Guidelines for mineral process plant development studies

P. R. Whincup*

This paper presents guidelines for studies required for the development of mineral processing facilities from initial feasibility studies through to commissioning. Mining project schedule and cost overruns can often be attributed to inadequate metallurgical testwork, engineering and cost estimating leading up to commitment to the project. In some cases this may result from lack of understanding of, and commitment by the project proponent to, the requisite metallurgical and engineering studies during the development stages. Guidelines for metallurgical testwork, process development, engineering and estimating requirements for each stage of precommitment studies are described together with those for the engineering phase.

Keywords: Mineral process plant, Metallurgical testwork, Engineering and cost studies, Feasibility studies

This paper is part of a special issue on Metallurgical Plant Design and Operating Strategies

Introduction

The continuing rapid rise in metal prices has resulted in an unprecedented global increase in the number of mineral project developments. There have however been instances where companies in their rush to exploit resources, have overlooked or cut short some of the necessary metallurgical and processing studies necessary to ensure that a project is properly implemented and performs in line with expectations. Consequences have included cost and schedule overruns and less than optimal plant performance. This has led to disaffected shareholders, non-performing loans and involuntary and disruptive changes at board and senior management level.

Requirements for the various levels of study leading to commitment of funding for mineral project construction have been well documented.[1–4] This paper focuses on the mineral processing aspects of these studies for which the outputs are:

(i) throughput and recovery models as well as operating cost and capital cost estimates for the project financial model
(ii) realisation cost information including transport cost, treatment and refining charge (TC and RC) data including penalty element deductions and paid metal recoveries
(iii) process plant operating costs to mine planners for pit shells/cut-off grade determination and mining schedules, which are used in an iterative financial modelling process to determine the project scale
(iv) flowsheet and design criteria for the process plant that provides for process variability.

These outputs result from metallurgical test programmes, engineering cost studies and this paper provides guidelines for the study managers and project metallurgists at each study level:

(i) scoping
(ii) prefeasibility
(iii) feasibility
(iv) engineering.

Processing studies will usually interact closely with other studies contributing to an assessment of project feasibility, which include mineral resource, mining, infrastructure, environmental and marketing studies.

Scoping studies

A scoping study would typically commence following an exploration success to:

(i) define the range of process options
(ii) establish the project scale
(iii) provide first pass metallurgical recoveries and ore processing costs for resource cut-off grade estimates
(iv) provide first pass cost estimates for a preliminary evaluation of the prospect.

Expenditure on extensive sampling and metallurgical testwork is usually not justified at this stage. It could be limited to optical mineralogy followed by the minimum bench scale testwork necessary to establish indicative metallurgical parameters and would be based on an assumed flowsheet. Examples include an agitated cyanide leach or a roughing/cleaning flotation test at one or two grind sizes with a typical reagent regime. Limited comminution would be undertaken, which may include determination of approximate work indices using comparative methods.

Samples would typically be diamond drill hole quarter core covering identified major mineralisation types and should be selected in consultation with study geologists.

Projects and Technical Services, OZ Minerals Ltd, 31 Queen St., Melbourne, Vic. 3000, Australia

*Corresponding author, email whincup@optusnet.com.au

Published by Maney on behalf of the Institute and The AusIMM
Received 18 August 2008; accepted 1 September 2010
DOI 10.1179/037195510X12791826058217

For most projects a sample weight of between 5 and 10 kg for each mineralisation type should be sufficient.

Scoping study testwork would typically cost USD30 000 to USD50 000 including sample collection and freight.

Results of testwork would provide the basis on which to develop process options. For each option a strengths, weaknesses, opportunities and threats (SWOT) analysis is recommended as at a low level of cost certainty this may be the only way to differentiate between options. From these options a process route would be selected as the basis for the scoping study.

It is important to focus on selecting a processing rate or project scale at this time. It is surprising how often detailed studies are attempted without serious efforts to establish the project scale. It requires capital and operating estimates to be conducted over a range of treatment rates for the entire project including the mine, infrastructure and services. The 'base case' mining and treatment rate may be determined by:

(i) observing the best project net present value (NPV) return over the range examined although sometimes the numbers are too approximate and unless there is an obvious NPV difference or 'step change' this method may be unreliable

(ii) using a rule of thumb by assuming a mine life (no less than 5 years or greater than 10 years) and applying this to the expected mining inventory size. For example, the base case treatment rate of a potential base metal resource of ~80 Mt could be 8 Mt/year based on a 10 year project life. In this case a range of preliminary capital and processing cost estimates at say 4, 6, 8, 10 and 12 Mt/year would be conducted.

During the preliminary evaluation one also needs to consider the likely price cycle of the commodity. In the above example the life of the project would be expected to see production through at least one base metals 'low cycle'.

Unless capital data are available from a recent ore processing plant of the type and capacity envisaged, preliminary capital estimates will usually require some engineering and vendor pricing, which would typically cost USD50 000 to USD100 000.

Capital estimates would be based on:

(i) assumed flowsheet showing all major mechanical equipment and 'base case' major process flows

(ii) preliminary layout sketches

(iii) 'base case' mechanical equipment and electrical load lists

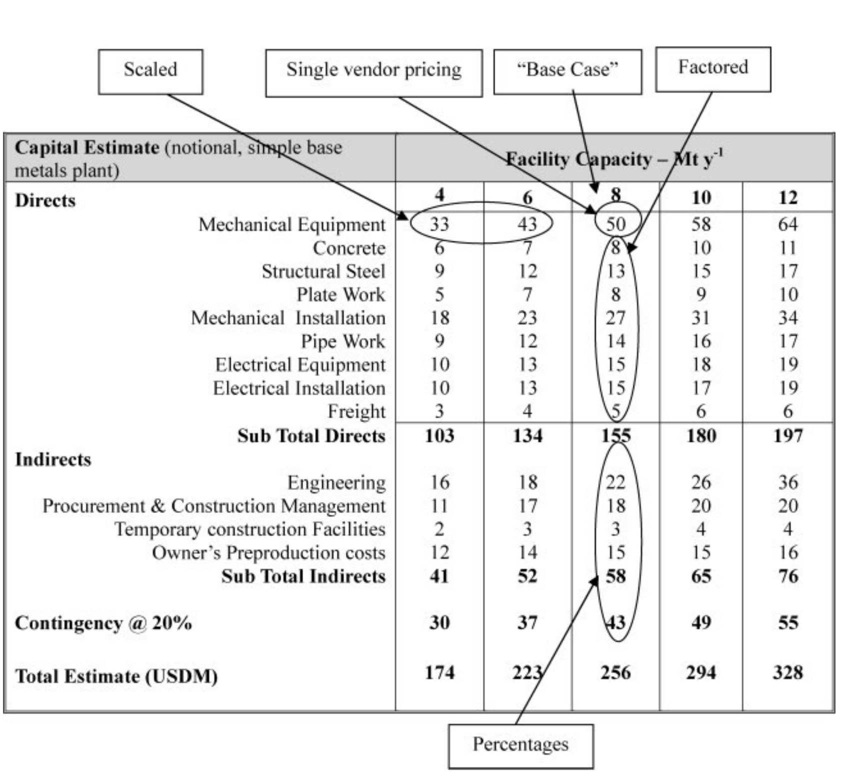
(iv) mechanical equipment pricing using recent pricing from other projects or single vendor budget pricing

(v) direct cost estimates for other commodities (e.g. steelwork, concrete and piping) factored from the estimated mechanical equipment cost and/or estimated installed electrical load. Most mineral process plant engineers will have in-house factors for determining these, for example percentages of the mechanical equipment cost or \$ kW^{-1} installed

(vi) indirect costs (e.g. engineering, procurement and project management) determined as percentages of the directs total

(vii) from the 'base case' capital estimate, estimates covering the range of treatment rates would be made by scaling 'base case' capital using for example the 6/10 rule: Capital 2=Capital 1 × (Rate 2/Rate 1)$^{0\cdot6}$

(viii) review of step changes in capital. These could be additional costs arising from issues such as additional process lines, change in water supply or electricity sources.



Capital Estimate (notional, simple base metals plant)	Facility Capacity – Mt y^{-1}				
Directs	**4**	**6**	**8**	**10**	**12**
Mechanical Equipment	33	43	50	58	64
Concrete	6	7	8	10	11
Structural Steel	9	12	13	15	17
Plate Work	5	7	8	9	10
Mechanical Installation	18	23	27	31	34
Pipe Work	9	12	14	16	17
Electrical Equipment	10	13	15	18	19
Electrical Installation	10	13	15	17	19
Freight	3	4	5	6	6
Sub Total Directs	**103**	**134**	**155**	**180**	**197**
Indirects					
Engineering	16	18	22	26	36
Procurement & Construction Management	11	17	18	20	20
Temporary construction Facilities	2	3	3	4	4
Owner's Preproduction costs	12	14	15	15	16
Sub Total Indirects	**41**	**52**	**58**	**65**	**76**
Contingency @ 20%	**30**	**37**	**43**	**49**	**55**
Total Estimate (USDM)	**174**	**223**	**256**	**294**	**328**

1 Scoping level comparative capital estimates (USDM)

Figure 1 shows an example of the capital estimating process for a large simple base metals mineral processing plant covering the required range of processing rates for the example described above.

In this example a contingency of 20% was allowed and represents the lower limit of the range of contingency allowances applicable to a properly conducted scoping study. At this and subsequent stages of the project an enthusiastic but inexperienced project proponent may be tempted to delete or reduce the contingency. This is an early warning sign that a project could be heading for cost overruns.

Bench marking at this level of study is valuable as a check but care needs to be taken that a comparative project and scope are being examined. Capital estimates using this methodology are considered to be accurate to no better than $\pm 30\%$.

Preliminary processing cost estimates for each treatment rate would be produced from either current cost data from similar operations or from first principles. The setting-up of a processing cost model that reflects fixed and variable cost components is recommended. Once established, the model can then be used over a range of processing rates and refined as the project develops.

Table 1 shows typical sources of scoping level processing cost estimates.

For projects where a concentrate would be produced for transport to a downstream processing facility realisation costs must be taken into account at the scoping study stage as they usually impact materially on project economics and resource cut-off grade. Realisation costs include concentrate transport, treatment and refining charges and can amount to 10–15% of the *in situ* ore value. Indicative transport costs can be obtained from specialist road transport and rail freight operators. Treatment and refining charges are available from commodities research groups.

It is recommended that at the scoping stage a risk and opportunity register be established and reviewed during each subsequent stage.

Time required for a scoping level processing study will be dependent on availability of data; however, for planning purposes a minimum of six months is recommended.

Prefeasibility studies

The prefeasibility study (PFS) has three functions:

(i) to evaluate all process options by establishing preliminary financials for each
(ii) selection of one or two options for more detailed cost analysis
(iii) refinement of capital and operating cost estimates, metallurgical recoveries and concentrate quality ranges for project financial modelling.

These objectives would be met by metallurgical testwork, and engineering and cost studies.

Testwork would be aimed at providing sufficient data on which to:

Table 1 Basis for preliminary ore processing cost estimates

Expense element (notional, simple base metals plant)	Basis
Operating and maintenance labour	Conceptual manning schedule. Total employment costs from recent industry remuneration surveys or similar operations. Employee related government charges can be sourced from government websites.
Grinding metal	Annual grinding mill relines cost from other similar projects or single vendor pricing. Annual crusher relines cost from other similar projects or single vendor pricing. Typical grinding media consumption and current pricing.
Consumables	Typical or preliminary test work consumptions and current pricing.
Maintenance materials and services	5% of direct capital cost. Allowance for lubricants.
Technical services (e.g. assays, metallurgical consultants, audits)	Allowances based on similar projects.
Services (e.g. freight, engineering, other consultants)	Allowances based on similar projects.
Energy	Preliminary electrical load list, diversified load or an allowance of 35 kWh t^{-1} of plant throughput. For grid power use available gazetted prices. For diesel generated power use current or recent comparable build-own-operate vendor pricing and the diesel price selected for the project. Allowances for other energy sources.
Water	Project unit cost based on a consumption of 1 kL t^{-1} treated.

(i) undertake comparative evaluations of process options
(ii) establish the key preliminary design criteria on which to base the engineering work needed to upgrade capital and processing cost estimates to prefeasibility level.

Testwork will typically also produce samples for tailing storage, environmental and marketing studies.

The source of sample material for prefeasibility testwork would be as for the scoping study testwork, i.e. drill core. However, a minimum total sample weight for each mineralisation type of ~50 kg would be required for bench scale concentration or extraction testing. An additional 80–100 kg of unbroken composite core sample material would be required for comminution testing. Residual sample and selected test products should be retained in storage until at least completion of plant performance testing or abandonment of the project.

It is strongly recommended that the detailed test programme be developed well in advance of sample selection, in consultation with the selected laboratory and with one or more specialist metallurgical consultants to reduce the risk of significant additional sample material and testwork being required at detailed feasibility or design stage to resolve flowsheet uncertainties.

The scope of comminution testwork on a composite sample or, depending on variability of the lithology, a number of individual samples of the major lithology types, should be sufficient to establish the comminution circuit. Testwork would usually include:

(i) unconfined compressive strength (UCS)
(ii) Bond crushing work index (CWI)
(iii) Bond rod mill work index (RWI)
(iv) Bond ball mill work index (BWI)
(v) abrasion index (AI).

SAG Mill Comminution Tests (SMC Tests) may not be required at this stage if there are other strong indicators that the mineralisation would or would not be suitable for SAG milling:[5]

(i) mineralisation is not from a very competent uniform zone or a fully oxidised clayey zone
(ii) UCS>180 MPa
(iii) BWI>20 kWh t^{-1}
(iv) RWI is not significantly higher than the BWI and both are not significantly >15 kWh t^{-1}.

Morrell[6] has provided guidelines for the number of comminution samples required using classical statistical analysis of comminution parameters starting with a minimum of 10 samples, respectively representative of each production year, if possible, as well as guidance on selection of tests, test equipment and modelling techniques.

It is advisable to have preliminary comminution parameters of potential ore types bench marked for SAG milling amenability using a specialist comminution consultant.

Initial prefeasibility leaching, flotation, gravity and other beneficiation testwork would focus on elimination of process options. For example, combinations of flotation, gravity and cyanide leach tests on a copper–gold ore would be aimed at resolving questions such as whether to include a gravity circuit for gold removal, merits of intensive cyanide leach on a gravity gold concentrate or cyanidation of an auriferous pyrite flotation concentrate. Comparative capital and processing costs may be required to identify preferred process options.

Bench scale batch tests will usually suffice but the number and complexity of tests required will be specific to the mineralogy of the prospect.

Following determination of a preferred process route some optimisation testwork should be undertaken, particularly to determine the grind/recovery relationship for major mineralisation types, and in the case of a concentrate, the grind/recovery/concentrate grade relationship.

A single locked cycle test and single test on reground middling for each major mineralisation type would usually be the limit of prefeasibility testwork.

Reagent optimisation would not normally be done at this stage unless reagent selection has potential to materially impact project viability.

The study metallurgist should consider engaging an independent third party to review the metallurgy and processing aspects of PFS and subsequent studies leading up to commitment to the project.

An allowance of at least USD70 000 to USD100 000 is recommended for prefeasibility level testwork for simple metallurgical processes. Complex processes such as those for refractory gold mineralisation treatment would need to be estimated on a case by case basis but a cost within a range of USD200 000 to USD500 000 would not be unexpected.

Engineering at prefeasibility level would usually be undertaken by an engineering consultancy experienced in the design type of the mineral processing facility anticipated. For most ores any one of over 20 internationally recognised engineers would be appropriate. Selection of the engineer would be based on considerations of cost, relevant experience, quality, availability of people and location.

Prefeasibility engineering would typically cover delivery of an engineering and cost study covering:

(i) key design criteria
(ii) preliminary flowsheets and piping and instrumentation diagrams (PIDs)
(iii) preliminary mass balance, including plant preliminary water balance
(iv) site selection and layout drawings
(v) a limited number of preliminary general arrangement (GA) drawings and plans and sections taking into account safety, operability and maintainability. It is not unusual to commence the development of 2D CAD and in some instances 3D models at this stage to provide GA and plan layouts with sufficient detail to allow preliminary materials takeoffs (MTOs) for cost estimating
(vi) preliminary mechanical and electrical equipment lists
(vii) preliminary electrical load list
(viii) preliminary MTOs and commodity pricing
(ix) capital cost estimate
(x) processing cost estimate
(xi) preliminary schedule including a capital disbursement schedule
(xii) study report.

Engineering design should take into account known environmental and regulatory constraints.

Capital estimates would be typically based on:

(i) mechanical and electrical equipment pricing using a single vendor quotation
(ii) structural steelwork, plate work, concrete, major piping and architectural MTOs and single vendor written quotation
(iii) factored costs for other commodities shown in Fig. 1, and including architectural. Use of factors for prefeasibility direct capital estimates assumes that the process plant is typical of those from which the engineer has derived the factors. If however, the process plant is known, for example, to have an unusual amount of pipe work or specialty pipe or plate work, then MTOs and pricing should be used for that commodity
(iv) owner's preproduction capital from preliminary quantities and current rates and should contain an allowance for spare parts based on a percentage of mechanical equipment capital
(v) estimated feasibility level metallurgical testwork and engineering costs
(vi) an assessment of working capital
(vii) other indirect costs as percentages of directs
(viii) a preliminary engineering and construction schedule.

It is recommended that during prefeasibility engineering a work breakdown structure (WBS) be developed for the entire project (including mining, infrastructure and indirect costs) and the estimating package set-up.

Capital estimates produced for a PFS should have an overall accuracy in the range from ± 20 to $\pm 25\%$.

The processing cost model developed at the scoping study stage would be updated and refined and include:
(i) a preliminary ore processing and production schedule
(ii) a revised manning schedule and current industry rates applicable to the location
(iii) estimates associated with onsite accommodation and rotational travel
(iv) consumable costs determined using rates from testwork and current vendor pricing
(v) maintenance materials as a percentage of the direct capital cost
(vi) allowances for services
(vii) electrical energy costs based on electrical load list and written vendor pricing
(viii) other energy from estimated consumption derived from preliminary equipment vendor data, engineering and current pricing, taking into account freight and storage for items such as diesel fuel oil and liquefied petroleum gas (LPG).

The processing cost model should be extended to cover preproduction capitalised processing costs and set up on a quarter by quarter basis for at least 4 years from project commitment and annually thereafter. The required time to commission the process plant needs to be considered at this stage to assist in assessing working capital requirements.

Realisation costs should be updated based on:
(i) product quality determined from metallurgical testwork
(ii) preliminary transport studies including vendor budget pricing
(iii) current or predicted industry treatment and refining costs, penalties, deductions and price participation arrangements. For smaller companies use of a mineral commodity marketing consultant is suggested.

At this point the financial and technical aspects of the project are reviewed and further testwork, options evaluation and value engineering may be required before committing to feasibility level studies. Corporate self-discipline may be required so as not to rush into a detailed feasibility study with significant technical issues unresolved.

A time of 8–12 months for the PFS could be assumed for study planning purposes.

Detailed feasibility studies

At this stage of the project there is a reasonable expectation that the project will proceed and metallurgical testwork and process plant engineering would be undertaken on this basis. Study results may form the basis for a project funding request.

During the process plant feasibility study all design level metallurgical testwork should be completed together with ~30% of the engineering.

In the current environment, it may be prudent to complete sufficient testwork and engineering to allow ordering of long delivery equipment (e.g. grinding mills) prior to project approval. On more than one occasion urgent additional comminution testwork and grinding mill specification work have been required after project commitment to allow the mills to be ordered to meet the committed project schedule.

Design level metallurgical testwork should be commenced early in the study and should be scoped in consultation with the proposed laboratories, a recognised comminution consultant and, if applicable, a metallurgical consultant specialising in the subject metallurgy and processing techniques, e.g. flotation.

Early in the feasibility study dedicated metallurgical samples should be taken. Sample locations should be selected in consultation with resource geologists and a consulting mineralogist. Samples should include dilution waste rock.

Morrell[7] has advised that while large diameter diamond core PQ (85 mm diameter) size samples may be taken, use of smaller diameter core, e.g. NQ (50 mm diameter) as comminution sample material is satisfactory. Generally few contemporary test procedures, in particular the drop weight test that forms the basis for the SMC Test, make any practical use of the information from larger rocks.

Sample weight for comminution testing would typically be 700–1000 kg for each lithological domain. Ideally the domain should be defined in terms of comminution properties, which may not necessarily coincide with the mineralogical domains.

The additional sample weight required for other design level testwork and variability testing is likely to be an additional 200–500 kg per geological/mineralogical domain if these domains are not the same as those identified by comminution properties.

Mineralogical investigations should be conducted on samples or specimens from each geological/mineralogical domain before finalisation of the test programme and include the following:
(i) mineralogical examination including multiple optical evaluations

(ii) mineral liberation analyser (MLA) or QemSCAN bulk modal analysis.

The following two stage approach to comminution testing is also suggested by Morrell.[6]

In the first, limited stage, sufficient samples are tested to carry out a statistical analysis, following which a more extensive programme is undertaken, based on results of the first. The wider the spread of results from the first stage, the more samples would be needed for the second. The first stage would typically involve four to five samples from each domain.

Comminution test requirements for samples from each domain are as for the comminution testing recommended for PFSs together with:

(i) Bond AI and UCS if not included in previous test programmes
(ii) JK Mineral Research Center (JKMRC) drop weight tests or the recently developed JK rotary breakage tests (JKRBT)
(iii) SMC Test
(iv) if geotechnical core is being point load tested then consideration could be given to having point load testing done on comminution test samples to provide a link between the two databases. Point load tests correlate quite well with the SMC Test results and hence the geotechnical data can provide a good indication of SAG mill competency variability.

The crushed products from the drop weight and SMC Test can be reused for the Bond mill work index work if sample quantity is a problem.

Pilot scale comminution testing is not generally required as comminution consultant databases are now sufficiently large to preclude the need for pilot scale testing; unless rarer circuits are being designed (e.g. single stage autogenous grinding milling or high pressure grinding rolls).

Other feasibility bench scale testwork is process specific but, for example, for a large copper–gold orebody for which treatment by flotation to produce a saleable concentrate is proposed, the testwork should include for each ore type as a minimum:

(i) roughing and cleaning batch tests to establish baseline flotation conditions
(ii) bench scale locked cycle tests to establish optimum grind sizes, flotation conditions and reagent regime leading to definition of a standard test flowsheet.

Variability testing for the recovery and throughput using the standard test flowsheets should be undertaken:

(i) by production year in which composites representing production periods are evaluated
(ii) characterisation of the deposit by testing a variety of samples representing the spatial distribution of each mineralogical and lithological zone within the deposit.

Pilot scale beneficiation testing needs to be considered. For simple mineralogy, and established unit processes, pilot scale testwork is usually not justified. Indicators of the need for pilot scale testing include unusually complex mineralogy and use of new or uncommon technology. Between a clear case for not including pilot scale testing and clear necessity lies a range of situations for which consideration would be given to time, cost and risk to arrive at a decision. As a general principle pilot scale testing hydrometallurgical processes must be considered as issues such as penalty element build-up and side reactions leading to scaling may not be apparent during bench scale testing.

Testwork samples should be made available to equipment vendors to enable equipment specification and pricing. These will include, for example, settling testwork for thickener sizing and viscosity testing for pump selection. Samples of testwork residues should be retained for testing by the tailing storage facility engineer.

The cost of feasibility level testwork will vary but the following may be taken as a general guide for a large orebody with three domains:

Mineralogy	USD100 000
Comminution	USD250 000
Bench scale testing	USD300 000 to USD400 000
Vendor testwork	USD50 000
Pilot scale testwork	USD250 000 to >USD1 000 000

These allowances exclude the cost of sample collection and freight.

Feasibility process plant engineering should be awarded to an appropriately qualified and experienced process plant engineer in a process where tenders are evaluated on:

(i) ability to meet the scope and deliverables
(ii) experience in the type of facilities proposed
(iii) price
(iv) acceptability to proposed financiers (usually decided at the prequalification stage)
(v) quality of the proposed study team
(vi) availability and timing
(vii) location.

The project metallurgist plays a role in the engineering and cost study by:

(i) timely provision of results of metallurgical testwork
(ii) providing input to the plant design operating and maintenance philosophies
(iii) making process related decisions
(iv) participating in Hazard and Operability (HAZOP) studies
(v) initiating value engineering, if required
(vi) sign-off of key process documents
(vii) provision of any necessary processing cost input data, e.g. manning schedule.

Engineering deliverables will include:

(i) detailed design criteria
(ii) detailed flowsheets
(iii) mass balances for both design and operating departures
(iv) life of mine ore treatment and production schedule by ore type
(v) PIDs
(vi) detailed site layout drawings showing site roads, hardstand, plant service buildings and services (consideration may need to be given at this stage of the project to provision for future expansion of the ore processing facilities)
(vii) GA and plan/section drawings taking into account safety, constructability, operability and maintainability. The applicable CAD 2D or 3D

model would be considerably refined and optimised from that commenced at prefeasibility level

(viii) mechanical and electrical equipment lists

(ix) electrical load list

(x) data sheets and specifications for any critical long delivery equipment (e.g. grinding mills and large transformers)

(xi) MTOs and written quotation pricing for all commodities

(xii) estimated construction hours and construction labour rates

(xiii) detailed capital cost estimate in the WBS format to an accuracy of no less than $\pm 15\%$

(xiv) processing cost estimate to an overall accuracy of no less than $\pm 15\%$

(xv) engineering, construction and commissioning plans and schedules including a quarter by quarter capital disbursement schedule

(xvi) plant and unit process performance guarantees

(xvii) study report.

The design criteria and mass balance should provide for a certain amount of variability however to accommodate short term variability may be unjustified from a capital perspective and this variability would be taken up in operations by stockpile management.

The process plant production and processing cost models should be refined and updated to include:

(i) ore processing and production schedule by ore type on a quarter by quarter basis for at least 2 years following commissioning and semiannually thereafter

(ii) metallurgical parameters determined from testwork (recoveries and product quality) for each ore type

(iii) realistic ramp-up factors (recovery, plant availability and product quality)

(iv) labour costs from feasibility study manning schedule and rates agreed with operations management

(v) consumables usage determined from metallurgical testwork results and process engineering (metal wear, power and reagent consumptions) and written vendor pricing

(vi) maintenance materials as a percentage of the feasibility capital

(vii) energy costs from feasibility engineering, electrical load list and written vendor pricing

(viii) services costs (e.g. laboratory, freight and consultants) from written vendor pricing.

During the feasibility study revision of the resource model may be required to take account of updated metallurgical parameters and processing costs.

Realisation costs should be updated based on:

(i) product quality determined from metallurgical testwork

(ii) detailed transport studies and vendor written pricing

(iii) negotiated offtake agreements with product purchasers (e.g. smelters).

The updated capital, processing and realisation cost estimates will be included in the project financial model. The project metallurgist should be proactive in reviewing the total model to ensure its completeness and accuracy from a processing perspective and to reduce the risk of items being omitted or double counted, particularly at the process plant/mine and process plant/infrastructure interfaces.

The feasibility study should include a project risk analysis of risks associated with the delivery and operation of the process plant.

For planning purposes a minimum of 12 months should be allowed for completion of processing facilities feasibility studies.

Engineering and construction

Engineering and construction is usually managed by an engineering and construction company under, for example an Engineering, Procurement and Construction Management (EPCM) contract, which may include commissioning in conjunction with the owner's operations team.

The quality of the preceding feasibility study notwithstanding the success of a project is very dependent on selection and management of, in this example, the EPCM contractor. Like the feasibility engineer the EPCM contractor must be selected on the ability to meet key performance criteria. A dedicated owner's team with experience in project delivery (as opposed to operations experience) would be formed to support and manage the EPCM contractor.

For the study metallurgist the engineering phase in the development of a project commences the transition from providing input to the final design and engineering of the process plant to preparation for commissioning and operations.

During detailed engineering the study metallurgist will assist with equipment selection, layout and process control and will review critical documents such as process design criteria, mass balance and flowsheets and recommend these for sign off for construction. Some additional metallurgical testwork may be required for which sample material from the preceding feasibility study testwork would be used.

During the engineering phase facilities required for process monitoring and control will be defined and there may be the temptation to include all the control systems that might be required. On the other hand, there will sometimes be pressure by others in the owner's team to remove control systems, including sampling systems as the capital cost increases, often without undertaking any value engineering. One approach to resolve the potential conflict is to include all facilities that are normally or typically included for the type of process plus any for which there is demonstrated short term economic value. In cases where uncertainty exists, allowances should be made in the estimate outside of the normal project contingencies for inclusion of these items post-commissioning and where economic benefit can be demonstrated.

At a point where $\sim 60\%$ of engineering has been completed, the estimate should be to an accuracy of no less than $\pm 10\%$, and becomes the control budget for construction.

Acknowledgements

This paper has been reproduced with the kind permission of the Australasian Institute for Mining and Metallurgy from Metallurgical Plant Design and

Operations Strategies (MetPlant) 2008, 18–19 August 2008, Perth, Western Australia. http://www.ausimm.com.au/metplant2008/.

References

1. M. E. White: 'Feasibility studies-scope and accuracy', in 'Mineral resource and ore reserve estimation – the AusIMM guide to good practice', (ed. A. C. Edwards), 412–434; 2001, Melbourne, AusIMM.
2. D. J. Noort and C. Adams: 'Effective mining project management systems', Proc. Int. Mine Management Conf., Melbourne, Australia, October 2006, AusIMM, 87–96.
3. N. Cusworth: 'Predevelopment expenditure', in 'Cost estimation handbook for the Australian Mining Industry', (ed. M. Noakes and T. Lanz), 252–259; 1993, Melbourne, AusIMM.
4. M. J. Warren: 'Pre-feasibility and feasibility studies: a case for improvements', Proc. Mining Industry Optimisation Conf., Sydney, Australia, June 1991, AusIMM, p 1–11.
5. AMMTEC Ltd: Technical feature: 'Comminution', available at: http://www.ammtec.com.au/public_panel/technical.php#comminution (originally accessed February 2008, last accessed 07 August 2010).
6. S. Morrell: 'Generating optimum value from ore characterisation programs in design and geometallurgical projects associated with comminution circuits', Proc. 10th Mill Operators Conf., Adelaide, South Australia, October 2009, AusIMM, 167–170.
7. S. Morrell: Personal communication, 2008.