P9R: Optimising Mineral Operations with Multi Component Models

July 2023

Executive Overview

- Amira P9 program series initiated in 1962.
- A progressive focus on automating and optimising Mineral processing.
- Current P9R objective is to create a platform with multicomponent unit process models for integrated and circuit wide optimisation.
- Ultimate objective is to enable whole system real time optimisation on multi component mineral ore feeds.
- Seeking commitment of sponsorship for this phase – Amira P9R

Benefits

- Access to improved, calibrated and validated multicomponent models for deployment at sponsors' own operations.
- Ongoing skills transfer to sponsor personnel throughout the duration of the project.
- Active participation by leading researchers to ensure applicability of multi component models at sponsor sites to optimise throughput, recovery and cost.
- Sponsor's research funding is leveraged via the AMIRA collaborative project model.

Cost: Sponsorship Model

Sponsor Category	Year 1 Investment AUD $ 1000	Total investment over 3-year project life AUD $ 1000
Operator**	150	450
New* Operator	180	540
Supplier**	60	180
New Supplier*	75	225

* New is defined as non-sponsor of P9Q

** To qualify as an Operator or Supplier sponsor, the company must have been a sponsor of P9Q

Cost: Level of funding Scenarios

Threshold	Project Funding AUD $ 1000	Project Scope
Minimum level	3x OS, 1x NOS, 2x SS, 1x NSS **$ 3,44M**	Scope & deliverables to be agreed at project kick off meeting
Mid-level	5x OS, 3x NOS, 4x SS, 2x NSS **$ 4,50M**	Scope & deliverables to be agreed at project kick off meeting
Full - level	6x OS, 3x NOS, 4x SS, 2x NSS **$ 5,49M**	Full scope as per the Expression of Interest – to be verified at project kick off meeting.
P9X 1:1 bolt on project requested by individual sponsor/s	Cost subject to specified scope and related budget	Project scope to be agreed by requesting sponsors/s and participating researchers.

OS – Operator sponsor NOS – New Operator sponsor
SS – Supplier sponsor NSS – New Supplier sponsor

Intellectual Property

- Sponsors retain ownership of their disclosed background technology.
- Project IP owned by inventing researchers, subject to their individual institutions' legal protocols.
- Sponsors will be granted perpetual, royalty- and license-free, non-exclusive rights to Project Technology (new IP generated in the project).
- There will be an 18-month Confidentiality Period after project conclusion.
- There will be an 18-month Non-use Period after conclusion of the project.

Amira project management

For further information about this initiative please contact:

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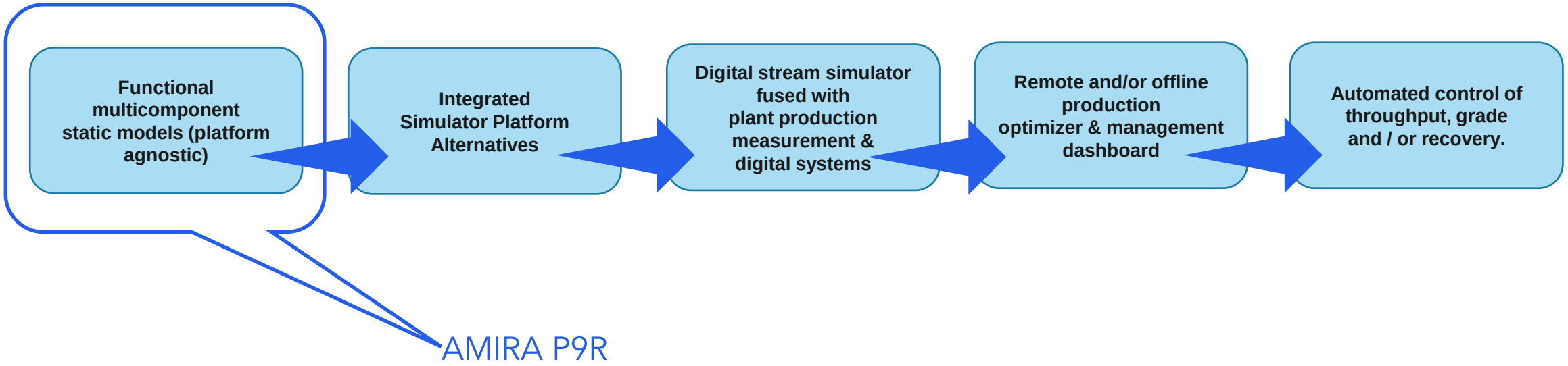
Industry postulated long term goal for a completed P9 project

"The use of online plant data and P9 multicomponent models to automatically control throughput, grade and recovery at operating mineral processing sites."



P9R vs P9Q Deliverables

- P9Q delivered
  - P9Q Researchers validated 15 process models (with limited degrees of multicomponent capability) on a collated data set (from previous P9 surveys, with sparse multicomponent data), and
  - verified their outputs operating on the Integrated Extraction Simulator (IES).
  - CRC Ore upgraded the IES for full uptake of the multicomponent data requirements and improved mass balancing and model calibration capabilities.
- P9R will
  - Complete the R&D for enhanced multicomponent P9Q steady state models.
  - Acquire adequate multicomponent data sets via site circuit surveys for validation of the multicomponent models.
  - Use common coding to ensure independent fitting & calibration of individual models in different integrated platforms, including but not limited to the IES.
  - Define information transfer interfaces from one model to the next to ensure stream data integration.
  - Develop offline lab-scale tests for calibration data.

Chalmers University Model Enhancements

- Cone Crusher Model
  - Develop multicomponent capability.
  - Extend current Hydrocone type cone crusher model to Symons type cone crusher and Primary gyratory crusher.

- Dry Screen Model
  - Develop multicomponent capability.
  - Extend model to include screens of different design e.g., Banana screens.
  - Include prediction capability of wear effects (aperture size variation) and screen blinding effects.

Hacettepe University Model Enhancements

- HPGR Model
  - Extend the multicomponent capability.
  - Include a pressure-gap relationship to extend prediction capability to include throughput prediction (currently only predicts product size distribution).
  - Extend prediction capability to include flaky ores.

Federal University of Rio de Janeiro Model Enhancements

- Dense Medium Separator Model
  - Implement Dunglison´s model of the dense medium cyclone, with enhanced capabilities to describe medium rheology.
- Jig Model
  - Improve sub models describing the effect of particle size on stratification constant, horizontal velocity profile and jig waveform.
- Mechanistic Mill Model
  - Current model inherently multicomponent but is computationally intensive.
  - Coding improvements to reduce running times.
  - Extend DEM simulation database to cover different liner profiles, mill geometries and grinding conditions.

University of Queensland Model Enhancements

- VR2 SAG/AG Model
  - Improving the discharge function and materials transport for multicomponent SAG/AG milling model.
- Regrind Mill Model
  - Further development of the mineral dependent appearance function.
  - Incorporation of Austin equation to better model mineral breakage rates.
- Bazin Particle Characterisation Model
  - Develop an offline lab-scale test for predicting mineral distribution by size data for the Bazin model.

University of Cape Town Model Enhancements

- RoM/High Steel Load Mill Model
  - Improve the model response to feed size distribution and ore competency.
  - Improve the discharge and transport functions for high ball load conditions.
- Multicomponent Hydrocyclone Model
  - Include component interactions in the cyclone model.
- Mechanistic Flotation Model
  - Add a model for prediction of froth performance.

P009R Research Team

Prof. Luís Marcelo Tavares
Universidade Federal do Rio de Janeiro

After successfully completing his PhD under the supervision of the late Prof R.P. King, at the University of Utah he founded the Laboratory of Mineral Technology at the Univesidade Federal do Rio de Janeiro (UFRJ). This would later become the leading Latin American research group in the field of comminution. He has been a member of the faculty of the Department of Metallurgical and Materials Engineering of UFRJ for the last 25 years, holding a Full Professor position since 2015. His work is published in over 130 peer-reviewed journal papers, +150 conference proceedings in events in Brazil and overseas, besides several book chapters and a book on gravity concentration technology. He has worked closely with industry, having been principal investigator of over 100 research, development and consulting projects, besides supervising over 50 masters and PhDs.

Marcelo has been deeply involved in bridging the fundamentals of particle breakage to advanced models of comminution, applied to a variety of crushers and mills, besides problems involving degradation during handling. His breakage model – called Tavares UFRJ model – is implemented in the leading commercial DEM platforms (Altair EDEM and ESSS Rocky), whereas the mechanistic mill model developed under his guidance – the UFRJ mechanistic mill model – was the first DEM-based mill model ever available in a commercial mineral processing plant simulator (Orica IES). His expertise also includes topics such as ore characterization, comminution, classification, besides physical concentration and iron ore agglomeration, with particular interest in multicomponent modeling and simulation.

P009R Research Team

Prof. David Deglon
P9R Technical Lead
University of Cape Town

David Deglon is a Professor in the Department of Chemical Engineering at the University of Cape Town. He has a BSc Chemical Engineering (Wits, 1989), a PhD (UCT, 1999) and an MBA (UCT, 2002). He worked for some years within the Rand Mines group as a metallurgist on coal, gold and platinum operations. He left Rand Mines in 1992 and joined UCT as a research officer in the Department of Chemical Engineering. In 1996 he was appointed as a senior lecturer and was promoted to associate professor in 2006 and full professor in 2010. In 2013 he was appointed as the Anglo American Platinum Chair in Minerals Processing and Director of the Centre for Minerals Research. The Centre for Minerals Research is a multi-disciplinary research centre consisting of 30 staff and 30 to 40 postgraduate students. His primary research focus is in the area of flotation cells, including related research in the areas of computational fluid dynamics and slurry rheology. He is a Fellow of the South African Academy of Engineering and in 2020/2021 was Vice-Chairman of the International Mineral Processing Council and Chairperson of the Organizing Committee for the XXX International Mineral Processing Congress (IMPC 2020).

P009R Research Team

Prof. Aubrey Mainza
University of Cape Town, South Africa

Aubrey Mainza is a Professor in the Department of Chemical Engineering, University of Cape Town (UCT). He graduated from UCT with a PhD in 2006. He has 22 years of collective experience in academia, research and industry. He is the Head of the department of Chemical Engineering at the University of Cape Town and is a Deputy Director and Head of Comminution and Classification Research in the Centre for Minerals Research, which is a large multi-disciplinary research centre. His area of expertise is in comminution and classification and uses Discrete Element Method (DEM), Computational Fluid Dynamics (CFD), and Positron Emission Particle Tracking (PEPT) as tools in his modelling methods. He has participated in many local and international research projects and has worked on numerous comminution circuit design and optimisation projects in various parts of the world. He has supervised many postgraduate students to graduation some of whom hold high positions in industry and is still an active supervisor of postgraduate students and has published widely in the international mineral processing and aligned disciplines literature.

He has held position of Chairman for the Global Comminution Collaborative (GCC) and chairperson for the International Comminution Researchers Association (ICRA) African Chapter and chairperson for the Western Cape Branch of the Southern Africa Institute of Mining and Metallurgy (SAIMM) and is currently a committee member for all of these associations. Aubrey is on many advisory committees for international conferences and is a consultant for the Minerals Engineering International Comminution Conference. He is a founder member of PEPT Cape Town, a facility established in Cape Town for studying flow behaviour in different systems and for medical research.

P009R Research Team

Prof. Dr Hakan Benzer
Hacettepe University

Prof Hakan Benzer has a Doctorate in Mining Engineering from Hacettepe University, Turkey in 2000. He graduated and gained his Master of Science degree from the same university in 1992 and 1996 respectively. He worked at Julius Kruttschnitt Mineral Research Centre (JKMRC) in Australia as a visiting academic in 2001. Currently, he is working as a full Professor at Hacettepe University Mining Engineering Department.

Prof Benzer is a highly experienced consultant providing a range of services to the mineral processing community, with extensive experience in the design and optimisation of mineral processing circuits as well as eco-efficient comminution technologies (dry/wet). Hakan has 28 years of experience in the mining industry and has managed over 70 large projects globally to date. In addition to his consultancy role directly to the industry, he has been running research programs directly with the major mining houses globally and major equipment suppliers. He supervised several MSc and PhD theses in mineral processing. He has published two book chapters on comminution. Over 100 technical papers were presented at conferences and journals. He is a founding member of the GCC. He has delivered numerous technology transfer workshops to the industry.

P009R Research Team

Prof. Dr Magnus Evertsson
Chalmers University of Technology

Dr Magnus Evertsson is a professor at the department for Industrial and Materials Science at Chalmers University of Technology in Gothenburg, Sweden. He got his PhD in Machine and Vehicle Design in 2000 focusing on cone crusher modelling and simulation. In 2006 Magnus was appointed the Swedish academic Docent degree. He was appointed professor in Machine Elements in 2012. Prof Evertsson founded the research group Rock Processing Systems (CRPS) in 2002. Over the last to decades the research activities have covered fundamental modeling and crushing and screening equipment, process modelling and optimization.

The current research activities are focused on: Dynamic simulation and optimization of coarse comminution; Real-time optimization and control of crushing; DEM-modelling of comminution equipment; Simulation of environmental impact in crushing and screening processes.

Prof Evertsson has industrial experience and has worked with aggregates production for the Heidelberg Cement Group. He has also worked for 10 years as a senior process specialist at Sandvik Mining and Construction focusing on R&D of crusher equipment. Prof Evertsson is one of the founders of the spin-off company Roctim AB specializing on cone crusher control and crushing plant simulations. He is an esteemed lecturer in several courses in machine elements and he has been awarded with the Chalmers Pedagogical Prize and also multiple times a best lecturer at the mechanical engineering programme.

P009R Research Team

Prof. Mohsen Yahyaei
Julius Kruttschnitt Mineral Research Centre

Professor Mohsen Yahyaei is leading the Advanced Process Prediction and Control (APPCo) program. This program aims to transform unit process modelling and simulation, moving on from the steady-state models previously developed at JKMRC, to develop and apply new techniques that make greater use of data generated on-site and sensor technologies in combination with advanced process control, computational analytics and modelling techniques.

Mohsen did his undergraduate study in Mine Exploration. In 2002 he completed his Master's degree in Mineral Processing and worked on the application of column flotation in in Sarcheshmeh Copper Complex (Largest copper mine in the Middle East) as his Master's thesis. After the Master's degree, he worked with the R&D centre of Zarand coal washing plant in Iran for two years. Mohsen then moved to an operational role as plant manager of a Coal washing plant in Zarand. In 2007 he returned to University of Kerman to do his PhD, investigating the effect of liner wear in charge motion and power draw of SAG mills. He completed his PhD in 2010 and after working in several industry-funded projects in Iran, he joined JKMRC in 2011.

Mohsen has extensive experience in conducting applied research and over the past 15 years he has successfully delivered number of industry-funded projects. Mohsen is comminution specialist who has a strong desire to implement fundamental understandings in his research for offering solutions to minerals industry and also educate engineers and researchers with problem solving skills for tackling future challenges of resource industry.

P009R Research Team

Martin Harris
University of Cape Town

Martin Harris has been employed, principally as a researcher, in the Department of Chemical Engineering at the University of Cape Town since 1986. From the outset, his position has been supported by industry, and has focussed on research collaboration with industry, in terms of technology development, technology transfer and the development of human resources via undergraduate and postgraduate research projects and the development and delivery of industry courses and workshops. His main research focus is the design, modelling, simulation and control of industrial-scale flotation circuits. Martin completed a Bachelor of Engineering (Chemical Engineering) at UCT in 1983, and an MSc (Engineering) at UCT in 1987.

P009R Research Team

Dr. Marko Hilden
Julius Kruttschnitt Mineral Research Centre

Marko's main research interest is in advancing capabilities in simulating and modelling of comminution processes and assessing their performance. For the past few years, he has been developing a comprehensive revision of the JKMRC AG/SAG variable rates mill model which is designed to enable improved prediction of production-scale milling performance. His current mill modelling research is extending the SAG mill models to work with multi-component feeds and within dynamic simulators for on-line process prediction. His equipment specialisation also extends into HPGR, stirred milling, screening, and other similar equipment. Marko also has extensive experience in circuit modelling and simulation and developing new circuit simulation tools to deal with multi-component simulation problems, novel circuit configurations and linking comminution to separation processes through modelling the mineral liberation process.

Marko is a mineral processing engineer and has worked as a comminution researcher at the JKMRC for the past 10 years where he mainly collaborates on industry-focussed comminution projects and advises post-graduate students. His PhD research on "A dimensionless analysis approach to modelling industrial screening" included being awarded the Ian Morley prize in 2007. Marko has 7 years industry experience working as a project metallurgist at a large iron-ore operation in Western Australia and as a technologist in a coal research and technology group in Melbourne before joining the JKMRC.

P009R Research Team

Associate Prof. Kim Runge
Julius Kruttschnitt Mineral Research Centre

Associate Professor Kym Runge is the leader of the Separation Research Program at the SMI-JKMRC. This program aims to develop novel separation processes that will make a step change in mining and involves research into high voltage comminution, coarse and fine particle flotation, improved classification and novel dewatering. Prior to this appointment, Kym worked 25 years as a flotation specialist. She has worked as a researcher and consultant, focused on development of flotation simulation and diagnostic procedures. She is currently the technical director of a collaborative industry sponsored research program into coarse particle flotation (CPR). She is also a chief investigator within the Australian ARC Centre of Excellence for enabling eco-efficient beneficiation of minerals.

Confirmation of Sponsorship

- The P009R Confirmation of Sponsorship document is now established through our legal repository system – Concord.
- If your company is interested in Committing to Sponsorship of the P9R project, please email Ann Woolley / Redeemina Bonnah, on

  ann.woolley@amira.global / redeemina.bonnah@amira.global

  who will create a link for you to commit to sponsorship.

  Or click on this link

  P009R Expression of Interest

  Or scan this QR code

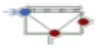
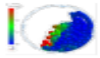
Appendix

Past Amira P9 Projects

Appendix 1a:

In addition to the models' outcomes listed in Table 1, the IES (Integrated Extraction Simulator) was developed in conjunction with CRC Ore. Currently, a good number of the models have been fully demonstrated and are operational in the IES.

Table 1 Latest P9 (P9Q) outcomes

Models		Specifications
	Particle-Based Flotation Model (FLT-01)	Integrated process predictive capabilities added by incorporation of a Bazin model (standalone unit and feeder model) which can convert particle size distribution to the mineral by floatability data required for flotation models.
	Mechanistic Flotation (FLT-02 and FLT-03)	A phenomenological flotation model based on the P9 flotation infrastructure. The model is capable of predicting concentrate and tail volumetric and mass flow rates as well as the separation of species based on true flotation and/or entrainment.
	Hydrocyclone (CLS-01)	Cut-size, separation and water split. Response to continuous density distribution.
	Cone Crusher (CMN-01)	Semi-mechanistic. Response to closed side setting, speed, chamber design.
	HPGR (CMN-02)	Piston and Die breakage. Verified on fully liberated material.
	Dry Screen (CLS-02)	Multiple decks, variable inclination, aperture +2mm. Response to generic media, throw, frequency. Particle size distribution predicted at every point on screen.
	Jig (SPR-01)	Response to component density, relative cut height, jig area, throughput.
	Dense Medium Separator (SPR-02)	Basic equipment model.
	VR2 SAG/AG Mill (CMN-03))	Accurate throughput-filling relationship. Power based breakage, improved discharge and slurry holdup. Full multicomponent.
	Mechanistic Mill (CMN-04)	Use particle fracture tests. Inherently multicomponent and predictive. Response to liner design, ball size & mill conditions.
	RoM Ball Mill (CMN-06)	Same as VR2 with high ball load.
	Weir Minerals HPGR model (CMN-07)	HPGR model fitted to Weir Minerals data
	Weir Minerals Hydrocyclone model (CLS-03)	Hydrocyclone models fitted to Weir Minerals data
	Inventory models (CMN-08)	Predictive models for bin, conveyor, pump, sump and stockpile.
	Regrind model (SPR-03)	A regrinding model capable of predicting the mineral and floatability distribution of a product from a regrind unit based upon a perfectly mixing ball mill modelling approach.

Appendix 1b: 2017 – 2020 P9Q Project Deliveries

- 15 models, most of multi-component capability, operating on the IES platform.
- Models included databases for calibration and verification resident on IES.
- Models and simulation verified on 2 demonstration flowsheets.
- Significant documentation and technology transfer on operation and use of models on IES was accomplished.
- One site study was conducted.
- IES Platform improvements including improved operator interface and material balancing.
- All Sponsors were provided with immediate access to P9 models to test, familiarise and give feedback.
- Technology transfer to staff of P9Q sponsors through face-to-face workshops, online webinars, and developing training materials.
- Support P9Q sponsors for implementation of P9Q models on their projects.

Appendix 2a:

New knowledge delivered through P9P:

- Grain size distributions in 3D of sulphide minerals.
- Predictive multi-component ore bed compression testing based on bed porosity reduction and t10.
- Use volume not mass in multi-component ore breakage.
- Techniques & advantages of generic mechanistic mill model.
- Applicability of the random liberation model to sulphide ores.
- Database of turbulence in conventional flotation cell.
- New framework for flash cell - dual classification - flotation device.
- Relationship between energy/power input and flotation kinetics.
- Fundamental models for particle-bubble contacting.
- Linear dependence of froth stability on particle surface area.
- Relationship between water recovery & top-of-froth.

Table 2 P9 (P9P) outcomes

Model		Enhanced Capability developed in P9P
Crusher	New	Totally new, semi-mechanistic: introduces chamber design, volumetric feed limit & speed. Uses CSS, throw, power. Links to detailed mechanistic design model
Screen	New	Totally new, mechanistic: response to apertures, open area, screen size, inclination, frequency and throw. Predicts capacity, overload, carry-over.
HPGR	Enhanced	Multicomponent - blends of different competence ore, gap-pressure response, power draw. Suited to high circulating loads and fine product, predictive from piston & die test.
Ball Mill (Power based)	New	Based on mill power - provides energy consistency. Discharge function, overload warning, Ball filling. Ore-specific appearance function from fine breakage test.
Mechanistic ball mill	New	Inherently multi-component and predictive, speed, ball size and filling, liner design, changes efficiency as ore loading and feed rate change. Currently off-line Researcher code.
SAG VR2	Enhanced	Power-based, Accurate throughput-filling, Enhanced pebble discharge, discharge & slurry holdup sensitive to filling and grate layout, power prediction. Multi-component enabled
RoM ball mill	New	Based on SAG VR2, customised to high ball load and closed-circuit operation Implementation early P9Q
Cyclone	Enhanced	Multi-component: cut-size, sharpness of separation and water split based on continuous density distribution. Enhanced capacity, % solids, variable efficiency with operation
Fine wet screen	New	Down to 50µm aperture size, inclination, % solids, capacity
Jig - density separator	New	Component densities, relative cut height, jigging area, throughput, separation performance.
Flotation		Upgraded sub-components operational but not ready for uptake in IES. Uptake in P9Q.
Inventory	New	Allow for unbalanced flows in circuit - essential for crusher circuits. Bin fill and empty rates, Conveyor capacity & power limits, Pump, Sump and Stockpile capacity.

Appendix 2b:

Amira research team to site ensure applicability of multi component models at sponsor sites

RESEARCH TRANSLATION STORIES

	Sunrise Dam	Vale Timbopeba	Ernest Henry Mine
Objective	Determine the root cause of throughput reduction with new ore; evaluate potential of IES for future improvements.	Determine the cause of haematite losses and reasons for poor cleaner and recleaner selectivity.	Identify potential process challenges when processing new ore types.
Who	Researchers, site staff, corporate staff- Australia and international	Researchers, site staff, CDM, ITV and CPT	Researchers, site metallurgists,
Activities	Detailed Comminution survey; training- surveying, statistics, process devices, characterisation and modelling; simulation of comminution circuit	Detailed Flotation survey; training of Vale staff in survey methodology and sample characterisation, comparison of current flotation circuits across Vale business units, daily interactions between researchers and Vale staff, detailed technical outcomes workshops at site.	Detailed integrated survey, training in survey and sampling methodologies and equipment, integrated simulation of comminution, classification and flotation, simulated evaluation of alternative ores, training in setting up an integrated simulation framework, ongoing support for implementing the recommendations.
Outcomes	Recovery of full throughput, identification of bottlenecks and inefficiencies, intensive training of site staff, simulations in IES for future process improvements; **potential revenue increase of A$35M per year.**	Identification of causes of losses and poor selectivity, optimisation scenarios to implement to solve problems, set up of ongoing hydrodynamic optimisation regime, training in best practice flotation circuit diagnostics and optimisation,	A robust assessment of the performance of the new ore, identification of potential circuit flexibility to manage changes in head grade without throughput losses, Identification of improvements in circuit sampling points that will improve future data collected.