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Enhancing project delivery through operational experience

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CLOSING THE FEEDBACK LOOP: ENHANCING PROJECT DELIVERY THROUGH OPERATIONAL EXPERIENCE

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ABSTRACT

Engineering, procurement and construction management (EPCM) remains a prevalent approach for greenfield project delivery in the mining and minerals sector. While effective in coordinating complex works, it frequently culminates in a hard handover, with limited mechanisms to capture and reuse operational learnings in future designs. Consequently, design deficiencies can be repeated and addressed late during commissioning, increasing ramp-up duration and elevating capital expenditure (CAPEX) risk which can undermine investor confidence.

This paper advocates integrating operational experience and subject matter expertise early in design to close the feedback loop between operations and projects. Key themes include recognising operational realities not evident on piping and instrumentation diagrams (P&IDs); designing for variability in ore and process conditions; and embedding metallurgical requirements within digital control system philosophy. By aligning control objectives with process needs, avoiding unnecessary complexity and creating structured feedback pathways, projects can reduce technical risk and improve commissioning efficiency and long-term operability.

INTRODUCTION

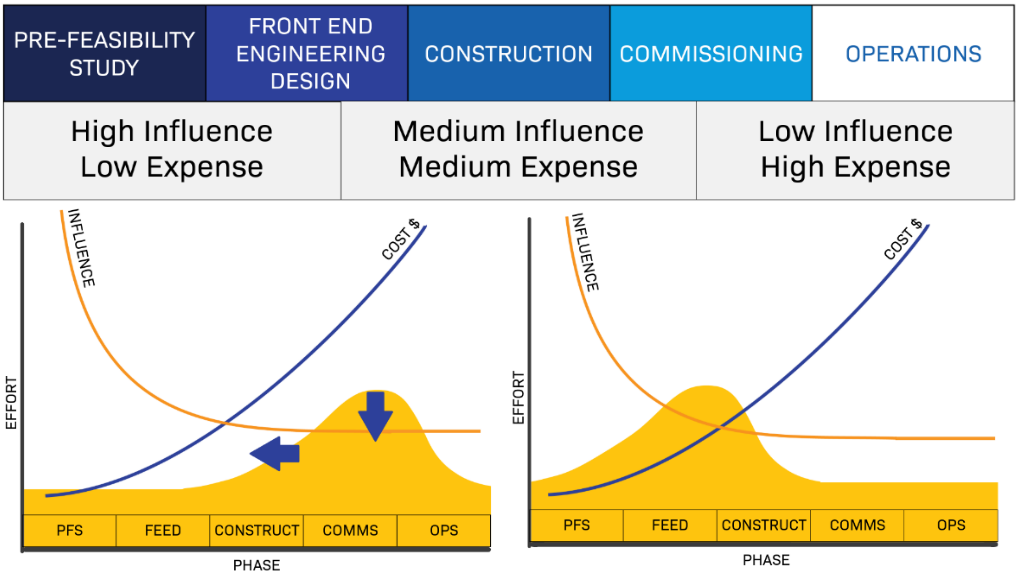
EPCM provides structure, accountability and access to specialist capability across engineering disciplines and vendors. However, the segmentation of phases—engineering, construction, commissioning and operations—can impede knowledge transfer. When operational stakeholders are involved late, issues relating to accessibility, maintainability, instrumentation, control logic and metallurgical assumptions may only be discovered after construction. These late discoveries often require workarounds, scope growth and schedule and budget pressures. This paper proposes a more iterative, experience-driven approach that integrates operations and commissioning expertise from the outset and institutionalises feedback from commissioning and operations into subsequent designs.

EPCM'S CURRENT ROLE AND LIMITATIONS

EPCM contracts can provide cost and schedule discipline for the project owner and commercial certainty for the contractor. EPCM allows project owners to set the terms of engagement while outsourcing execution to experienced firms, leveraging specialised expertise without ceding total control. EPCM allows the contractor to use their disciplinary expertise to deliver a plant that is effective and cost efficient in construction. The EPCM agreement starts with the contractor promising to deliver a plant that meets the owner's scope and ends with the contractor delivering the plant that the owner paid for. The definition, agreement and mutual understanding of the scope is one of the key predictors for a project's success.

The linear delivery model of the EPCM structure creates rigid segmentation of roles and phases. The delivery model starts with the owner providing the project scope to the contractor, the contractor then manages the engineering, procurement, construction and commissioning, finally handing the plant back to the project owner. The opportunity to make changes that may optimise the circuit occurs early in the design phase when information on engineering detail is minimal, limiting the probability of opportunity discovery and quantification. When the optimisation opportunity is discovered and quantified the engineering has progressed and the cost of making the change increases, as shown in Figure 1. First described by Boyd, 1976[1].

Figure 1 Shifting the Influence to Reduce Cost



Involving operational experience early will promote the early discovery of operational issues rather than the sole focus on equipment sizing and constructability. The agility available at the early stages of a project design allows for optimisation learning to be incorporated into the initial design rather than post construction which is typically more costly.

To meet goals of the plant construction and the plant delivery at the lowest cost, a similar previously designed plant is used as the baseline for the new plant design. Reproduced engineering produces replicas of previously constructed plants that may not have been verified as satisfactorily operational by their owners and they may not meet the process requirements of the proposed plant. Owners need to ensure that the baseline design has been operationally tested, and lessons incorporated into it. Depending on project timing, the lessons learned from the construction and commissioning of the baseline project may not have been completed at the start of the design phase for the current project. Unless a mechanism is established to incorporate feedback from the latest commissioned project, the information will not be utilised. Lane and Clements[2] opine that the best time for operations input is;

- "during the project feasibility study [*and the front-end engineering design (FEED)*] when operator wish lists can be assessed based on cost benefit analysis without affecting schedule
- during project reviews to check for any fatal flaws that may have occurred during detailed design
- as part of operational readiness planning in identifying mod-squad projects and plans to address serious defects."

They also conclude that the tension between operations and projects can be described in the difference in focus and time frame, which is summarised in Table 1. Operations have a long-term view, making incremental improvements over a longer time frame, typical of operating budgets. While the contractor

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[1] Paulson, Boyd C. 1976. "Designing to Reduce Construction Costs." Journal of the Construction Division 102 (4): 587-592.

[2] Lane, G, and Clements, B, 2012. Operations versus Projects – How Do People Think and What are the Implications, in 11th Mill Operators' Conference, pp 11-16 (The Australasian Institute of Mining and Metallurgy: Melbourne).

has a shorter-term focus, based on the project schedule and is accustomed to spending large sums to return a project quickly back on track, typical of capital budgets.

Table 1 Conflicts between operations and projects

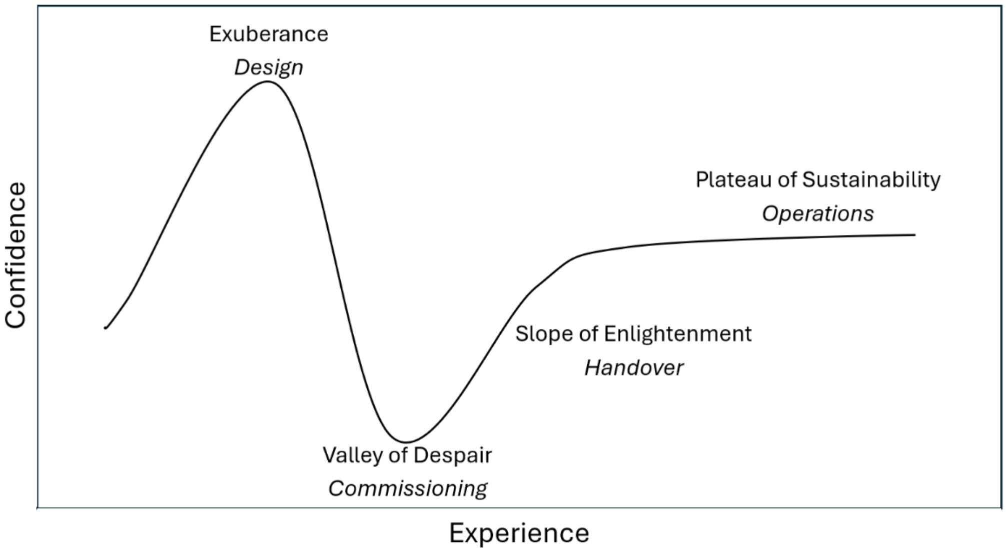
	Focus	Decision Driver	Decision Cycle
Operations	• Production and operating costs • Detailed	• Monthly - annual budgets, life of mine • Long term	• Long view for incremental improvements
Projects	• Project deadline • Scope delivery • Macro	• Project life • Short term	• Near view for large scale improvements

The opportunity loss can occur when an operational improvement idea is suggested too late to be included in the construction design and it is slated to be included as a later project. The design of the improvement may not include the EPCM contractor, and the feedback may not be reported to them to incorporate into future designs.

VALUE OF OPERATIONAL EXPERIENCE AND DESIGN

The value of operational experience can be illustrated using Figure 1, a stylised experience confidence curve that is interpreted from the results of a study by Dunning and Kruger[3] . They recognised that subjects who had low level experiences thought that they would perform well in a task, which when tested found they over-estimated their ability, while subjects considered expert underestimated their ability and performed better than their expectations. The plot shows the levels of perceived experience and confidence are not linear. Confidence can be thought of as the perception of success and experience as the knowledge base.

Figure 2 Stylised Experience – Confidence Curve



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[3] Dunning, D and Kruger, J, 1999. Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments, Journal of Personality and Social Psychology, 77(6):1121–1134.

When a project is starting, the confidence (and exuberance) is high while the knowledge base, the detailed engineering, is at a low level. As the engineering progresses, operational issues not recognised or known by the designers may not be addressed. Confidence remains high with the design, as commissioning starts the previously unknown operational issues start to arise, this erodes confidence. Solutions to the now known operational issues are developed and process understanding increases as a result, confidence starts to increase when the knowledge base reaches a point where the process is understood and the path forward is becoming clearer. If the operational issue is identified during the detailed engineering, confidence will reduce (frustration and stress will increase) as the fix is being implemented all the while as the knowledge base increases. If the operational issue was known at the feasibility/FEED stage, as knowledge and experience increase, understanding increases and causes a turnaround in confidence, until the process becomes situation normal.

By front loading operational expertise to inform and review design, the project will be moved further down the experience axis. While the project is in the exuberant high confidence/low knowledge phase, the expert will be the advocate who tempers expectations and introduces details. Complexity increases for people driving the project as the comprehension of issues is revealed. While annoying to some, the analysis, interrogation and thought will pre-empt issues and introduce mitigations into the scope rather than in a costly, live commissioning environment. Operational experience may shed light on mineralogy concerns or observed phenomena that require the assumptions to be re-visited early, and on brownfield expansions incorporate the hard lessons already learnt.

Being further up the experience axis has the effect of commissioning occurring in the Slope of Enlightenment rather than the Valley of Despair. Operational expertise during the feasibility study and FEED promotes the asking of “what if?” questions so they can be considered and risk assessed in the earlier phases when change is easier to implement. Perceived operating issues can be interrogated and investigated. If justified, the mitigation is included in the design, and this will produce a more robust circuit rather than just copy and pasting a “proven design”, with repeated flaws. Incorporating iterative lessons in each design is a process of continual improvement. Reducing costs for future clients and driving efficiency gains for the EPCM, a true win-win situation.

Operational experience encompasses the firsthand knowledge of individuals who have worked in similar facilities, commissioned the previous iteration of the design, and navigated unexpected process behaviours. These professionals—be they plant operators, metallurgists, maintainers, or control system technicians—bring a pragmatic lens to engineering decisions. They ask the questions that don’t appear on a datasheet:

- Can improved mixing be achieved by modifying the pipework or reagent addition point?
- Is the instrument measuring a representative sample of the process stream?
- Why is the weightometer positioned so far away from the feeders at the top of a conveyor rather than back near ground level, where is it responsive in control and accessible for maintenance?
- Does the sample point need to be on the 13th floor and the lab on the ground?
- Can we have a hose point here? Will there be enough pressure?
- How many bends are there in the slurry pipeline? Where will the solids settle once the flow stops?

Designing a mineral processing facility on paper rarely reflects the messy, unpredictable realities faced during daily operations. While engineering teams rely on simulations, standards, 3D modelling and diagrams like Piping and Instrumentation Diagrams (P&IDs), these resources don’t capture the nuances of how a plant needs to be monitored and observed, or how to best cover the operational area you are responsible for geographically as well as satisfying the process requirements. That’s where operational experience becomes invaluable by providing insight to improve operability. Some real-life examples include:

- The location of a sump pump and the piping route of the sump pump discharge can be designed in such a way to prevent the line from bogging due to the cyclical nature of sump pump operation
- The tyranny of stairs can be reduced by properly locating a platform to afford a supervisor a view of upstream and downstream processes or appropriately positioning storage for tools and consumables

- The location of a pH probe that allows for ease of access for maintenance while providing adequate time for the reagents to modify the process pH.

Basic decisions on instrumentation and communications should consider long-term flexibility and maintainability. For example, selecting between analogue 4–20 mA (with or without Highway Addressable Remote Transducer, HART) versus digital fieldbus or Ethernet, the location and environmental exposure of junction boxes, allowance for spare pairs on input/output (I/O) boards, and whether wireless is appropriate. These choices affect diagnostics, fault-finding tools and future expandability.

METALLURGICAL REALITIES AND TESTING LIMITATIONS

Metallurgical test work is the basis of process design. It influences equipment sizing, recovery targets, reagent selection, and throughput predictions. Unfortunately, ore bodies are rarely homogenous or simple and understanding the complexity of the orebody is necessary for the successful extraction of the target mineral. Typically, the orebody is divided into geological domains which define the deposition events of the target minerals which is a useful start for metallurgical testing. The deposition event can identify the mineral associations of the target mineral, and the test work will confirm and quantify the associations;

- Is it free or locked?
- Is it locked in gangue or with other minerals?
- Is the target mineral recovery contaminated with deleterious minerals?
- Is the host rock hard or friable?
- Is the host rock abrasive?
- What grind size is required to achieve economic liberation?

Variability testing within domains needs to be undertaken to identify if further division of the domain is required to define any metallurgical anomalies affecting throughput, recovery or processing methodology.

The domains can be ranked according to mineral value to facilitate decision making on test work. A high value large domain will warrant extra samples to test variability to a high degree of confidence. Further, if there are multiple large value domains with different processing characteristics and requiring varying processing regimes, the best value proposition needs to be determined between bespoke plants for each domain, sequential processing through a single hybrid plant or blending through a hybrid plant.

The life of mine (LOM) timeframe will also provide a judicious input into the calculation, providing information for when the ore types are available for processing or if a planned cut back will require a reprise of the processing methodology for that ore type. Understanding how the LOM processing schedule affects the processing plant's requirement is critical to plant design. For example, a plant designed around an averaged or idealised LOM may falter in specific periods, with operations having to introduce on-the-fly fixes to mitigate the underperformance due to variations in ore types. Using the LOM production schedule to inform the plant requirements across different time periods will produce a plant that is fit for purpose and more robust than an idealised one scenario plant.

When designs are shaped by results from idealised or underinformed samples, the consequences can be costly. If a bulk composite sample is used to inform the design criteria, parts of the ore body may be diluted out or omitted, and their effect may not be recognised until they are processed. For example, high elemental carbon assay results in an epithermal orebody could be ignored or not recognised due to averaging a sample, the effect of preg-robbing from the organic carbon could make part of the orebody unviable if a Carbon-in-Pulp plant is designed instead of a Carbon-in-Leach plant.

Sample availability is often constrained, particularly for deep orebodies where sample acquisition costs are high. The quantity of sample required varies according to type of test performed, the number and type of assays that need to be performed, if the test is to be batch or continuous and if any follow up tests are required on that sample. The decision about which samples to test and what to test for needs to be assessed through a geometallurgical lens. Owners need to consider providing samples in sufficient quantities for metallurgical testing to allow for more representative test protocols—such as variability test suites, pilot plants with fluctuating feed rates, and stress-testing control responses under upset conditions. The drilling of holes specifically for metallurgical testing should not be discounted offhand as too expensive and needs to be framed against the project's value. These approaches, while more costly up front, yield dividends in smoother ramp-up, greater resilience and allow for more appropriate and beneficial processing strategies.

Other testing requirements should consider blending of ore types. This is important if different domains present to the processing plant at the same time in the LOM. Domains can be singularly quantified for the plant response, and the requirements to treat effectively to maximise recovery, but sensitivity analysis of blending can determine benefits from blending. Metallurgical testwork may recognise that overall recovery can improved through blending rather than domain batching and design the plant accordingly. Also the opposite is true where antagonistic minerals in one ore type can kill recovery when blended with other otherwise high-performing ore types. Yet can perform well in isolation

The impacts of ore oxidation also need to be tested and considered in plant design. If flotation performance is compromised by oxidation, efforts need to be made to address residence times in stockpiles and conditioning circuits. Otherwise valuable commissioning time can be consumed troubleshooting preventable flotation underperformance factors.

While many processing situations can be tested there are some that cannot be due to conditions not being able to be replicated with laboratory equipment or samples are not available. Test work rarely accounts for operational dynamics such as high shear rates that may affect the slurry during pumping or variations in process and raw water quality. For example, a coarse, low viscosity slurry will be prone to sanding. Designing the hopper and discharge line for the additional flushing water requirement and pump discharge lines reconfigured to stop sanding and line blockages.

To mitigate these risks, design teams must embrace uncertainty. Rather than treating variability as an error, it should be factored into design tolerances, control logic, and performance envelopes. This shift requires collaboration between design engineers, metallurgists, control engineers, and operators to define probabilities and ranges rather than absolutes.

Designs should therefore embrace ranges rather than single-point assumptions and plan for uncertainty through controllability and buffering.

DIGITAL CONTROL SYSTEMS – DECISIONS THAT ECHO

Control loops that utilise a standard PID use the relationship between a controlled process parameter (PV) and the controlling element (MV) to return the (PV) to set point (SP). Working knowledge of the plant or unit process is key to the selection of the appropriate form of controller, and control strategy achieve a stable circuit and deliver the metallurgical objectives. Operational experience can inform selection of the best functional blocks to suit the desired outcome and how instrument selection and placement can improve the design.

Flexibility

Control systems are frequently designed with a technology, purchasing and maintenance primacy. With system architecture and security often being the Control Systems Engineer's main focus. An effective control system also requires a good control philosophy that identifies what parameters need to be monitored and what parameters need to be manipulated for good operational control and how the parameters interact. Considerations in the design should include:

- Can an upstream parameter be used as a feed forward signal for process control? Example, flow output from the flotation feed pump providing a feed forward signal to pre-empt level change and narrow the band of control
- Is there redundancy and reliability built into the architecture?
- Is averaging level control on a hopper introducing or amplifying variability to circuit?

- Is the instrument location suitable to provide an accurate reading of the process, can it be accessed for maintenance?
- Does a high or low level need to be an alarm, a notification via pop-up or does it require process controller intervention? Are the alarms functional or noise?
- Is cascade control warranted?
- Is advanced process control warranted?

Flexibility is key in the design of control strategies. To have flexibility, the control loops need to be configured to the process characteristics. Having an accurate process model and understanding of the interaction of the parameters within the model will determine the configuration of the control loops. Some process models can use the control system to inform set points through the use of cascade control. If a control loop is nested within another control loop, the inner loop can provide the setpoint for the outer control loop.

Control systems should be designed with a view to upstream and downstream processes, assessing opportunity to provide a feed forward signal to give the control loop a prompt for what is going to occur. An example is a thickener designed with auto-control of underflow density and bed level using relevant instruments, where improved control can be achieved through the introduction of the flowrate from the upstream process to allow for proactive changes in the thickener manipulated variables rather than relying solely on reactive ones.

Variability

Mineral processing plants are inherently variable, orebodies change over time and exploration programs don't always allow us to understand the variance. Therefore, designing with only steady-state performance in mind leads to unresponsive systems that struggle under pressure. Controllers may be tuned for a narrow band of conditions, causing instability when real-world inputs deviate. Removing the variability in the processing plant can improve the controller performance. For example, fluctuations from water addition valves can be removed by installing a pressure regulating valve in front of the control valve and at the end of the main. The flow through a valve is proportional to the valve opening and the fluid pressure at the valve, so by keeping the fluid pressure at the valve constant, the flow through the valve is no longer affected by disturbance in pressure. A factor creating variability has been removed!

Another cause of variability is the use of a proxy value instead of using a value of the parameter that actually affects plant performance. Examples are measuring SAG mill weight instead of SAG volume to maximise breakage or measuring pH instead of titration to determine total acid present. The relationship between the proxy and the actual parameter also needs to be understood and modelled to achieve control.

What gets measured gets managed. What should be managed?

One common mistake is information management. A corrupted and perniciously misrepresented quote from V F Ridgeway is abridged to:

- "What gets measured gets managed" [4]

What was actually said in full was:

- "What gets measured gets managed-**even when it is pointless to measure and manage it, and even if it harms the purpose of the organisation to do so**."

The concept that Ridgeway argues is not to say measurement is pointless, bad or counterproductive, but what is important to manage needs to first be measured and then managed. The qualitative aspect

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[4] Ridgeway, V F, 1956. Dysfunctional consequences of performance measurements Administrative Science Quarterly 1(2):240-247

of the measurement is the reason for taking the quantitative value. Measurement provides information, and it is the information that the measurement provides about the process that is important.

For example, measuring throughput rate is important, but optimising the plant throughput is more than hitting a simple t/h target. The optimised throughput rate is dependent on many factors including:

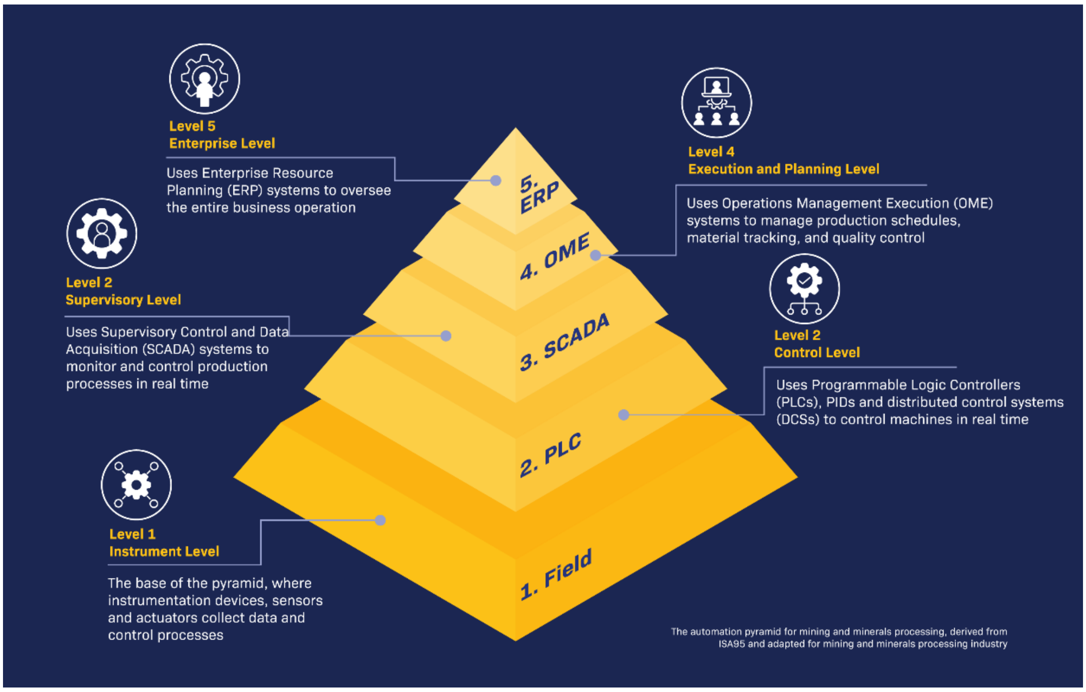
- Mill power draw
- Ore hardness
- Feed size
- Target product size
- Classification efficiency
- Downstream processing capacity

Knowing the process will allow the right instrument to be placed in the right location which is the base level of the Automation Pyramid shown in Figure 3. The levels of the automation pyramid are;

1. Field level: enables predictive maintenance by monitoring equipment health and detecting potential failures before they occur
2. Control level: improves process stability and safety, ensuring that critical systems operate reliably under varying conditions
3. Supervisory Level: provides real-time insights into operational performance, helping teams respond quickly to issues
4. Execution level: aligns production activities with business goals, ensuring that resources are used efficiently
5. Enterprise level; facilitates strategic planning by providing a holistic view of operations and their impact on financial and market outcomes[5]

Unless the pyramid is correctly constructed on a solid base it will fail.

Figure 4 - Automation Pyramid



The automation pyramid for mining and minerals processing, derived from ISA95 and adapted for mining and minerals processing industry

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[5] Mipac, 17 February 2025. The Automation Pyramid, [online]. Available from https://www.mipac.com.au/insights/mining-automation-pyramid [Accessed:14 November 2025]

The real opportunity lies in aligning control design with metallurgical understanding from the outset. This means involving metallurgists and commissioning engineers when choosing instrumentation, defining control philosophies, and establishing alarm thresholds. An understanding of the process will allow questions such as:

- Is the currently selected instrument measuring a proxy for the process variable or is there an instrument available that measures the actual variable?
- Is the correct process variable being measured? Is it the fundamental parameter that is to be controlled or is it a “driven” parameter?
- Does that measurement need to be alarmed? Is it a critical control parameter that will assist an operator or is it something that will consume operator time for no purpose?
- Can the set point be cascaded using the controller rather than requiring operator input?

By designing control systems using metallurgical insight to develop accurate processing models, EPCM teams can avoid flawed control systems. Instead, they can create control environments that support stability, adaptability, and long-term operability by measuring and managing the things that matter most.

CREATING FEEDBACK LOOPS FOR DESIGN IMPROVEMENTS

To meet project schedules and avoid cost overruns there needs to be a be a point in the schedule where the design and receipt of vendor data is frozen. This is normally at the 20-25% engineering complete stage, typically the point at which operations personnel are introduced to review the design. Observations from the review of the frozen design are classified into either fatal flaws or a wish list, with the fatal flaws to be addressed in the next design phase. The wish list items are generally implemented later if these known issues are experienced regularly during commissioning. Operational input into the FEED phase is critical, not only because it will provide value to the completeness of the wish list items that address plant flaws, but it will also inform how the flow sheet should be configured and what features need engineering mitigation. Lessons learnt are incorporated back into the feedback loop for incremental design improvement.

Opportunity needs to be provided for operational expertise to be incorporated into the feasibility study and FEED, especially for brownfields projects where operational knowledge is present., Operational experts need to use the opportunity to forge the future and alleviate future aggravation. The result is an accelerated commissioning, start-up and ramp-up to target, potentially on budget.

Fast tracking a FEED can limit the interaction of operational input, prematurely pushing a project into the design phase, leading to a deeper Valley of Despair (Figure 1). Utilising operational experience in feasibility studies will allow for an increased knowledge base prior to design. A shallower Valley of Despair will result during the commissioning process.

A mix of operational experience from the older wiser stalwarts of industry who hold a wealth of knowledge and personnel with current operational experience, particularly on brownfields, can provide the lessons forgotten and those just found to the design. Bringing together a collaborative team from operations, mechanical, technical and electrical fields ensures operational design with reliability defining success.

CHANGING INDUSTRY MINDSETS AND CULTURAL SHIFTS

While technical improvements in design processes are crucial, they cannot be sustainably achieved without an accompanying shift in industry mindset. The mining sector has historically valorised deep specialisation, where expertise is siloed into narrowly defined roles:

- Engineers engineer
- Operators operate
- Metallurgists analyse.

But this compartmentalised model, while efficient in theory, limits cross-pollination of insights and overlooks the power of diverse experience. Operations personnel should not be limited to processing types, as other disciplines such as geologists can provide valuable information and insight to the plant design process.

Mining houses need to be more cognisant of the benefits of earlier intervention in design. Recognition of the value of early design review and wider consultation would drive better shareholder returns before they become costly delays, protecting the long-term value of the investment. While deep consultation and rigorous design review might feel like an "upfront cost," they function as an insurance policy. For shareholders, a project that is delivered 6 months late but on budget is almost always preferable to one that starts on time but suffers a 40% capital blowout.

EPCM’s embracing digital process models, that are iteratively being upgraded with feedback from completed projects, will deliver more efficient projects into the future. Adaptation of AI and Large Language Models being developed in the SCADA environment are incorporating first principles of mineral extraction sciences and design knowledge embedding years of knowledge at the hands of the user. Instead of waiting for a rare plant failure to "learn" what happens, engineers use first-principle models to simulate millions of failure scenarios. The AI trains on this "synthetic" expertise before it even touches the live environment.

Software advances are reducing design times to a fraction of the current requirements. Shared knowledge sets of the future will be large datasets of prior knowledge from prior plants built and running, further enhancing the process models. Data is becoming a commodity for design, with companies already approaching process engineers seeking their input to train AI models, known as “industrialisation of expertise”. Major EPCM companies are already turning their past project libraries into proprietary LLM’s where optimisation templating produces an estimated 95% of the design and 5% of design is left to the engineers looking at design exceptions. The lessons learnt but not incorporated back into design are going to be repeated again until the feedback loop is completed.

CONCLUSIONS

Integrating operational experience throughout the project lifecycle improves design relevance, commissioning performance and long-term operability. Key enablers include: the early engagement of operational stakeholders, developing a robust and well-informed scope of work that is understood by all stakeholders, and development of accurate processing models to be used in control systems. These measures reduce rework and risk, accelerate ramp-up and contribute to stronger project outcomes.

A well-defined and fully informed feasibility study will provide the information required to design a well-defined and fully informed plant, the information that goes into the design will be reflected in the constructed plant. Taking the time and money to define the plant in geometallurgical terms, testing the necessary parameters and the variability of the ore body will provide prudent information for the design that will be suitable for the ore body.

To efficiently embed operational lessons learned into the design process they need to be available so they can be designed into the process. Detailed design, before project construction, is often fast paced to produce the drawings and plans required to construct the plant. The importance to complete a functioning operating plant on schedule and on budget is immense and many stakeholders are involved: projects, operations, management, executives, shareholders and the community. Construction is not the time to introduce changes as they affect both schedule and cost. The feasibility study and design stages are the time to introduce changes so they can be costed, tested, optimised, validated and then designed. They need to have the time and budget available to allow a successful project to be delivered, one that is able to process the ore body that it was designed for. Experienced operations personnel need to be included and engaged in the process as do experienced designers, using the best information that is available.

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