Data driven infrastructure strategies in coal preparation

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Abstract. The coal preparation industry faces increasing challenges, marked by escalating capital and operational costs since 2019, alongside stricter environmental, social, and governance regulations. To navigate these obstacles, there is a growing emphasis on implementing advanced processing and blending strategies, necessitating the use of data science and analytics. Operations are increasingly investing in dedicated remote operations centres and individual site analytics to optimize short-term and long-term operational efficiency, enhancing profitability across the entire mine site. This evolution includes the development of geometallurgical modelling software designed to maximize returns from coal resources by analysing resource databases and financial models to assess various processing strategies. Enhanced capabilities using R Shiny coding and Power BI visualizations enable swift evaluations of infrastructure investments and production strategies over the mine's lifespan. The tool's application extends to individual equipment strategies, focusing on efficiency metrics to determine optimal feed rates and necessary upgrades. A series of case studies illustrate the practical use of this technology for scheduling capital improvements and optimizing supply chain dynamics for ROM and product stockpiling across multi-seam operations, ensuring resource management aligns with financial and operational goals.

1 Introduction

In the current capital constrained environment for the coal preparation industry projects are increasingly relying on advanced data analytics and modelling to demonstrate sufficient returns to attract investment. This requirement is motivated by scarcity of capital for new coal projects and upgrades and is being applied to infrastructure ranging from whole of plants, to individual circuits and raw and product coal handling systems. The application of sophisticated data analytics software to these projects not only demonstrates the financial viability or incentive for proceeding but also defines and derisks key design parameters upon which to proceed.

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1.1 Coal preparation industry challenges

Escalation in both coal handling and processing plant (CHPP) capital and CHPP operating costs since 2019, similar to the costs in most other mineral processing industries, has been very high (Fig. 1). Higher capital costs for new projects have made them less attractive investments than investing capital in other areas of business or other diversified businesses. This era of high escalation has also transpired in higher operating costs that have further reduced profitability of most operations.

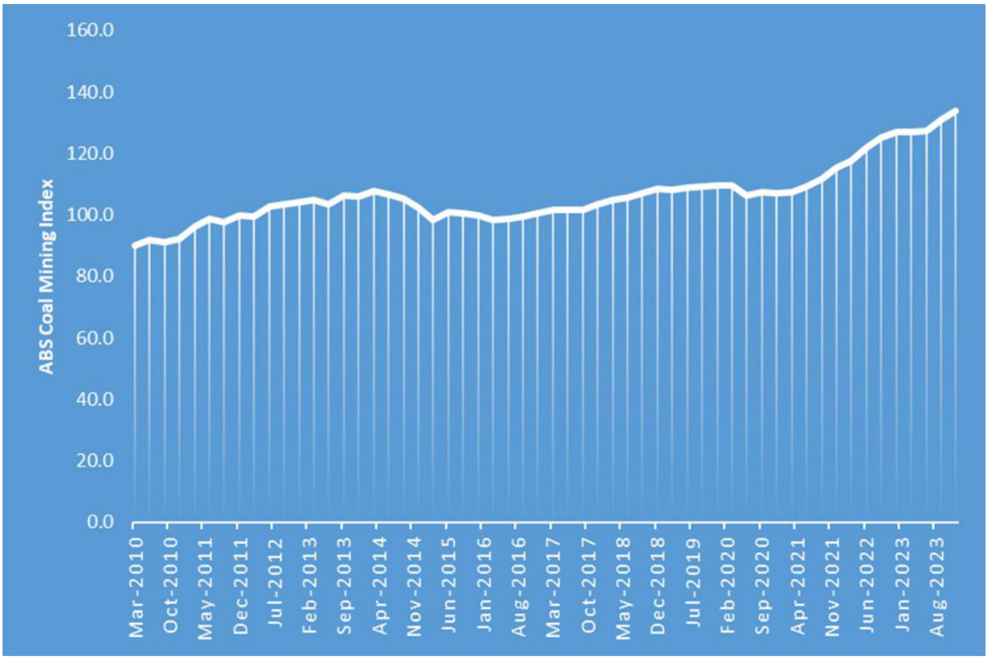

Fig. 1. Australian Bureau of Statistics - Coal Mining Index [1]

Aside from the cost pressures, increasingly marginal resources are being treated that require more advanced processing and blending strategies to meet expected product specifications and maximise resource revenue. Many of the residual resources that are now being mined or targeted for new projects are the next tier of quality and can be thinner seams, highly stratified [2] and of widely divergent properties. Unlike the top tier of resources that have been largely exploited in many of the developed mining basins of the world, the next tier is much more complex and improved geometallurgical modelling is required to identify blending and product strategies that are not only workable but also produce saleable products and maximise project revenue.

The sentiment towards the coal industry has become increasingly negative and the use of renewable energy has accelerated rapidly over the last few years. The legislative environment has been gradually changing over the last decade and now it can be quite challenging to gain the approvals necessary for a new coal project to be built. Within this framework, optimal tailings management and closure practices are a significant area of focus for many operations. Strong policies on environmental, social and governance (ESG) requirements are also being implemented on most sites [3].

Projects are being sought to deliver safer, lower cost, higher efficiency, or higher throughput from existing operations.

1.2 Data science and analytics

One of the areas that has seen substantial work from most coal operations over the past decade has been in the field of data science and analytics as indicated by BHP's investment in the BHP's Innovation Centre [4]. Multiple remote operations centres operating out of Brisbane are working extensively in the field of data science analytics, mainly targeting short term operational gains. Data visualisation software plays a large role in this field, and it can also be applied in the longer term for developing infrastructure strategies.

A&B Mylec has specialised experience with maximising value from data sources such as financial databases, industrial plant data, laboratory data, exploration database and development of models relating to these data sources.

Remote monitoring of plants involves the use of advanced analysis routines that can review plant data to identify problems and suggest solutions. Separate analysis routines are used for assessing short term trends, to review aspects such as response to control loops, as well as long term trends for identifying aspects such as drifts in performance due to maintenance. This functionality enables the identification of opportunities to stabilise and improve plant operations.

Automated generation of routine reports is a subset of the tools that can be utilised for monitoring of plant operations. Standard reports can be automated to minimise labour costs associated with the generating routine outputs. Reports can be dynamic to allow management to view the highlights shown in the report.

Beyond routine reports, are more advanced business intelligence tools that involve the development of dashboards using Power BI or R Shiny. Using these types of software enables data sources larger than that typically analysed using Microsoft Excel to be analysed and evaluated. Dashboards improve data analysis efficiency leading to greater insights into plant operation and financial performance. Customised data visualisations are often developed with these dashboards to facilitate ease of interpretation of critical performance aspects.

2 Geometallurgical modelling: Whole of Resource Optimisation Model

The aim of the Whole of Resource Optimisation Model (WOROM) is to boost revenue and profitability of a coal mine utilising a coal handling and processing plant (CHPP) to improve coal value. Inherent coal resource characteristics cannot be changed, but the processing methodology, blending strategies and portfolio of products can be altered to maximise financial return. Each element of the supply chain contains variables which can be modified for economic effect. The complexity of linking these supply chain element variables together to examine whole of resource implications is the challenge of the WOROM. A&B Mylec has been developing WOROMs for over ten years, with each WOROM uniquely addressing the coal quality and operational challenges of the mine.

Each WOROM was originally developed using Microsoft Excel, but new versions are being developed using the programming language R. R is used to perform the data processing and optimisation functions and the new WOROM application is generated using R Shiny [5,6]. The new version of WOROM is accessed via a web browser and features a number of important improvements including:

- Faster data processing
- Improved optimisation algorithms to identify the global optima
- Additional options and constraints to improve flexibility when developing scenarios to investigate
- Faster performance, e.g. solution time has been reduced from 50mins to 1 min
- Data analytics and reporting features

Fig. 2 graphically represents the inputs, outputs and data processing stages of a typical WOROM.

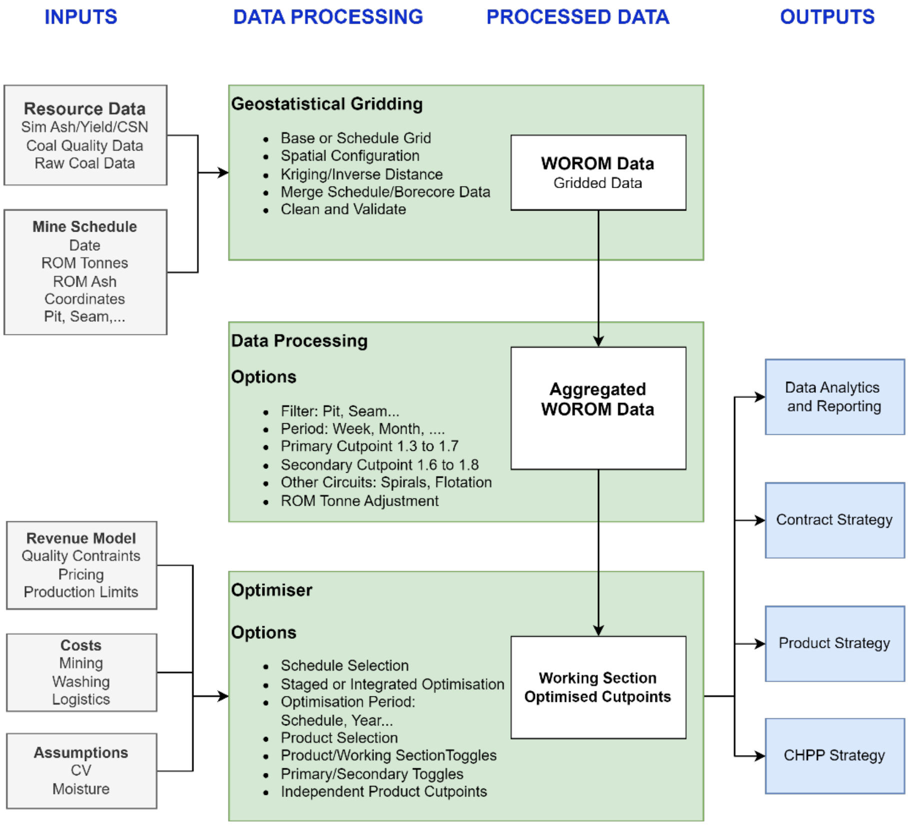

Fig. 2. Overview of data processing in WOROM

2.1 WOROM inputs

The main input parameters for WOROM include:

Resource Data: Resource quality information is a fundamental input to the model. Specifically, spatial data of the following parameters is the minimum input requirements: ROM ash, product ash and yield from CHPP under "normal" processing conditions, and any available product quality information from clean coal composite data.

Mine Schedule: Mining schedules contain the time period, seam/working section, ROM tonnage, ROM ash, block centroids and pit/strip/block information. This data is merged with resource data during geostatistical gridding.

Revenue Model: A revenue model is required in to determine product pricing and consequently revenue. The model can be built with any number of product types, which ideally contain parameters such as coal price, ash/energy targets or rejection limits, ancillary parameters (such as fluidity, CSN, sulphur) penalties and rejection limits. Contract tonnages and market caps can also be selected e.g. a minimum of 1million tonnes of product must be produced each year. The model is built so that all factors affecting price can be changed by simply editing a cell, meaning sensitivity analysis and the comparison of different product types and pricing structures can be undertaken very easily and efficiently.

Costs: Cost assumptions, such as mining, washing and logistics costs can be factored into the model.

Quality Assumptions: The model utilises a number of parameters that require various coal quality assumptions. Relationships such as an ash vs calorific value (based on actual resource sample analysis) and assumptions for in situ, plant feed and product moistures are utilised within the WOROM.

2.2 WOROM data processing

The data processing steps involved include:

Geostatistical Gridding: This step is not required if an integrated schedule e.g. from a Micromine Spry model is provided which has Schedule, Washing and Coal quality parameters gridded across the resource. A base grid is required to grid data to which may use Northing/Easting spacing of 10m and cover the mine lease area as specified in a polygon/s. Otherwise the grid as specified in the schedule can be utilised which can sometimes not be uniform. Spatial interpolation is required to match the schedule data and resource data to the base grid using techniques such as kriging and inverse distance weighting. The processed data is cleaned and validated to ensure for example, yield values range between 0 and 100% and standard column names are used to facilitate the further processing steps. Columns that are not required maybe deleted to minimise data handling.

Data preprocessing: The gridded WOROM data must be prepared for the optimiser by further alteration and transformation. Unneeded data should be removed by filtering e.g. required simulations are only targeting the first 10 years of the mine lease should have other years removed or if simulations using specific seams or work sections should have other data removed. The gridded WOROM data must be aggregated to a designated time period which could be weekly, monthly, yearly etc. The optimiser requires a number of designated primary and secondary cutpoints to optimise, which includes the range and cutpoint interval. Optimisations with small cutpoint intervals result in larger optimisation problems taking longer to solve. Other circuits can also be configured for optimisation options including spirals and flotation. Sometimes scenarios are required that change the ROM tonnes variation over time for different pits and seams. This can be done and avoids the cost of producing a new mine schedule.

Optimiser: Staged optimisation is performed when specific primary products need to be maximised, e.g. the production of coking product must be maximised, other products are of secondary concern. The staging is done by:

1. Primary Circuit Optimisation: This optimisation will often result in Unused ROM tonnes which could not be blended into the product/s and satisfy the constraints. Unused ROM tonnes can be used in Stage 3, if selected.
2. Secondary Circuit Optimisation: Uses the primary cutpoints and determines the best secondary products that can by produced given the available ROM tonnes from Stage 1.
3. Optimises the use of primary unused ROM tonnes into products selected to be produced from the secondary circuit.

An optimisation or product period can be selected that is different from the aggregated WOROM data e.g. the aggregated WOROM data might use a weekly time interval, but a monthly time interval can be used for the optimisation. This means that the optimised cutpoints can be generated on a weekly basis, but the product metrics will be determined on a monthly basis. The historical WOROM allowed products produced from each working section to use the same primary and secondary cutpoints. The new WOROM allows each product to use the best cutpoints for each product to achieve the best overall outcome.

A variety of optimiser options can be made such as:

Product selection: Products can be selected to include in the optimisation

Product/Working section Selection: Sometimes users do not want particular working sections or seams to go into specific products e.g. seams with poor coking characteristics might be blended into semi-soft coking products or thermal products instead of a hard coking coal product.

Primary/Secondary Products: User might prefer only coking products are made from the primary circuit. This option allows users to select which products can be produced from the primary and secondary circuits.

2.3 WOROM data analytics and reporting

The new version of WOROM includes data analytics features to aid data analysis of scenarios. Dashboards utilising a range of visuals such as bar, trend, scatter, boxplots, tables and maps can be included. Data is filtered before utilisation by a variety of options such as scenario, time, products, pit, seam and working section. The three figures below show examples of 3 dashboards included in WOROM:

Scenario Comparison (Fig. 3): This dashboard was designed to compare key parameters across scenarios. The data is either tabulated for the life of mine or plotted over time in a trend chart e.g. R

Scenario Deep Dive (Fig. 4): This dashboard allows a deep dive into a particular scenario. It features a summary table, summary bar chart, trend chart, boxplot and histogram. The trend chart can be converted into a scatter plot by selecting an X parameter different from year. Data can be analysed in a number of ways including by product, pit, seam, working section, cutpoint, Primary/Secondary etc.

Sankey Tonnage flow (Fig. 5): Dashboard allows the tonnage flow to be analysed and mass transfers through different resource data such as pit, seam and working section, through primary and secondary cutpoints to the products. The dashboard highlights how much of each coal block washes at different cutpoints and what products the washed coal is assigned to.

Coal Specifications: Dashboard displays selected coal specifications across customised categories such as scenario, product, pit, seam, or cutpoint.

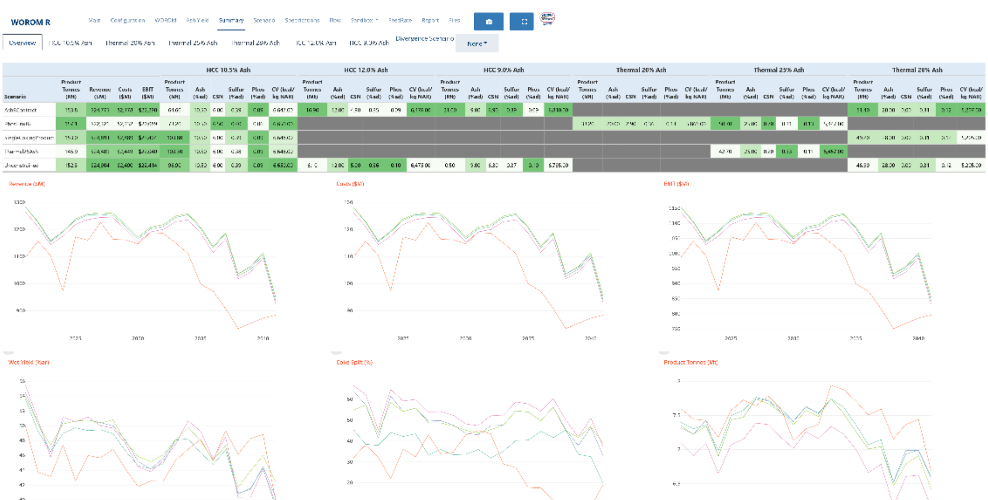

Fig. 3. WOROM dashboard to evaluate and compare summarised scenario data

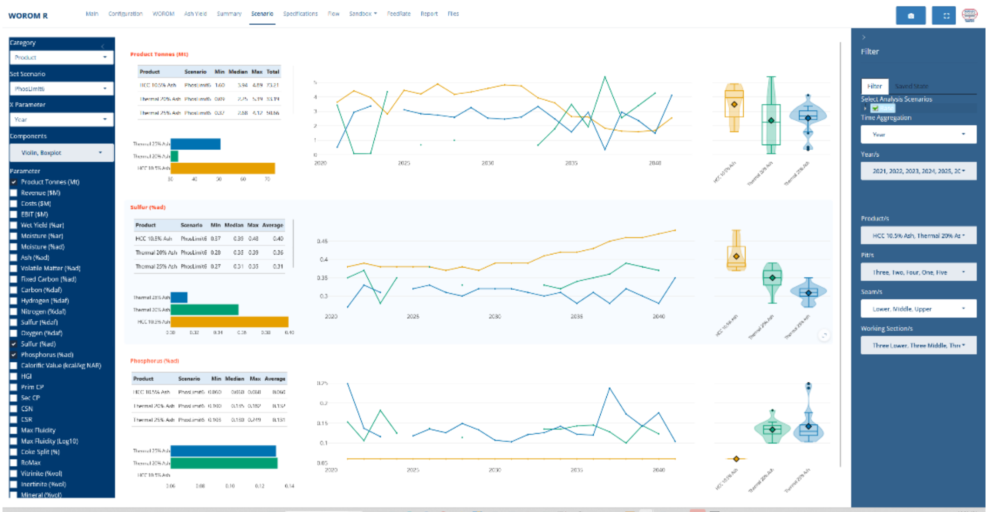

Fig. 4. WOROM dashboard to evaluate trends and distribution of different parameters.

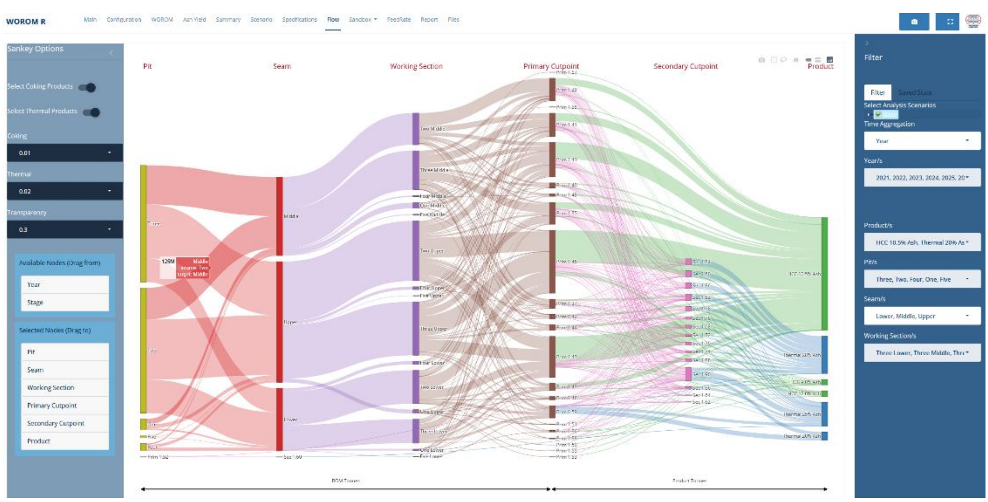

Fig. 5. WOROM dashboard to evaluate the flow of ROM and product tonnes though resource descriptors, circuit configurations and product placements.

2.4 Case studies

A number of case studies were performed to highlight the versatility and power of the new WOROM. Investigations similar to the ones presented can be completed within minutes, ready for analysis. All case studies utilised the same mine schedule which was aggregated by year. The variation in ROM tonnes and ROM ash over the life of mine as designated by the mine schedule is shown in Fig. 6. ROM tonnes varied from 9.5Mt in 2021 to 10Mt from 2031 onwards to the close of mine in 2041. ROM ash fluctuated yearly with a general increase in ROM ash from 2033 to the end of life. Low ROM ash level of 28.1% occurs in 2021 and 2027.

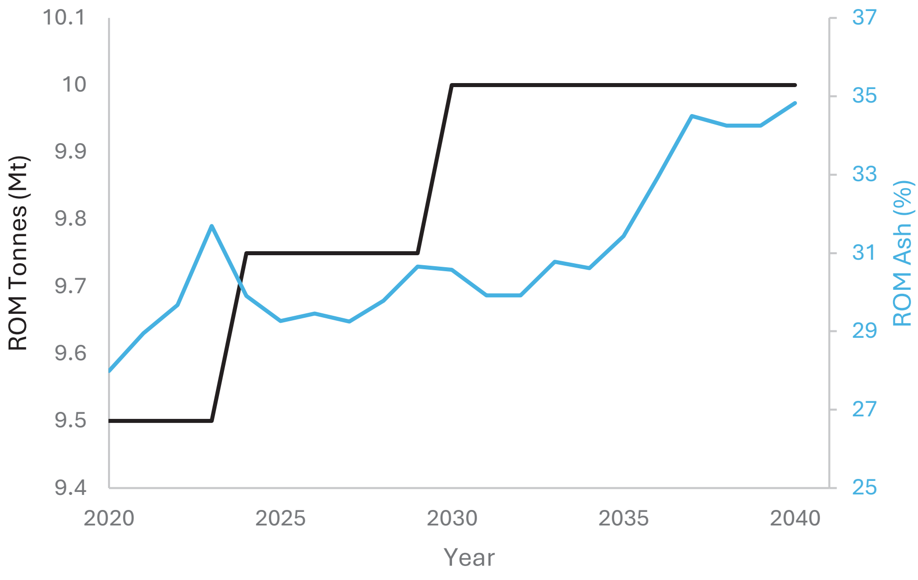

Fig. 6. ROM tonnes and ROM ash over the life of mine for the schedule.

Five case studies were optimised using the WOROM including:

1. **Unconstrained:** The unconstrained case acts as the base case and all products can be produced with constraints only for ash and CSN. This case study will achieve the best revenue as there are minimal constraints on the optimiser.
2. **9% Ash Contract:** There is an existing customer contract to supply 1Mt per year of a 9% ash coking product with a CSN of 6. This case study evaluates whether the contract can be achieved over the life of mine and the impact on revenue. If the contract cannot be achieved over the life of mine, then the contract may not be renewed after completion or may be adjusted if another contract is required.
3. **Single Coking Product (10.5%Ash)**: The unconstrained case showed HCC 9%ash and HCC 12% ash products were not produced consistently over the life of mine. It will be easier for marketing and logistics if just one coking product is produced. This scenario evaluates the effect of producing one 10% ash coking product. Other possible scenarios could evaluate the other HCC products too.
4. **25% Ash Thermal Product:** The marketing team advised that a 28% ash thermal product will be a difficult sell into the market and suggested producing a 25% ash product instead. This case study will determine the potential loss in revenue if a 25% ash product is generated instead of a 28% ash thermal product.
5. **Phosphorus Limit:** The marketing team has advised that they have multiple customers willing to purchase coking coal if the phosphorus is less than 0.06%ad. This case study evaluates whether this can be achieved and the effect on revenue.

Product coal quality constraints are shown in the Table 1 for the five case studies. Two versions of the HCC 10.5% product are provided as one product has the additional phosphorus constraint for case study 5.

Table 1. Coal quality constraints and case study product selection

Product	HCC 9.0%	HCC 10.5%	HCC 10.5%	HCC 12.0%	Mid Vol PCI	Thermal 20%	Thermal 25%	Thermal 28%
	Products							
Coal Quality Constraints								
Ash (%ad)	9	10.5	10.5	12	10.5	20	25	28
CSN	6	5	5	4				
Phosphorus (%ad)			0.06					
Pricing (US$/t)	$ 215	$ 200	$ 200	$ 180	$ 160	$ 94	$ 90	$ 84
Primary	Yes	Yes	Yes	Yes	Yes	No	No	No
Secondary	No	No	No	No	No	Yes	Yes	Yes
Scenarios								
1 Unconstrained	Y	Y		Y	Y	Y	Y	Y
2 9% Ash Contract	Y	Y		Y	Y	Y	Y	Y
3 Single Coking Product		Y						Y
4 25% Ash Thermal Product		Y					Y	
5 Phosphorus Limit			Y			Y	Y	

A comparison of revenue and product tonnes for the case studies is shown in the Fig. 7. Each column chart has the columns sorted by either the total revenue or total product tonnes. The case study with the highest revenue, the unconstrained one, does not generate the highest product tonnes. This is due to the optimiser determining that lower tonnage of higher value coking coal is the best method of maximising revenue. The first 3 case studies show very similar revenue totals with the Single Coking Product Scenarios achieving $11M less revenue than the Unconstrained case study and the 9% ash Contract Scenario achieving $129M less revenue than the Unconstrained case study.

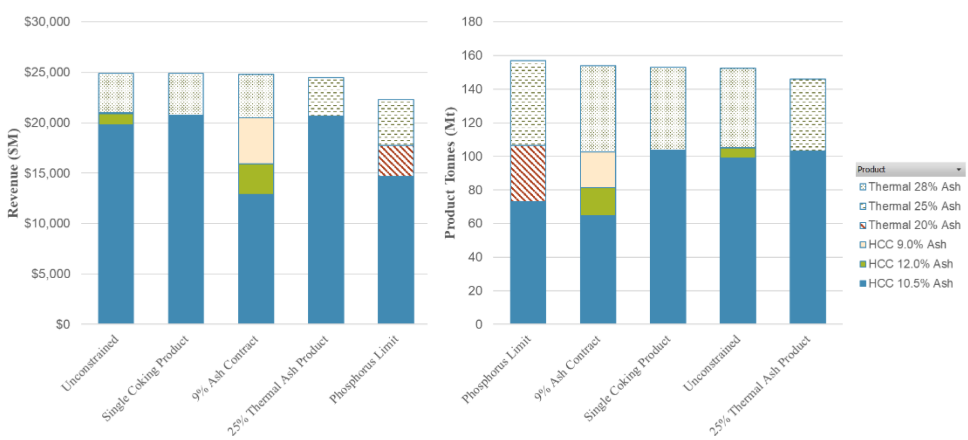

Fig. 7. Revenue and product tonnes for generated products for each scenario

The 25% thermal ash product case study achieved $415million less revenue than the Unconstrained case study, a significant amount. A larger price increase could be investigated for the lower ash thermal products. A combination of low and high ash thermal products could also be produced.

The phosphorus limit case study produced a significant drop in revenue from the unconstrained case study ($2,583million). The case study could be investigated further by increasing the coal prices for low phosphorus products and potentially produced low and high phosphorus products.

A comparison of product tonnes for the Unconstrained case is shown below. The HCC 12.0%ash and HCC9% ash products could not be generated reliably and consistently over the life of mine. Very small product tonnes of HCC 9% product were produced. The HCC 10.5% ash product was the dominant coking product, and tonnages were relatively steady until around 2035 where tonnages reduced to around 3Mt in 2041.

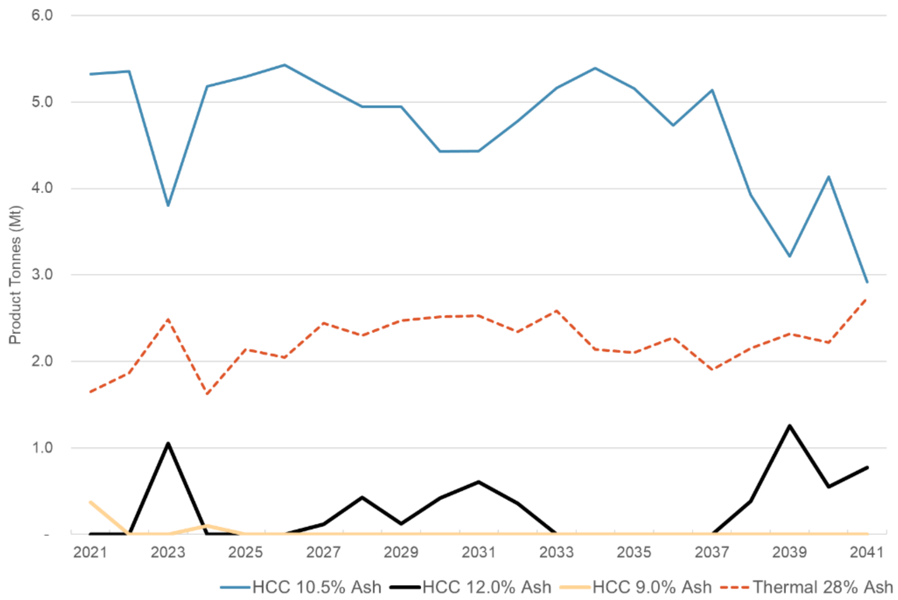

Fig. 8. Variation in product tonnes for unconstrained scenario

A comparison of product tonnes for the 9% ash Contract Scenario is shown in Fig. 9. Consistent 1Mt product tonnes of HCC 9.0%ash product were achieved over the life of mine. Product tonnes for the other coking products varied significantly year to year, more than the unconstrained case. Production of the thermal product was relatively stable over the life of mine.

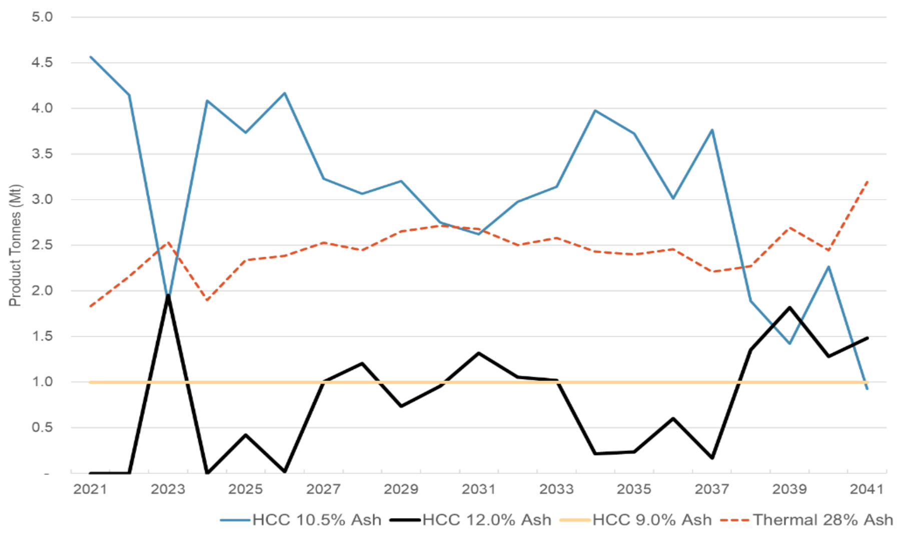

Fig. 9. Variation in product tonnes for 9%ash contract scenario

A comparison of product tonnes for the single coking product and 25% thermal ash product case studies are shown in Fig. 10. Both case studies generated the exact same trend for the HCC10.5%ash product A steady reduction in the production of HCC10.5%ash product is observed over the life of mine. Production of the thermal coal product was relatively steady over the life of mine. The 25% ash product showed lower tonnes each year than the scenario with the thermal 28% product but showed the trend year to year over the life of mine.

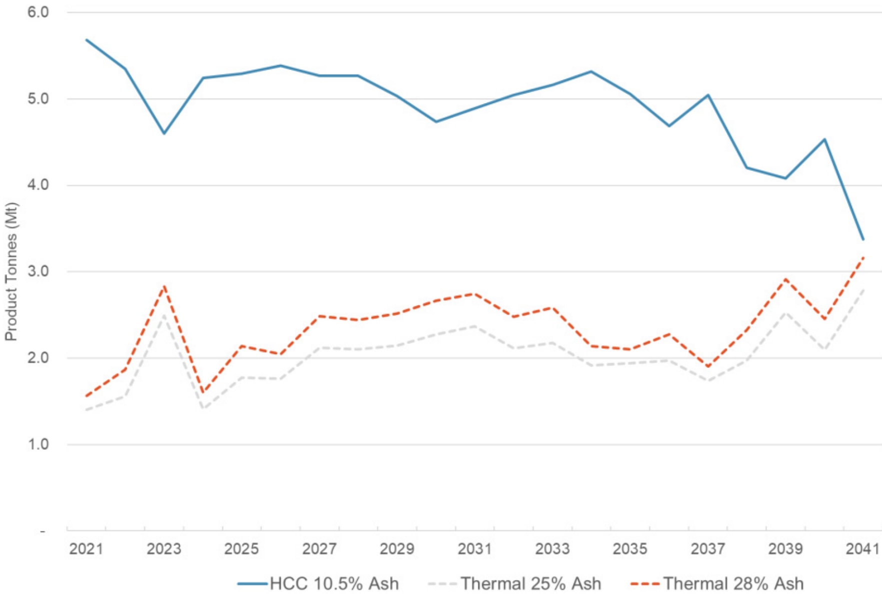

Fig. 10. Variation in product tonnes for single coking product and 25% thermal ash product case studies.

A comparison of product tonnes for the phosphorus limit case study is shown in Fig. 11.

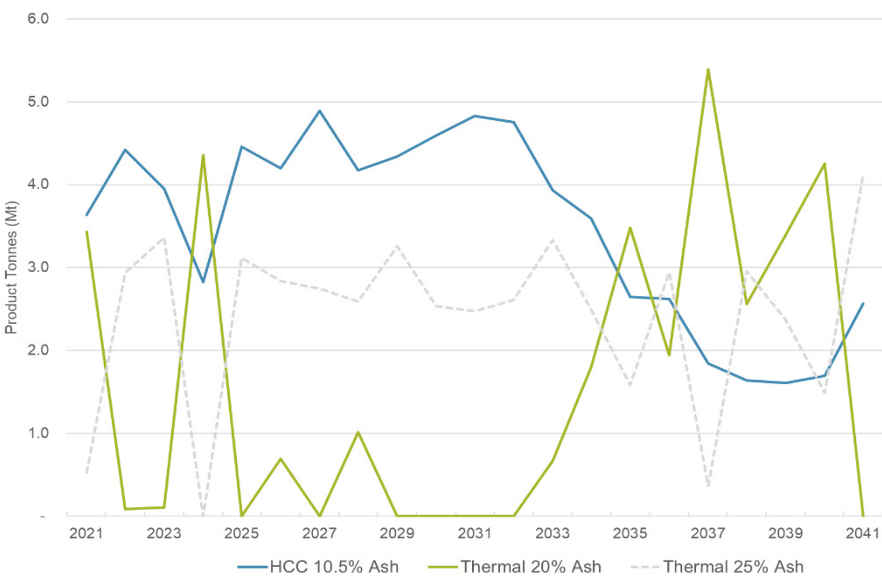

Fig. 11. Variation in product tonnes for phosphorus limit case study.

3 CHPP future proofing and plant feed rate tools

CHPP Future Proofing develops a strategic plan for the modification and upgrade of CHPP infrastructure driven by the resource data and Life of Mine Plan (LOMP) processing requirements.

Time slice (data grouping of time specific data into relevant sections for investigation i.e. mining sections) is used to generate simulation feed files of suitable format for use in custom Limn®: The Flowsheet Processor (Limn) simulation package, software. Custom Limn models using in-house and industry benchmark by-size efficiency, solids and volume loading metrics to deliver traffic light indication by feed type and time where upgrade is required.

By breaking down the data into these smaller mining area snapshots further detail can be identified in the operational requirements of the CHPP to ensure optimal processing of the entire resource.

3.1 Case study

Enhancing Coal Beneficiation Efficiency at Mine 1: A Case Study of Optimized Coal Handling and Preparation Plant (CHPP) Upgrades

This case study details the optimization of coal handling and preparation plant (CHPP) operations at Mine 1, Mozambique. Utilizing advanced simulation tools, A&B Mylec Pty. Ltd. identified critical bottlenecks in the desliming screen, pre-scalp dense medium cyclone (DMC), sieve bend, and thickening cyclone systems. Preliminary designs for strategic upgrades to these systems are presented, incorporating detailed cost-benefit analyses. The results demonstrate the significant improvements in plant efficiency, yield, and revenue achievable through targeted infrastructure modifications.

3.1.1 Introduction

Mine 1, a significant coal producer in Mozambique, sought to optimize its CHPP operations to enhance efficiency and profitability. This case study focuses on a preliminary design study undertaken by A&B Mylec Pty. Ltd., to analyse existing plant performance and propose targeted upgrades to enhance CHPP1 and CHPP2. The study utilized advanced simulation software and data analysis to develop detailed upgrade strategies, including comprehensive cost-benefit analyses and risk assessment.

3.1.2 Methodology

The project commenced with the selection of representative time slices across the Life of Mine (LOM). These time slices were strategically chosen to align with significant changes in mining sections, ensuring that the simulations accurately reflected the anticipated variations in coal characteristics over time. A comprehensive resource database for Moatize, incorporating thousands of exploration drill holes, each containing washability data, seam thickness, and precise location information, formed the foundation for generating accurate simulation feed files.

Time Slice	Years	Mining Sections
1	2021-22	S1, S2B, S4 and S6
2	2023-25	S3, S4, S6 and commencement of S5
3	2026-31	S3, S6 and S5
4	2032-38	S5 only
5	2039-45	S5, S2A an S2B

Fig. 12. Future proofing time slices

These individual drill hole datasets were combined to create representative feed files for each area and time slice. The mine plan, detailing the tonnes mined per area and time slice, was then employed to determine the weighted averages for each major seam mined within each time slice. This meticulous process enabled the generation of highly accurate average feed files that effectively captured the expected variations in coal feed characteristics across the LOM.

These feed files were then converted into a format compatible with the Moatize custom Limn software. This custom software allowed for the accurate modelling of equipment loading and yields within each CHPP.

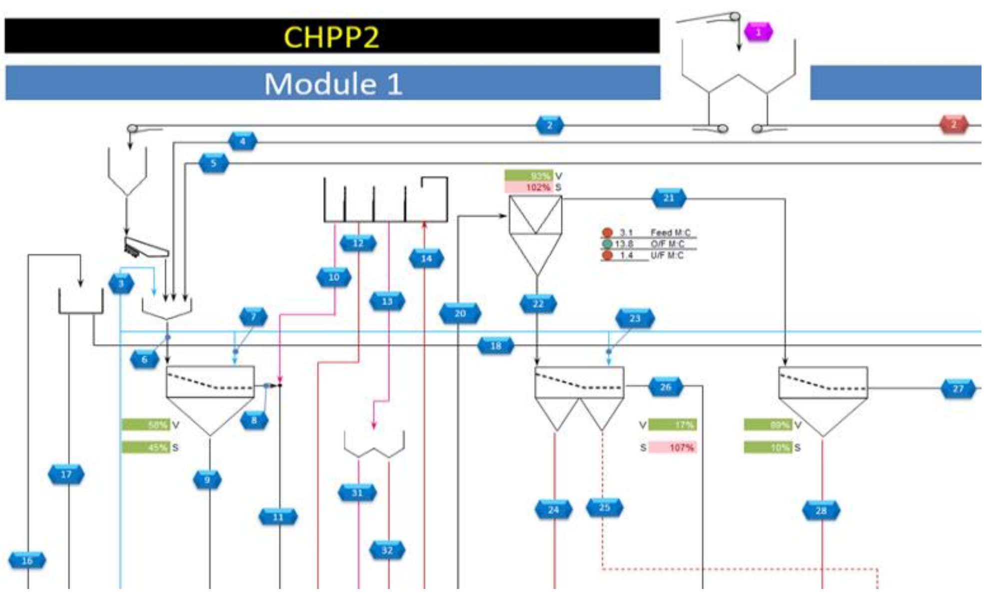

Fig. 13. LIMN feed rate model

Simulations were subsequently conducted for each time slice, and the outputs were systematically collated. A key output from each simulation was a tabulation of equipment loading at a target feed rate of 1000 t/h (as received). This analysis served to highlight any bottlenecks within the system, comparing the model-predicted capacities against actual installed equipment capacities.

Each piece of equipment possesses specific maximum solids and volumetric throughput capacities which dictate optimum metallurgical efficiency. These modelled capacities were compared to the actual installed equipment capacities to clearly identify areas where operational constraints necessitated remedial actions. The generated Limn loading tables were collated for each CHPP, time slice and coal type to be processed during that period. The following is an example from the identified capacity limitations for CHPP2 and time slice 1 where DMC cyclone geometry changes resolved the identified performance issues. The installed and the modified geometry medium to coal ratio outcomes for the pre-scalp DMC's (Table 2).

Table 2. Pre-Scalp DMC M:C ratio overload and modified geometry [7]

Seam	Feed Rate (per Plant)	PS DMC Feed M:C	PS DMC UF M:C	PS DMC Feed M:C*	PS DMC UF M:C*
AVG_TS1_CHPP2 95	1,920	2.9	1.4	3.4	2.0
Section 1_UC_Fresh 10	1,920	2.8	1.5	3.3	2.1
Section 1_MC_Fresh 8	1,920	2.9	1.5	3.4	2.2
Section 1_LC_Fresh 7	1,920	2.9	1.7	3.3	2.8
Section 4_INL_Fresh 32	1,920	2.9	1.4	3.4	1.9
Section 4_BNU_Fresh 31	1,920	2.8	1.4	3.3	1.9
Section 4_BNL_Fresh 30	1,920	3.0	1.4	3.5	2.0
Section 4_UC_Fresh 37	1,920	2.9	1.4	3.3	2.0
Section 4_MC_Fresh 35	1,920	3.0	1.4	3.5	2.0
Section 4_LC_Fresh 34	1,920	2.9	1.6	3.4	2.5
Section 6_INU_Fresh 57	1,920	3.0	1.4	3.5	1.9
Section 6_INL_Fresh 56	1,920	2.9	1.4	3.4	2.0
Section 6_BNU_Fresh 53	1,920	3.1	1.4	3.6	1.9
Section 6_BNL_Fresh 52	1,920	3.1	1.4	3.6	2.0
Section 6_BR_Fresh 54	1,920	3.1	1.4	3.6	1.9
Section 6_UC_Fresh 61	1,920	2.9	1.4	3.4	2.0
Section 6_LC_Fresh 58	1,920	2.9	1.5	3.4	2.3

* Using recommended pre-scalp DMC geometries

4 Summary

Coal preparation faces many challenges in the current market, in particular:

- Escalation in both CHPP capital and CHPP operating costs since 2019 has been very high
- Increasingly marginal resources that require improved geometallurgical modelling to define optimal processing and blending strategies
- Increasing competition for capital for new CPP infrastructure

In the face of these challenges, progress is being made through:

- Remote and autonomous technologies for safer and lower operating cost operations.
- Advanced geometallurgical modelling and revenue optimisation through use of the WOROM tool.
- CHPP Future Proofing assessments for prioritizing, delaying and reducing capital requirements through LOM plans.
- Dynamic modelling for operational optimisation and prioritizing of materials handling infrastructure investment.

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