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cost estimation

Scoping Studies

The cost estimates for scoping studies are usually derived from rules of thumb, comparison with similar projects and some estimation from first principles. This approach can be surprisingly accurate when compared with subsequent estimates. However there is a risk that a significant factor pertaining to the proposed operation will be misunderstood or ignored causing a substantial error in one or more of the estimate components. Examples of some rules of thumb are presented below.

The "Six-Tenths Rule"

To use the six-tenths rule, a capital or operating cost for a similar operation of known capacity must be available. In such cases...

$$(Cost1/Cost2) = (capacity1/capacity2)^{0.6}$$

For example, a 30,000 TPD concentrator cost $\$60x10^{6}$. The cost of a similar 40,000 TPD plant is;

$$Cost1 = 60 \times 10^{6} \times (40{,}000/30{,}000)\ 0.6 = \$71.3 \times 10^{6}$$

To update the cost for inflation, a current cost index must then be employed. The exponent, 6/10, is an average and in fact depends on the type of plant. Some estimators prefer to use a "7/10" rule. Such factors as type of site, economic conditions prevalent, geographic location and regional productivity are responsible for substantial variation. It is also possible to apply the method to components of operating cost. The relevant exponents are set out below (Mular, 1982):

Estimate Required	Capacity	Exponent
Open Pit Mine Labour Costs	tpd(mined)	0.5
Open Pit Mine Supplies	tpd(mined)	0.5
Underground Mine Labour	tpd(mined)	0.7
Underground Mine Supplies	tpd(mined)	0.9
Treatment Plant labour	tpd(treated)	0.5
Treatment Plant Supplies	tpd(treated)	0.7
Open Pit(mine & mill)Electric Power	tpd(treated)	0.5
Underground (shaft mine & mill)Electric Power	tpd(treated)	0.7

Note that for operating costs the rule is applied to the annual total cost, not to the unit cost per tonne. If applied to unit costs it makes smaller operations cheaper! (The procedure can be applied directly to unit costs, however, if new exponents are calculated by subtracting 1 from the exponents listed above).

Equipment Cost based on Weight

This method works for most equipment. It is described here for underground equipment. It assumes that the cost of fabricated machinery is proportional to its dry weight. This works well for mobile equipment, but a cost premium is added for the sophisticated hydraulics in a drilling machine. Factors in 1994 were:

- Mobile Units:$20/kg
- Drill Units: $270,000 + $20/kg

Ideally, all estimates would be within 20% of actual costs.

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Prefeasibility Studies

As much direct estimation as possible should be done to maximise the reliability. In practise time and resources limit the amount of work done and reliance must be placed on factoring costs. The study accuracy is unlikely to exceed plus or minus 20%. This is usually sufficient to establish confidence in expending the cost of a final feasibility study or underground exploration.

The recently published Cost Estimation Handbook for the Australian Mining Industry (Noakes and Lanz 1993) provides guidelines for cost estimation at a prefeasibility level of accuracy. That publication is an invaluable reference for people involved in feasibility study work. It must be emphasised however that it is no substitute for experience and for detailed estimation, particularly as the prefeasibility study advances towards a final feasibility study.

The necessary detail depends on the extent to which items may be sub-contracted out. For example mine preproduction stripping could be let as a contract and in that case several indicative prices from contractors may be accepted as a sufficient estimate. This reduces the need for detailed equipment selection, manpower estimates etc. For an underground mine typical equipment requirements would include, for example;

- pump station
- workshop equipment
- power distribution
- loaders
- trucks
- 4-wheel drives
- graders
- forklifts
- ventilation fans
- blasting equipment
- rock drills
- pumps
- ANFO loaders
- crib room equipment
- mobile toilets
- safety equipment and mine rescue equipment.

Included in the capital cost estimates will be decline or shaft development, vent raises, levels and advance development at least 6 months ahead of production and a mill stockpile of ore.

There is an increasing trend for both pre-production and production mining cost estimates to be based on contractor's indicative prices. This is true for open pit and increasingly for underground mines. An experienced consultant will have access to a database of recent and current contracts to cross-check these estimates. For larger and international projects, it is essential that "first principles" estimating be applied rather than relying on contractor's estimating skills. Free advice is worth what you pay for it. For owner-mining, "first principles" estimating is essential.

After determining fleet requirements the cost of drill rigs, loaders, trucks, excavators etc. would be estimated from recent feasibility study quotations or purchases, adjusted for exchange rates and inflation.

Unit rates or estimated unit costs would be applied to site clearing, grubbing, topsoil removal and stockpiling, preparation of stockpile pads, haulroads etc.

The process plant costs would be estimated from a combination of equipment factoring and "takeoff" based costs. ("Takeoff" indicates quantities etc. which have been "taken off" plans by simple measurement or counting.) A general site plan would be prepared, along with a flowsheet, equipment list and process plant general arrangement drawings. Piping and electrical costs would be factored from delivered and installed equipment costs as detailed in Noakes and Lanz (1993).

Buildings including stores, administration, changehouses, laboratories etc. would be estimated per square metre of floor area, with special items such as laboratory equipment, computers etc. separately listed and factor costed.

Preliminary designs or at least floor plans are required. More detailed designs may be required for very site-specific items such as concentrate handling and shipping facilities and water supply dams or borefields. Earthmoving volumes should be estimated. Some package items such as diesel power stations may be factored directly from other projects despite their underlying complexity.

Camp costs may be estimated per person, with pro rata allowance for messing and common facilities.

Indirect costs are often underestimated. They include:

- engineering
- general site costs
- procurement
- construction management
- administration
- working capital
- insurance

For a prefeasibility study the indirects may be estimated as a percentage of estimated capital cost, with allowances for specific project location and complexity. Working capital is typically 10 weeks of operating costs plus the cost of the spare parts inventory. Factors affecting working capital are described in detail under "Working Capital", and it may be worthwhile to consider these briefly at prefeasibility level to confirm the suitability of the 10 weeks figure.

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Final Feasibility Studies

For each activity or process, complete equipment lists must be prepared as a basis for estimation. General arrangement drawings then show how these components are related with connecting services and enclosures. From the lists and drawings, material takeoffs allow estimation to a 10% to 15% accuracy.

It is usual to specify the type and capacity of each major piece of equipment and to obtain written quotations from two or three suppliers. Preferably the final selection of a particular supplier is not made in the feasibility study although this may be necessary for proprietary metallurgical processes. Tenders may also be called for major earthworks and mining as part of the feasibility study, but only if "fast track" development is anticipated and the tender can be awarded within the currency of bids.

Major civil works such as access roads, hydro dams and tailings dams may require detailed site investigations and design before indicative prices or bids are obtained.

Detailed drawings and equipment specifications would be used to obtain quotations for process plant components. Material takeoffs would be used for steel structures, earthworks, concrete and cladding. Pipe and electrical layouts would be used to estimate costs on a unit length basis, with allowance for fittings, valves etc.

For some buildings such as accommodation and office units, costs per square metre or per person may be acceptable based on floor and layout plans.

Indirect costs should be separately estimated wherever possible. These include:

Engineering: The cost of engineering can be estimated from a drawing list, specification list, estimate of workhours by discipline, and allowances for disbursements and consumables. Estimates should include travel, accommodation and site allowances.

Procurement: Costs include land transport by the supplier, shipping, land transport to site, import duties, nett value-added taxes in some countries and the cost of inspection visits to suppliers.

Construction Management: Manpower requirements can be estimated from the construction schedule. Consultants and vendor's engineers costs should be included. The capital and operating costs of camp accommodation, commutes and bonuses should be included.

Administration: This may also include Owner's Costs as discussed under "Owner's Costs". It includes owner's staff seconded to the project and any administration or management fees that will be charged against the project.

Working Capital: A properly prepared estimate of working capital is required as discussed in "Working Capital".

Start-up costs may extend into the early production period. These should be carefully considered, including an allowance for the learning curve as discussed in "Learning Curve".

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Cost Codes

A cost code structure is essential to bring together the various parts of the estimate and as a checklist to ensure that major items have not been forgotten.

The cost code should permit identification of the physical area and the type of work within that area. Scott (1993) gives the following example:

Code Area:

2XX Mining
1XX Site Development
3XX Milling
4XX Tailings/Reclaim
5XX Utilities
6XX Ancillary Facilities
7XX Indirects

Within 3XX, Milling, a further breakdown could be as follows:
31X Crushing/Stockpiling
32X Grinding
33X Flotation
34X Thickening/Filtration
35X Concentrate Handling 38X Reagents
39X Structures

The second subdivision of the cost code for plant construction might be:

Code Description:

1YY Civil
2YY Concrete
3YY Structural Steel and Platework
4YY Architectural
5YY Mechanical
6YY Piping
7YY Electrical
8YY Instrumentation
9YY Indirects

Additional numbers can be included as required. For example, the concrete foundation for the number 2 grinding mill might be coded as 320 - 210 - 02. Pipework for the third bank of cleaner flotation cells might be 333-620-03.

The cost code within each area must be adapted to suit the activities. Another example of the breakdown within Area 200 (Mining) for a large open pit is set out below.

a) Capital cost codes will be 200, where;

1st Digit (2) designated mine capital
2nd Digit (1-6) designated equipment type

b) Operating cost codes will be 0200, where

1st Digit (0) designated operating cost
2nd Digit (2) designated mine
3rd Digit (0-9) designated equipment/event type
4th Digit (1-4) designated operating/maintenance/parts/labour

c) 3rd Digit designations.

(021) , 1, Blasthole drilling, BE45R IR DM 25th
(022), 2, Blasting
(023), 3, Loading, Demag 185, Cat 992C
(024), 4, Hauling, Cat 785
(025), 5, Auxiliaries, Dozers, grader, lighting plant, heavy service vehicles, dewatering
(026), 6, Staff - Salaries
(027) 7, Engineering, Operating supplies & training, maintain supplies, mine engineering, construction.
(028)8, Vacation/Sickness/Absenteeism

d) 4th Digit designations.

(0231) 1 Operating labour (distributed)
(0232) 2 Operating "consumables" (fuel, tyres, ground engaging tools, drillstring)
(0233) 3 Maintenance labour (distributed).
(0234) 4 Maintenance "parts" (oil, filters, pm, repairs, component exchange).

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The Learning Curve

Refer Fatseas and Vagg, 1982.

In any new task that is repeated, people experience a learning effect. The first time a new task is performed one is unfamiliar with it. The second time it is performed, with the benefit of experience, it is usually performed better and in a shorter time. Over repeated performances one becomes more skilled and usually shortens the time taken, at least up to a point. The reason that the time taken decreases is that there is a learning experience occurring. Obviously the majority of the benefit from learning occurs over the first few performances, but there does tend to be a continual slight improvement over time.

This phenomenon is described as the learning curve, because if the average time taken to manufacture new products is plotted against cumulative units of production, the points plotted form a curve. The learning curve has been noted in many industries, the most notable being airframe manufacturing. Formally, the learning curve proposition is: Each time the quantity of production is doubled, the cumulative average unit time will be some constant percentage of the previous cumulative average time. An 80% learning curve is common, meaning that each time production quantity is doubled the cumulative average unit time is 80% of the previous average. The following tabulation illustrates an 80% learning curve:

Units of Output	Add. hrs	Cumulative hrs	Cumulative Av.hrs/unit
1	100	100	100
2	60	160	80
4	96	256	64
8	153.6	409.6	51.2

The first unit required 100 hours to produce. When the output was doubled (that is, a second unit was produced), the second unit required 60 hours, giving a total of 160 hours for the two units, or a cumulative average of 160/2 = 80 hours per unit. The new cumulative average is exactly 80% of the previous 100 hours per unit average.

When output is doubled to 4 units (i.e., another 2 units are produced) the additional 2 units required 96 hours for a total of 256 hours for the 4 units; this gives a cumulative average of 256/4 = 64 hours per unit, which is 80% of the previous cumulative average of 80 hours per unit. Similarly, when output is doubled to 8 units (another 4 units are produced) the cumulative average is 51.2 hours per unit, which is 80% of the previous 64 hours cumulative average per unit.

One can observe that the doubling of progressively larger output quantities to give the 80% reduction in cumulative average hours per unit means that the curve of cumulative average hours per unit will quickly flatten out, indicating progressively smaller gains from learning, as expected.

Mathematically, the learning curve can be expressed as the exponential equation...

> $y = axI$
> where y = cumulative average hours per unit
> a = number of hours for the first unit
> x = cumulative number of units
> I = an index of learning equal to the log of the learning rate divided by log 2.

If a learning curve is plotted on log-log graph paper it appears as a straight line, and is often easier to use in this way. This can be seen by taking logarithms of both sides of the equation, $\log y = \log a + I \log x$ to give a linear equation.

The theoretical limits of the learning curve are a 100% learning curve, meaning no learning at all, and 50% where no time is taken for the additional doubled output (1st unit 100 hr, av = 100; 2 units for a total time of 100 hr, or a cumulative average of 50 hr). In practice, learning curves are usually between 70% and 80%.

It should be fairly obvious that when making cost predictions attention should be directed to which part of the learning curve the project is on. For new projects there will be a large learning factor over the first few weeks and months. However, the learning process continues as theory suggests and minor progressive gains can be perceived for at least the first two years.

The effect of the learning curve is often ignored or underestimated in feasibility studies, leading to over-optimistic production schedules and budgets for the first 6-12 months of production.

The learning index is different for different parts of the project. It may be 70%, for example, where an experienced contract crew does overburden stripping. It is close to 50% for the startup of underground mining with an untrained crew. Examples which conform to the theoretical curve are the advance rates in a new decline or shaft with an inexperienced crew.

A non refractory open cut gold operation with simple metallurgy will achieve processing proficiency quickly but it may take longer to optimise the grade control methods. A multi metal base metal underground operation will take considerably longer to achieve full proficiency. It can take as long as 6 months to optimise the process and the probability is that the underground operators may take two years to reach their potential. The process optimisation is likely to be on a number of interdependent fronts - concentrate quality versus recovery, concentrate A versus concentrate B, throughput versus recovery.

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Working Capital

Working capital must be estimated as one of the project capital cost items. It can be substantial particularly in a base metal deposit which requires a large concentrate stockpile prior to the first shipment and where final payment is not received until the concentrate is received at the (foreign) smelter. It could be necessary to fully finance the operation for a few months.

The main components of working capital are:

Inventory

- Mining is generally capital intensive and thus even a three months holding of equipment spares can be substantial.
- The combination of the remoteness of the operation, the source of the spares (perhaps Europe or the USA) and of the reagents (xanthate, the main flotation reagent, is made in non-western countries), and the criticality of some items, such as onsite power generation with the associated fuel stocks, results in a large inventory of consumables. Three months average is common. Six months may be necessary for critical items.

Broken Stocks and other Flexibility

- Depending upon the variability of the mineralisation, it may be necessary to have perhaps 6 weeks broken stocks in an open cut or broken in stopes underground.
- The mining method - for example shrink stoping, where only about one third of the tonnes can be drawn while mining progresses - may result in high broken stock levels.
- Not all of the underground development required for the "balanced" mine will be undertaken prior to commencement and an "accelerated" rate will continue for some months. This may be accounted for in the mining costs, but it is a form of working capital as is the above average waste/ore ratios required in the early years of an open cut operation.

Concentrate Shipment Frequency and Payment

- There will be a certain minimum shipment size which may represent several weeks production, particularly during the early commissioning/learning phase. Furthermore, full payment (the outstanding 10% to 15%) will not be received until receipt at the purchasers works some 6 weeks later. Therefore the full cost of several weeks full operation has to be borne as working capital.

First Fill Consumables

- Though it will vary with the complexity of the process the "first fill" - in such respects as grinding media, carbon, reagent suite etc. - can be a substantial figure.
- Perhaps as an extreme example the initial inventories for a substantial nickel operation were $14.7M. The scheduled annual concentrate production represented some 6 average shipments and therefore the operating costs incurred prior to shipment were about $15M.

Owner's Cost

- The definition of this is not very clear. It can perhaps be viewed as a "catch all" category to collect the owner's ongoing administration costs during project construction. This would include staff costs for the owner's project manager, and liaison officers and inspectors handling relationships with construction contractors. It could also include capitalised interest costs.
- During the preproduction phase of construction, owner's costs could include recruitment and training costs for the workforce. There will be a number of preparatory costs incurred which, once the project is in operation, will be part of the normal operating costs. The boundary between owner's costs and working capital may be somewhat vague in this area. Perhaps it can be defined by classifying tangible items, such as inventory and "first fill", as working capital, and intangibles, such as training, as owner's cost.

Whatever the classification used, the important thing is to ensure that relevant project costs are not overlooked.

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