The Bateman approach towards achieving economic and financial requirements for feasibility studies

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Synopsis

Bateman, like other engineering contractors, carries out or participates in many studies of potential projects in the Minerals Industry. This paper aims to explain the contracting approach to feasibility studies as practiced by Bateman, particularly where this differs from a traditional mining company approach.

A brief description is provided of the usual phases of a project and the types of estimate needed to proceed from one phase to the next. Possible organizational structures involving different forms of association between owner, contractor and consultants are then outlined.

The bulk of the paper then demonstrates that the cost estimates prepared stem directly from the mining plan, metallurgical process design and engineering design philosophy. The steps to be followed in order to prepare a credible estimate which accurately reflects the design constraints are described. The importance and the methodology of carrying out value engineering and of preparing contingency estimates based on a thorough risk analysis exercise are then discussed. Financial modelling techniques are described briefly.

The paper concludes with short summary case studies of two recent investigations of potential projects in Africa.

Introduction

The focus of this paper is on the contribution that we perceive can be made by an engineering contractor to a bankable feasibility study. This contribution is a consequence of the breadth of experience and comprehensive technical and cost data bases from many projects which all such contractors have. It is our opinion that the great variety of types of project and of owner approach to projects to which contractors are exposed enables them to offer a service which owners are often unable to provide themselves from within their organizations. Owner's project teams and new business investigation departments are often extremely motivated but usually have access to a relatively limited body of cost data. They can also lack sufficient experience if they are moving into a new technical field. Contractor study teams are therefore able to supplement the owner's detailed knowledge of his own project with a substantial body of supporting information from similar investigations.

This paper concentrates on the metallurgical plant and surface infrastructure since this represents Bateman's area of core expertise, and several other presenters at this colloquium have dealt with non-metallurgical aspects of feasibility studies.

Phased approach to projects

Different types of estimates and studies[1]

The American Association of Cost Engineers has adopted a widely used classification of cost estimates. The classes are:

- Order of magnitude, -30% to +50% accuracy range.
  Calculated from cost capacity curves and cost capacity ratios.
- Budget, -5% to +30% accuracy range.
  Calculated using flowsheets, layouts and equipment details.
- Definitive, -5% to +15% accuracy range.
  Calculated using defined engineering data, basic drawings and detailed sketches.
- Detailed, -2% to +10% accuracy range.
  Calculated from finalised engineering drawings, etc.

This classification is used quite commonly by mining companies and engineering contractors in southern Africa, except that the upper limits of the accuracy range for order of magnitude and budget estimates are usually reduced to +30% and +25% respectively.

Naturally the time and cost involved with the production of these estimates increases as greater accuracy is sought. Table I indicates the level of activities and deliverables generally considered to be necessary in each case[1,3,7].

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Table I

Activities and deliverables associated with the principal estimate types[1,3,7]

Item	Type 1	Type 2	Type 3	Type 4
Accuracy range	-30% to +30 –50%	-15% to +25 –30%	-5% to +15%	-2% to +10%
Deliverables required				
Location, topography and climate	Yes	Yes	Yes	Yes
Ownership and royalties	No	No	Yes	Yes
Current status and history	No	Maybe	Yes	Yes
Geological map and cross-sections	Map only	Yes	Yes	Yes
Drilling, sampling and assays	Limited	Preliminary	Yes	Yes
Mineral resource estimate	No	Preliminary	Yes	Yes
Ore reserve estimate	No	Preliminary	Yes	Yes
Mining method and plans	Conceptual	Preliminary	Yes	Yes
Hydrology/geotechnical investigations	No	Preliminary	Yes	Yes
Production schedule	Preliminary	Yes	Yes	Yes
Plant soil and foundation tests	No	Preliminary	Pre-liminary	Yes
Site visits	No	Desirable	Yes	Yes
Metallurgical testwork	No	Laboratory	Pilot scale	Pilot scale
Process flowsheets	Block flow	Preliminary	Final	Final
Process design parameters	Minimal	Preliminary	Final	Final
Equipment list	Minimal	Yes	Yes	Yes
Material balance	No	Yes	Yes	Yes
General arrangements	No	Preliminary mechanical	Pre-liminary	Yes
Specifications	No	Duty	Yes	Yes
Vendor quotations	Database	Single source	Multiple quotes	Orders
Civil work design and estimates	Factorized	Factorized	Rates and take-offs	Con-tract
Mechanical erection estimates	Factorized	Factorized	Multiple quotes	Tender
Structural design and estimates	Factorized	Factorized	Take-offs and rates	Con-tract
Piping and instrumen-tation estimates	Factorized	Factorized	Take-offs and rates	Take-offs and rates
Electrical work estimates	Factorized	Cost per kW	Take-offs and rates	Take-offs and rates
Indirect cost estimates	Factorized	Factorized	Calcu-lated	Calcu-lated
Operating labour cost estimates	Assumed	Calculated	Owner supplied	Owner supplied
Other operating cost estimates	Database	Calculation and database	Calcu-lation and quotes	Calcu-lation and quotes
Infrastructure list	No	Yes	Yes	Yes
Infrastructure cost estimates	Factorized	Area calcu-lation and database	Quotes	Tenders
Environmental permits	No	No	Maybe	Yes
Environmental impact assessment	No	Preliminary	Yes	Yes
Environmental compliance estimates	Factorized	Preliminary	Yes	Yes
Development schedule	Overall duration	Bar chart	Critical path network	Detailed
Value engineering and risk analysis	No	No	Yes	Yes
Financial analysis	Overview	Preliminary	Modelled	With financier input

However, care must be taken in referring to this Table. As a guideline it is extremely useful, but all studies are unique, and there is no doubt that the level of deliverables varies from estimate to estimate. The reasons for this are many and diverse. The major influences on the amount of work carried out for any particular study are usually related to the size and expected cost of the project, and to the degree of perceived risk associated with the proposed operation. Risk can be a consequence of the metallurgical process, location, tenure, constructability, operability, political or environmental factors or market influences as well as other parameters.

Stages of project development[1,3]

The order of magnitude conceptual study is a preliminary evaluation of a mining project. Some drilling and sampling must already have been undertaken to define a resource, but metallurgical definition is often based on little or no testwork. This type of study is useful as a tool to define subsequent study requirements. It is not valid for economic decision making unless the project is clearly not viable in even the most optimistic scenario of estimated costs, process efficiencies and product prices. Such a study can usually be carried out in less than two weeks following receipt of the resource data, and is normally prepared by the owner's team based on information in the public domain.

Budget estimates are normally associated with pre-feasibility studies. Several development options are usually considered at this stage, when the testwork, engineering and estimation costs of such investigations are still relatively insignificant. Economic evaluation is used to assess various development alternatives as well as overall project viability. Cost estimates and engineering parameters are not considered to be of sufficient accuracy for final decision making, but will normally be used to support any decision to proceed to the next stage of the investigation. The items which usually set the duration of this phase are drilling and testwork, but in most cases pre-feasibility studies can be completed in about three to four months including a short laboratory test programme. Although some owner's teams from larger mining companies often execute pre-feasibility studies without external assistance, engineering contractors are frequently invited to assist. At this stage, the contractor's input is particularly useful in the assessment of alternatives with which the owner's personnel are unfamiliar, as well as in the definition and quantification of appropriate cost factors for different types of metallurgical installation.

Feasibility studies incorporating definitive cost estimates are of sufficient detail and accuracy to be used as a tool to assist in making the decision to proceed with a project. Study reports represent an important package of documentation within a 'bankable document'. The accuracy of the cost estimate varies considerably depending on the owner's project funding plans, but the estimate is always supported by accurate reserve estimates, a logical mining plan, comprehensive testwork, well defined metallurgical plant and infrastructure, and cost estimates backed up by a well documented calculation and compilation process. Economic evaluation is based on annual cash flow calculations for the planned life of the operation. This type of study normally takes six to twelve months to complete. Engineering contractors are usually retained either to implement or audit the study.

Detailed or project control estimates are carried out by the engineering contractor during the first part of the engineering design for the project itself, and are then used to monitor and control expenditure for the remainder of the project. In order to reach the level of accuracy required, it is often necessary to complete as much as 60% of the total project engineering, so this type of estimate is rarely if ever carried out unless a decision to proceed with the project has already been made.

The feasibility study is the accepted project evaluation technique used to support a search for debt financing for a project, and makes up a significant portion of any bankable document. The remainder of this paper describes our company's typical approach to the preparation of studies and documents of this nature.

Organizational structure of study teams[7]

There are two generic structures for the preparation of bankable documents. These are illustrated in Figures 1 and 2, which also demonstrate the many essential portions of a bankable document. From our point of view, there are two fundamental differences between these structures. The first relates to the compilation of the overall summary document, development of a valid financial model, and responsibility for bankability. In the structure shown in Figure 1, the contractor co-ordinates the entire study, usually with limited assistance from a very small owner's team. Juniors as well as larger companies without the necessary project development track record often follow this approach.

In Figure 2, the structure illustrates the case where the owner's team carries the responsibility for all of these. This approach is commonly followed by mining houses with adequate resources of personnel with the necessary project experience.

The second major difference between the two structures is the approach to obtaining project funding. Over a period of many years, Bateman has established a network of close links internationally, firstly with companies interested in entering into joint ventures or other associations with the initial developers of new mining projects, and secondly with commercial banks and government backed institutions prepared to offer or support loan funding according to attractive project specific terms. The organizational structure in Figure 1 often leads to a situation whereby we begin work in the pre-feasibility or feasibility study for a project on a simple contractual basis, then gradually assume a greatly increased role in facilitating some or all of the project funding. In the absence of such support the projects would be unlikely to proceed to the implementation phase because of lack of funds.

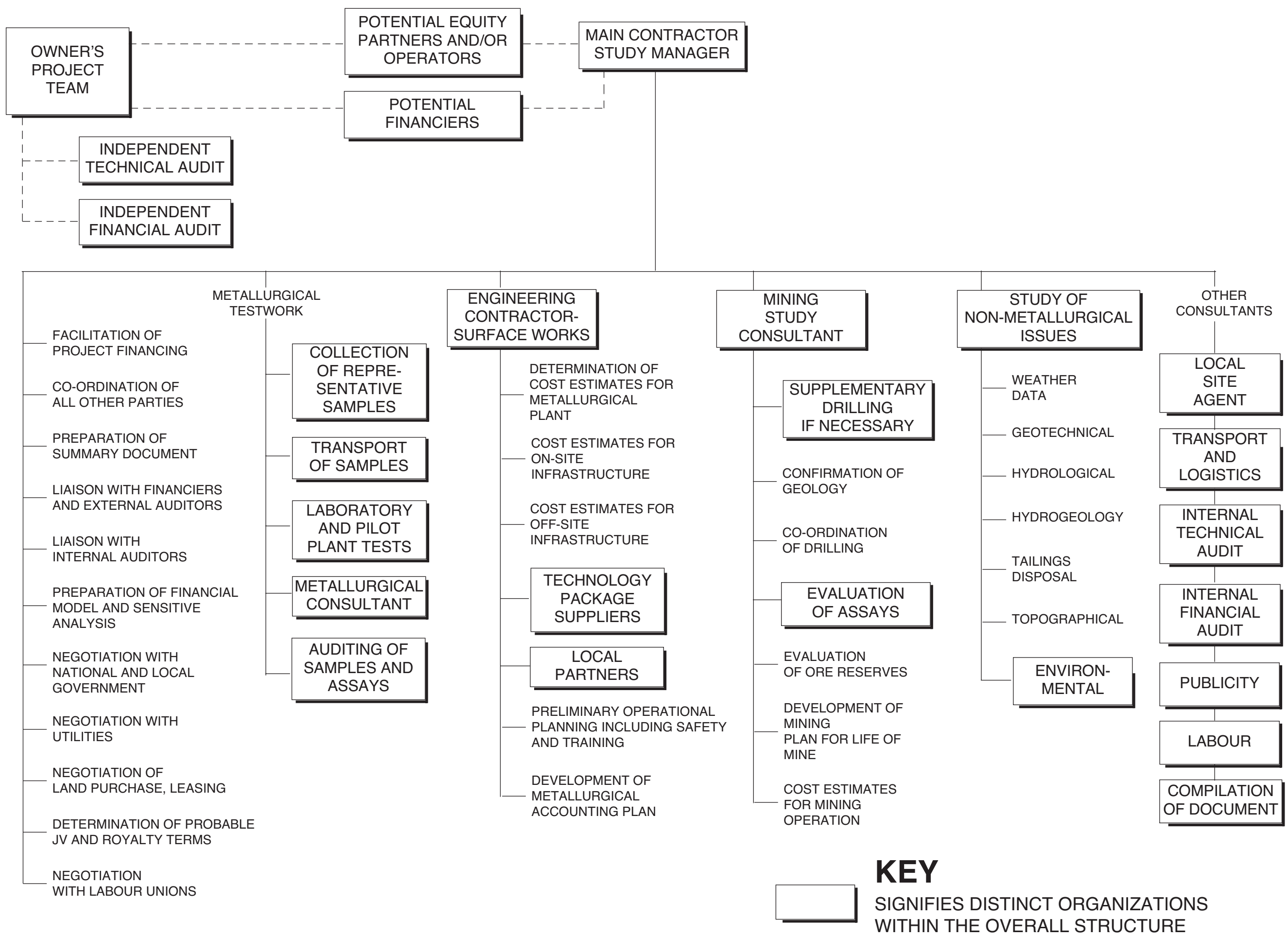

Figure 1. Study team structure: co-ordination by contractor

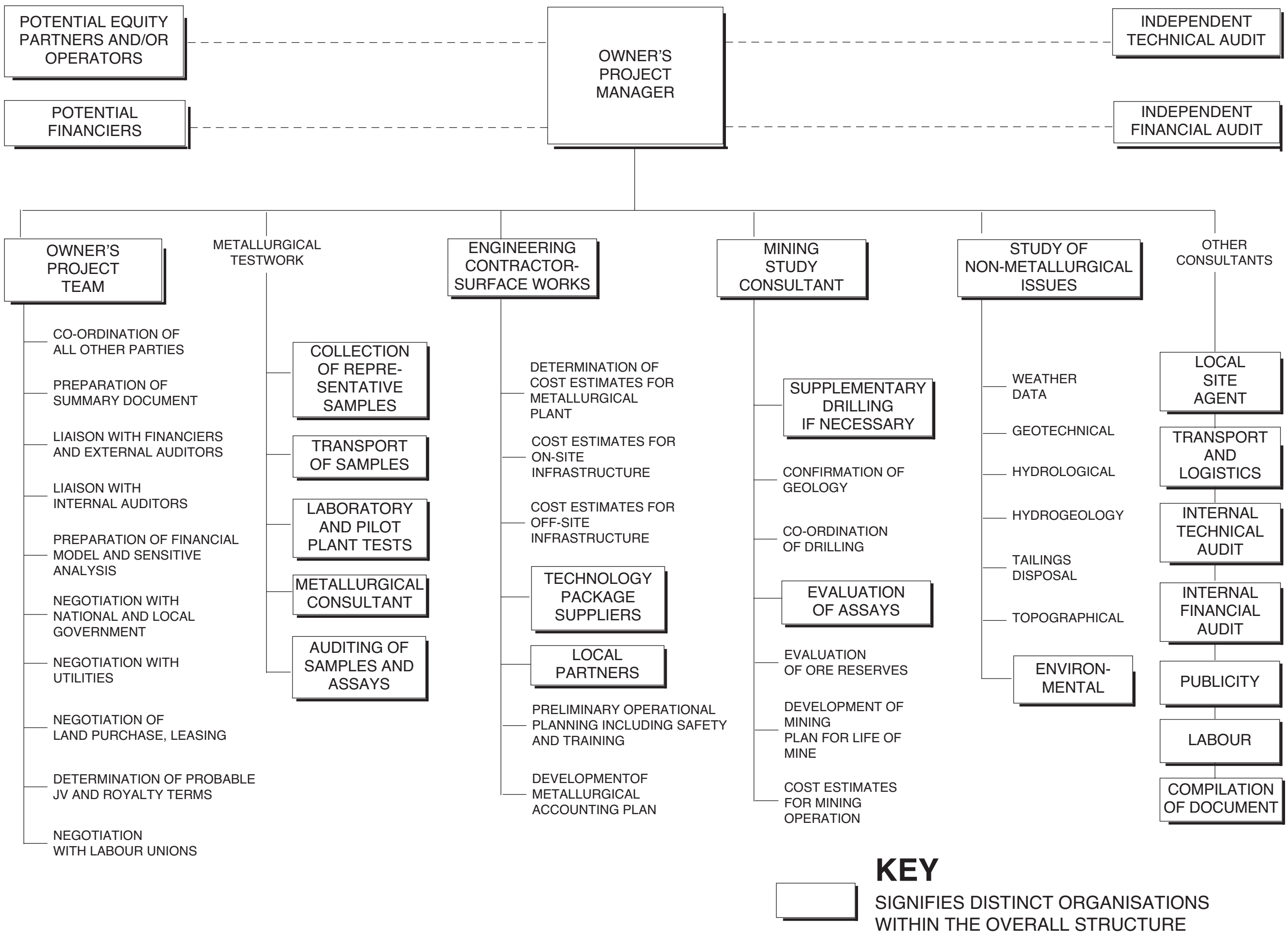

Figure 2. Study team structure: co-ordination by owners team

Requirements for bankability[6]

Mining companies in southern Africa have historically tended to finance projects on their own balance sheets, using corporate debt and equity. The deliverables of a feasibility study carried out to establish project viability and demonstrate an acceptable rate of return may be relatively simple and inexpensive. In some cases, depending on the company's general project development philosophy, cost estimates of no better accuracy range than ±20% may suffice. The reason for this is, presumably, that owners take a long-term view, recognizing that they can achieve very high returns over the whole life of projects even if there are initial cost overruns. Banks, on the other hand, lend funds which are repaid from project cash flows. Their recourse is limited to ensuring that the loan capital is repaid before any distribution of revenue is made to the owner's shareholders, and the potential for large profit margins is limited unless there is a high degree of risk associated with the project. Banks, therefore, have somewhat different and stricter criteria compared with mining companies to assess feasibility studies of potential projects, and are often perceived to be sceptical.

White[6] reported that there are eleven broad categories of information that must be addressed in any bankable feasibility study. These are project background and ownership, geology, ore reserves, reconciliation (e.g. provisions made for metallurgical accounting), mining, processing and metallurgy, infrastructure and support services, environmental baselines and permitting, development schedule, cost review and finally management and personal issues.

Non-metallurgical issues dealt with by third parties

This section is brief since many of these sub-sections of bankable studies are dealt with comprehensively in other papers being presented at this colloquium.

Bateman's core business is the design and construction of metallurgical and other surface plants. Studies are only carried out in support of this core business. Consequently, we do not retain the skills in-house to investigate all non-metallurgical aspects of a project. We prefer to associate with one or more companies specializing in such tasks to execute these facets of studies. The associations can be in the form of joint ventures or sub-contracts. Referring to Figure 1, either Bateman or one of the other companies could be the main contractor.

The main non-metallurgical issues to be dealt with by specialist companies are summarized briefly below[6,7].

Mining and geology

A company specializing in mine development is always required. Additional drilling of the ore reserves may be needed. The mining study consultant would select drilling methods, review drill hole data already in existence, appoint and monitor a drilling contractor, set up procedures for assuring validity of the sampling, arrange for analyses and review the assay procedure. This aspect of feasibility studies is extremely important because the drill core data are used to calculate ore reserves and develop a mine plan. Some countries now have statutory guidelines for the development of ore reserve models prior to stock exchange listing.

The mining consultant is normally responsible for the geological study, which may simply imply a review of work carried out at an earlier stage. An analysis of the regional and local geological setting is required. Geological maps and cross sections are presented, and the orebody is described with reference to the drill hole assay data. As full a description of ore and host rock mineralogy as possible is included. Ore reserves are reported. The modelling techniques and software used are explained, data analyses and statistics are compiled and reported, recovery and dilution factors are estimated, and an ore reserve calculation is presented using internationally accepted parameters for the various grades of reserve and resource.

Geotechnical and hydrogeological characteristics of the area to be mined are investigated. Several possible mining methods may be considered, particularly if both open pit and underground operations are envisaged. A single mining method is then normally recommended, and a mine development programme and production schedule are proposed. A full mine equipment list is prepared including shaft equipping, and capital and operating cost estimates are prepared. It is essential that the mine plan is prepared in close consultation with the metallurgical plant study contractor to ensure that the design basis is the same in both cases.

Site data

At remote sites, an aerial or ground-based topographical survey may be necessary. It is usually necessary to install a small station on site to establish rainfall, temperature and wind patterns. The site information is normally supported by long-term data from the nearest population centres. Frequency and severity of exceptional climatic events (e.g. hurricanes, volcanic action) are investigated, and the applicable seismic profile for the site is established.

Hydrology

The surface and ground water availability and flow patterns are determined. In order to select optimal plant, township, tailings dam, open pit, shaft and building sites, 50 and 100 year floodlines are normally superimposed on the topographical map. The effect of drawing water for the planned operations from boreholes or rivers on water tables and downstream users is investigated. At isolated sites, it may be necessary to consider the use of rivers to transport material to site and product from site. In this case, freezing in winter can become an issue.

Tailings disposal

The location of a tailings dam, method of transport and deposition, method of construction of boundary walls, water recovery strategy, cost of constructing and maintaining the dam, and vegetation establishment plans must all be considered.

Environmental investigations

In South Africa there is now a detailed statutory procedure to be followed in order to obtain environmental clearance for a project. If the intention is to proceed rapidly from feasibility study to implementation, then most of this work has to be done during the study. In this event, public consultation becomes very important and time consuming. Studies in flora and fauna, archeological investigations and socio-economic studies are some of the other items included in the environmental investigations. A closure plan and rehabilitation strategy are also required.

Geotechnical

It is essential to establish the applicable ground conditions wherever structures are planned, in order to set foundation parameters. This is very important since piling adds considerably to project costs.

In addition to the comprehensive investigations discussed above, some other small sub-studies are also usually required.

Local facilitation

It is frequently expedient and useful to appoint a local agent. As well as providing site office facilities, he assists with communication with local authorities, identifies local contractors and suppliers and facilitates import and export of equipment and material (e.g. samples) needed to complete the study.

Transport and logistics

A route survey is normally commissioned to establish load constraints of access roads, rail lines and harbours. This is a relatively simple exercise. However, at isolated sites it will probably also be necessary to investigate air and river access, and frequency and cost of transcontinental shipping. In all cases where borders must be crossed, documentation requirements, duration and cost of obtaining customs clearance and prioritizing clearance at congested points must be investigated. It cannot be overemphasised that delays at ports and border posts can place major pressure on the project schedule. Normally, several routes are assessed and a comparison with recommendations is produced.

Internal audits

Independent companies are appointed to audit the technical and commercial content of the study. Normally, banks will still insist on a further external audit.

Labour

It may be necessary to enlist the aid of a labour consultant to assess the cost and skill level and availability of both local and expatriate labour for the design, construction and operational phases of the project.

Compilation of document

This is a specialized task involving a production run of as many as several hundred copies of a small book in a glossy magazine format. This is the high level summary of the project, which is supported by a large number of study documents containing more detailed information, which are prepared by the various contractors and consultants involved in the study.

Infrastructure

Services and utilities

Usually, power and water supply and treatment are investigated with the assistance of parastatals or private utility companies. Often, the utility company will undertake the necessary work (e.g. a new power line or water pipeline with pump stations) within the project time frame and recover its investment in future charges to the operating company. Alternatively, it may be necessary for the project to finance the new investment. In this case, the utility company may prepare an estimate of the capital costs and take responsibility for implementing the works. A third possibility is that the main study contractor may prepare the estimate and a schedule for implementation within the main EPCM or LSTK contract. Database information from previous similar projects is used to support new quotations for supply and installation.

Construction power and water are often supplied using generator sets and boreholes. Some drilling for water may be required during the study, following which quotations are solicited for a small borehole-based water supply system.

At remote sites, communication links and access roads often need to be provided or at least upgraded. Utility companies and government departments may be approached as previously described, but it is sometimes necessary to include costs in the estimate for a satellite telephone link, and to make provision for a new all-weather access road capable of handling heavy loads.

Sewage disposal can only rarely be integrated with existing municipal facilities. It is, therefore, essential to make provision for sewage treatment plants both during construction and for the production facility itself.

Liquid plant effluents and even water runoff from within the plant area cannot usually be handled by domestic waste treatment facilities and must be impounded for recycle or evaporation. Provision must therefore be made in the estimate for lined ponds, the exact specification to depend on the quantity and chemical form of any potential groundwater contaminants present. Concentrated liquid plant effluents are to be avoided wherever possible. If present, it may be possible to have them removed by a specialist disposal company, or else a hazardous waste disposal pond will be required on site.

Solid domestic refuse can be transported to municipal dumps in many cases. At remote sites, or at those where existing municipality arrangements are only just adequate, it will be necessary to make provision for construction and operation of a new dump. Solid plant wastes which are chemically unstable or potentially hazardous or toxic are normally drummed for sale or disposal.

Environmental monitoring stations for dust and gas emissions may need to be set up around the operation. If so, estimates must be included for these.

On-site works and equipment

Estimates of capital and operating costs must be prepared for, *inter alia,* the following items : Fencing, removal and refurbishment of existing buildings, security checkpoints, roads within the project site, stormwater drains, area lighting, temporary construction stores yards and facilities, administration buildings, stores, ablution blocks, workshops equipped to service plant and mine equipment, MCC buildings and substations, refueling depots and vehicle washbays, vehicle weighbridge, plant and mine offices, clinic, and metallurgical/analytical laboratory. Our normal policy for studies is to establish the owner's general standards for infrastructure as well as the essential needs of the project (e.g. sealed roads are essential next to an electrowinning cell house to minimize dust ingress). We then establish the approximate size of the facilities and use drawings, takeoffs and quantity estimates from similar projects to compile enquiry documents. Current rates and prices for major equipment are then applied to build up the cost estimate.

The construction village represents a special case among site facilities. The village is usually located close to the site, and must be large enough for employees of all construction contractors, the construction management company and vendors supplying equipment. During a feasibility study an assessment is made of possible construction camp locations and of the number of workers requiring accommodation at any time during the construction phase. The number is built up by obtaining competitive quotes for the various erection contracts and supplementing this information with data from similar projects. An enquiry is then usually issued for the camp itself, including accommodation, recreational facilities, food, security and possibly basic medical facilities. Provision must be made in the estimate for temporary supply of services to the camp.

Off-site facilities

The principal item to be considered is housing. In some cases housing is not provided by the mine, but it often forms part of the scope of work of the project. In this event, land purchase, township proclamation, recreational provisions, house designs, township services (including schools, police station, post office, shops, clinic, roads, lighting, churches etc.) must all be investigated and included in the cost estimate. It is possible that such items as an airfield and guest houses may also be required. Having carried out similar investigations previously, we would normally expect to be able to define off-site infrastructure for any given project clearly and concisely. A combination of database information and competitive quotations would then be used to prepare the cost estimate for this area.

Other non-metallurgical issues

Preparation of financial model[2]

A model of the project must be established in order to determine the internal rate of return for the base case as well as to test the sensitivity of the calculation to changes in key input parameters and to compare different flowsheet, detail design or equipment options. Bateman has established a simple model which has been used successfully on a number of projects. Important input data include life of mine, predicted grade and recovery year by year, prices for all products, joint venture arrangements, taxation, loan fund repayment terms, capital expenditure by year, operating costs (variable and fixed portions), depreciation, taxation and discount rates. This enables a non-escalated project cash flow to be determined which in turn allows net present value and rate of return to be calculated.

Negotiations with national and local government

Some of the issues to be discussed during the study include mineral rights and tenure legislation, royalties, project tax benefits, infrastructural support, project finance benefits, expatriate labour legislation, local labour legislation and permission to export products. Many of these impact upon project costs or return on investment.

Land purchase

In some cases, it may be necessary to purchase land either at the operation or at the proposed housing location. The costs of this have to be assessed, taking demand inflation into account.

Determination of probable joint venture and royalty terms

In cases where there is a local owner of the deposit, or where local legislation requires part ownership or operation of the mine, then the costs and benefits of this arrangement must be determined. This is done by negotiation with the prospective partners concerned as well as by reference to similar projects in the same country.

Negotiations with labour unions and local companies

If possible, preliminary discussions should be held with unions to establish the likely level of support for the project as well as the potential for demand inflation. Local attitude towards expatriates, training and development, and safety should be assessed.

Where practical, it is usually politically expedient and financially prudent to utilize the services of local companies to develop a project. This can include using local suppliers of consumables (particularly items such as limestone), local agents and vendors of equipment, civil and building contractors, architectural and other consultants, erection contractors and local engineering companies. The forms of association can include subcontracts, joint ventures and partnership. The association may commence during the study, or the study estimate can include a provision for local company involvement during project implementation.

Parallel investigations

In former Soviet Union countries, it is necessary to produce a second study document, working in close conjunction with local design institutes, in order to obtain project approval. This document has to be produced in parallel with the conventional bankable document.

Metallurgical plant

Testwork [7]

Several different parties are involved in the testwork programme.

Collection of representative samples

It is of paramount importance that the samples on which testwork is carried out are representative of the orebody or of more than one ore type. It is therefore essential that the drilling pattern is sufficiently comprehensive, that the drilling and sample collection method is suitable, and that the samples are preserved against oxidation or other degradation during collection and transport to the test laboratory.

The mining study consultant is normally used to oversee this work.

Laboratory and pilot plant tests

The metallurgical laboratory used should itself have a 'bankable' reputation. In South Africa, Bateman often works with Mintek, and there are a number of laboratories world-wide with a suitable track record and capability.

The test programme is planned carefully with the owner's participation, sometimes supported by the main study contractor. It is necessary to be flexible as the tests develop because changes to the test programme often occur as a consequence of unexpected interim results. However, it is preferable that this flexibility does not extend to the duration of the test programme, and the study contractor is often employed to co-ordinate the testwork and minimize delays.

The preparation of the sample, including size reduction and blending, is extremely important. Thereafter, execution of the work according to set procedures with comprehensive reporting requirements, monitoring and appraisal of results and sampling techniques by an independent party, and analysis according to established techniques plus checking of analyses by an independent laboratory are all of great importance. The importance of testing materials handling and liquid/solid separation steps in addition to the metallurgical process also cannot be over-emphasised.

As well as discussing interim results with the owner's team and engineering contractor as they become available, the laboratory will produce a final report with recommended flowsheet, mass and water balance including key elements, and major process design criteria. This document forms the basis of the process design for the study.

Metallurgical consultants

In all fields of the metallurgical industry, there are consultants recognized internationally who have had exposure to projects implemented by several different contractors, or operated by different mining companies. By involving these consultants as advisors to the study team at the testwork stage, it is possible to introduce process design concepts which could otherwise be unknown to the project team. The use of recognized consultants also has the potential to improve the bankability of a project feasibility study document.

Basis of design and process engineering [7]

The core of all Bateman studies, particularly for projects with complex metallurgical flowsheets, is the preparation of a sound preliminary process design. This is based on interpretation of the testwork data (agreed with the owner) as well as on incorporation of as much relevant data from previous projects as possible. In our opinion, reliance on tried and tested unit processes lessens the risk associated with any new project. Of course, one has to take care not to interpolate data from other projects into an inapplicable situation. Provided caution is exercised in this respect, then this approach allows the process design for feasibility studies to be completed cheaply and with less need for testwork than would otherwise be the case. In some cases, process information is provided by a technology supplier, which can also decrease study costs and improve confidence levels.

The key process parameters are incorporated into a process design criteria summary which, accompanied by a process description, becomes the master document for the study. Mass and water balances and process flow diagrams (PFDs) are developed from the design criteria. Once again existing spreadsheets, mass balance models and PFDs are used as far possible. Metallurgical recoveries for the products are estimated at this time.

From the PFDs, an equipment list is developed using standard nomenclature and equipment coding system. Preliminary motor ratings are applied based on similar equipment from other projects. A standby equipment philosophy, plus provision for bypassing equipment, is prepared with the aid of the owner's team.

A materials investigation is undertaken taking into account corrosion and abrasion propensity of the solids, slurries, solutions, vapours, molten liquids, dust laden gases and other materials to be transported through the plant. Generally, a rapid assessment is made of the cost effectiveness of various technically acceptable materials of construction and suitable materials are specified for equipment, tanks, piping, structures, civils and corrosion protection and cable racking. The materials of construction are then shown on data sheets, PFDs and bills of material are reviewed again later in the study during normal design review, value engineering and risk analysis sessions as well as by informal review of the interim documents.

From the mass balance and equipment list, standard equipment sizing calculations are carried out based on the flow rates as well as on good engineering practice with respect to surge capacity. The equipment sizing information is then incorporated onto standard data sheets for each class of equipment item. Tank data sheets also incorporate information concerning nozzles, baffles and other internals. The data sheets are grouped by equipment type, and a general process duty sheet may be prepared to include in the mechanical specification which will be taken from our library of specifications and customized with minimal changes for the purposes of the specific project.

For minor items such as pumps, the data sheets will be based on very preliminary calculations because costs of these items do not vary greatly over a significant range of sizes. Similarly, all other data sheets will only contain sufficient information to obtain accurate prices. At the basic engineering stage of the project, additional information will be incorporated. After preparation of these preliminary data sheets the study mechanical engineer takes ownership of them for incorporation in enquiries.

The process engineer is responsible for preparing a narrative section of the study report which is split into two sections. The first portion of this narrative discusses the chemical reactions and the fundamental metallurgical process, while the second section describes the process flow with reference to each equipment item.

The services and utilities requirements (quantity, chemical quality, temperature, pressure etc.) for each section of the plant are quantified, together with reagent and consumables needs. Labour requirements for operation and maintenance of the plant are then determined as inputs to the operating cost estimate.

Piping and instrumentation diagrams (P & IDs) are prepared showing all equipment, piping and valves, and most field instruments plus major control loops. The remaining control loops are not shown, and these P & IDs are considered to be preliminary and pre-HAZOP. Bateman has a large library of typical P & IDs as well as typical valve arrangements or control instrumentation for particular equipment items. As much use as possible is made of information from other projects to develop the study P & IDs.

Engineering design philosophy[7]

From the basic process design, the other engineering disciplines develop preliminary design information which is sufficient to generate an accurate estimate, but is by no means complete or adequate for the purposes of final project procurement or construction.

The key tasks or deliverables of the various disciplines are listed below.

Project and document control set up is aimed at utilizing Bateman project control systems to a limited degree during the study phase, under the direct control of the Study Manager and without introducing extraneous personnel in the study team. The control systems established now are compatible with and can be expanded to allow full control of any consequent project.

Mechanical engineering input includes preparation of the technical portions of enquiry documents, approval and checking of material and piping takeoffs, preparation of specialized specifications for items such as high security access control systems, development of a vendor list, liaison with equipment vendors during the tender period, technical evaluation of tenders or budget quotations, review of layouts produced, participation in value engineering exercises, and checking of the mechanical portion of the estimate for completeness.

Drawing office work is limited to the minimum possible for estimating purposes. Consequently, many of the drawings produced are based on models from other projects, and is relatively lacking in detail compared with final engineering drawings from completed projects. Apart from PFDs and P & IDs, the main drawings produced are mechanical general arrangements with plans and elevations, which are then assembled into an overall plot plan with contours and topographical features. Major piping is normally sketched by hand onto the mechanical GAs and isometric sketches are then produced in order to generate a piping and valve list and takeoffs. Civil and structural work is normally limited to sketches by the engineer preparing the takeoffs. Electrical single line diagrams and MCC room sketches are produced, but it is unusual for instrument loop diagrams to be generated.

Civil and structural engineers prepare material takeoffs, compile the necessary specifications for enquiry (with particular emphasis on corrosion protection), may accompany contractors to site, and evaluate erection contract offers. The civil takeoffs will include provision for internal roads, drainage and storage ponds.

The study electrical engineer is responsible for consolidating the electrical drive list. Preliminary MCC designs and sizing are based on this. Single line diagrams are prepared based on the consumer list. General engineering specifications are compiled as well as project equipment specifications for large electrical items such as transformers. MTOs are prepared for electrical cabling and racking, and area lighting plus lighting requirements within buildings as well as small power needs are defined. The electrical engineer participates in liaison with suppliers and evaluation of quotations received.

The instrumentation engineer prepares field instrument schedules, checks instrumentation shown on the P & IDs, compiles I/O schedules, prepares instrumentation cabling and racking MTOs and draws up control system hardware, software and MIS specifications with project specific requirements. A preliminary process control philosophy is developed with the process engineers. Generally, cost database information is used to compile the field instrumentation estimate, but the cost information for particular instruments is checked regularly by obtaining updated quotes from local suppliers.

Estimating philosophy—capital and operating costs

Introduction[1,4]

There are two fundamentally different approaches to preparing cost estimates for plants to the level of accuracy required for bankable studies. The first approach is based on component cost ratios. A comprehensive equipment list is first produced. Equipment supply costs are then compiled from database information or by soliciting quotations. The next step requires that a current cost database of actual ratios from recent projects be available. Factors based on equipment supply are applied to determine estimated costs of everything associated with each equipment item. This includes equipment installation, piping material and labour, electrical material and labour, instrumentation, process buildings, auxiliary buildings, plant services, site improvements, field expenses and project management including engineering. This enables a total capital cost to be calculated.

The approach works well in industries such as oil and gas, chemicals or defense, where many plants of similar design are built. It also requires steady prices in a stable currency. Not surprisingly, in the minerals industry in which plant designs are frequently unique, and in Africa where currencies are continually weakening at an unpredictable rate against the dollar, it is difficult if not impossible to develop an adequate cost database to be able to use this estimating methodology, and Bateman has so far had little success in doing so.

The second approach requires development of preliminary engineering drawings and other documentation. Equipment quotations are solicited competitively, material takeoffs are prepared, and a direct field cost estimate is developed supported in its entirety by competitive bids. This approach is used by Bateman and is described in more detail, and follows.

Capital cost estimate[4,5,7]

A project-specific agreed supplier list is developed with the owner's team, and truncated commercial conditions are prepared. These ensure that the vendors are aware of any project constraints or unusual commercial requirements. They also contain a check list which ensures that complete bids including validity, delivery times, foreign currency exposure, spares costs, transport costs, erection supervision costs and exclusions are all dealt with in the responses.

Mechanical equipment enquiries are issued for virtually all items including tanks and conveyors. The quotations normally include motors at this stage of the project. Similar enquiries are also issued for major electrical equipment.

Mechanical equipment loads are quantified by item, and specialized erection problems for large items of equipment are identified. An enquiry for mechanical erection is then issued. Site visits and lengthy discussions with suppliers are usually required to obtain accurate bids.

Similar large enquiries are issued for piping supply, painting and erection, structural steel supply, painting and erection, civil construction and earthworks, corrosion protection of civils, electrical MCC, cable and rack installation and possibly for instrumentation installation. An important aspect of quotation evaluation is a comparison of the percentages of erection costs allowed for preliminary and general costs.

The on-site and off-site infrastructural items such as buildings, access roads, construction camp and so on are also specified fully and quotations are then obtained and evaluated.

Vendors are asked to include itemized provisions for transport, spares and vendor support (supervision of erection) in their quotations. This information is included in the equipment cost schedules. Where it is not forthcoming then equipment weight and bulk are applied to general transport rates also obtained by competitive quotations, and estimates of spares and vendor support are made based on experience. Costs of clearing customs and port handling costs must be included in the transport estimate.

The cost data discussed above are incorporated into a consolidated project cost estimate which we refer to as the direct field cost. This estimate is often split by process area into a number of supporting and subordinate cost summaries. First fill of reagents is added in by process calculation followed by application of the operating cost rates. This can be a significant figure if expensive solvents and reagents are required.

Indirect costs are now calculated and added into the estimate. These are costs for services or for intangibles which do not form part of the final installation. By far the largest of these figures is the main engineering contractor's cost estimate for engineering, procurement, construction management and project management, commonly known as the EPCM cost for the project. Our methodology for developing the EPCM cost involves defining the manhours by job category and by month through the project, based on a preliminary estimate of project duration which is partly based on the delivery periods or contract duration quoted as well as on experience from similar jobs. Manhour rates generally set to cover cost of employment plus company overheads are then applied to the manhours. Site allowance provisions are included, and sundry cost estimates (e.g. stationery, photocopies, CAD costs, telephone charges, flights, accommodation, site establishment, car hire) for the engineering design, construction and commissioning phases are added. A fee is normally shown separately.

The general procedures by which each discipline predicts manhour requirements is to consider the preliminary design development for the study, identify the activities needed to improve the design to 'issued for construction' stage, and apply standard durations from our records to those activities. All possible use is made of previous similar designs in order to improve EPCM efficiencies. If a local partner or technology supplier is involved, their costs are estimated by soliciting written quotations.

Other significant indirect costs which must be included in the overall estimate include technology supplier design packages, owner's team costs, project insurances, project consultant costs, mandatory third party inspection, operational start-up costs, pilot plants, cost of temporary construction facilities and government charges of any kind. These estimates will all be based upon written quotations or communications.

A foreign currency schedule and cash flow estimate are normally prepared based on the quotations and project schedule.

Working capital[1]

A generally accepted method of calculating working capital is to determine the sum of one month's cost of the following items: raw material supply at cost; materials-in-process value at cost; product value at cost; accounts receivable at selling price; available cash to meet expenses of wages, raw materials, utilities and supplies. Usually the owner's team prepares the working capital estimate and we have little experience of this in consequence.

Operating costs[1]

Within Bateman, the process engineers are normally given the task of generating the operating cost estimate. There are several different classes of cost to be captured.

Utilities

Costs of electricity, raw water and fuel are normally obtained by negotiation with the utility company. Quite often, the utility will pay the initial capital cost and then recover this over a period of time as an operational charge. If capital is the major constraint for the project, then oxygen can be treated similarly.

Compressed air, steam, vacuum and demineralized, cooling and potable water are usually generated on site. Labour, electricity, consumables and maintenance costs for these are usually calculated and incorporated under those headings rather than splitting out the cost of each individual utility.

Reagents and consumables

Consumption of chemical reagents is calculated from the mass balance and process reaction data. Faxed or letter quotations for the expected quantity per year delivered to site are solicited, and a total reagent cost is calculated. Exactly the same procedure is applied to determine the cost of non-chemical consumables such as grinding balls, for example.

Labour

A complete organizational structure is developed for the proposed operation, including production, maintenance and support staff. The owner's team has a major influence on this structure. Pay grades are determined and rates supplied by the owner are applied to calculate a total labour cost.

Maintenance

Annual cost of maintenance labour and supplies is generally estimated as a percentage of direct field or mechanical equipment costs. The percentage varies from plant to plant, depending on the process and the initial materials of construction.

Other

Laboratory, quality control, product shipping, safety equipment, royalties and licenses, insurance, land rental costs and similar costs are usually included in the operating cost estimate. Quotations or experience can be used to determine these estimates.

In addition to the above, some fixed operating costs are normally shown in the financial model. Amortization or depreciation of capital, and loan interest, could be examples of this type of cost.

Value engineering, risk analysis and contingency[7]

Value engineering

Almost inevitably, we find that preliminary studies and cost estimates overlook certain cost items or underestimate costs for other reasons. In the great majority of cases, the feasibility study capital and operating cost estimates therefore exceed the owner's expectations. If nothing is done early in the study to redress this, then a cost-cutting exercise is usually undertaken at the end of the study, often without full consideration being given to possible consequences. In any subsequent project, serious design problems and cost overruns can occur because of this.

In order to develop an accurate cost estimate for a fit for purpose design, we therefore follow certain procedures.

Firstly, general project engineering philosophies are set with the owner's team at the beginning of the project. Some examples could be: all equipment to be outside; entire plant to be in insulated and heated buildings: no standby pumps on solution lines; all stainless steel tanks; no stainless steel because of presence of chlorides; civil corrosion protection specification to vary according to traffic; World Bank environmental guidelines to be followed, and so on.

Secondly, a full review of process documents is carried out when the P & IDs have been generated. This reviews materials of construction, surge and design safety factors, adherence to general philosophy, and completeness.

Following preparation of the layouts, a further review is held to try and reduce cost while maintaining the best possible operability. Use of terrain and double-story plant may be utilized to reduce pumping, for example.

Before each material take-off and erection or installation enquiry is completed and issued, the engineering functional managers ensure that all calculations have been checked and supply the benefit of their experience.

The Study Leader reviews all tender evaluations. Where an item is much more expensive than anticipated, or is out of line with previous estimates, he may call for a design and costing review around this item.

On compilation of the estimate, a full arithmetical check is performed by the Chief Estimator, but in addition the discipline engineers who prepared the original input schedules for the enquiry document check their portions of the estimate for completeness and accuracy, and are invited to make further suggestions for cost reductions.

At the formal risk assessment and price fix sessions for the estimate, project management and procurement staff, functional engineering managers and the team responsible for the estimate carry out a review of the design and costing methodology. Even at this late stage some further improvements are often suggested.

In addition to the above internal reviews, process consultants, technology design packages and lump sum packages are also frequently used to add value to the estimate. Process consultants usually assist in developing a more elegant and cost effective process route based on testwork, but they can also provide useful input to material selection and process control. Technology design packages often include detailed equipment specifications and even bills of quantity, supported by experience from similarly constructed plants. The technology suppliers always review an estimate and may recommend further improvements. Lump sum packages for items such as an acid plant usually represent a significant portion of the estimate and carry a low risk because they are based on well-proven designs.

Risk analysis and contingency[5–7]

White[6] reported that Rothschild Denver's experience of sixteen projects where they had been the lead or sole bank was that capital cost deviation from study to project implementation ranged from 1% to 57% overrun. On a weighted average the overrun was nearly 30%. Some minor reasons identified were poor construction management cost estimation, failure to capitalize interest during construction, and over-optimistic estimation by the study compiler. The main reason, however, was changes in scope as the projects progressed. No project, even when designs are supposedly duplicated from a previous example, is ever built exactly as defined by the initial cost estimate. The estimate's range of accuracy can only be defined for the design case which exists at the time the study is produced. Contingency is not intended to be an allowance to cover the effect of future unknown changes. By definition, the effect of these is unpredictable and, estimates should be revised and if necessary re-evaluated whenever scope changes are made.

For the project as defined at the feasibility study stage, Bateman has a formal procedure to assist in setting the range of the estimate and to determine a supportable contingency figure. The first step of this is to convene a small estimate review meeting with the engineering functional managers. Each major component of the estimate (e.g. mechanical equipment, civil works) is considered qualitatively and significant risks are identified which have not been adequately addressed during the study. Each Functional Manager then makes his best estimate of a suitable provision to cover these risks based on knowledge of similar completed projects. These figures set the upper limit for each component of the estimate. The Functional Managers aided by the Chief Estimator then make a reasoned assessment of the lower limit, based on a realistic appraisal of possible savings within the defined scope as a consequence of better buying, improved design efficiency etc.

For a recent Bateman cost estimate, some of the most important input ranges were –20 + 10% for mechanical equipment, –5% + 20% for piping supply and erection, –10% + 15% for civil and structural, electrical and instrumentation, and –15 + 20% for EPCM costs. Ranges approaching these values are quite common and should enable provision of an overall –5 + 15% estimate, particularly if internal growth allowances for items such as piping and civils are incorporated in the base estimate rather than in the contingency.

A software package called @Risk is then utilized. Normally we split the estimate into two sections, supply and erection, and show a minimum, most likely, and maximum value for each component using the ranges referred to above. The @Risk analysis takes these six columns of figures, approximately 60–72 figures in all, and carries out a Monte Carlo simulation to model the final outcome of a project. To explore the full effect of the uncertainties surrounding each item, one thousand iterations are done. In each iteration, a random value is assigned for each line item. The random value lies between the lower and upper limits for each item and is derived from a pre-selected triangular distribution profile. The left-hand corner of the triangle represents the minimum value, the apex represents the most likely value, and the right hand corner is the maximum value. Random values are only selected within the 10% and 90% quartiles to eliminate extremes.

The Monte Carlo simulation then calculates a mean value for each item such that 50% of the area of the triangle lies to the left of that value and 50% to the right. To confuse matters, the sum of these values results in an 'expected' value for the project which always shows that there is greater than 50% chance of exceeding this figure.

The model is structured to imitate actual dependencies. For supply, mechanical equipment is chosen as the independent variable, and all other items are defined as dependent variables having a positive correlation with the mechanical equipment. Correlation factors are selected by the estimator in consultation with the engineers involved. Civil erection and EPCM costs are also correlated with mechanical supply, but all other erection costs are correlated directly and strongly to the supply cost for that component.

An output range and distribution curve for the estimate is now plotted. As well as the overall range for the project cost estimate of about –5 + 15%, this allows a contingency figure to be selected with 90 or 95% confidence. In other words, one can say with 100% probability that the maximum figure will not be exceeded, but this would require 15% contingency to be added to the expected figure. If some risk is acceptable, then only sufficient contingency is applied to ensure 90 or 95% certainty of a cost under-run. This reduces the contingency to 5 to 10% of the estimated value, which is normally considered to be an acceptable risk.

The estimated capital cost value plus the contingency represents the final value which is included in the study report. As noted earlier, this does not cater for future scope changes.

A similar procedure can be followed for operating costs although this is usually not done. Sensitivity analysis applied to the financial model will quickly identify if operating cost variations have a major effect on project viability.

Case studies

Two case studies are presented briefly. These illustrate the organizational structures shown in Figures 1 and 2. Each feasibility study had a total cost of R15-20 million, with total project capital estimated at more than US$300 million.

Case study 1—copper/cobalt tailings treatment project[7]

The studies for this project were carried out by Bateman on behalf of a Canadian junior in 1996/97. The reserve consists of several tailings dams which were generated over an extended period from flotation concentrator operations in the Democratic Republic of Congo. The state mining organization Gecamines is a partner in the proposed project, and their technical staff had considerable input to flowsheet development as well as during site visits.

Bateman was approached shortly after the Canadian owner became involved, and was requested to prepare some very preliminary financial analyses based on ore reserve tonnage and grade information and leach efficiencies provided by the owner. The preliminary indications were that further investigations would be fruitful, and a prefeasibility study was commissioned.

The owner appointed firstly, a geological/mining consultant, then later a metallurgical specialist and a part-time manager to set up the study and provide general co-ordination to the study team. This co-ordination was provided almost entirely from Canada, with some brief visits to site and to Johannesburg. The day to day co-ordination of the study was therefore delegated to Bateman. Referring to the earlier description of activities and deliverables of the studies, the only area which really fell outside Bateman's scope was discussions with potential project partners, financiers and purchasers of metal product.

Following initial review of metallurgical laboratory scale testwork and a site visit, a drilling, sample collection and analysis programme was initiated, and an independent auditor was appointed to ensure that representative samples and accurate analyses were generated. The contractor responsible for collecting the samples was also made responsible for transporting them to Johannesburg. While the samples were being produced, arrangements were made to appoint subordinate parties to assist Bateman. These included a contractor to investigate routes, transport costs and logistics of supply, a consultant to study dump reclamation, hydrology, geotechnics, environmental impact and tailings disposal, and a metallurgical test laboratory. In addition, Bateman did not feed comfortable at this time with estimating erection costs in DRC, so a subcontract was issued to a small engineering company with recent experience of working there. They produced a preliminary design basis taking into account local engineering practice for this type of plant, and advised during the preparation of the cost estimates by Bateman. The project included a very considerable infrastructure component which was investigated jointly.

The process included dump reclamation, leaching, copper solvent extraction and electrowinning, iron removal, tailings disposal, cobalt stream purification, cobalt solvent extraction and electrowinning, and provision of utilities and services. For each of these areas, the study team prepared a process and mechanical design as described earlier, then generated factorized estimates for most of the other components of the estimate. Given the prevailing metal prices and apparent stable political conditions, the project appeared very robust and work proceeded into feasibility study stage. Pilot plant testwork was commissioned to be used as the basis of design.

The pilot plant results were extremely promising, and work continued by Bateman and the mining/environmental/tailings consultant. As is common, the work for the study was carried out in several separate offices and co-ordinated by us, with electronic transfer of documentation. The feasibility study engineering and estimation proceeded exactly as discussed earlier. The owner commissioned independent technical auditors and participated in design reviews, but otherwise generally concentrated more on discussing the financial model with potential partners and financiers. Side studies of a number of different processing rates were carried out, and discussions were held with Gecamines to secure additional reserves. A draft feasibility study intended to meet the requirements of bankers and of the Toronto Stock Exchange was issued to the owner.

At this stage, the owner wished to fast track the project and basic engineering commenced in parallel with finalization of the feasibility study. Bateman assisted with negotiations concerning project-bridging finance. Unfortunately, the resurgent guerilla activity in DRC and the Asian economic crisis which severely affected product metal prices have made it impossible to obtain the full project funding and this project is now on hold in consequence.

Bateman was therefore involved from an early stage and played a leading role in this case in bringing the project to the implementation phase.

Case study 2—zinc mine and recovery project

This project in southern Africa involves treatment of a high-grade orebody which was first identified over 20 years ago. The original owner reached an agreement about three years ago with a small UK-based mining company ('the operator') to carry out a feasibility study of the project in order to secure a controlling share. The operator had a prefeasibility study done in 1997 by a small engineering contractor then issued a contract to Bateman for assistance in preparation of a comprehensive feasibility study. In this instance, the approach was that illustrated in Figure 2. The operator appointed a multi-disciplinary team of engineers which was resident in Bateman's office throughout the study. This team retained responsibility for overall co-ordination of the various parties involved, participated in design and estimating decisions, maintained the primary or, in some cases, sole communication role in discussions with government and parastatal utilities companies, and was entirely responsible for preparing a financial model and a summary glossy document describing the project to potential investors. They also handled all direct communication with their Head Office in London, appointed independent consultants to audit the work, and were responsible for liaison with the joint venture partner.

The operator developed a technology supply agreement with two companies during the prefeasibility study. For the feasibility exercise, the companies were appointed to carry out pilot plant testwork encompassing leaching, iron removal, zinc solvent extraction and solution purification, and zinc electrowinning. They then generated test reports and preliminary engineering packages on which the Bateman estimate was based. The operator, the operator's internal process consultant, Bateman study personnel and a Bateman consultant with zinc processing experience, plus the technical auditor's process specialist and a process consultant from the joint venture partner all participated in the testwork implementation and interpretation.

The engineering contractor responsible for the prefeasibility study was appointed to produce a total estimate and design package for the ore receiving and milling section of the plant, including testwork. Similar subcontracts were issued for a geotechnical investigation and a tailings dam cost estimate: An acid plant cost estimate was produced to a similar level of accuracy by three potential suppliers.

The mining study was commissioned independently by the operator, but close liaison with Bateman was exercised in order to ensure that the correct basis for the plant design was selected. The environmental study was handled in the same fashion.

The report produced by Bateman in this case was therefore limited to narratives and cost estimates for the whole metallurgical plant plus the on-site and off-site infrastructure. The operator provided considerable assistance, direction and advice throughout this work, and an enhanced product was certainly generated in consequence.

Conclusions

This paper has attempted to illustrate the approach used for a bankable feasibility study by an engineering contractor, and particularly where it differs from the traditional mining company investigation. From our point of view, the most successful studies are those in which a dedicated owner's team participates in an integrated team with the contractor. This can be achieved in either of the study team structures described, and we have no particular preference between the two. Whichever is adopted, we strongly advise trying to combine the experience, the information databases and the methodology of owner and contractor to enhance the quality of product of feasibility studies of this nature.

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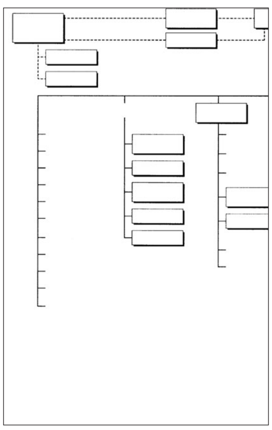

Professor Anthony Kelly

The 2000 Acta Metallurgica Gold Medal has been awarded to Professor Anthony Kelly of England. The Medal is an international award, established in 1974 to recognize outstanding ability and leadership in materials research. Professor Kelly's lifetime scientific interest has been the science of materials, in particular the strength of solid materials. He is internationally known for his pioneering work in the field of advanced composite materials, but his interests extend to crystalline solids generally and the relations between defects and mechanical properties. ◆

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