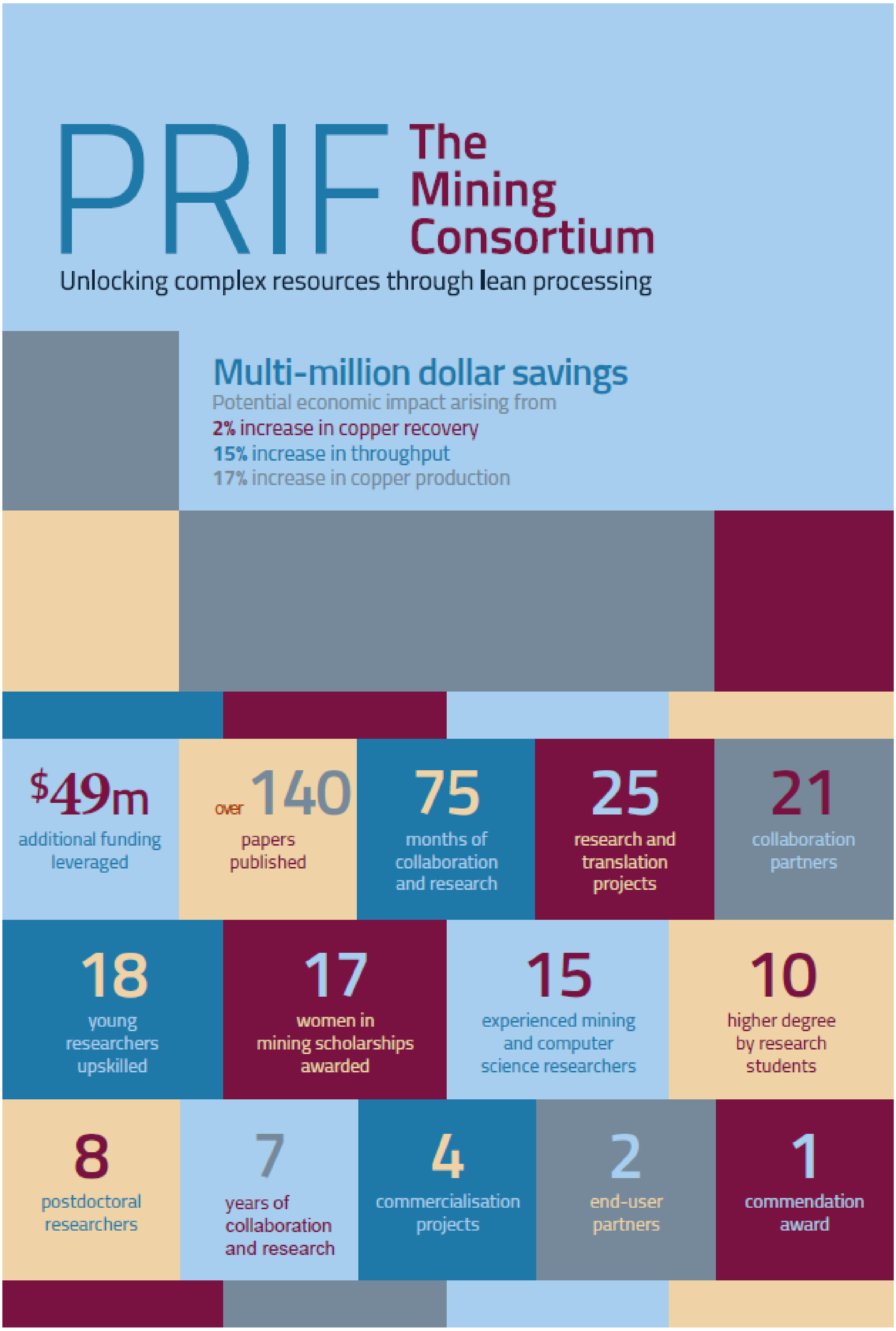
144	Amankwaa-Kyeremeh, B, McCamley, C, Zanin, M, Greet, C, Ehrig, K & Asamoah, RK (2024), 'Prediction and optimisation of copper recovery in the rougher flotation circuit', Minerals, vol. 14, no. 1, pp. 1-31. http://researchoutputs.unisa.edu.au/11541.2/37611	Published, 2023 full text available online
145	Owusu, KB, Skinner, W & Asamoah, RK 2023, 'Acoustic sensing and supervised machine learning for in situ classification of semi-autogenous (SAG) mill feed size fractions using different feature extraction techniques', vol. 2, no. 2, pp. 299-322. http://researchoutputs.unisa.edu.au/11541.2/33942	Published, 2023 full text available on line
146	Piotr Pawliszak, Bronwyn H. Bradshaw-Hajek, William Skinner, David A. Beattie, Marta Krasowska (2024), Frothers in flotation: A review of performance and function in the context of chemical classification. Minerals Engineering, Volume 207, February 2024, 108567 https://www.sciencedirect.com/science/article/pii/S0892687523005812?via%3Dihub	Published, 2023 full text available on Box and online

147	Linda Rozenberga, Witold Bloch, Todd A. Gillam, David G. Lancaster, William Skinner, Marta Krasowska, Anton Blencowe, and David A. Beattie: Europium Metal–Organic Framework Polymer Composites with Enhanced Luminescence and Selective Ferric Ion Sensing, ACS Applied Polymer Materials, Volume 6, Issue 6, Pages 3042-3572;	Published, 2024 full text available on online https://doi.org/10.1021/acsapm.4c00111
148	Tang D, Chen L, Yang L, Asamoah R and Hu E. Hydrocyclone overflow particle-size estimation: Size passing fraction P80 detection via solids impact mechanics. Minerals Engineering. Manuscript in preparation	2024 under preparation
149	Tang D, Chen L, Yang L, Asamoah R and Hu E. Hydrocyclone overflow particle-size estimation: Particle size distribution estimation via bluff-body hydrodynamics. Minerals Engineering. Manuscript in preparation.	2024 under preparation
150	Difan Tang, Lei Chen, Lin Yang, Richmond Asamoah, and Eric Hu, Online particle-size monitoring for hydrocyclone overflow: Where is the beacon? Minerals Engineering.	2024 under review
151	Tang D, Chen L, Yang L, Asamoah R and Hu E. Size estimation of gas-conveyed particles via solid-impact mechanics based on accelerometer measurement. Minerals Engineering. Manuscript under review.	2024 under review
152	Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Hydrocyclone roping prediction versus detection: Could prediction be possible? Minerals. Manuscript under review.	2024 under review
153	Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Online mass-flow-rate measurement of high-intensity gas-conveyed particle flow using force transducer. Powder Technology. Manuscript under review.	2024 under review
154	Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Online particle size distribution and P80 monitoring via force-measurement based vibration sensing. Minerals Engineering. Manuscript under review.	2024 under review
155	Tang D, Chen L, Yang L, Asamoah R and Hu E. Online estimation of particle size distribution in the overflow of hydrocyclones via force measurement: Theory and preliminary investigation. Minerals Engineering. Manuscript in preparation.	2024 under preparation
156	Tang D, Chen L, Yang L, Asamoah R and Hu E. Improving particle-size estimation at hydrocyclone overflow via data fusion. Minerals Engineering. Manuscript in preparation.	2024 under preparation
157	Tang D, Chen L, Yang L, Asamoah R and Hu E. Online particle density measurement for rotary air concentration used in Alluvial Gold Mining. Minerals Engineering. Manuscript in preparation.	2024 under preparation
158	Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Experimental investigation on the correlation between hydrocyclone roping and overflow air content. Minerals Engineering. Manuscript in preparation.	2024 under preparation

APPENDIX 12 INFOGRAPHICS – BENEFITS OF THE PRIF MINING CONSORTIUM PROGRAM



Unlocking complex copper resources

The Adelaide-based Integrated Mining Consortium of universities, METS partners, mining companies and research bodies has unlocked potential multi-million dollar savings arising from innovative projects that will increase copper recovery, throughput and production.

$mm
potential economic impact

The overall benefit is predicated on a 2% increase in recovery, 15% increase in throughput and 17% increase in production.

$49m
additional funding sourced

Leveraging additional funding

Catalysing additional funding and support across industry partners has added significantly to the scope and depth of projects since the Consortium began in 2017.

Collaborating for technology readiness

Coming up with new ideas is hard, devising new ideas that work is even tougher. Collaboration between our partners was critical for translating the research **ideas into marketable products.**

21
collaboration partners

25
research and translation projects

Realising the promise of research

Tackling multiple elements of the upstream and downstream mining processes through 14 research projects led to **opportunities for software and technology development** across 11 translation projects.

Delivering innovation to market

The Consortium brought four projects to **commercialisation**: applying machine learning for accurate domain modelling; optimised reclamation of ore stockpiles in near real-time; applying pulp chemistry advances to maximise mill throughput; and harnessing force measurements to cost-effectively improve online particle size measurements.

four

commercial-ready consortium technologies

18

young researchers skilled

Resourcing a sustainable industry

Playing an important role in training the next generation of scientists, engineers and data analysts, the Consortium builds capability for industry success well into the future.

Creating a national powerhouse

Establishing a **single focus targeting mining optimisation** has been overwhelmingly successful in combining research and industry knowledge and fostering collaboration to deliver wide benefits.

140

papers published

Programs like this strengthen our workforce with scientists skilled in the technologies of the future.

∞

potential

Data-driven deliverables

Aligning research with data-driven deliverables **future proofs the outcomes for miners**. Projects looked to harness sensors, machine learning, data analytics and other technologies to provide tools that integrate and optimise the mining value chain.

APPENDIX 13

PRIF Mining Consortium

Extension Report

1 September 2024 – 31 August 2025

Addition to Final Annual Report #7

Note, the Final Annual Report #7 was submitted to the Department of State Development (DSD) in July 2024.

This extension to the main report submitted in June 2024 presents the outcomes of two key research projects conducted under the PRIF Mining Consortium:

- *ATP4: Fast ROM Stockpile Modelling for Blending Optimisation* (Dr Shi Zhao)
- *BRP3: New Sensor Development for Particle Size Online Measurement at Hydrocyclones* (Dr Difan Tang)

Both projects addressed critical challenges in mineral processing and bulk material handling, focusing on the development and industrial translation of advanced modelling and sensing technologies.

ATP4 delivered near real-time, quality-embedded 3D stockpile models and integrated optimisation systems to enhance ore blending efficiency and value recovery.

BRP3 produced a cost-effective, plug-and-play sensor for real-time particle size monitoring and process optimisation at hydrocyclones, with demonstrated benefits for throughput, energy efficiency, and operational cost reduction.

The research outcomes have been validated through laboratory and field demonstrations, with strong engagement from industry partners. The findings and technologies developed are poised to deliver significant economic and operational benefits to the mining sector and broader community, supporting the State Government's objectives for innovation and sustainable resource development.

With the successful conclusion of both the ATP4 and BRP3 projects, the research teams have identified several promising directions for future development.

For ATP4, further work is recommended to enable real-time optimisation capabilities in stockpile management, including the integration of physics simulation engines and advanced 3D scanning technologies to enhance model accuracy and operational responsiveness.

For BRP3, the next steps involve industrial site testing of the particle size sensing system, validation of its commercial potential, and integration with automated control systems for mineral processing.

Both projects have laid a strong foundation for ongoing innovation in resource efficiency and digital transformation of mining operations. As these projects conclude, Dr Difan Tang and Dr Shi Zhao have transitioned to new roles within the university.

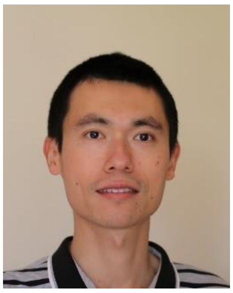
If you are interested in the developed technologies or would like to discuss potential collaborations, please contact Prof Nigel Cook, Director of the PRIF Mining Consortium, who will connect you with the appropriate research group.

FINAL RESEARCH REPORT

(extension September 2024 – August 2025)

BRP3: New Sensor Development for Particle Size Online Measurement at Hydrocyclones

Researcher(s): Dr Difan Tang



Chief Investigator(s): Dr Lei Chen

Commenced: December 2019

Completing: August 2025

Industry partner:

TRL: 5-6

CRL: 2

This report is a final research report for the Research Project B-RP3 ‘New Sensor Development for Particle Size Online Measurement at Hydrocyclones’ which has been extended, and covers activities for the extension period from **1st September 2024 to 31th August 2025**.

Statement: ***‘A cost-effective method for online analysis of particle size can help deliver energy-efficient mineral processing with economic implementation.’***

Introduction/Background

B-RP3 is one of the COMMINUTION Projects (Figure 1). As a classification device, hydrocyclones belong to a comminution circuit and play an important role in linking comminution to flotation as flotation takes its feed from hydrocyclone overflow.

Monitoring particle size-passing fraction (PSPF) at hydrocyclone overflow is critical to mineral processing as it not only assists gauging the quality of mill discharge and flotation feed but also significantly helps enabling closed-loop optimal control for energy-efficient comminution and downstream flotation. Further knowledge on particle size distribution (PSD) in addition to the single number of PSPF can be more beneficial. However, there has been a lack of cost-effective techniques for hydrocyclone overflow PSPF and PSD online sensing, especially when each individual hydrocyclone unit is to be monitored, given the large number of hydrocyclones typically employed on a mine site.

During the extension period, the project mainly focused on:

- Translating the research into a functioning prototype suitable for industrial trials.
- Exploring opportunities beyond hydrocyclone applications.

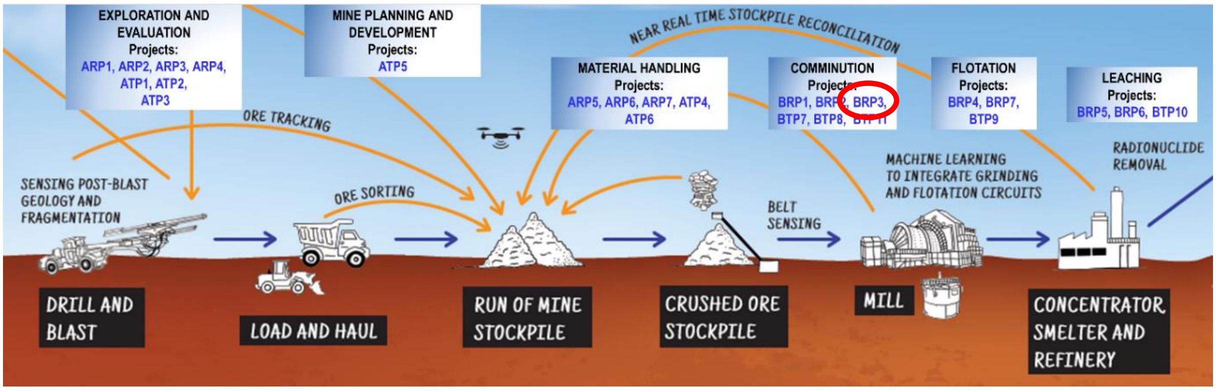


Figure 1: PRIF Mining Consortium projects.

Key Findings

- The particle size sensing unit (PSSU) prototyped as a plug-and-play module can be integrated into different mineral processing equipment used in both wet and dry applications (Figures 2 to 4).
- The current dry test setup cannot handle particles smaller than 40 µm, which are prone to electrostatic-induced clinging and airborne dispersion. A flow-rate regulated closed-loop setup is required and designed accordingly (Figure 4).
- Vibration measurement through the PSSU can detect and predict hydrocyclone roping if it is caused by feed pressure change (Figure 5).

Project Objectives

- Prototyping the PSSU as a plug-and-play module and testing it on different wet mineral processing equipment.
- Prototyping a particle handling system for dry mineral processing.
- Investigating hydrocyclone roping detection and prediction.

Technology Overview

The primary function of the new sensing system is to monitor particle size in real time at hydrocyclone overflow, using a probe inserted into the overflow pipe. It not only gives a single number of PSPF for target particle sizes but also provides information of corresponding PSD. Apart from PSD, it also simultaneously offers indication on two auxiliary variables – mass flow rate and flow viscosity. This represents a cost-effective multifunctional alternative to other existing methods that are single-function, costly and bespoke, and hence particularly suitable for deployment on, and individual monitoring of, every hydrocyclone unit at a mineral processing plant. In addition to gauging the quality of mill discharge and flotation feed, the new sensing system enables integration of automatic control for optimal grinding and hydrocyclone operation, which will deliver energy-efficient comminution and flotation with enhanced quality assurance. Beyond hydrocyclones, the new sensing system is also applicable in Dry Mineral Processing, where particles are conveyed in air or gas.

Experimentation and Main Findings

Experimentation has been conducted on laboratory-scale wet processing equipment: Salter 2-inch hydrocyclone and Metso high-intensity grinding (HIG) mill HIG5 pilot plant, with test setup shown in Figures 2 and 3, respectively.

Hydrocyclone with PSSU | Sensor Assembly | PSSU

Figure 2: Sensor integration with Salter 2-inch hydrocyclone.

HIG mill before PSSU integration | PSSU | HIG mill after PSSU integration

Figure 3: Sensor integration with Metso HIG mill pilot plant (HIG5).

The 2nd-generation particle handling system prototype for dry mineral processing aims for multi-purpose use: laboratory and in-situ testing. The design and fabrication of this new system is being undertaken by a group of Masters students. Its conceptual design is shown in Figure 4. For laboratory testing, the system operates in a closed-loop configuration from particle dispensing to collection. When embedded in an industrial process, it can be transformed into an open-loop setup without the particle dispenser and collector. In both cases, particle speed is regulated by controlling the air flow rate. Tests on this new system are expected to be conducted by the end of 2025.

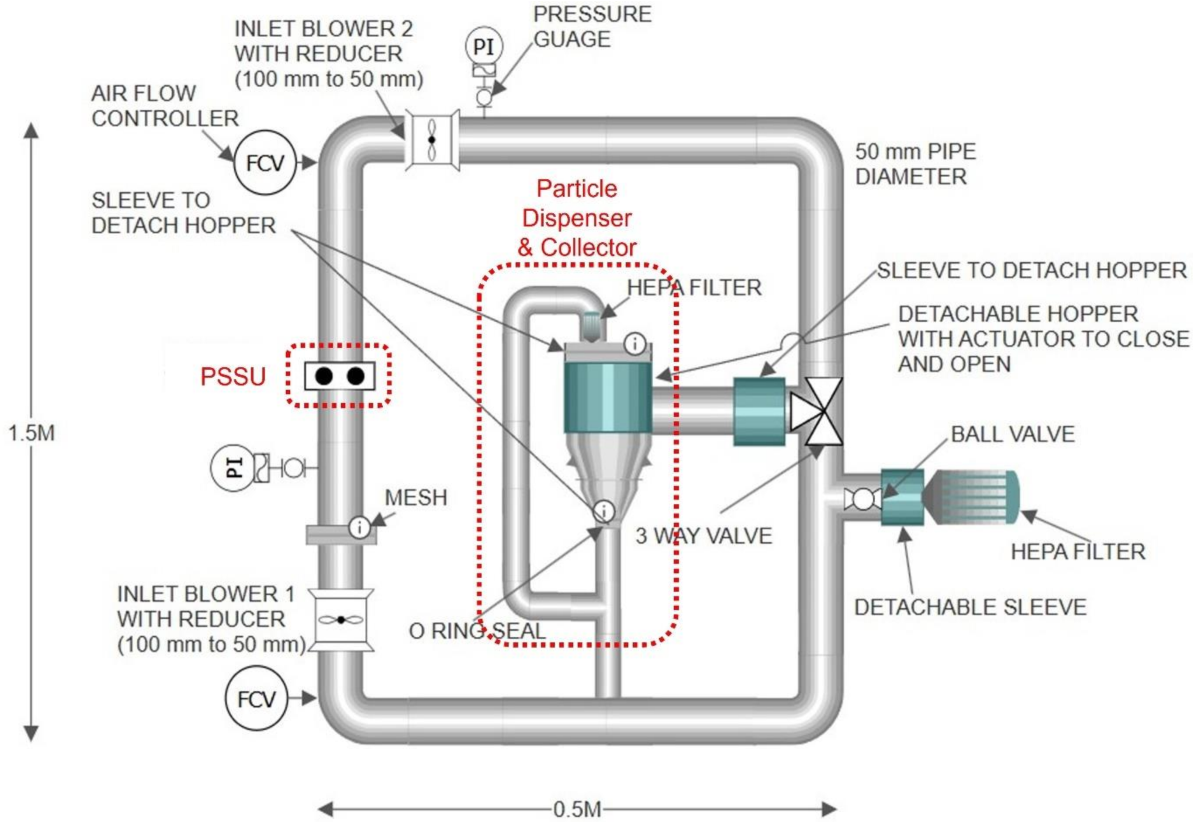


Figure 4: Sensor integration with a 2nd-generation particle handling system for particle size assessment in dry mineral processing.

In hydrocyclone tests, samples from various sources were tested for 10% – 50% feed solids concentrations (by weight):

- Perilya Broken Hill
- Tomingley
- Prominent Hill
- Unidentified South Australian deposit
- Blend: Prominent Hill, Freeport Ro Concentrate, Carrapateena R/G feed, and laboratory flotation concentrate blend.

The tests focused on roping detection and prediction. Feed pressure was adjusted to allow investigating both normal operation and roping. Figure 5 shows typical vibration signals measured via the PSSU probe, which suggest that:

- Hydrocyclone normal operation and roping states have distinct broad-band vibration signatures that can be monitored and identified in real-time.
- Probe resonance under the influence of slurry properties embeds indicators of roping. Analysis of probe resonant power can give an early sign of roping onset, allowing prediction of roping at an earlier stage.
- The roping prediction window interpreted from the undertaken tests only applies to scenarios under feed pressure change. It remains unclear whether roping caused by other factors can be predicted in the same way.

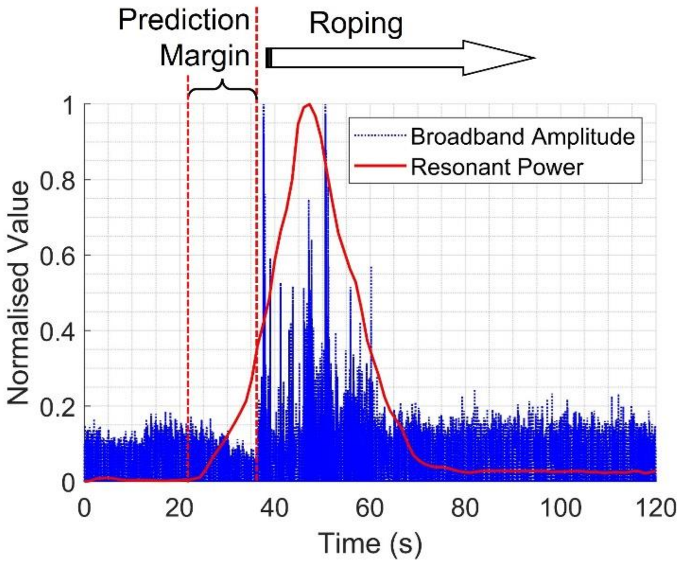


Figure 5: Roping detection and prediction through vibration measurement at PSSU.

In tests on the Metso HIG mill pilot plant, samples were ground for six passes (i.e., entered the mill six times). Only two sample groups were tested (blend ore and silica) due to limited mill access time and insufficient leftover samples. The solids concentration (by weight) was 50% in both cases. The following findings were observed:

- The feed rate (5.4 L/min) was insufficient to generate measurements with a decent signal-to-noise ratio. A higher mass flow rate, at least 10 L/min, is desired. This may not be an issue on industrial-scale HIG mills because of much higher throughput, but a dedicated sampling loop will be needed, as shown in Figure 6. This integrated sampling loop enables independently regulated flow rate for better measurement and allows easier maintenance without disruption to the main process stream.
- Feed-pressure fluctuations caused by the peristaltic pump were a primary source of noise in the probe vibration signals (from both force and acceleration measurements). The forced cyclic probe vibration largely suppressed its natural resonance, rendering it difficult to extract PSD-related information carried by resonance.
- Due to the use of a peristaltic pump to supply slurry feed, the probe sealing was subjected to cyclic pressure alternations throughout the tests. Potential leakage risks due to sealing breakdown as a result of material fatigue are of particular concern. The sealing mechanism of the PSSU needs to be reconsidered.

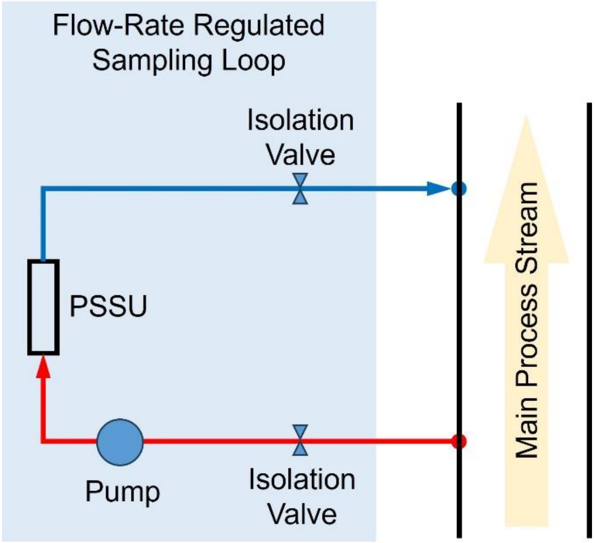


Figure 6: PSSU with flow-rate regulated sampling loop.

Benefits to Industry and the Wider Community

The new sensing system, upon improvement as documented in this report, offers the following benefits to its target industry:

- Easy installation, operation, and maintenance, with minimal modification to the existing plant.
- Real-time PSD monitoring.
- Real-time mass flow rate measurement.
- Real-time viscosity indicator.
- Enabling integration of automatic control systems for automated and optimised operation of mills and hydrocyclones.
- Low-cost deployment (hardware, installation, and ongoing maintenance).

Applications

Applications include both target industries and potentially applicable fields, covering:

- Particle sizing at cyclones and hydrocyclones for classification processes used in all industries.
- Particle sizing of solid-state fuels (e.g., biomass or coal) at power plants.
- Particle sizing for powder (e.g., cement, flour, infant formula, laundry powder, etc.) in powder-related manufacturing industries.

Potential Value

In the mining industry, a cost saving of over 90% is foreseeable for both translation partners and end-users given the total low cost involved in sensor procurement, installation, and maintenance, compared with using other existing technologies. The integration of automatic control using the new sensing system is predicted to enable up to 10% increase in throughput at the same particle size or up to 4.5% reduction in particle size at the same throughput. As an essential part of an automatic control system, the new sensing system will allow cost-effective integration and further benefit translation partners specialising in process optimisation solutions (e.g., Magotteaux, Manta Controls, and Rockwell Automation). Upon establishing optimal grinding and hydrocyclone control, the end-users (e.g., BHP Olympic

Dam Mine and Prominent Hill Mine) will gain increased throughput while being able to reduce energy consumption in the meantime.

The product could either be implemented for a single end-user or sold widely. Potential vendors include translation partners and all other entities offering advanced transforming technologies for mineral processing, power plants, and powder manufacturing industries.
Take BHP Olympic Dam Mine operation as a case study, with the new sensing system installed on every individual hydrocyclone, the total annual benefits is demonstrated in Figure 7. It is worth noting that the assumptions made in the case study are conservative and actual benefits can be more than the value given in Figure 7.

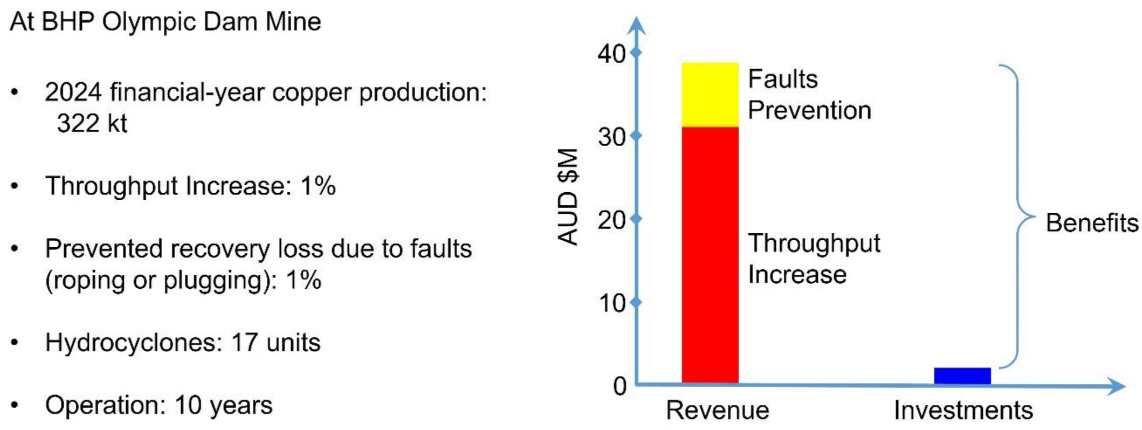


Figure 7: BHP Olympic Dam Mine case study: estimated additional revenue and sensor investments (per annum).

Similar to online PSD assessment, the density monitoring capability will benefit Alluvial gold production upon sensor integration into the existing rotary air concentrator control system, enabling optimisation of its classification performance via optimal closed-loop feedback control.

Potential Market

There have been some trials of other existing technologies which on the other hand have demonstrated vast needs. However, these existing technologies under trials are unlikely to constitute any potential competition in terms of being cost-effective. Therefore, the potential market will be highly inclusive, covering companies of various sizes and most industries that require particle sizing.

Future Work/Recommendations

We need access to site testing which will further demonstrate the technology along the commercialisation path. It not only serves as a competence test of the new sensing system but also provides an opportunity for the participating mine site(s) to witness as well as to gain first-hand experience of the effectiveness, convenience, and utility, of the new sensing system. By then, it will form a solid basis to perform detailed analysis of market size and competition.

Australia’s Economic Accelerator (AEA) Innovate Program will be considered as a potential funding source to support commercialising the new sensing system, targeting integration into the existing Magotteaux MagoPulp chemistry analyser and mine site hydrocyclones.

List of Publications and Conference Participations during the Lifetime of the PRIF

Patent Application

Tang D, Yang L, Chen L and Cook N. An adaptive life-long probing mechanism for in-stream particle-laden flow monitoring. Patent Application. Unpublished.

Conference Participation

Poster presentation, “High-intensity grinding mill media wear detection via real-time vibration monitoring: A case study on a Metso HIGmill™ pilot plant”, the 14th International Comminution Symposium (MEI conference of Comminution '25), Cape Town, South Africa, 31 March – 3 April, 2025.

Poster presentation, “Linking mill shell vibration to particle size reduction gradient along a high-intensity grinding mill chamber”, the 14th International Comminution Symposium (MEI conference of Comminution '25), Cape Town, South Africa, 31 March – 3 April, 2025.

Poster presentation, “Particle density online monitoring for Dry Mineral Processing”, Copper to the World (C2TW) Conference 2024, Adelaide, Australia, June 18-19, 2024.

Poster presentation, “Monitoring particle size at hydrocyclones and beyond”, South Australian Exploration and Mining Conference 2023, Adelaide, Australia, December 1, 2023.

Oral presentation, “Ultrafine-particle online detection and size-distribution approximation at hydrocyclone overflow”, the 13th International Comminution Symposium (MEI conference of Comminution '23), Cape Town, South Africa, April 17-20, 2023.

Poster presentation, “Next-generation online particle-size sensor for hydrocyclones”, South Australian Exploration and Mining Conference 2022, Adelaide, Australia, December 2, 2023.

Oral presentation, “New sensor development for hydrocyclone overflow particle cumulative percent passing size online monitoring – A preliminary experimental investigation under dry condition”, IMPC Asia-Pacific 2022, Melbourne, Australia, August 21-23, 2022.

Oral presentation, “A new approach for hydrocyclone overflow online monitoring for energy-efficient comminution”, the 7th International Symposium on Sustainable Minerals (MEI conference of Sustainable Minerals ‘22), July 11-13, 2022 (Online).

Oral presentation, “A new method for online estimation of particle size distribution in the overflow of hydrocyclones: A preliminary investigation”, the 12th International Comminution Symposium, (MEI conference of Comminution ‘21), April 19-22, 2021 (Online).

Journal and Conference Publications

Tang D, Chen L, Asamoah R and Hu E (2025). Online particle-size monitoring for hydrocyclone overflow: Where is the beacon? *Minerals Engineering*, 233, 109553.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D (2025). Hydrocyclone roping prediction versus detection: Could prediction be possible? *Minerals*, 15(2), 110.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D (2024). Online mass-flow-rate measurement of high-intensity gas-conveyed particle flow for dry mineral processing. *Powder Technology*, 448, 120329.

Tang D, Chen L, Yang L and Hu E (2022). New sensor development for hydrocyclone overflow particle cumulative percent passing size online monitoring – A preliminary experimental investigation under dry condition. In: Proceedings of the IMPC Asia Pacific 2022, Melbourne, Australia, 22-24 August 2022, Vol. 5/2022, pp. 625–631. Melbourne, Australia + Online: The Australian Institute of Mining and Metallurgy.

Papers Under Review

Tang D, Chen L, Yang L, Asamoah R and Hu E. Online particle density measurement for rotary air concentration used in alluvial gold mining. *Power Technology.* Manuscript under review.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Online estimation of particle size distribution in the overflow of hydrocyclones via force measurement: Theory and preliminary investigation. *Minerals Engineering*. Manuscript under review.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Online particle size distribution and P80 monitoring via force-measurement based vibration sensing. *Minerals Engineering*. Manuscript under review.

Yang L, Tang D, Chen L, Aldrich C, Zanin M and Peukert D. Experimental investigation on the correlation between hydrocyclone roping and overflow air content. *Minerals Engineering.* Manuscript under review.

Papers on Hold (due to Pending Patent Application)

Tang D, Chen L, Yang L, Asamoah R and Hu E. Hydrocyclone overflow particle-size estimation: Size passing fraction P80 detection via solids impact mechanics. *Minerals Engineering*. Manuscript in preparation.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Hydrocyclone overflow particle-size estimation: Particle size distribution estimation via bluff-body hydrodynamics. *Minerals Engineering.* Manuscript in preparation.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Improving particle-size estimation at hydrocyclone overflow via data fusion. *Minerals Engineering.* Manuscript in preparation.

Tang D, Chen L, Yang L, Asamoah R and Hu E. Size estimation of gas-conveyed particles via solid-impact mechanics based on accelerometer measurement. *Minerals Engineering.* Manuscript in preparation.

Acknowledgement

This research has been supported by the SA Government through the PRIF RCP Mining Consortium 'Unlocking Complex Resources through Lean Processing'. Special acknowledgments go to:

- Bureau Veritas: for supplying ore samples for our dry tests and coordinating site visits during the LOESCHE® Vertical Roller Mill operation.

- Nimble Resources: for their strong support throughout the process of an AEA grant application and their generous offer of alluvial gold mine samples.
- Manta Control: for providing valuable insights into the mineral processing industry and organising hydrocyclone overflow slurry samples sourced from Australian mines, though ultimately not delivered.
- University of South Australia: for providing precious laboratory space and excellent mineral processing facilities, which have significantly supported our experimental studies.
- Magotteaux: for offering samples, facilities, and support to test the new sensing system in industrial environments, as well as their tremendous contribution to an AEA grant application.

Additional Notes

Supported by Magotteaux, we have explored a new approach to real-time monitoring for HIG mills, which has the potential to lead to an AEA-funded project, starting at TRL 4 and targeting TRL 5.

A HIG mill is a vertical stirred-media mill with a tall and narrow chamber divided into cascaded grinding stages (sub-chambers). A single long shaft carries multiple disks that agitate small grinding media (beads). Mineral slurry enters at the bottom and exits at the top. The design delivers very high energy density, making HIG mills well suited to fine and ultrafine grinding.

However, there are rooms to improve. Grinding media wear shifts impact mechanics and energy transfer, causing product-size drift, rising energy per tonne, and unstable throughput. Also, there is no real-time axial profile to show how particle size reduction is occurring from bottom to top. Real-time information of grinding media wear state and axial particle size profile enable targeted actions including media top-ups and rotor speed or bead-size tweaks, before quality or energy metrics deteriorate. This improves stability, reduces media consumption, and supports lower operating cost.

Commercially available instruments (e.g., laser diffraction, ultrasonic attenuation) can provide accurate measurements of discharge PSD but no view inside the chamber and often need sampling/conditioning hardware. Power-based proxies and residence-time indicators are useful but not spatially resolved and do not separate media wear effects from other disturbances. Original equipment manufacturer (OEM) systems for wear monitoring exist for some mill types but typically do not provide an axial profile and can be vendor-specific.

Shell-mounted accelerometers are non-intrusive, retrofittable and safe. With sensors positioned at multiple heights, they capture impact-rich frequencies linked to bead–slurry interactions and local grinding activity, giving a multi-height, spatially resolved view. The hardware is robust for high-solids duty, can run continuously with low maintenance, and complements discharge PSD measurements by adding internal context and earlier detection of wear-driven drift.

On a Metso HIGmill™ pilot plant (HIG5) at Magotteaux, we installed 6 accelerometers along the axial direction of the mill shell external wall and observed stable, impact-rich frequency bands (10–30 kHz). Physics-guided features (e.g., envelope energies and cyclostationary markers) changed systematically with media condition and aligned with discharge PSD trends. These results provide evidence that vibration features can indicate both media wear and the internal axial particle size reduction profile.

An AEA Ignite Grant application has been submitted with an aim to validate, on one operating industrial-scale HIG mill at mine site, that non-intrusive, multi-height shell-vibration sensing can (a) track grinding media wear and (b) map the axial particle size reduction profile, delivering defensible accuracy and operational value.

With the help of Magotteaux, a pre-grant trial at the Iron Bridge Mine operated by Fortescue Metals Group (FMG) has also been arranged.

FINAL RESEARCH REPORT
(extension September 2024 – August 2025)

ATP4: Fast ROM stockpile modelling for blending optimisation

Researcher(s): Dr Shi Zhao

Chief Investigator(s): Dr Tien-Fu Lu, A/Prof Larissa Statsenko

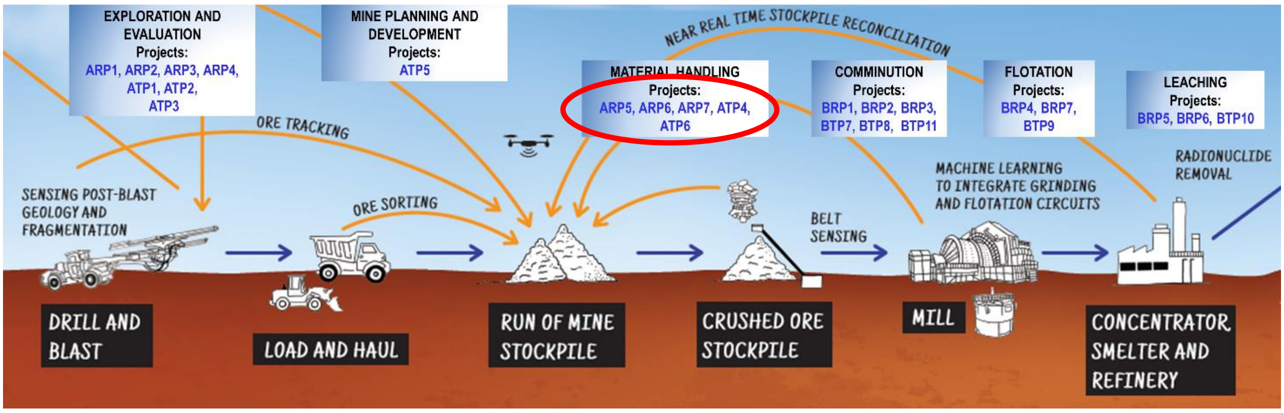
Commenced: 1st September 2024

Completing: 31st August 2025

Industry partner: Eka

TRL 6

CRL 1



This report is the final research report for the Translation Project ATP4 '3D ROM stockpile modelling' and covers activities from 1st September 2024 to 30th August 2025.

Statement: ***'3D stockpile modelling enables optimised reclamation in near real-time'***

- Introduction/Background

Iron Oxide Copper-Gold (IOCG) ores typically contain a complex range of impurities. Some of these impurities lower the value of ores because they can be detrimental to the environment and/or human health, cause equipment corrosion, and generate hazardous residues. Custom copper smelters impose substantial financial penalties to the presence of deleterious impurity elements (Lane et al., 2016). Therefore, customers use the grade and the grade consistency in price and quantity negotiations. As a result, producers are keen to control or remove penalised impurity elements from the beginning of the mining processing and maintain a low-grade variability throughout the process chain. ROM (Run Of Mine) stockpiles allow valuable ore to be stacked in different locations at stockyards based on its quality and reclaimed depending on the quality and quantity required for future processing. They play a critical role in quality control, ensuring that the ore meets the necessary standards throughout the process chain.

ROM stockpiles are widely used as buffers and blending units for quality control between mines and processing plants. They are generally located near the mine site where the raw ore is extracted. The blending function is achieved through two opposing processes. Ores with different quality parameters are stacked selectively into/onto different stockpiles. Loaders reclaim stacked ores from distinct locations within one stockpile or among multiple stockpiles. The mix of different grade ores will happen naturally during the reclaiming operations. Thus, Stockpile blending is widely recognised as an effective and primary method to reduce short term quality variations. However, it is difficult to achieve efficient and effective blending at most processing plants due to high heterogeneity of ore quality in situ and hence low accuracy of the ore quality information coming straight out of the mine. Currently, the most accurate quality assay result about the ore body carried by a haul truck is acquirable within 24 to 72 hours after receiving a sample. For this reason, the quality of the reclaimed material or mill feed is not available with the highest degree of accuracy. Once the material has been reclaimed from ROM stockpiles, it is too late to make the quality control more efficient. It must happen at stockpiles, or value will be lost from that point onwards. Solutions to this challenge do not currently exist commercially. Our modelling techniques and optimisation system minimise the negative consequences caused by lagging chemical assay results since they can serve as placeholders for the quality data.

- Key Findings

Generate/update 3D quality-embedded stockpile models in near real-time using operational data from a mining site.

Integrate such models with research outcomes obtained from RP5 project, resulting an optimisation system that meets the required quantity and quality with minimal violation factors (higher priority), and reduce the reclaiming time (lower priority).

- Outcomes

This project has developed two demonstration systems, a small-scale and a real-scale system, with an aim of increasing the TRL/CRL. Both systems are designed to showcase quality embedded 3D stockpile modelling process and to demonstrate the optimised reclaiming sequences for multiple front-end loaders (FELs) using these 3D models. More details will be presented in the technology overview section.

- Project aims for extension

To complete the development of the demonstration systems.

To run the real-scale demonstration system (RSD) in an operational environment, including the transmission of ore movement activities and assay results which are aligned by their respective timestamp as API messages to Eka's stockpile management software.

To adjust the project scope in alignment with Eka's development strategy, thereby advancing the project to a higher TRL/CRL and enhancing its commercialisation potential.

- Technology overview

This extension project utilises quality-embedded 3D stockpile models to optimise reclaiming processes for front-end loaders (FELs). These 3D models can be derived from either real measurement data or generated through computer simulations. Additionally, they are integrated with quality assay results obtained from a continuous underground sampling process. This integration ensures a high degree of accuracy in calculating both the overall quality of a stockpile and the quality distribution within it. Lastly, the quality-embedded models are converted into constraint files that reflect real-world operational requirements for FELs. These files are then input into the optimisation system developed under another PRIF research project, Program B RP5. The optimised reclaiming sequences for multiple FELs can be represented as time-stamped loading instructions, which guide the operation of each FEL to achieve the desired quantity and quality combinations.

Two demonstration systems have been developed during the extension.

The small-scale demonstration (SSD) was developed in Python and deployed as a free web-based application. It features three stockpile models derived from real measurement data and tits development was fully completed during the extension. It is integrated with the Deterministic Greedy Algorithm (DGA) and the Randomised Greedy Algorithm (RGA), both developed in RP5 for FEL optimisation. The current system can optimise reclaiming processes involving up to three Front-End Loaders (FELs) operating simultaneously.

The SSD consists of three sections: modelling, scheduling, and optimised reclaiming sequence display. The modelling section visualises the nodes for each stockpile in 2D and 3D formats, as shown in Fig.1. Each node has a fixed length of 9m. The scheduling section details the quantity and quality information of each node and predefined quality requirement. The parameter input module allows users to customise inputs such as number of requests, required quantity, number of FELs, as shown in Fig. 2. Both optimisation algorithms run with high efficiency, taking less than five minutes to identify the optimised reclaiming sequences for nine requests (each request is 24,000 tons) under all four-objectives configuration. The optimised results are presented either as a table or as an animation in the reclaiming demonstration, as show in Fig. 3.

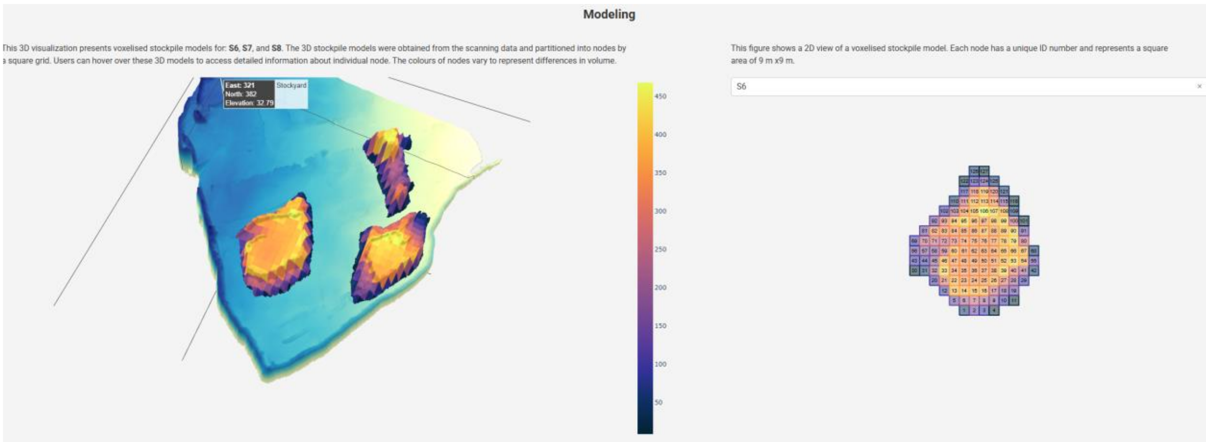


Fig. 1 Nodes displayed in modelling section in 3D and 2D formats.

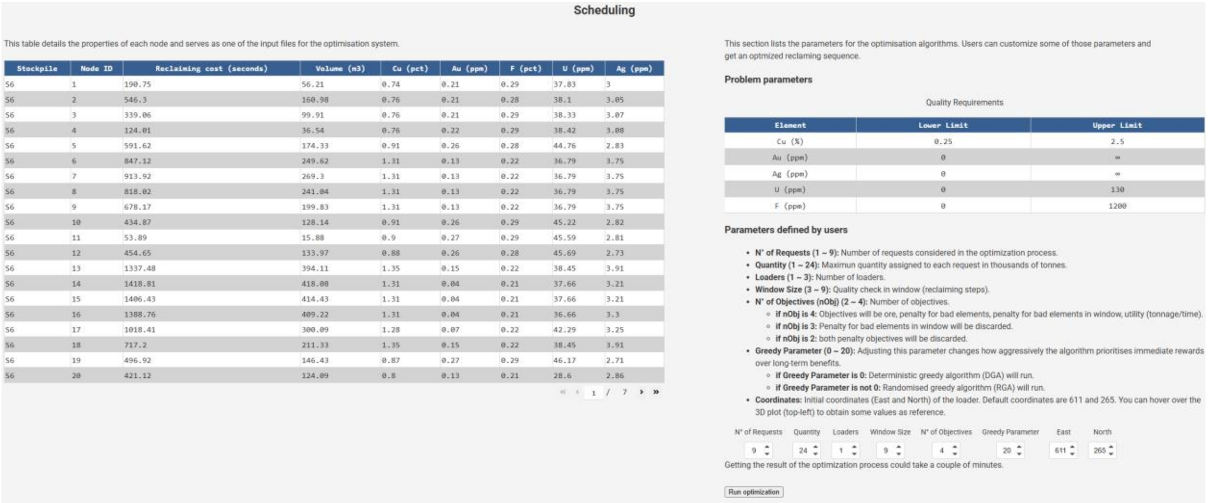


Fig. 2 Scheduling section allows users to adjust parameters for optimisation.

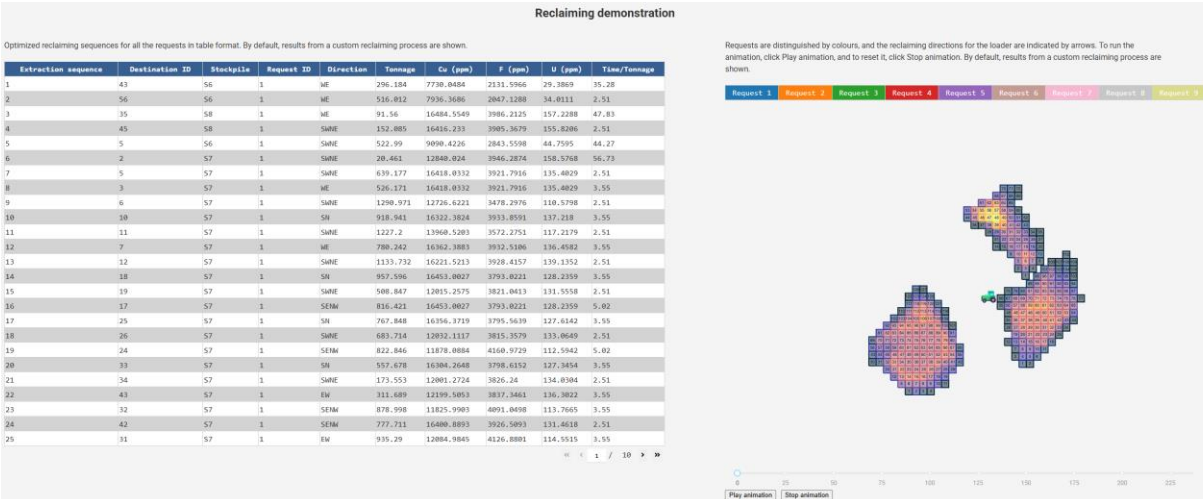


Fig. 3. Optimised reclaiming sequence.

The RSD is designed to model the entire ROM stockyard in a dynamic operational environment using the data provided by the end-user partner BHP. It comprises two distinct modules. The communication module, developed in Python, extracts key operational data from the mine and transmits it as API messages. The stockpile management module, developed by Eka as part of its standard stockyard management software *Insight CM*, is responsible for receiving, processing, and visualising these messages. Consequently, simulated stockpile models are generated and updated in near real-time, with quality distribution within each model calculated whenever the material flow is associated with quality assay results.

By the end of the extension, the following activities have been completed for the RSD:

1. New data sets for modelling all mine activities from August 2024 to September 2024 were received. Details are listed in Table 1.
2. All new Vulcan models were converted into a format compatible with the in-site CM software and sent to Eka. The final import has been pending Eka's action since October 2024.
3. SQL backup files were restored to a SQL Server hosted on a university-provided cloud machine.

4. SQL tables containing the required ore movement information were verified.
5. The previous Python program was updated to retrieve the necessary data from the SQL Server to generate new API messages.
6. New Python functions were developed to generate and send API messages containing all ore movement procedures, as detailed in Table 2.
7. All API messages were verified through the in-site CM software, successfully establishing links between assay results and ore movement activities.
8. Existing issues identified were reported to Eka and require only Eka's actions to resolve.

Table 1 New data sets for the FSD system

File/Folder Name	Description
Pitram.zip	Raw SQL backup file for underground ore movement
Jmineope_reporting	Raw SQL backup file for surface ore movements
grab sample.csv	Assay results
Vulcan Models	3D measurement models for stockyard and stockpiles
stockpile-stockpile movements.xlsx	Report for surface ore movements

Table 2 API messages

Name	Description
Material lot	Assay results.
Mine sublot	ore blasted at different stopes or ore movement between stopes.
In-Pit Stack Sublot	Ore movement from stopes to in-pit stockpiles
In-Pit Reclaim Sublot	Ore reclaiming by FELs at in-pit stockpiles
Truck Sublot	Ore carried by trucks after In-Pit reclaiming events.
Truck Unload (ROM)	Ore dumped by trucks to the ROM stockyard.
FEL Reclaiming	Ore reclaiming by FELs at the ROM stockyard.
Truck Load	Ore carried by trucks after ROM reclaiming events.
Truck Unload (from ROM to Crusher)	Ore dumped by trucks to the crushing plant from ROM stockpiles.
Truck Unload (from In-Pit to Crusher)	Ore dumped by trucks to the crushing plant from in-pit stockpiles (bypass ROM).
Plant Load (from In-Pit to Crusher)	Ore crushing events
Set Vehicle Locations	Display Trucks and FELs locations

Key factors contributing to the delay of the RSD include:

1) Since Eka was acquired by Quor, my contact has been assigned more critical tasks to prioritise over the RSD demonstration starting from the beginning of 2025.

2) I must take on software engineering responsibilities because the position has remained unfilled since early 2025.

3) The development of the communication module was a new task proposed by Ben in October 2024. It took longer than I expected, primarily because it required a deeper understanding of Eka's system despite the documentation provided.

- Benefits to industry and the wider community

Geologists or operation managers will gain a better insight into the quality of stacked materials and even the quality distributions within a stockpile through these quality embedded 3D stockpile models. They can apply this knowledge in on-site decision-making. For example, directing haul trucks to different dumping locations to adjust stockpile quality or instructing FELs to reclaim materials from stockpiles to meet required quantity and quality standards. Additionally, researchers can use these models as a platform and apply different optimisation algorithms to control the quality and reduce the operational costs in blending for short- or long-term purposes. This project produced a proactive solution for reclaiming operations that reduces the complexity of stockpile blending optimisation problem. Given the key contribution of this project is to meet the required quantity and quality with minimal violation and reduce the reclaiming time, it will improve blending efficiency, reduce operational cost, minimise waste, improve the grade consistency, and increase the value of exports.

- Applications

IOCG ore is used as a case study to improve the quality control in blending. However, techniques developed by this project are applicable for most bulk material handling operations, such as iron ore, black coal, and bauxite. Furthermore, the integration of modelling and optimisation can be used at any ROM stockyards, processing plants, ore exporting ports, which aim to control the quality and reduce the variations through stockpiles.

- Potential Value

In 2019, Australian mineral exports (excluding petroleum products) amounted to approximately $234 billion, this project can realise two aspects of enormous value. If we can improve the quality control of ore, concentrate, or metal by a conservative 1%, it would translate into approximately $2.34 billion in value to our economy. Additionally, the increased efficiency in capital expenditures (CapEx) and operating expenditures (OpEx) for the mines and processing plants could add even more value. This will increase operational margins for mines, extend the life of mines, and provide greater overall value. If one mine alone can lose as much as $100 million per annum through inefficient stockpile management, imagine what that might translate to across our entire mining industry, worth over $400 billion per annum to Australia.

- Potential Market

At the beginning of the PRIF extension period, we also explored stockpile modelling techniques using CoppeliaSim, a physics simulation engine. It can simulate the truck dumping process through generating random shaped rigid bodies to mimic the interaction between the ore bodies. The results indicated that it requires a more powerful CPU and GPU to run these simulations effectively. Considering the time and efforts needed, we did not proceed further with this technique. However, there are also many Discrete Element Method (DEM) technology companies in the market offering such physics engines and simulations. Additionally, another modelling solution is to continuously scan stockpiles using sensors such as a 3D laser scanner. This method produces more accurate models compared to simulations. Any Mining Equipment, Technology, and Services (METS) company that provides ore quality optimisation solutions for mining operators could further investigate these two options. Subsequently, the modelling and optimisation system could be developed into a standard product for their customers.

Eka is a METS company, whose goal is to "Optimise your mine-to-market value chain and maximise operational efficiency by connecting every step from ore to manufacturing for base metals, refined, steel, scraps, concentrates and more." Eka's digital stockyard management system traces the quality of material by individual sample lot as it is moved and blended throughout a terminal using near real-time 3D stockpile models. They have collaborated with the University of Adelaide for over 10 years. It is Eka's business objective is to create a digital twin through accurate 3D modelling and movement processes, which will enable more precise ore mixing. At the beginning of the PRIF extension period, with the assistance from Eka, we prepared a list of tasks to merge the project outcomes into their software. To date, Eka have completed 60% of the tasks and are willing to complete the remainder by the end of this year. There is a high chance that the modelling and optimisation system will become one of the modules in their software suite.

- Future work

The author is continuing to work with Eka to finalize a demonstration based on the completed tasks. It is expected that a short video can be produced to showcase the system's modelling functionality.

The remaining tasks for the RSD system are listed below:

5. To extract 3D dumping models as point cloud data to produce the input files for the optimisation system,
6. To update the In-sight CM software to support voxelised stockpile models,
7. To enable the API function to receive and display optimised reclaiming steps.

- Recommendations

The optimisation results obtained from this project are based on the assumption that there is no stacking operation during reclaiming operations and vice versa. Thus, the next critical upgrade to either or both demonstration system(s) is to enable real-time optimisation capability. For example, once a new quality-embedded model becomes available to the management system, it could be added into the optimisation module to update current reclaiming sequences or produce a new set of reclamation sequences. We are seeking research grants, i.e. AEA Seed funding, to advance this project to a higher level through two aspects: (i) upgrading the system structure to enable real-time optimisation; and (ii) using a physics simulation engine to model dump stockpiles. The completion of these two objectives will further improve the TRL/CRL for this research.

- List of publications and conference participations during the lifetime of the PRIF

Journal publications

2. Zhao, S., Lu, T.-F., Statsenko, L., Koch, B. and Garcia, C. (2022), "A framework for near real-time ROM stockpile modelling to improve blending efficiency", Journal of Engineering, Design and Technology, Vol. 20 No. 2, pp. 497-515.
3. Zhao, S., Statsenko, L., Lu, T.-F., Assimi, H, Koch, B. and Garcia, C. "Short term reclamation optimisation for front end loaders (FELs) using quality embedded 3D ROM stockpile models ", under review

Conference participations

1. PRIF Mining Consortium workshop - "Pathways to Commercialisation and Implementation", Copper to the World 2022 conference.
2. The Copper to the World 2022 conference and PRIF Mining Consortium workshop - "Pathways to Commercialisation and Implementation".
3. The South Australian Exploration and Mining Conference 2023 (SAEMC) – Poster presentation

4. METPLANT 2023 – Poster presentation.
5. The Austmine 2023 conference – Poster presentation
6. The Copper to the World 2024 conference – Poster presentation

- Acknowledgement

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- References

Lane, D. J., Cook, N. J., Grano, S. R., & Ehrig, K. (2016). Selective leaching of penalty elements from copper concentrates: A review. Minerals Engineering, 98, 110-121.

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