Information Circular 9143

Bureau of Mines Cost Estimating System Handbook

(In Two Parts)
2. Mineral Processing

Compiled by Staff, Bureau of Mines

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FOREWORD

Need for the Handbook

A computerized mineral inventory system to help the United States Government appraise critical shortages of materials has been eatablished. This involves evaluation of mineral deposits using the Bureau of Mines Minerals Availability System (MAS). The MAS is concerned with costing mineral occurrences where it is unknown, if they can be mined and/or processed at a profit. Therefore a consistent functional method of costing both mining and mineral processing is a requirement of the financial analysis phase of MAS. The objective of this handbook is to develope a manual method for preparation of feasibility type estimates for capital and operating costs of mining and primary mineral processing of various types of mineral occurrences using state-of-the-art technology.

Use of the Handbook

This handbook has been developed for a user with knowledge and experience in both mining and estimating procedures. The user should not use this handbook to try to determine the cost of any single component of a mining or mineral processing system. The combination of components will produce a reliable feasibility type estimate which should fall within 25 percent of expected actual cost. The estimated values from the use of the handbook are not intended to duplicate any specific mineral producer's capital or operating costs. Individual component costs may vary.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu	British thermal unit
Btu/ft^3	British thermal unit per cubic foot
cm	centimeter
cm/yr	centimeter per year
^oC	degree Celsius
^oF	degree Farenheit
ft	foot
ft^2/st	square foot per short ton
gal	gallon
gal/d	gallon per day
g/mt	gram per metric ton
gpm	gallon per minute
gpm/m^2	gallon per minute per square meter
h	hour
ha	hectare
h/d	hour per day
hp•h/mt	horsepower hour per metric ton
Hz	hertz
in	inch
kg	kilogram
kg/h	kilogram per hour
(kg/h)/cm	kilogram per hour per centimeter
kg/mt	kilogram per metric ton
(kg/m^2)/h	kilogram per square meter per hour
kg/m^3	kilogram per cubic meter
km	kilometer
kW	kilowatt
kW•h	kilowatt hour
kW•h/mt	kilowatt hour per metric ton
L	liter
lb	pound
(lb/ft^2/h)	per square foot per hour
lb/ft^2	pound per square foot
lb/ft^3	pound per cubic foot
L/min	liter per minute
L/s	liter per second
lb/mt	pound per metric ton
(L/s)/m^2	liter per second per square meter
m	meter
m^2	square meter
m^2/mt	square meter per metric ton
m^2/mtpd	square meter per metric ton per day
m^3	cubic meter
m^3/d	cubic meter per day
m^3/mt	cubic meter per metric ton
m/min	meter per minute
um	micrometer
mg	milligram
mg/L	milligram per liter
MMBtu/mt	million British thermal units per metric ton
MMmt	million metric tons
mt	metric ton
mtpd	metric ton per day
mtph	metric ton per hour
mt•km	metric ton kilometer
MV•A	megavolt ampere
ppm	part per million
tr oz	troy ounce
yr	year

BUREAU OF MINES COST ESTIMATING SYSTEM HANDBOOK

(In Two Parts)

2. Mineral Processing

Compiled by Staff, Bureau of Mines

ABSTRACT

This Bureau of Mines report and its companion report (Information Circular 9142) have been prepared to assist in the preparation of prefeasibility type estimates for capital and operating costs of beneficiation of various types of mineral occurrences using current technology. The handbook provides a convenient costing procedure based on the summation of the costs for the unit processes required in any particular mining or mineral processing operation.

The costing handbook consists of a series of costing sections, each corresponding to a specific mineral processing unit process. Contained within each section is the methodology to estimate either the capital or operating cost for that unit process. The unit process sections may be used to generate, in January 1984 dollars, costs through the use of either costing curves or formulae representing the prevailing technology.

The mineral processing handbook includes individual cost estimation sections for unit operations associated with comminution, beneficiation, solid-liquid separation, hydrometallurgy, and special applications as well as infrastructure and plant general and administrative costs. When using this system for estimating cost data for a mineral processing facility or for checking or verifying processing costs from an existing facility, a minimum amount of background information is necessary.

INTRODUCTION

The Interior Department's Bureau of mines systematically measures and classifies identified domestic and foreign mineral resources according to their respective extraction technologies, economics, and commercial availability. To this end, the Bureau collects data on major mines and deposits worldwide and uses these data in estimating and monitoring production costs and availabilities for 34 strategic mineral commodities. The estimation of production costs includes such items as capital expenditures and operating costs for mining and mineral processing operations, as well as transportation and infrastructure costs. A consistent method of costing is a requirement for such analysis. The cost estimation system (CES) has proven invaluable to the Bureau's work in this area.

The CES handbook was developed in 1975 to assist in the preparation of prefeasibility type estimates for capital and operating costs of mining and beneficiation of various types of mineral occurrences using current technology. The system provided a convenient costing procedure based on the summation of the costs for the unit processes required in any particular mining or mineral processing operation. This edition of the handbook is essentially a revision of the earlier effort, updated to reflect the costs of technologies employed as of January 1984. To provide continuity, the numbering system used in the original handbook has been retained.

The following are the 34 strategic commodities targeted for coverage by the updated handbook:

Aluminum	Cobalt	Hafnium	Mercury	Rare earths	Titanium
Antimony	Columbium	Iron	Molybdenum	Silver	Tungsten
Asbestos	Copper	Lead	Nickel	Sulfur	Zinc
Barium	Fluorspar	Lithium	Phosphate	Tantalum	Zirconium
Beryllium	Gold	Magnesium	Platinum	Thorium	
Chromium	Graphite	Manganese	Potash	Tin	

The updated edition of the CES handbook consists of this Information Circular (IC) on mineral processing and IC 9142 on surface and underground mining.

EVOLUTION OF CES

The first edition of the Bureau's Capital and Operating Cost Estimating System Handbook was prepared by STRAAM Engineers, Inc., Mining Division, under contract J0255026. The handbook was developed for use by individuals with knowledge and experience in both mineral engineering and cost estimation. The handbook was designed to produce a reliable prefeasibility type estimate, acurate to within 25% of the expected actual cost.

The first edition was introduced in 1975 and, accordingly, the costs therein reflected 1975 technology. In the decade since the introduction of the handbook, considerable technological change has taken place and mining and mineral processing costs have been significantly affected. Further, other important developments such as decreasing metal prices, rising labor costs, and environmental restraints have resulted in a series of austerity measures effected by the management of many mineral operations. In view of these considerations, a complete revision of the handbook was warranted.

In order to ensure adequate coverage of the 34 strategic commodities by the CES, it was necessary to reevaluate each cost section from the 1975 version of CES and also to develop a considerable number of new unit processes sections. The task of updating and revising the manual was assigned primarily to three Bureau groups. The Intermountain Field Operations Center (Denver, CO) was assigned the responsibility of providing updated replacement sections for the majority of the surface mining and mineral processing unit operations contained in the original manual, while the Western Field Operations Center (Spokane, WA) held primary responsibility for updating and supplementing the sections for underground mining. Additionally, several new mineral processing unit operations were provided by both field centers. Finally, 29 completely new unit operations sections were prepared by Pincock, Allen and Holt, Inc. under contract J0245002. The entire update project was coordinated by the Minerals Availability Field Office (Denver, CO).

The CES handbook consists of a series of costing sections, each corresponding to a specific mining or mineral processing unit process. Contained within each section is the methodology to estimate either the capital or operating cost for that unit process. The unit process sections may be used to generate costs through the use of either costing curves or formulas, depending on the option of the estimator. The cost curves are typically presented on a logarithmic scale of cost versus capacity and the corresponding cost formulas are (usually) of the form $Y = A(X)^B$, where X and Y represent the independent and dependent variables of size or capacity and cost, respectively. For the operating cost formulas and graphs presented for the various unit process throughout this handbook, the Y subscripts L, S, and E indicate labor, supplies, and equipment operation, respectively. All cost estimation methodologies contained in this manual have been prepared in January 1984 dollars and represent the prevailing technology at that date. None of the curves or equations in this handbook contain allowances for property and/or inventory taxes, general insurance or depreciation.

The reader will notice that all cost equations and curves are linear, logarithmic, or exponential, and that associated with each cost section is a range of applicability. The data obtained within these stated limits are reliable, but the same cannot be said for costs obtained by extrapolation outside of these limits. In most cases, the upper and lower limits encompass production parameters for actual mining and mineral processing operations used in the preparation of the unit process sections with values beyond tending to fall outside the range of current technology.

The data used in the development of this handbook was derived from information gleaned from a number of sources including industry contacts, equipment suppliers and vendors, Bureau files, and Government contractors. The major steps involved in the development were essentially the same for all unit processes, and involved the following progression:

1. Accumulation of data relating to each unit process through literature review, industry contacts, equipment vendors, etc., to provide the data base for development of the capital and operating cost estimates.

2. Determination of the types of the equipment for the unit process used in industry as of January 1984, and the establishment of the range of capacities for which the unit process is employed.

3. Selection of a minimum of three capacity data points for detailed cost analysis and subsequent preparation of a bottom-up cost estimate for each data point.

The majority of the data points corresponded to a capacity of an existing operation. In isolated cases where an existing operation of appropriate capacity could not be located, or because of insufficient data, the costs for an operation were modeled from the other estimates. In all cases, the limits of applicability stated for each section are within 15% of the maximum and minimum data points, respectively.

4. Calculation of the costing formulas and drafting of the cost curves. Generally, the costing formulas were derived through geometric regression analysis of the cost estimates prepared for each capacity, although a few curves are linear or exponential.

5. Verification of the cost formula through comparison with actual data. The total facility costs projected by the handbook have been demonstrated to fall within the limits of a prefeasibility estimate (i.e., within plus or minus 25% of actual costs).

METHODOLOGY

The CES handbooks for surface and underground mining and mineral processing are each divided into three major sections. The first of these sections, capital costs, involves the construction of the mine or mineral processing facility. The second section, operating costs, allows for the computation of the operating labor, supplies, and equipment operation of an existing or hypothetical operation. The last section, infrastructure, contains cost equations and curves for an assortment of infrastructure items.

Each cost generated by use of the costing handbook may be broken down into its respective subcomponents. A brief discussion on this aspect of the costing system, as applied to capital and operating costs, follows.

Capital Cost

The capital cost estimates were prepared to correspond to the actual range of capacities for which the unit processes are employed in industry. Detailed cost estimates were prepared for a minimum of three separate capacities covering this range. For the capital cost estimates, each unit process estimate was composed of the construction labor cost, the construction materials cost, a purchased equipment cost, and the cost of transportation. Each capital cost section gives a breakdown of these four components as a percentage of the total fixed capital cost for the unit process.

Modest contingencies, generally ranging from 5% to 10%, were applied to cover incidental items not specifically addressed in the estimates for some of the capital cost sections. However, it must be stressed that this contingency was applied only in areas where there was a degree of uncertainty on the part of the evaluator preparing the cost section and it must not be inferred that an overall blanket contingency has been applied.

Construction Labor

Construction labor costs were estimated from worker-hour requirements for each unit operation for each capacity studied. Average labor costs were determined from local union wage rates for a variety of job classifications common to mineral industry construction. The average labor wage rates applied to the worker-hour estimates include labor burden and fringe benefits of 21% of the base wage rate. For this analysis, the construction labor burden and fringe benefits have been assumed to include the employer's contribution to union funds for health and welfare, vacations, holidays, sick leave, retirement, Social Security (FICA), Federal Unemployment Insurance, (FUI), State Unemployment Insurance (SUI), and Workmen's Compensation.

A shift adjustment factor has been included in some of the capital cost estimation sections for mining, since it is conceivable that certain operations may operate either one or three shifts per day. Since the base case sections were designed for two-shift-per-day operation, it was necessary to include a mechanism for adjusting the cost per day total for an alternative operating schedule. The job classifications and associated base wage rates used in the computation of the construction labor component of the capital costs are presented in Table 1.

Table 1.--Construction labor job classifications and hourly wage rates

Job	Wage[1]
Boilermaker, journeyman	$21.00
Boilermaker, apprentice	17.32
Carpenter, journeyman	20.50
Carpenter, apprentice	15.89
Concrete finisher, journeyman	21.40
Concrete finisher, apprentice	15.88
Electrician, journeyman	23.11
Electrician, apprentice	12.71
Equipment operator	19.15
Equipment operator, apprentice	15.80
Ironworker, journeyman	22.08
Ironworker, apprentice	16.01
Laborer	12.71
Millwright, journeyman	22.52
Millwright, apprentice	17.27
Painter, journeyman	19.23
Painter, apprentice	14.34
Pipefitter, journeyman	20.90
Pipefitter, apprentice	13.71

[1] Includes 21% burden and fringe benefits.

Construction Materials

The estimates for construction materials include support steel, steel reinforcing bars, concrete, sand and gravel, timber, etc. Also included are small handtools, welding rods, and other miscellaneous equipment. It was generally assumed that construction materials are readily available at the mine or construction site and that the freight cost associated with these materials is negligible.

Purchased Equipment

In the capital cost sections for both mining and mineral processing unit operations, purchased equipment refers to the major mining or process equipment directly associated with the operation. The development of the capital cost estimates for each unit process included the construction of a major equipment lists with the equipment sized according to the capacities analyzed.

Transportation

Transportation, or freight, costs have been estimated using the basis of a midwestern (Denver, CO) mine or construction site. In most cases, freight costs were estimated using the nearest supplier-vendor for each piece of equipment to calculate the total distance for the shipment. Average transportation rates were then applied to the distance to calculate the cost of transporting the major equipment items from the manufacturer to the construction site. In each capital cost section, the percentage of the fixed capital cost for the particular unit operation is given and can be applied to the cost generated by the costing formulas (or curve) to derive the transportation cost.

Adjustment Factors

Many unit process sections contain one or more adjustment factors that may be used to address circumstances other than those assumed for the development of the cost section. These factors are generally multiplied by the product of the cost formula (or the cost taken directly from the curve) to obtain a cost representative of these special circumstances.

All curves in this handbook have been adjusted to a common base with every effort having been made to present data representative of a typical application of the particular mining method or beneficiation process under consideration. Often, however, the estimator will be privy to information that can substantially upgrade the quality of the estimate through the judicious application of adjustment factors. In order to properly apply the adjustment factors, the estimator must be capable of discerning any differences between the method or process under consideration and that presented in this handbook. When the estimator encounters an abnormal situation, proper adjustment of curve data, either upward or downward, must be made. For that reason, whenever certain adjustment factors may apply they have been explained and referenced. Mention of some of the common adjustment factors has been omitted from the narratives in order to avoid repetition. These factors include the various cost indexes and the labor rate and power cost conversion methods, as well as more subtle variables such as rock hardness. Even though many variables have been considered in the preparation of the handbook, every mineral deposit has its own unique differences that the individual estimator must be able to recognize and include in the cost estimation.

Four general adjustment factors are common to almost every section within the cost estimation system handbook.

Shift factor: Consistent with industrial practice, most mine capital and operating cost sections were developed on the basis of a two-shift-per-day operation and mineral processing plant sections were developed using a three-shift-per-day operation. Departures from this basis are noted within each individual cost estimation section. To adjust for alternative operating schedules, the estimator should determine the quotient of the design basis number of shifts (n_1) divided by the actual number of shifts for the operation under consideration (n_2). The quotient can then be multiplied by the daily feed rate to obtain an adjusted daily feed rate. The adjusted daily feed rate is then substituted for the independent variable, X, in the cost equations.

Power factor: In all of the cost estimation sections, the cost of electrical power was assumed to be $0.05.kWh. To adjust the costs for a different power rate, the estimator should multiply the power cost obtained from the cost equation (a percentage of the operating supplies curve) by the quotient of the actual power cost divided by the assumed power cost of $0.05/kW·h.

Water factor: The cost of purchased water was taken to be $0.10/m^3. To adjust the costs for a different water rate, the estimator should multiply the water cost obtained from the cost equation by the quotient of the actual water cost divided by the assumed water cost of $0.10/m^3.

Sales tax: A uniform 4% sales tax was applied to the total fixed capital cost for each unit operation. This approach reflects the construction of a greenfield mine or mineral processing facility by an independent contractor. If the sales tax for the area being estimated differs from the standard 4%, then the appropriate adjustment to the total capital cost should be made.

Operating Cost

The operating costs presented in these sections include the mining and mineral processing costs and mine or plant overheads. The operating cost section for each unit process includes distinct formulas and curves allowing for the independent calculation of the operating labor cost, the operating supplies cost, and the equipment operation cost. Fixed charges of insurance, taxes, royalties, depreciation, packaging, product freight, selling expense, or general and research expense are not included. The costs associated with supervision are not included with the individual unit processes, but are included in aggregate form with the general and administrative expense curves.

Labor

The labor costs generated through the use of this handbook include both direct operating labor and maintenance labor. Each operating cost section of the handbook provides the relative percentages of direct and maintenance labor that may be applied to the aggregate operating labor cost generated by the costing formula. The text also presents a tabulated summary of the direct labor component of the operating labor cost, providing a breakdown of job classification and the average wage rates for the direct labor involved in the operation. An example listing of job classifications and wage rates used in the estimation of the operating labor costs is presented in Table 2.

Table 2.--Operating labor job classifications and hourly wage rates

Job	Wage[1]
Operations:	
Rotary drill operator	$16.78
Shovel operator	18.11
Truck driver	15.89
Cave miner	18.11
Production loader	16.33
Control room operator	17.23
Mill operator	16.78
Mill helper	13.66
Sampler	15.44
Mill laborer	11.68
Maintenance:	
Mechanic/welder "A"	16.78
Mechanic/welder "B"	16.33
Electrician	18.11
Instrumentation	18.11
Oiler	14.56
Machinist	17.32

[1] Includes 32% burden and fringe benefits.

All labor rates (costs) used in the preparation of curves are based on the Denver, CO area as of January 1984, and include an allowance of 32% to cover all applicable payroll burdens and fringe benefits. Shift differentials of $0.30 per hour for the second shift and $0.45 per hour for the third shift have been included in the labor estimates. Area and/or incentive bonus premiums are not included and the estimator's judgment must determine the application of adjustment factors for these items.

Supplies

The supplies portion of the operating cost sections is comprised of electrical power, natural gas, reagents and industrial chemicals and other consumables. A standard sales tax of four percent was added to all nonfuel items. The costs in table 3, reflective of January 1984, were used in preparing the estimates of supply operating costs:

Table 3.--Base case supply costs

Commodity	Unit	Cost
Fuel Oil	gal	$ 1.00
Natural Gas	1,000 ft^3	3.20
Coal, 84%-subbituminous	st	25.00
Electricity	kW•h	0.05

Equipment Operation

Equipment operation costs are considered to include fuel, lubrication, repair parts and tires for all process equipment related to the unit processes. The fuel costs used in the preparation of the cost estimates on which the equipment operation curves are based were those in effect in the Denver, CO, area in January 1984. The gasoline and diesel fuel costs were both $1.00/gal. A standard sales tax of 4% was added to all nonfuel items.

To adjust fuel costs to more recent, local rates, the user should first obtain the percentage of the total equipment operation cost due to fuel, and then multiply that percentage, in decimal form, by the current cost per gallon of gasoline or diesel fuel.

Adjustment Factors

Similar to the capital cost sections, many operating cost sections contain adjustment factors to address operating circumstances other than those that were assumed for the development of the costing section. Again, these factors are generally multiplied by the product of the costing formula (or the cost taken directly from the curve) to obtain a cost representative of these special circumstances. A more detailed explanation of the development and use of adjustment factors has been included in the previous discussion of capital costs.

Infrastructure

In addition to the unit process modules, a number of auxiliary sections representing the various infrastructure elements associated with mining and mineral processing operations have also been provided. These sections include long-distance transportation, loading facilities, storage, waste water treatment, access roads, townsite and camp operation, among others. The application of these sections is virtually the same as for the unit process sections.

COST UPDATING

The mining and mineral processing estimating procedures presented in the handbook, using individual cost component breakdowns, provide a methodology by which the base costs derived from the system can be adjusted to be applicable in different locations and/or be updated through time. Labor productivities can also be adjusted to reflect cost differences due to differences in manpower requirements.

Two methods may be used to adjust the labor cost curves. Method one, the more accurate of the two, is to use the prevailing labor rates for the area under consideration, in the year of desired escalation, and apply the appropriate payroll burdens and premiums. By dividing the new rate by the one given in the narratives, a labor adjustment multiplier is obtained, which is applied to the labor cost calculated from the formulas or from the curves. The second method is to use a labor rate for the area under consideration, in the base year. By dividing the new rate by the one given in the narrative, a labor adjustment multiplier is obtained, which is updated from either labor index number 1 or 2 (table 4). By dividing the index corresponding to the year of desired escalation by the one in January, 1984, a ratio is derived, which when combined with the labor adjustment multiplier is applied to the calculated labor cost. This factor can be used for all classes of labor throughout the estimate.

Table 4.--U.S. Cost indexes, 1980-85

	1980	1981	1982	1983	1984[1]	1985
Mining Wage............	9.19	10.06	10.82	11.27	11.56	11.90
Construction Wage......	2,767.0	3,025.0	3,345.0	3,587.0	3,679.0	3,747.0
Equipment/Repair Parts.	288.9	320.8	343.9	351.9	354.3	362.3
Bits and Related Steel.	305.0	333.8	339.0	343.4	354.1	355.6
Timber and Lumber......	325.6	325.1	310.8	352.6	353.2	340.0
Fuel...................	674.3	805.9	761.2	684.3	669.7	633.8
Explosives.............	251.1	288.9	298.9	302.1	301.3	312.8
Tires and Rubber.......	249.7	270.2	271.6	260.0	258.0	247.0
Construction Materials.	287.7	310.3	330.1	352.9	355.5	358.2
Industrial Materials...	274.2	304.1	312.3	315.7	319.2	323.9
Transportation.........	311.3	355.3	387.3	395.4	409.7	414.4

[1]January, base.

Operating cost differences due to varying productivities can be adjusted through the individual unit process labor costs or through the combination of the components of underground mining, surface mining, or mineral processing. Contained in the labor portion of the narrative of each unit operation is a weighted average labor rate of all laborers necessary for that particular unit operation. The number of workers per day for each unit operation can be calculated by dividing the daily adjusted base year labor cost by the product of the average labor rate and 8 h per shift. An adjustment can be made on each unit operation if the estimator replaces the number of workers per day calculated above with a new estimate and multiplies by the average labor rate times 8 to derive the new adjusted labor cost based on a new productivity. If specific information is not available on each unit operation, the user can compute the number of workers per day for each unit operation and add them to get the total workers for the mine or mineral processing plant being evaluated. A productivity ratio is determined by dividing the known number of workers per day by the computed value, which when multiplied by the total adjusted labor cost gives the new labor cost.

Often, productivities are expressed as metric tons per worker-shift or metric tons per worker-hour. If the previous calculation is carried further by introducing the capacities of the mines or processing plants, productivity ratios can be derived to adjust the labor costs.

Most of the supplies and equipment operation costs are composed of more than one component. In these cases, it is necessary to calculate the component cost for each index classification. By dividing the index corresponding to the year of desired escalation by the one for January 1984, for each component, a ratio is obtained that is multiplied by the calculated cost component. Combining these escalated components produces a final updated cost.

Electricity, natural gas, propane, and water costs do not have corresponding index classifications for updating. The method used to update these categories by location is to use the prevailing rates for the area under consideration, either in the base year or the year of desired escalation, and to divide the new rate by the one given in the narratives resulting in the adjustment factor. This factor is next multiplied by the corresponding cost from the curve to obtain the site-specific cost.

Cost Indexes

The mining wage rates index includes both mine and plant labor. This index includes skilled, unskilled, local, and expatriate labor along with burden and fringe benefits (employer's contribution to union funds for health and welfare, vacations, holidays, sick leave and retirement, Social Security, Federal and State Unemployment Insurance, and Workmen's Compensation).

The construction wage rate index includes all labor (see mining wage index for inclusions) employed in the construction of mines and mineral processing facilities.

The equipment and repair parts index relates to equipment and repair parts relevant to mining and mineral processing operations and related infrastructure, e.g., front-end loaders, shovels, load-haul-dumps (LHD's), trucks, jumbo drills, as well as crushers, grinding mills, flotation cells, thickeners, filters, etc.

The drill bits and related steel index includes steel for mining and mineral processing such as drill bits, pipe, fan liners, track, shovel and loader teeth and liners, etc., as well as replacement parts such as steel balls, rods, shell and head liners, scoop lips, etc.

The timber and lumber index covers the timber and lumber that is most readily available for applications such as cribbing, lagging, and supports in underground mining.

The fuel index covers refined fuel products weighted toward diesel. However, the fuel index is also considered applicable to other petroleum products.

The explosives index includes all types of blasting supplies, e.g., propellent powders, blasting caps, etc.

The tires and rubber index includes all types of tires applicable to mining operations, e.g., for LHD's, trucks, as well as other parts made of rubber such as conveyor or other belts for machinery.

The construction materials index is applicable to materials such as sand, gravel, cement, limestone, reinforcing rods, steel fasteners, etc., for use in construction of mine and mineral processing plants and related infrastructure.

The industrial materials index includes mining and mineral processing chemicals used in daily operations, e.g., wetting agents, mining reagents, dust depressants, flocculants, flotation reagents, etc.

The transportation index measures transport cost based upon an assessment of the country's normal freight transport network relevant to the mineral industry and could include, in addition to rail and truck, means such as barge and pipeline.

GUIDELINES FOR MINERAL PROCESSING COST ESTIMATION

The CES handbook is a tool to be used for capital and operating cost estimation and comparison. As with any tool, the skill of the user will ultimately determine the quality of the product. The evaluator must realize that the extent of thought and understanding in the input will directly affect the accuracy of the final result. When estimating the cost of an operating plant, as much information as possible should be compiled prior to cost estimation. When costing a proposed operation, it is imperative to develop a detailed flowsheet before using this handbook. The method providing the maximum economic benefit given the restrictions of mineralization, ore grade, ore throughput, geographic location, and availability of labor, supplies, and energy must be selected.

The mineral processing handbook includes individual cost estimation sections for unit operations associated with comminution, beneficiation, solid-liquid separation, hydrometallurgy, and special applications, as well as infrastructure and plant general and administrative costs. When using this system for estimating cost data for a mineral processing facility or for checking or verifying processing costs from an existing facility, a minimum amount of background information must be obtained. This will include geology, mining, economics, environmental, infrastructure, and any extreme circumstances that would have an impact on the costs.

An explanation is included with each cost section. Each explanation lists the cost items used to develop the cost section, and specifies what is covered. Since the content of many of the mineral processing sections is so variable, each explanation must be read carefully and fully understood. Only by understanding the scope of each section can the estimator be assured that every required item will be accounted for once, and only once, in the final cost estimate.

The successful utilization of this mineral processing cost estimation handbook is dependent on the completion of the following procedure:

1. Preparatory study of the particular process under consideration.
2. Establishment of a materials balance and process flowsheet.
3. Selection of the appropriate cost sections.
4. Calculation of capital and operating costs for each section.
5. Summation of costs.

The following pages present some guidelines for the application of the mineral processing cost estimation system. As with any guidelines, numerous exceptions exist, and many situations are not considered. In the final account, the individual evaluator's knowledge of the basic principles of engineering and of the particular processing system under study will determine the accuracy of the estimate.

Preparation

Geology

Geologic information such as the available ore reserves and grade is a necessary component of the cost estimation method. The major type and character of the mineralization is critical to the design of the extraction system. Ore types can be classified as massive, intergrown, or disseminated. The ore type will directly affect the choice of the mineral processing method to be employed in the extraction of the minerals. For example, the comminution circuits must be designed to ensure that the desired minerals are adequately unlocked to achieve sufficient grade and recovery.

Mining

The mineral processing facility must be designed to operate in harmony with the mine plan. Therefore, for costing of a new facility, it is necessary to know the proposed capacity and operating schedule of the mine prior to beginning the development of the metallurgical flowsheet. If multiple ore sources are a possibility, then each of the feed sources must be carefully analyzed.

Economics

The economics of the various processing methods available must of course be considered. Once the characteristics of the mineralization have been delineated, the choices of a general extraction method are narrowed significantly. In general, the flowsheet considered initially for any ore must be based on the type of separation that appears to be most effective, considering the relative value of the recoverable minerals, the types of recoverable minerals, and market and location considerations. Occasionally, more than one beneficiation method may appear to be applicable to a given ore. At this point, if no other factors prohibit the choice, the least expensive remaining alternative is selected.

The process selected will ultimately rest on those factors (location, capacity, etc.) that will strongly influence the overall project economics. The best overall metallurgical plan may not produce the most favorable economics, therefore, optimum recovery is not necessarily maximum recovery.

Environmental

Although the benefits are often economically intangible, a prudent engineer must certainly study the advantages of reducing the environmental impact. Serious environmental problems associated with mineral processing operations include aesthetics, noise, dust, and solid and liquid waste treatment and disposal.

Other Parameters

Before deciding on a processing technique, all remaining available information should be examined. Environmental, geographical, personnel, and financial restrictions may each influence design. Since many sections have factors for unusual situations, this information will also increase the exactness of the cost estimation process.

Geographical characteristics and plant site location also affect the selection of the method of extraction. In rugged or remote areas, it may prove difficult and expensive to bring in large equipment and operating supplies. In such a case, the most economically effective alternatives may include labor-intensive methods or the selection of a less effective extraction scheme. Mineral processing plant design in extremely remote areas may be governed by the availability of power.

The labor force deserves careful attention during the design process. If skilled labor is unavailable locally, a highly mechanized facility may prove more economically attractive than importing personnel. Unskilled local labor, if plentiful, indicates the necessity of a labor-intensive method using simpler equipment. Some labor skills are easily transferable, and should be used to advantage.

Flowsheet and Material Balance

In order to effectively apply the costing system, the estimator should develop a reasonably detailed flowsheet and material balance incorporating all operations to be costed. A comprehensive process flow diagram and material balance will enable the estimator to apply the system rapidly, as most of the formulas or cost curves generate costs directly as a function of capacity (usually metric tons per day). This preparatory work should be sufficiently detailed to establish the grades and recoveries for all major product streams as well as to delineate the mass flow rates (both solid and liquid) for all major product streams. Finally, any special information (required for adjustment factors) should be noted as it will enhance the accuracy of the final estimate.

The estimator must first obtain the following minimum information to generate the costs for a desired actual or proposed operation:

The processing method employed and any peculiarities associated with the deposit.

The input and output streams for all unit operations.

The applicable labor rates, number of shifts operated per day, and water and electrical rates.

Once the general process flowsheet has been established, it is combined with the proper auxiliary systems to complete the plant design. This entails the inclusion of buildings, vehicles, administration, communication, electrical, and water systems, along with any other items required for operation. All sections required for the cost estimate should be studied to determine other information required for adjustment factors. In order to obtain the best results, the estimator should proceed through the sections in the sequence they are presented in the handbook.

Because the handbook was developed expressly for the purpose of calculating total plant costs, the user is cautioned against using costs developed in any single section or, especially, in combination with costs derived through other methods. For maximum accuracy, the costs should be developed for a complete facility.

Selection of Processing Sections

The initial step in using this handbook is the selection of sections and individual formulae and curves within the sections to be used in the evaluation. It is presumed the estimator will have adequate knowledge of mineral processing engineering and cost estimation procedures before attempting to prepare an estimate using the methods presented herein. After the data requirements have been prepared, the sections that apply should be studied until their contents are fully understood.

Mineral processing can be broadly defined as the treatment of raw materials (minerals) from the earth's surface to yield marketable products by methods that in general do not destroy the physical or chemical identity of the minerals. Separation is accomplished primarily by exploiting the physical differences between gangue and valuable minerals.

The general processes covered by this handbook include the following:

1.) Comminution
2.) Beneficiation
3.) Solid-liquid separation
4.) Hydrometallurgy
5.) Special applications

Although hydrometallurgy and some of the special applications fall outside the definition of mineral processing, they have been included within the handbook because of their close relationship with mining and mineral processing operations.

The following narrative reviews the major unit operations encompassed by mineral processing with emphasis on the contents of this handbook.

Comminution

Crushing: Crushing reduces run-of-mine ore to fragments with the coarsest (final) product being 1/4 to 3/8 in. Crushing generally takes place in two or three stages: Primary or coarse crushing reduces run-of-mine ore (maximum 60 diameter rock) down to a 6-to 8-in product through the use of either jaw or gyratory crushers. Secondary crushing takes the primary crushing product and reduces it in turn to a 3- to 2-in product. Gyratory or cone crushers are the usual choices for secondary crushing applications. Finally, a tertiary stage may be included to reduce the ore to a 1/4- to 1/2-in size. Cone crushers are almost exclusively used for tertiary crushing.

Grinding: Grinding composes the final stage of size reduction or particle liberation of ores. Generally the grinding circuit is designed to reduce a maximum upper feed range of approximately 10,000 mi (3/8/in) to some upper limiting product size between 35 and 200 mesh (420 to 74 mi). The optimum product size is dictated by combination of technical and economic considerations. Grinding can be accomplished in a variety of mills, typically rod mills and ball mills get the bulk of the applications, although autogenous and semiautogenous mills area becoming increasingly important.

Beneficiation

Flotation: Flotation is a physiochemical process for the separation of finely divided solids from one another. Separation of these dissimilar, discrete solids from each other is effected by the selective attachment of the particle to either a gas or a liquid phase. This mechanism is, in most cases, greatly assisted by modification of the particle surface by surfactants.

Gravity separation: If liberation of the desired mineral particles occurs at a relatively coarse size and there is a marked specific gravity difference between the value mineral(s) and the gangue, then gravity concentration methods such as the following may be employed.

1. Methods that depend on differing buoyancy between two particles of different densities when placed in a liquid of intermediate density.
2. Methods that depend on particle inertia resulting from both density and size difference. Important properties include particle size, density, fluid resistance, particle shape, and interparticle interference.

A brief discussion of some of the important gravity separation methods included in this handbook follows.

Heavy media: Heavy media process consists of continuously feeding a stream of crushed and washed (deslimed) ore into a fluid within a vessel so arranged that the float (light) and sink (heavy) products are continuously discharged along with the medium. The process is applicable to both metallic and nonmetallic minerals of size ranging from 8 in down to 65 mesh.

Jigs: Jigging is a form of gravity concentration carried out by pulsation of water through a screen that lies on a bed of crushed and sized ore. A mixture of sized particles of varying density is continuously fed into a box closed by screen on the underside through which water pulsates, a bed of heavier particles forms in the box above the screen. Concentrate is drawn off the top of the screen at intervals by means of a dam--the hutch product is removed through a valve.

Spirals: Spirals make use of a combination of centrifugal action, film flow, and heavy media separation forces. A spiral consists of descending spiral launder with modified semicircular cross section. Pulp is fed to the top of the spiral and as it flows downward, heavy particles concentrate in a band along the inner side of the pulp stream.

Tables: Shaking tables can be used for gravity separation when the materials are too fine for effective separation by jigging (approximately minus 20 mesh).

Other beneficiation processes included in the handbook are photometric separation and magnetic separation. These sections are applicable only to certain mineral commodities and should be applied with caution.

Solid-liquid separation

The solid-liquid separation sections have been designed to complement the beneficiation sections, however they may also be applied to the hydro- metallurgy sections. Capital and operating cost sections are provided for thickening, filtration (disk, drum, pressure, centrifugal), and countercurrent decantation. The importance of utilizing the adjustment factors provided in each section cannot be overemphasized for solid-liquid separation.

Hydrometallurgy

The field of hydrometallurgy involves the recovery of valuable components from ores or concentrates by relatively low temperature reactions accomplished in an aqueous phase. The three distinct operations can be identified in any hydrometallurgical flowsheet:

1. Leaching.
2. Solution concentration and/or purification.
3. Product recovery.

Leaching: The various leaching processes that are encountered can be classified with respect to reaction chemistry. Generally, the particular lixiviant selected for a given raw material is one that results in good selectivity for the valuable components to be recovered. If many components of the raw material are dissolved, then the subsequent leach liquor concentration and purification step will be more difficult. Leaching systems extend from the leaching of marginal low-grade ore in which there is no materials handling to the leaching of high-grade concentrates produced from physical and physiochemical separations by mineral processing technology.

Solution concentration and purification: Impurity removal is accomplished by a number of techniques in order to prepare the leach solution for product recovery. These techniques can be conveniently classified according to the following categories:

1. Solvent extraction.
2. Precipitation.
3. Cementation.
4. Ion exchange.

The application of any one of these processes depends mainly on the impurities to be removed and the component to be recovered. In some instances this intermediate stage of processing will involve the selective recovery of a solid phase containing the valuable component, e.g., copper cementation from dump leach liquors. In other instances, impurities may be removed (either in the solid state or in aqueous stream) with the valuable component to be recovered from a concentrated, purified solution, e.g., rejection of impurity components in raffinite during solvent extraction of uranium, copper, or other metals.

Product Recovery

The valuable component is finally converted into a marketable product with associated quality specifications. The product recovery phase of hydrometallurgy may involve purification of a solid phase or recovery from a concentrated purified aqueous solution. Common techniques employed for product recovery include

1. Gaseous reduction
2. Electrolysis
3. Precipitation

The hydrometallurgical sections included within this handbook are highly commodity specific. Most of the sections tend to cover a complete process rather than discrete unit operations. The estimator is advised to carefully read the text of each section to determine exactly what is included to avoid double counting.

Special Applications

This category encompasses a number of unit operations that do not readily fit the other descriptors. Included are unusual mineral processing techniques, chemical engineering processes, and thermal processes.

EXAMPLE APPLICATION OF CES: SEMIAUTOGENOUS GRINDING

For purposes of illustration, the following example briefly outlines the procedure for calculating capital and operating costs for a single unit process for mineral processing. A similar sequence of calculations is required for any of the unit process sections contained in this handbook. The unit process sections for calculation of the capital and operating costs for semiautogenous grinding are the subject of this example. A hypothetical capacity of 20,000 mtpd of ore has been assumed.

Capital Cost

Two curves are presented in the handbook for costing semiautogenous grinding (SAG) circuits. The proper formula for the calculation of the capital cost of the 20,000 mtpd circuit considered in this example is:

$$Y = 563.836(X)^{0.972}$$

By substitution:

$$Y = (563.836)(20{,}000)^{0.972}$$

$$Y = \$8{,}546{,}000$$

The capital cost breakdown indicates that 77% of the cost is purchased equipment, 16% is construction labor, 4% is construction materials, and 3% is transportation (freight). Therefore, the capital cost breakdown may be calculated as follows:

Construction labor cost.......	(0.164)(8,546,000)=	1,401,000
Construction materials cost...	(0.036)(8,546,000)=	308,000
Purchased equipment cost......	(0.773)(8,546,000)=	$6,606,000
Transportation cost...........	(0.027)(8,546,000)=	231,000
Total..................		8,546,000

Operating Labor

The first objective of CES involves the calculation of the total labor (direct operating labor plus maintenance, including fringes and burden) for the unit process under consideration. In the case of SAG, the formula for calculating the operating labor cost (per day) is

$$Y_L = 116.035(X)^{0.304}$$

By substitution: $Y_L = 116.035(20,000)^{0.304}$

$$Y_L = \$2,356/\text{day}$$

Subsequently, the relative amounts for direct operating labor and maintenance labor can be calculated using the percentages given in the text of 55% mine labor and 45% maintenance labor.

Operating labor..........	(0.55)(2,356) =	$1,296/day
Maintenance labor........	(0.45)(2,356) =	1,060/day
Total labor............		2,356/day

Operating Supplies

The cost per day of operating supplies for SAG grinding is calculated by substituting the capacity, 20,000 mtpd, into the equation:

$$Y_S = 0.614(X)^{0.986}$$

By substitution: $Y_S = 0.614(20,000)^{0.986}$

$$Y_S = \$10,690/\text{day}$$

The costs of the components of the operating supplies cost in this case consists 100% of electrical power.

Equipment Operation

The cost per day of equipment operation for SAG grinding is calculated by substituting the capacity, 20,000 mtpd, into the equation:

$$Y_E = 0.312(X)^{0.998}$$

By substitution: $Y_E = 0.312(20,000)^{0.998}$

$$Y_E = \$6,118/\text{day}$$

The costs of the components of the equipment operation cost can then be calculated using the percentages given in the text:

Wear materials (liners, balls).......	(0.94)(6,118) =	$5,751/day
Replacement parts...................	(0.06)(6,118) =	367/day
Total equipment operation cost.....		6,118/day

Adjustment Factors

To illustrate the application of adjustment factors, assume that fully autogenous grinding of a sulfide ore (power requirement of 14.3 kW·h/mt) is desired. Since the base section was designed for semiautogenous grinding of an ore with a power requirement of 10.44 kW·h/mt, two adjustment factors will be required: Autogenous grinding and hardness.

Capital Cost

Autogenous grinding (sulfide) factor:
$(F_A) = 0.995$

Hardness factor:
$(F_H) = 0.1058/(N)^{-0.959}$
where N is the new power requirement, in kilowatt hours per metric ton.
$(F_H) = 0.1058/(14.3)^{-0.959} = 1.36$

Total Adjusted Costs

Total capital cost $8,546,000 X 0.995 X 1.36 = $11,564,000

Operating Cost

Single-stage (sulfide) autogenous grinding factor:
Labor factor $(F_L) = 0.911$

Supply factor $(F_S) = 1.000$

Equipment operation factor $(F_E) = 0.270$

Hardness factor:
$(F_H) = N/10.4$
where N is the new power requirement, in kilowatt hours per metric ton.
$(F_H) = 14.3/10.4 = 1.37$

Total Adjusted Costs

Total labor cost $2,356/day X 0.911 X 1.37 = $2,940/day

Total supplies cost $10,690/day X 1.0 X 1.37 = $14,540/day

Total equipment operation cost $6,118/day X 0.270 X 1.37 = $2,250/day

Summation of Costs

Finally, the estimator should sum the capital and operating costs. Significant figures should be taken into account at this time if the estimator has not already done so. The cost equations given in the text have not been reduced to significant figures, as they are the product of a statistical analysis. It is recommended that the estimator express no more than three significant figures (depending on the precision of the input data).

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