O' Hara Alan T. SME mining engineering handbook Vol. 1 1992 ch. 6.3 pp 405-424

Chapter 6.3
COSTS AND COST ESTIMATION

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6.3.1 ESTIMATION OF COSTS

A mineralized deposit should not be developed into a mine unless the estimated annual operating profit after taxes is judged to be sufficient to recover, with interest, the estimated capital cost of developing the mine. The accuracy of estimation of capital costs and operating costs depends on the quality of the technical assessment and knowledge of expected mining and mineral processing conditions.

6.3.1.1 Cost Estimation for Preliminary Feasibility Studies

Estimation of capital and operating costs of a proposed mining venture is usually required after ore reserves have been determined, but before major capital costs are committed for detailed ore exploration, mine design layout, detailed metallurgical studies, and general plant design. At this stage of preliminary feasibility studies, there is usually insufficient technical knowledge to accurately estimate costs, and costs are estimated approximately to provide guidance on probable mine feasibility, optimum plant size, and possible need for additional geological studies and further exploration to prove and extend possible ore reserves. Estimates of costs are based primarily on computed average costs of existing mining projects and operations, with appropriate allowances for general site conditions, mining methods, and milling processes.

The costs estimated in a preliminary feasibility study are unlikely to be more accurate than ± 20%, and this degree of accuracy is insufficient to provide a sound basis for major mine financing or confident assurance of a profitable mining operation.

6.3.1.2 Estimation of Costs for Detailed Feasibility Studies

Estimation of costs with an accuracy of ± 10%, which is needed for a detailed feasibility study, requires completion of extensive technical work and studies on mine planning, general plant layout and design, environmental studies, and assessment of supplies, labor, and equipment required for mining, milling, and service operations. The cost and time required for the completion of the technical activities to permit accurate cost estimation required for a detailed feasibility study may not be warranted if the preliminary study indicates the proposed mining venture will not be adequately profitable.

Accurate capital costs are estimated from the lengths, sizes, and unit costs of planned mine development; manufacturers' quotations for specific equipment; quantities and contractors' unit costs for excavation, concrete foundations, and installations of piping, electric services, and equipment.

Accurate operating costs are estimated from the quantities and unit costs of all components of supplies and labor, as determined by accurate knowledge of the ore body, the mine planning, and the plant design.

Any aspect of the mine, plant, or service facilities that is not adequately determined in terms of technical requirements and quantities of supplies, labor, and construction requirements is incorporated in a contingency allowance, that is added to capital costs and operating costs. The contingency allowance expresses the probability of capital costs and operating costs being higher than anticipated when it is difficult to determine the precise characteristics of an aspect of the mine or plant.

Because accurate cost estimation requires tailoring of mine and plant design and operating characteristics to the localized characteristics of the ore body and plant site, the actual capital costs and operating costs of apparently similar mines should not unduly influence the estimated capital costs and operating costs of a prospective mining venture. The experienced cost estimator should attempt to visit one or more mines with known similarities to the prospective mine, so that a judgment may be made as to whether the local conditions at the visited mine are more or less favorable than those at the prospective mine. This judgment should be reflected in the estimate of higher or lower operating costs for the proposed operation.

Unlike capital cost estimation, which is based primarily on the size and unique nature of the mine and plant site, estimation of operating costs depends on the assessment of the probability of imperfect coordination of human effort in equipment operation and consumption of supplies.

To standardize calculations, the majority of the equations employed here are stated in English units. Also the emphasis in this chapter is on noncoal mining.

6.3.2 ASSESSMENT OF MINING CONDITIONS AFFECTING COSTS

The capital costs and operating costs of a mining project will be influenced by many factors that must be assessed before costs can be estimated for a preliminary feasibility study. The most important factor affecting costs is the size of the mine and processing plant as expressed in terms of tons of ore mined and milled per day of operation.

6.3.2.1 Mine Size or Production Rate

After discovery of an ore body, the mining and milling rate for the proposed mine project should be chosen such that the operating profit maximizes the return on capital invested in developing the mine and constructing the plant and services. If the mine size is too large in relation to the reasonably assured ore reserves, the operating life of the mine will be too short to yield an adequate return on capital invested in the mine project, and there will be insufficient opportunity to adjust or correct plant defects or operating inefficiencies before the ore reserve tonnage is significantly depleted.

If the mine size is too small in relation to ore reserve tonnage, the operating profit will be too small to recover invested capital and necessary return over the first few years of operation. After the mine is placed in production, the capital cost of enlarging the mine plant will be much higher than the additional cost of an initially enlarged mine plant.

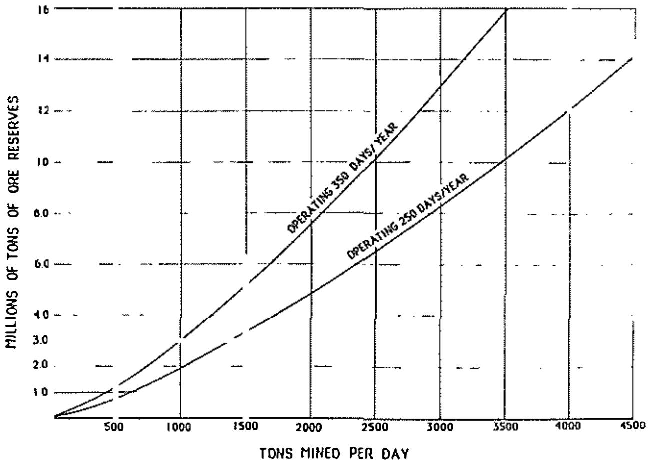

Fig. 6.3.1. Daily tonnage rate vs. ore reserves.

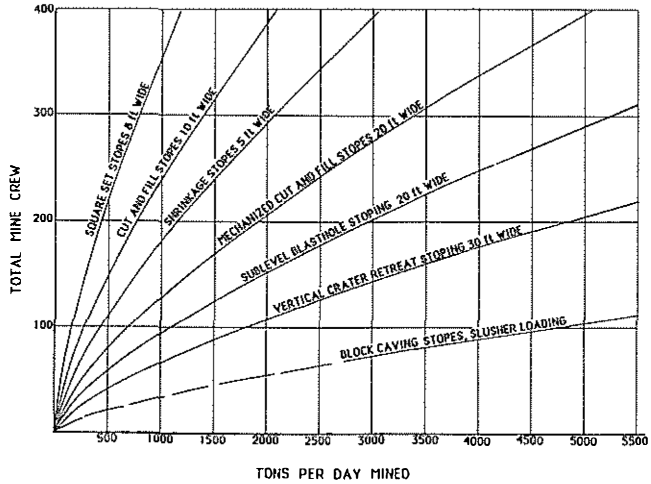

Fig. 6.3.2. Underground mine crew for various stoping methods and ore widths.

A useful guide to the optimum mine tonnage rate is the Taylor (1986) formula (Fig. 6.3.1). This formula, modified for English short ton units, is

$$\text{Optimum mine tonnage rate } T = \frac{4.88\,T_r^{0.75}}{D_{yr}} \qquad (6.3.1)$$

where T is short tons (2000 lb) of ore mined or milled per operating day, T_r is estimated short tons of diluted ore reserves that are judged to be reasonably assured (i.e., proven ore plus probable ore, but excluding possible ore with no assurance of its existence), and D_{yr} is the number of days per year of operation at full capacity. D_{yr} is approximately 250 for a mine operating on a 5-day week and 350 for a mine or mill operating continuously 7 days per week with only minor shutdowns or holidays per year.

6.3.2.2 Personnel Requirements

Operating costs and capital costs are influenced by the number of personnel required to operate the mine, mill, and services at any specific daily tonnage rate, because the number of personnel required varies with the methods to be used for mining and milling and whether or not the mine plant is extensively mechanized or computerized.

Guides for the number of personnel required for mining, milling, and services follow.

For underground mines the following relationships may be used to estimate the number of mine personnel required for mines using various mining methods (Fig. 6.3.2). T is the short tons of ore mined per day, W is the average stope width in feet, and Nmn is the number of persons required by the mine.

$Nmn = 8.0\ T^{0.7}/W^{0.5}$ for unmechanized square set mines (6.3.2)

$= 6.5\ T^{0.7}/W^{0.5}$ for small mines resuing narrow veins (6.3.3)

$= 6.0\ T^{0.7}/W^{0.5}$ for unmechanized cut and fill mines (6.3.4)

$= 2.5\ T^{0.7}/W^{0.3}$ for mechanized cut and fill mines (6.3.5)

$= 3.2\ T^{0.7}/W^{0.5}$ for unmechanized shrinkage mines (6.3.6)

For mining methods unsuitable for narrow stopes, where the slope width W is typically greater than 20 ft (6 m):

$Nmn = 0.75\ T^{0.7}$ for sublevel stoping mines with blastholes of small diameter (1 to 2 in. or 25 to 50 mm) (6.3.7)

$= 0.53\ T^{0.7}$ for vertical crater retreat mines using large diameter (3 to 6 in. or 75 to 150 mm) blastholes (6.3.8)

$= 0.72\ T^{0.7}$ for room and pillar mines in flat dipping hard rock (6.3.9)

$= 0.38\ T^{0.7}$ for room and pillar mines in flat-bedded, soft rock (increase up to 70% if mine is water-bearing) (6.3.10)

$= 0.35\ T^{0.7}$ for block caving mines using load-haul-dump equipment for loading ore (6.3.11)

$= 0.27\ T^{0.7}$ for block caving mines using slusher loading (6.3.12)

$= 0.42\ T^{0.7}$ for continuous mining in flat-seam mines (6.3.13)

The number of mine personnel required in open pit mines may be estimated from the following formulas in which Nop is number of open pit personnel and T_p is tons of ore and waste mined daily.

$Nop = 0.034\ T_p^{0.8}$ for open pit mines in hard rock using shovels and trucks for loading and haulage of ore and waste (6.3.14)

$= 0.024\ T_p^{0.8}$ for open pit mines in competent soft rock (6.3.15)

The number of mill personnel Nml required to operate mills treating T tons of high-grade underground ore daily may be estimated from the following formulas:

$Nml = 0.78\ T^{0.6}$ for cyanidation of precious metal ores (6.3.16)

$= 0.57\ T^{0.6}$ for differential flotation of base metal ores (6.3.17)

$= 0.95\ T^{0.6}$ for leaching, solvent extraction, and precipitation of uranium ores (6.3.18)

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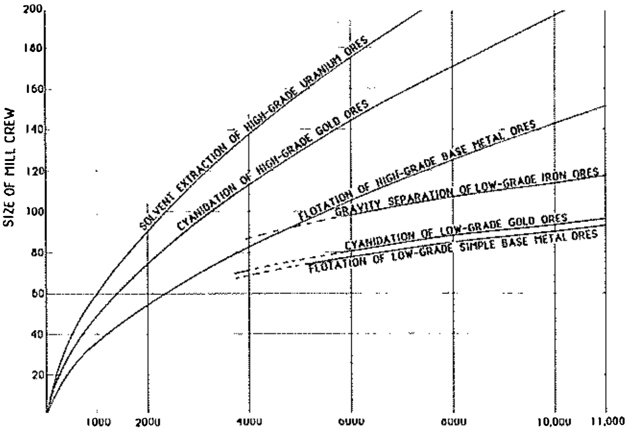

Fig. 6.3.3. Mill crew vs. mill process and size.

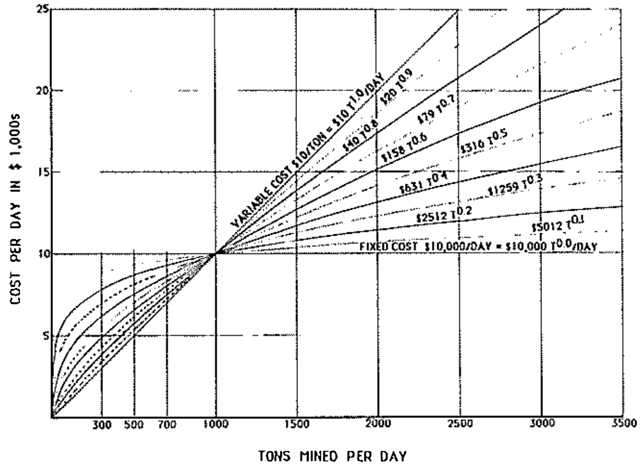

Fig. 6.3.4. Patterns of cost variability.

The number of mill personnel Nml required to operate mills treating T tons of low-grade ore mined by open pit methods may be estimated from the following formulas:

$Nml = 5.90\ T^{0.3}$ for cyanidation of precious metal ores (6.3.19)

$= 5.70\ T^{0.3}$ for flotation of low-grade base metal ores (6.3.20)

$= 7.20\ T^{0.3}$ for gravity concentration of iron ores (6.3.21)

See Fig. 6.3.3 for mill crew vs. mill process and size.

The number of service personnel Nsv may be estimated as a percentage of the total mine and mill personnel as shown below:

$Nsv = 37.5\%$ of $(Nmn + Nml)$ for medium and large underground mines that are mechanized in drilling and ore transport (6.3.22)

$= 20.6\%$ of $(Nmn + Nml)$ for small and medium underground mines with manual drilling and little mechanization (6.3.23)

$= 25.4\%$ of $(Nop + Nml)$ for open pits mining low-grade ore (6.3.24)

The number of administrative and technical personnel Nat required for a mining and milling plant may be estimated as a percentage of the total required for mining, milling, and services:

$Nat = 12\%$ of $(Nmn + Nml + Nsv)$ for underground mines and mills (6.3.25)

$= 11\%$ of $(Nop + Nml + Nsv)$ for open pit mines and mills (6.3.26)

It should be noted that the formulas for personnel required for mining, milling, services, and administrative and technical activities do not allow for personnel required for smelters, refineries, mine townsite services, concentrate transport, or offsite head offices, because these services may not be required for many mine projects. Whenever these services can be financially justified for the mine project circumstances, the additional personnel should be estimated separately.

Patterns of cost variability are shown in Fig. 6.3.4.

6.3.2.3 Electrical Power Demand

The peak load in kilowatts per month and the average daily power consumption in kilowatt hours can be estimated from the following formulas:

Peak load in kW $= 165\ T^{0.5}$ for underground mines milling T tons of ore daily (6.3.27)

$= 78\ T^{0.6}$ for open pit mines milling T tons of ore daily (6.3.28)

Power consumed in kWh/day $= 1800\ T^{0.57}$ for underground mines hoisting ore to a surface concentrator (6.3.29)

$= 1400\ T^{0.6}$ for open pit mines with shovel and truck haulage to concentrator (6.3.30)

Typically, the concentrator and related facilities account for about 85% of the total power consumption for open pit mines and concentrators, whereas the concentrator and related facilities account for only about 45% of the total power consumption for underground mines hoisting ore to a surface concentrator.

6.3.2.4 Mine Site Clearing

Area A to be cleared in acres $= 0.0173\ T_p^{0.9}$ for open pits mining T_p tons of ore and waste daily (6.3.31)

The area to be cleared extends to the ultimate pit limits.

Area A to be cleared in acres $= 0.011\ T^{0.7}$ for underground mines hoisting ore up a central shaft around which service buildings are sited. This area to be cleared does not include the mill and accessory buildings (6.3.32)

Area A to be cleared in acres $= 0.05\ T^{0.5}$ for concentrator building, crusher building, substation, warehouse, and ancillary buildings (6.3.33)

6.3.2.5 Assessment of Underground Mines

Costs of a proposed mining project are difficult to estimate unless the specific underground conditions are numerically assessible. These should be assessed by a person familiar with the site topography, ground conditions, and structural geology of the ore body.

Underground Mine Drainage System: This system comprises the underground sumps, multistage pumps, controls, standby pumps, and piping for pumping drainage water from the mine. The cost of this system is a function of the total installed horsepower of the operating pumps (but excluding the standby pumps), which in turn is a function of the total of the gallons per minute (liters per second) multiplied by the pumping head in feet (meters) for each of the installed pumping stations.

The rate of pumping in gallons per minute (US) for each pump is several times the inflow at each station sump, and the pumping head will typically be between 400 and 1500 ft (120 and 450 m). It is difficult to estimate the probable inflow of water in an ore body that has been drilled but not developed by underground crosscuts, drifts, and raises. However, some indication of whether the water inflow will be slight or heavy can be attained by examination of the drill core data to determine the presence of faulted water-bearing zones and drilling records showing loss of drilling water.

Total pump system horsepower Hp $=$ total of (gpm $\times$ Hd)/2350 (for all pump stations) (6.3.34)

This formula assumes metric units are converted to US gallons per minute and to feet of pumping head in numerically determining the horsepower required at each pumping station. In general, when the pumping system has not been planned in detail, the installed pump horsepower can be approximately estimated from the following formulas:

Installed horsepower Hp $= 8.0\ T^{0.5}$ for dry mines with little inflow and mine depth less than 1000 ft (300 m) (6.3.35)

$= 26\ T^{0.5}$ to $32\ T^{0.5}$ for mines with medium inflow and 1500 to 3000 ft (460 to 900 m) depth. (6.3.36)

$= 62\ T^{0.5}$ for mines with heavy inflow (6.3.37)

Underground Ventilation System. The cost of installing and operating a ventilation system varies with the total installed horsepower of all mine fans in the system. The total installed horsepower varies with the total quantity of air in cubic feet per minute, multiplied by the average fan pressure in inches water required to move this quantity of air. In general, larger mines require larger quantities of air than smaller mines, but the fan pressure required to move larger quantities of air increases in relation to the square of the velocity. The larger mines usually have larger development openings and larger bulk mining stopes, thus the average fan pressure in large mines is generally not much larger than in small mines ventilated by smaller quantities of air.

Quantity of air required Q in cfm:

$Q = 1400\ T^{0.8}$ for underground gold and metal mines (6.3.38)

$= 1900\ T^{0.8}$ for underground uranium mines (6.3.39)

$= 500\ T^{0.8}$ for underground nonmetallic mines without dust of a siliceous nature (6.3.40)

Typical fan pressure $= 2.4\ T^{0.1}$ in. water (6.3.41)

Total installed fan Hp $= Q$ cfm $\times$ in. water/3800 (6.3.42)

$= 0.88\ T^{0.9}$ approximately (6.3.43)

The typical fan pressure and installed horsepower may vary widely if mine openings are small in relation to tonnage of ore mined daily.

Compressed Air Plant:

Capacity of plant C in cfm $= 170\ T^{0.5}$ for underground mines using small-hole drilling and stoping by shrinkage or cut and fill methods in medium-width stopes (6.3.44)

$= 230\ T^{0.5}$ for small underground mines using small-hole drilling, air-powered slushers, and loaders in narrow stopes (6.3.45)

$= 130\ T^{0.5}$ for large underground mines using large blastholes in wide stopes with diesel-powered mechanized equipment for loading (6.3.46)

Hoisting Equipment: Two types of hoists are used in hoisting ore in underground mines: double-drum hoists and friction hoists. Double-drum hoists are suitable for hoisting ore or transporting men and supplies from several different levels for all sizes of mines. Friction hoists are suitable for deep mines hoisting ore from the lowest level and generally consume less power than double-drum mines hoisting the same tonnage from deep levels. Despite the operating economies of friction hoists, double-drum hoists are more often used because they are applicable over a wider range of operating conditions, and also because of the availability of used double-drum hoists that can be reserviced for operations at less cost and sooner than purchasing a complete new hoist.

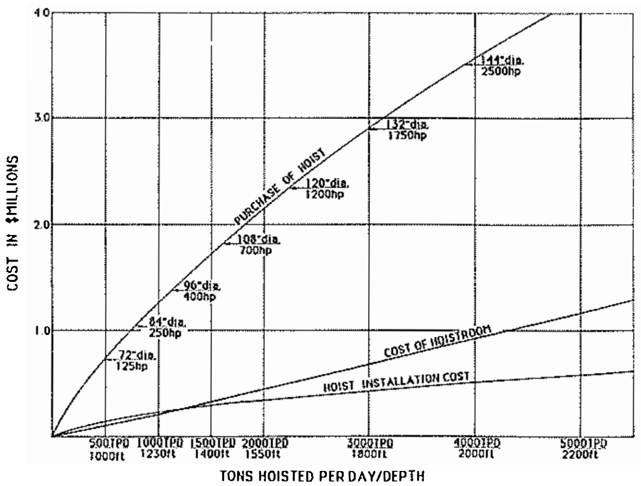

Fig. 6.3.5. Costs of hoisting plant.

The cost of a double-drum hoisting plant (Fig. 6.3.5) depends on the hoist drum diameter D in inches and on the horsepower of the hoist motor Hp, which in turn will be dependent on the loaded skip weight and rope speed. Usually small mines hoisting less than 1500 tons of ore in two 8-hr shifts/day install one hoist with combined skips and cage to hoist ore and transport miners and supplies. Medium-sized mines hoisting 2000 to 4000 tpd generally install one large hoist for hoisting ore only and a second smaller hoist for transporting miners and supplies in a multi-compartment shaft. Larger mines hoisting more than 5000 tpd will generally have two separate hoisting plants.

The optimum rope speed S in feet per minute (fpm) for hoisting ore is about:

S in fpm $= 1.6\, h^{0.5}\, T^{0.4}$ for hoisting T tpd from a depth of h ft (6.3.47)

The rope speed for transporting miners and supplies is generally about 30% slower than the optimum rope speed for hoisting ore.

The hoist drum diameter D in inches should be about

$$D = 4.13\, T^{0.3}\, h^{0.14} \qquad (6.3.48)$$

The total installed horsepower of the hoist motor, or motors, should be:

Horsepower Hp $= 0.5\,(D/100)^{2.4}\, S$ where D is drum diameter in in. and S is the rope speed in fpm (6.3.49)

Transport of miners and supplies is normally at slower rope speeds by a hoist with a drum diameter at least 80 times the rope diameter, and the hoisting rope diameter must be such that there is an adequate safety factor when hoisting the cage with the maximum load of miners and equipment.

The area A of the hoist room required for double-drum hoists with drum diameters of D inches will need to be about:

A(in ft^2) $= 0.10\, D^{2.2}$ for one double-drum hoist (6.3.50)

$= 0.085\,(D_1^{2.2} + D_2^{2.2})$ for two double-drum hoists with drum diameters D_1 and D_2 (6.3.51)

Headframe Size: The height of the headframe above the shaft collar must be sufficient to allow the skips to dump into ore bins that must have storage capacity of ore adequate for the daily tonnage rate, plus a safe vertical distance for skip overtravel and hoist braking distance below the sheave center elevation.

The headframe height H in feet of the sheave center above the shaft collar is shown by:

$$\text{Headframe height } H = 8.0\, T^{0.3} + 1.2\, S^{0.5} \qquad (6.3.52)$$

in which T is the tons of ore mined daily, which is hoisted to surface ore bins 16 hr/day, 5 days/week, and S is the rope speed in fpm. The $8.0\, T^{0.3}$ factor represents the allowance for skip dump height and the $1.2\, S^{0.5}$ factor represents the allowance for skip overtravel.

The weight of structural steel W in pounds in a steel headframe with a sheave center height of H ft is approximately:

$W = 0.12\, H^3\,(D/100)^2$ for a headframe safely designed for the breaking strength of the hoist ropes of a diameter not less than 1/80th of the drum diameter of the hoist (6.3.53)

If the headframe also serves another smaller hoist employed as a cage hoist, the weight of structural steel should be increased by about 20%.

Shaft Area: Because of the trend to more extensive mechanization of mines over the last two decades, the cross-sectional area of shafts sunk during the 1980s is somewhat larger in order to deliver and service larger loading and drilling equipment to the underground workings.

The shaft area A in square feet of rectangular shafts hoisting T tons of ore daily is now:

$A = 24\, T^{0.3}$ for underground mines hoisting up to 5000 tpd in two skip compartments and cage hoisting miners and supplies in cage compartments (6.3.54)

The shaft diameter (D in feet) of circular shafts for skip hoisting ore and cage hoisting miners and supplies is:

$D = 5.5\, T^{0.15}$ for circular shafts of underground mines hoisting less than 5000 tpd and transporting miners, supplies and equipment in separate cage compartments (6.3.55)

See Fig. 6.3.6 for shaft sinking costs vs. shaft depth.

6.3.2.6 Mine Development Required for Underground Mines

Mine development consists of two items: (1) development of drifts, crosscuts, ramps, raises, orepasses, ventilation raises, substations, and sumps to provide access to and services for the mining of sufficient ore for the first few years of mine production; and (2) stope preparation of sufficient stopes to permit subsequent mining of ore for six months, during which time current stope preparation will have prepared sufficient ore for a further six months of mining.

The costs of development (Fig. 6.3.7) for ore access and mine services (Fig. 6.3.8) together with the cost of initial stope preparation are considered to be preproduction capital costs, and mine development costs are typically the largest component of

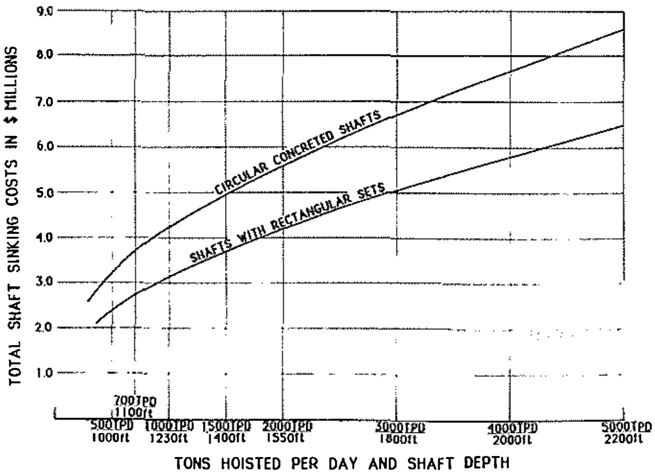

Fig. 6.3.6. Shaft sinking costs vs. shaft depth.

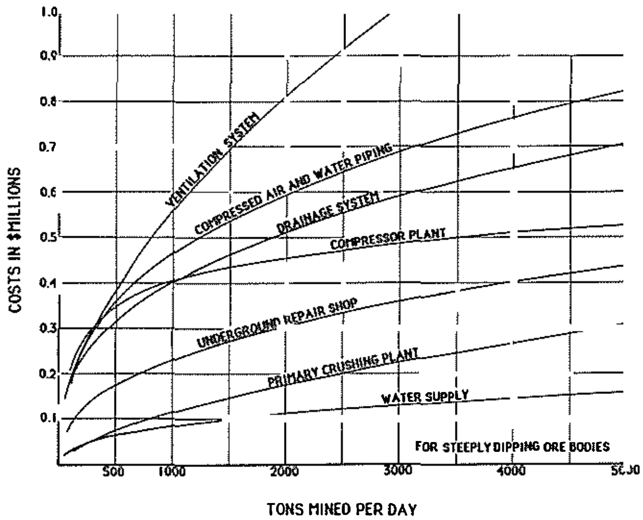

Fig. 6.3.8. Costs of mine services.

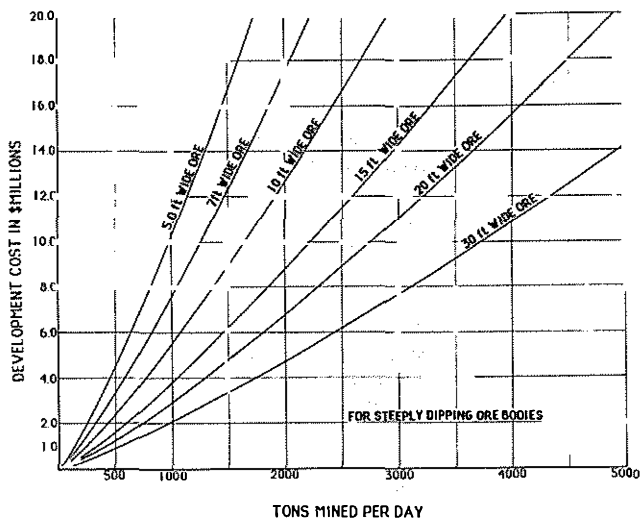

Fig. 6.3.7. Cost of mine development.

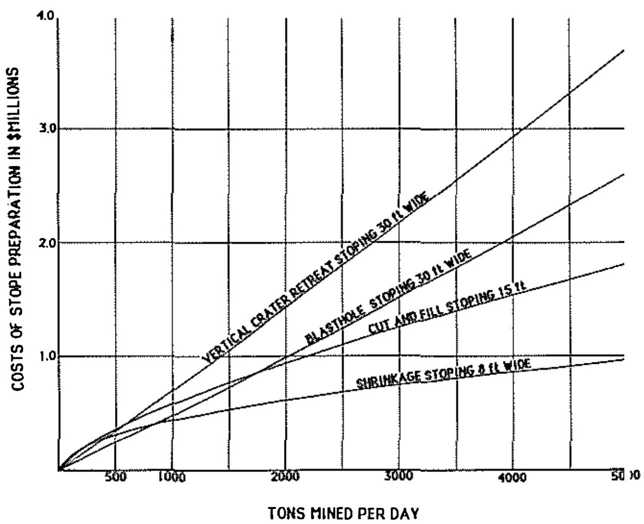

Fig. 6.3.9. Costs of preparing stopes for mining 125 days of ore.

mining capital cost and requires the longest time period of any mine activity in preparing the mine for production.

Mine development is often the most difficult cost to estimate of all preproduction capital costs prior to detailed mine planning, because of the uncertainty of many optional development plans that may or may not be suitable for subsequent efficient mine production.

In general, the mine development for a new mine should access ore equal to 1800 days of production and prepare stope ore equal to 125 days of production (Fig. 6.3.9). Less development leads to problems in maintaining steady ore production, and more development may be excessively costly.

The amount of mine development varies in relation to the volume of ore reserves, rather than the tonnage of ore reserves, so that an ore with a high specific gravity requires less development in waste to access this ore than an ore with a lower specific gravity.

One ton of ore with a typical specific gravity of 2.7 has an in situ volume of 11.866 ft^3; therefore, the ore reserve tonnage of T_r tons has a volume of:

$$\text{Ore reserve volume in ft}^3 = 32.04\ T_r / \text{SG} \qquad (6.3.56)$$

where SG is the specific gravity of the ore.

The estimator should estimate the length and height (in feet) of the rectangular shape, which fully encloses 1800 days of ore tonnage in the longitudinal section (or the length and width of 1800 days of ore tonnage in a flat-lying ore body). This length and height (or length and width) determines the amount of mine development necessary. The normal location of the ore hoisting shaft is generally near the center of gravity of the rectangular shape but offset from the ore zone by 200 ft or more. Mines in mountainous areas may be accessed by adits that extend well beyond the ore zone, and for such mines that do not require a hoisting plant, the mine development required is determined by the number and lengths of these adits.

When mine planning has not been done, an approximate measure of the amount of mine development required may be estimated from the length and height (or length and width) of the shape enclosing 1800 days of ore reserve tonnage, but the cost of the mine development will also depend on the sizes of the drifts, crosscuts, ramps, orepasses, raises, and various excavations. In general, the cost per foot of any excavation of sectional area A in square feet is proportional to the 0.6 exponent of the area A. Thus one can relate the cost per foot of length of any sized excavation of cross-sectional area A to the cost per foot of a standard 8 × 8-ft drift by the following ratios:

Drifts or crosscuts of cross-sectional area A	$0.0825\ A^{0.6}$
Inclined ramps of cross-sectional area A	$0.0970\ A^{0.6}$
Timbered raise @ 60° of cross-sectional area A	$0.1122\ A^{0.6}$
Bare raise @ 50° of cross-sectional area A	$0.0923\ A^{0.6}$
Service excavations of cross-sectional area A	$0.0948\ A^{0.6}$

By using these cost ratios, it is possible to convert all mine development openings into equivalent feet of 8 × 8-ft drift that would cost the same.

In general, the larger-tonnage mines require larger drifts, ramps, crosscuts, ventilation raises, orepasses, and service excavations than smaller mines, because the larger mines use larger equipment and move larger quantities of air and larger tonnages of ore through the mine openings.

The amount of mine development expressed in equivalent length of 8 × 8-ft drift is difficult to determine by any universal formula because of the variety of shapes and sizes of mine ore bodies. The amount of development required to access and service ore equivalent to 1800 times the daily tonnage has been estimated for hypothetical steeply dipping ore bodies. These hypothetical ore bodies are assumed to dip at 80°, to have a specific gravity of 2.7, to have a horizontal extent that is twice the vertical extent, and to have waste distributed over 30% of the overall extent of ore. The average width of ore in each ore body is assumed to increase by 63% for each doubling of daily mining rate. The results of this hypothetical study are tabulated below:

Mining rate in tpd	500	1000	2000	4000	8000
Ore width in ft	5.0	8.1	13.2	21.4	34.8
Height of ore in ft	1230	1491	1654	1835	2036
Length of ore in ft	2460	2982	3308	3670	4072

Amount of development in equivalent length of 8 × 8-ft drift:

Shaft stations, etc.	2290	3639	5299	7720	11,255
Levels and ramps	21,068	35,552	50,278	71,103	100,550
Orepasses and pockets	1149	1941	3013	4679	7269
Vent raises, manways	3069	5297	8902	15,347	26,954
Service excavations	422	724	1263	2248	4085
Total ft of 8 × 8-ft	27,998	47,153	68,755	101,097	150,111

The results of this study indicate that the following formulas should apply to development in similar shaped ore bodies, which have an average ore width of W ft and a tonnage rate of T tpd:

$$\text{Equivalent ft of } 8 \times 8\text{-ft drift} = 74.29\ T^{1.2}/W^{0.9} \tag{6.3.57}$$

If the specific gravity of the ore differs from 2.7, this formula converts to:

$$\text{Equivalent ft of } 8 \times 8\text{-ft drift} = 244.66\ (T/\text{SG})^{1.2}/W^{0.9} \tag{6.3.58}$$

These formulas may be used to compute the approximate amount of mine development for steeply dipping ore bodies of similar shape to that shown, but if the ore body differs drastically in shape, attitude, and width, the formulas become unreliable.

6.3.2.7 Stope Preparation for 125 Days of Ore at Daily Tonnage Rate

The amount of stope preparation for any given vertical area of ore depends on the stoping method, the level interval, and the degree of mechanization intended for stoping practice. Since the tonnage contained in any vertical area of ore depends directly on the width of the ore, the amount of preparation required for an ore tonnage equivalent to 125 days of mine production normally varies inversely with the ore width.

Although larger mines generally mine ore from wide ore bodies, whereas small mines typically mine ore from narrow ore bodies, some small mines may have portions of their ore bodies that are locally quite wide. In such instances, the small mine may develop the locally wide portion of the ore body with larger development openings to utilize larger mobile mucking and drilling equipment.

The formulas shown in the following offer guides to the amount of stope preparation required for mines with differing stoping methods, different daily tonnage rates, and differing ore widths.

Amount of stope development for 125 days of stoping, expressed as equivalent length of 8 × 8-ft drift:

Feet of 8 × 8-ft drift = $72\ T^{0.48}\ W^{0.2}$ for shrinkage stoping mines in steeply dipping ore bodies with ore less than 15 ft wide in which T is the number of tons mined daily and W is ore width in feet (6.3.59)

Feet of 8 × 8-ft drift = $8.15 T^{0.7}\ W^{0.5}$ for cut and fill stoping mines with ore less than 15 ft in width (6.3.60)

Feet of 8 × 8-ft drift = $16.25\ T^{1.06}/W^{0.6}$ for blasthole stoping mines that have ore widths over 15 ft (6.3.61)

Feet of 8 × 8-ft drift = $24.5\ T^{1.04}/W^{0.6}$ for vertical crater retreat mines that have ore widths over 20 ft (6.3.62)

Feet of 8 × 8-ft drift = $185\ T^{0.6}\ H^{0.2}$ for block caving mines stoping flat-lying ore at least 40 ft thick. H is the height of ore stoped (6.3.63)

It may be noted that stoping methods, such as shrinkage and cut and fill that require the least amount of stope preparation per stope, are usually higher in operating costs per ton than the bulk mining methods such as blasthole mining, VCR (vertical crater retreat) stoping, or block caving.

6.3.2.8 Assessment of Open Pit Mines

Open pit mines may have a greater diversity of ore body shape and daily tonnage of ore than underground mines. However, since waste overlying the ore is removed prior to open pit ore mining, the method of mining the ore is not influenced by the need to support waste from diluting the ore. The capital and operating costs of open pit mines is influenced by the number and sizes of equipment for drilling, blasting, loading, and haulage of open pit ore and waste.

The typical open pit mine in North America produces about 43,000 tpd (39 kt/day) of ore and waste from a pit depth of about 400 to 500 ft (120 to 150 m), with an oval shaped periphery 2200 ft (670 m) wide and 4700 ft (1430 m) long. Pit benches are typically 40 ft (12 m) high, and the overall pit slope (excluding roads) is about 57° in pits with competent rock, and 44° in pits with oxidized or altered rock, with in-pit haulage road gradients averaging 9%.

Pits may vary greatly in shape, size, and pit slope, especially in mountainous areas or where the ore and/or waste rock varies greatly in competence. The formulas shown in the following for equipment sizing, preproduction stripping, and maintenance facilities presume that the shape and type of open pit is similar, except in daily tonnage, to the typical open pit described previously.

Size and Number of Open Pit Drills: The size, hole diameter, and number of drills required depends on the tons of ore and waste to be drilled off daily. In general, there should be not less than two drills, and not more than four, for open pit mines mining less than 60,000 tpd (54.4 kt) of ore and waste. In medium-drillable rock, with a penetration rate of about 500 ft (152 m) per shift, the tons of ore or waste that is drilled off by a drill with a hole diameter of d inches is:

$$\text{Tons of ore or waste } T_p \text{ per day} = 170\ d^2 \qquad (6.3.64)$$

$$\text{For easily drillable rock, } T_p \text{ per day} = 230\ d^2 \qquad (6.3.65)$$

$$\text{For hard drilling rock, } T_p \text{ per day} = 100\ d^2 \qquad (6.3.66)$$

Typically, drill hole sizes have standard diameters (in inches) of 4, 6.5, 7.875, 9.875, 10.625, 12.25, 13.25, and 15 (or 102, 165, 200, 250, 270, 310, 336, and 380 mm); thus drill selection will be limited to one of these sizes. For tonnages up to 25,000 tpd (22.7 kt/day), two drills of appropriate hole diameter should be chosen, three drills should be adequate for up to 60,000 tpd (54.4 kt/day), and four or more drills will be required for daily tonnages over 60,000.

Size and Number of Shovels Required: The optimum shovel size S in cubic yards of dipper size in relation to daily tonnage of ore and waste (T_p) to be loaded daily is

$$S = 0.145\ T_p^{0.4} \qquad (6.3.67)$$

The number of shovels N_s with dipper size S that will be required to load a total of T_p tons of ore and waste daily will be

$$N_s = 0.011\ (T_p)^{0.8}/S \qquad (6.3.68)$$

In practice, the size of shovel chosen will be one with a standard dipper size close to the size calculated by Eq. 6.3.67, but the number of shovels N_s required is usually a fractional number that should be rounded off to the nearest smaller unit number. The omitted fractional number expresses the need for either a smaller-sized shovel or a front-end loader for supplemental loading service, as long as this smaller shovel or front end loader is adequate to load into trucks of a size appropriate to the shovels with dipper size S.

Size and Number of Trucks Required: The optimum truck size t in tons that is well matched with shovels of S bucket size in cubic yards is

$$\text{Truck size } t \text{ in tons} = 9.0\ S^{1.1} \qquad (6.3.69)$$

The total number of trucks N_t of t tons capacity required for the open pit truck fleet, plus an allowance for trucks under repair, should be approximated by the following formula:

$$\text{Number of trucks required } N_t = 0.25\ T_p^{0.8}/t \qquad (6.3.70)$$

The formula for N_t determines the size of the truck fleet under the typical conditions where the average haulage distance and gradient outside the pit periphery is less than the haulage distance and gradient inside the pit periphery. If the waste dump and the ore dump over the primary crusher are well removed from the pit boundaries, or if the haulage road beyond the pit has a steep gradient, it may be necessary to increase the truck fleet size to allow for the longer trip time per load.

Amount of Preproduction Waste Stripping: Before open pit mining can begin, the soil and rock overburden above the ore must be stripped to expose sufficient ore to supply the planned daily tonnage of ore for four to six months. The soil overburden should be stripped to the peripheral limits of the ultimate pit and an estimate made of its amount. An acre of moist soil that averages 10 ft (3 m) in thickness contains about 23,000 tons (20.9 kt) of soil; thus if the area of the ultimate pit periphery is known and the average soil thickness can be found from drilling logs or ultrasonic techniques, the amount of soil overburden can be calculated.

It is assumed that the location and area of the uppermost ore, sufficient for four to six months of mining, can be determined from ore body mapping, and the average thickness and area of the waste rock overlying this ore can be computed. Each acre of waste rock that averages 10 ft (3 m) in thickness contains about 40,000 tons (36 kt) of waste.

Because of the inverted conical shape of the ultimate open pit, the waste/ore tonnage ratio at each horizontal bench decreases with each lower bench, but the uppermost ore bench to be exposed typically has a waste/ore ratio of at least twice the waste/ore ratio of the ultimate pit. If insufficient ore is exposed by the preproduction stripping of waste, it may become difficult to continue mining ore because of the proximity of waste benches where blasting, loading, and haulage of waste may interfere with ore mining.

Open Pit Maintenance Facilities: The size of maintenance facilities for repair and maintenance of open pit equipment depends primarily on the number and size of the main haulage trucks, which in turn depends on the daily tonnage of ore and waste to be hauled. Repair and maintenance of the shovels and drills, which are slow in moving, is normally performed on the site by mobile repair vehicles.

The area in square feet required by the open pit maintenance shop, which should be located close to the open pit, is as follows:

$$\text{Area of open pit repair shop} = 360\ T_p^{0.4} \qquad (6.3.71)$$

Thus the areas of repair shops required for open pit mines are:

Mine size, tpd	10,000	20,000	40,000	80,000
Repair shop area, ft^2	14,300	18,900	25,000	33,000

6.3.2.9 Assessment of Miscellaneous Characteristics of Mine Projects

In addition to the numerical assessments of various mining features there are many other characteristics that cannot be easily assessed numerically, but which affect capital costs and operating costs. These characteristics can be described or tested so that a judgment can be made as to their effect on costs.

Climate at Mine Location: Weather station records at localized towns, airports, and specific sites should be collected and analyzed in terms of topographic similarity, exposure to prevailing winds, differences in elevation, which tend to decrease temperatures by 5 °F for each 1000-ft (9.1 °C for each 1000 m) increase in elevation, and differences in growth of plants and trees.

Climatic factors may affect building design, seasonal restrictions on pouring of concrete, leaching of metals from ore, size and cost of heating plants, etc.

Access to Mine Plant: The estimator should determine the distance and regional topography between the mine site and the nearest terminal of roads, power lines, and railroads, plus the nearest town where employees could find housing within acceptable commuting distance to the mine plant.

Construction Materials: The estimator should investigate the nearest site where adequate quantity and quality of gravel, water, and tailings storage can be obtained or stored. The sensitivity to pollution of the environment must be assessed and a study of the environmental impact of the mine plant by a team of experts may be warranted at an early stage.

Metallurgical Testing: Testing of drill core samples suggests the preferable ore processing method and the probable recovery of valuable minerals by ore processing. In general, these tests will indicate, but not positively assure, metallurgical performance. However, bulk samples of ore for comprehensive testing and/or pilot plant tests are preferable. The cost of extensive metallurgical testing or pilot plant runs of bulk samples may not be justified before the preliminary feasibility study.

Geologic Assessment: The geologist should examine the core samples, core recovery, and the records of core drilling to assess faulting or areas of incompetent wall rock. This could provide the necessary information on the probable selection of mining method, need for rock bolting of drifts and crosscuts, preferred areas for shaft location or drainage water sumps.

Overburden Removal: Assessment of overburden depth from drilling records and the general competence of subsurface rock strata offers guides to the amount of excavation and foundations for the surface plant.

Location: If the location of the mine is so remote that it is not feasible for employees to commute to work from an existing townsite with adequate available housing and service facilities, it may be necessary to establish a mine townsite or trailer camp adjacent to the mine. The site of such a mine townsite or trailer camp must be chosen with great care and concern for the quality of life of the subsequent residents.

6.3.2.10 General Characteristics of Capital Costs and Operating Costs

Cost formulas are offered as estimators of capital costs and operating costs where the numerical value of the main factor or factors affecting these costs is incorporated into an algebraic equation of the form

$$\text{Cost} = KQ^x, \text{ or Cost} = KQ^x\, T^y$$

where K is a constant, Q and T represent the numerical value of the factor or factors having the greatest influence on the costs, and x and y are exponents (normally between zero and 1.0) that measure the rate at which changes in the value of Q or T result in changes in costs.

Conventional accounting practices tend to regard costs as being either *fixed* (i.e., costs that remain relatively constant regardless of the size or complexity of the mining plant) or *variable* (i.e., costs that vary in direct relationship to some quantity Q that reflects the size of the mining plant). Alternatively, some costs may be considered to be a mixture of fixed costs and variable costs.

In mining practice, however, no costs are truly fixed or truly variable, neither are they a mixture of fixed and variable costs. It is more accurate to regard all mining costs as being somewhere between slightly variable (cost $= KQ^{0.1}$) and strongly variable (cost $= KQ^{0.9}$).

Virtually all items of purchased capital cost vary with plant capacity C at an exponent of about 0.6 or 0.7; consequently one large item of equipment will invariably be less costly to purchase and install than two smaller items of equipment with the same total capacity. Most items of labor cost per day vary in relation to daily tonnage at an exponent of between 0.4 and 0.8, whereas most items of supplies vary with tonnage at an exponent of between 0.6 and 0.9. The net result of this cost behavior is that if two or more mines are operated in the same manner under the same conditions, the lowest operating cost per ton will be attained by the mine with the largest tonnage output per day.

6.3.3 COST GUIDES FOR CAPITAL COSTS OF MINING PROJECTS

The cost formulas for mining projects described in this segment are based on the actual costs of mine projects completed since 1980, which have been escalated by statistical indices to the equivalent costs for the third quarter of 1988.

6.3.3.1 Underground Mine Projects

Site Clearing: The capital cost of clearing the site for the mine headframe, hoistroom, changehouse, and miscellaneous service buildings depends on the area A in acres to be cleared and, to some extent, the density of tree growth and the slope of the area to be cleared. The choice of site for the hoisting plant allows a limited amount of flexibility to optimize the costs of clearing the site, while avoiding adverse rock conditions for sinking the shaft or unstable ground for the headframe and hoist room foundations.

The area to be cleared can be determined by Eq. 6.3.32 or by judgment of the local site conditions:

$$\text{Clearing cost for mine site} = \$2000\, A^{0.9} \qquad (6.3.72)$$

Capital Cost of Shaft Sinking: The cost of shaft sinking depends on the area of the shaft, which can be estimated from Eqs. 6.3.54 for rectangular shafts or 6.3.55 for circular concreted shafts. The costs of sinking a shaft include a fixed cost of erecting a temporary sinking plant and concreting the shaft collar.

The major cost for shafts sunk 1000 ft (300 m) or more is the unit cost of shaft sinking per foot (meter) of shaft. These unit costs tend to increase as the shaft deepens because of the longer hoisting trip time for hoisting shaft muck. The unit costs also include the cost of excavating shaft stations as the shaft deepens:

$$\text{Fixed costs for rectangular shafts} = \$140{,}000\, A^{0.25} \qquad (6.3.73)$$

$$\text{Unit costs per ft} \times \text{shaft depth in ft} = \$139\, A^{0.45}\, D_s^{1.05} \qquad (6.3.74)$$

where A is area in ft² of the rectangular shaft sets and D_s is shaft depth in ft.

$$\text{Fixed costs for circular shafts} = \$135{,}000\, d^{0.5} \qquad (6.3.75)$$

$$\text{Unit costs per ft} \times \text{shaft depth} = \$307\, d^{0.7} D_s^{1.05} \qquad (6.3.76)$$

where d is concreted shaft diameter in ft and D_s is shaft depth in ft.

Capital Costs of Hoisting Plant: The cost of the hoisting plant depends on the size and type of hoist, or hoists, hoisting rope speeds, shaft depth, and the tons to be hoisted per day. For mines hoisting less than 1500 tpd in two 8-hr shifts, it is probable that the optimum hoisting system will be a double-drum hoist with combination skip/cages for hoisting ore and transporting miners and supplies. This hoist should have a drum diameter D in inches as determined by Eq. 6.3.48, and a motor horsepower Hp as determined by Eq. 6.3.49, if the rope speed is close to the optimum rope speed S in feet per minute as determined by Eq. 6.3.47.

Cost of hoist: = \$700 $D^{1.4}$ Hp$^{0.2}$ for new hoist skipping ore plus cage service (6.3.77)

= \$540 $D^{1.4}$ Hp$^{0.2}$ for reconditioned used hoist shipping ore plus cage service (6.3.78)

= \$700 $(0.9\ D)^{1.4}$ Hp$^{0.2}$ for new hoist for ore skipping only. (Drum diameter needs to be only 90% of D as determined by Eq. 6.3.48.) (6.3.79)

= \$700 $(0.8\ D)^{1.4}$ Hp$^{0.2}$ for new hoist for cage service only. Hoist drum diameter needs to be only 80% of D as determined by Eq. 6.3.48 (6.3.80)

Hoist installation = \$64 $D^{1.8}$ for installing a hoist with an actual drum diameter of D inches (6.3.81)

Hoistroom construction = \$4.90 $A^{1.4}$ for a hoistroom with an area of A square feet as determined by Eqs. 6.3.50 and 6.3.51 (6.3.82)

Capital Cost of Headframe: The cost of the headframe depends on the weight of steel required, which in turn depends on the height H in feet and the breaking strength of the hoist rope. Eqs. 6.3.52 and 6.3.53 estimate the headframe height and the weight of steel in the headframe.

Cost of headframe structure = \$19 $(W)^{0.9}$ for single-hoist headframe structure including shaft collar and foundations (6.3.83)

= \$19$(1.2W)^{0.9}$ for two-hoist headframe structure with shaft collar and foundations (6.3.84)

Note: Add 15% to costs if headframe is sheathed and insulated, with heating plant to ensure moist ore never freezes in skip dumps and ore bins. Cost of enclosed ore bins, skips and skip dumps, cages, and counterweights will tend to vary with daily tonnage, but costs are also affected when the mill operates for more days per week than the mine, thus requiring more ore storage for weekend milling.

Cost of ore bins, skips, etc. = \$700 $T^{0.7}$ for mines that operate the same work schedule as the mill (6.3.85)

= \$1150 $T^{0.7}$ for mines that operate 5 days/week while the mill and crusher operate continuously (6.3.86)

Mine Development and Stope Preparation: The amount of mine development and stope preparation that must be completed in the preproduction phase before the mine can start production of ore is discussed in 6.3.2. This amount of development, expressed in terms of equivalent footage of 8 × 8-ft drift is shown in Eqs. 6.3.57 to 6.3.63. The estimated cost of an 8 × 8-ft drift in 1988 is \$148/ft of drift.

The cost of \$148/ft for an 8 × 8-ft drift is appropriate for hard-rock drifting requiring little or no rockbolting. In incompetent rock requiring extensive rockbolting or grouting of water inflow, this unit cost should be increased.

The cost of mine development for a steeply dipping ore body with ore having a specific gravity of 2.7, an average ore width of W ft, and an expected production rate of T tons of ore daily would be:

Mine development cost = \$11,000 $T^{1.2}/W^{0.9}$ (6.3.87)

= \$36,200 $(T/\mathrm{SG})^{1.2}/W^{0.9}$ when SG is the specific gravity of ore greater than 2.7 (6.3.88)

The cost of initial stope preparation of ore stopes containing ore equivalent to 125 times the expected daily tonnage of ore to be mined depends on the type of stoping method to be employed as shown in the following:

Cost = \$10,620 $T^{0.48}$ $W^{0.2}$ for shrinkage stopes (6.3.89)

= \$1,200 $T^{0.7}$ $W^{0.5}$ for cut and fill stopes (6.3.90)

= \$2,400 $T^{1.06}/W^{0.6}$ for blasthole stopes (6.3.91)

= \$3,630 $T^{1.04}/W^{0.6}$ for VCR stopes (6.3.92)

= \$27,400 $T^{0.6}$ $H^{0.2}$ for block caving stopes (H is stope thickness in feet) (6.3.93)

Cost of Drilling, Loading, and Haulage Equipment: This cost includes all equipment for drilling, loading, and hauling ore, where such equipment is not fixed in place nor installed on foundations.

The mobile equipment cost of similarly equipped mines varies with tons mined daily, but mines with the same daily tonnage may vary in the cost and degree of mechanization if the mines have differing ore widths.

The width of ore in the stopes determines the feasible use of mobile drills, large capacity loaders, and haulage equipment. To accommodate such equipment, larger stope development openings are required. Mines with narrow ore bodies are restricted in the choice of stoping method; drilling is performed with manually controlled drills, and ore loading or scraping is accomplished with small air-powered equipment.

$$\text{Cost of equipment} = \$24{,}600\ T^{0.8}/W^{0.3} \qquad (6.3.94)$$

Although a highly mechanized mine will attain a higher productivity in tons per manshift than an unmechanized mine, it also will require more extensive ventilation and a larger maintenance crew and facilities.

Cost of Mine Ventilation System: The cost of the ventilation system is influenced by the extent of mechanization in the activities of drilling, loading, and haulage, but this cost will be somewhat lessened by the large development openings necessary to accommodate this equipment.

Ventilation costs are adversely affected when the mine is very deep and increased air temperatures at depth decrease human energy and comfort. The quantity of ventilation air and the costs are also increased if siliceous dust or radiation emanates from the mining of ore.

In general, the most reliable measurement of the cost of the installed ventilation system is the total installed horsepower (Hp) of all ventilation fans in the system. The total installed horsepower can be estimated from Eqs. 6.3.38 to 6.3.43.

Cost of ventilation system = \$14,000 $Hp^{0.6}$ for gold and base metal mines (6.3.95)
= \$16,800 $Hp^{0.6}$ for uranium mines (6.3.96)
= \$7,500 $Hp^{0.6}$ for nonmetallic mines without siliceous dust (6.3.97)

Cost of Mine Pumping System: The cost of the mine drainage system depends on the total installed pump horsepower (Hp) as estimated in Eqs. 6.3.34 to 6.3.37. This cost includes the concreting of dams and pump stations, the installed cost of pumps, the cost of standby pumps, the installation of piping from pump stations to shafts (but shaft piping is included in shaft sinking costs), pump control equipment, and sludge removal equipment.

Pumping system cost = \$3,400 $Hp^{0.7}$ for mines with medium water inflow and 1500 to 3000 ft (460 to 910 m) depth (6.3.98)
= \$1,400 $Hp^{0.7}$ for shallow mines with little water inflow and depth of less than 1000 ft (300 m) (6.3.99)
= \$5,800 $Hp^{0.7}$ for mines with heavy water inflow at depths below 1000 ft (300 m) (6.3.100)

Cost of Water Supply System: The cost of the water supply system depends primarily on the amount of drilling and the type of drills used for mine development. Small tonnage mines typically use jacklegs and stopers for drilling, but the larger tonnage mines typically use larger jumbo drills and large-bore drilling in stopes and development. A typical 500-tpd mine uses about 43,000 gal (162 kL) of water daily, while a typical 8000-tpd mine uses about 230,000 gal (870 kL) per day.

$$\text{Cost of water supply} = \$5{,}300\ T^{0.4} \qquad (6.3.101)$$

where T is tons of ore mined daily.

Cost of Primary Crusher Installed Underground: The primary crusher is usually installed underground, except in small mines where the stoped ore is finely broken with little oversize. Primary crushing of ore prior to hoisting reduces problems with hangups in skip loading pockets, skip dumps, and conveyor transport of mined ore.

Jaw crushers are suitable for primary crushing of stoped ore for underground mines, except very large underground mines over 10,000 tpd (9 kt/day) where the size of rock broken in stopes requires a gyratory crusher. Jaw crushers are available in sizes from 24 × 36 in. (610 × 910 mm) to 48 × 60 in. (1220 × 1520 mm) and require much less head room for installation than gyratory crushers.

The area (A in square inches) of the feed opening for jaw crushers determines the ore capacity in tons per day T that can be crushed in most hard rock mines:

$$A = 29\ T^{0.5} \qquad 6.3.102)$$

$$\text{Cost of jaw crusher} = \$24.50\ A^{1.2} \qquad (6.3.103)$$

$$= \$1{,}370\ T^{0.6} \text{ approximately} \qquad (6.3.104)$$

The cost of installing a jaw crusher in an excavated crusher station, including foundations, ore feeder system, and dust collection, is:

$$\text{Installation cost} = \$\ 210\ T^{0.7} \qquad (6.3.105)$$

Cost of Underground Repair Shop: Although small mines producing less than 600 tpd (544 t/day) of ore typically have a surface repair shop to service mining equipment plus small mobile equipment from the mill and services, large mines, which are extensively mechanized with large equipment, usually prefer to locate the mine repair shop underground to avoid delays in hoisting the mine equipment to a surface repair shop.

The cost of equipping and stabilizing an underground repair shop excavation for mines with an ore production of T tons of ore daily is estimated to be:

$$\text{Cost of maintenance shop} = \$14{,}600\ T^{0.4} \qquad (6.3.106)$$

This maintenance shop is usually located adjacent to the hoisting shaft and may also include a facility where rock drills are serviced.

Cost of Mine Compressor Plant: The compressed air capacity C in cubic feet per minute required for underground mines can be estimated from Eqs. 6.3.44, 6.3.45, and 6.3.46. The cost of the compressors and all accessory equipment installed in a compressor house on concrete foundations can then be estimated as follows:

$$\text{Cost of compressor plant} = \$920\ C^{0.7} \qquad (6.3.107)$$

Cost of Compressed Air and Water Distribution: The cost of piping installed to distribute compressed air and water to all working places in the mine depends mainly on the length of lateral development expressed in equivalent length of 8 × 8-ft drift, and partly on the total compressor capacity in cubic feet per minute. The length of lateral development L is usually a function of daily mined tonnage T and stope width W:

$$\text{Length of lateral development } L \text{ in ft} = 1276\ T^{0.6}/W^{0.4} \qquad (6.3.108)$$

$$\text{Cost of pipe installation underground} = \$2.80 L^{0.9} C^{0.3} \qquad (6.3.109)$$

Cost of Fill Distribution System (for Cut and Fill Mines): The cost of the hydraulic fill system depends on the length of lateral development L in feet and on the tons per day of ore T mined by the cut and fill method.

$$\text{Cost of fill distribution} = \$1.30\ L^{0.9}\ T^{0.6} \qquad (6.3.110)$$

Cost of Underground Electrical Distribution: The cost of

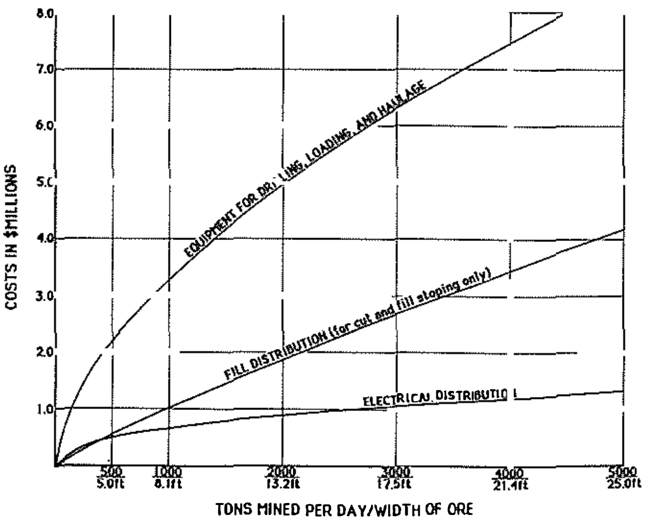

Fig. 6.3.10. Mobile equipment, fill and electrical.

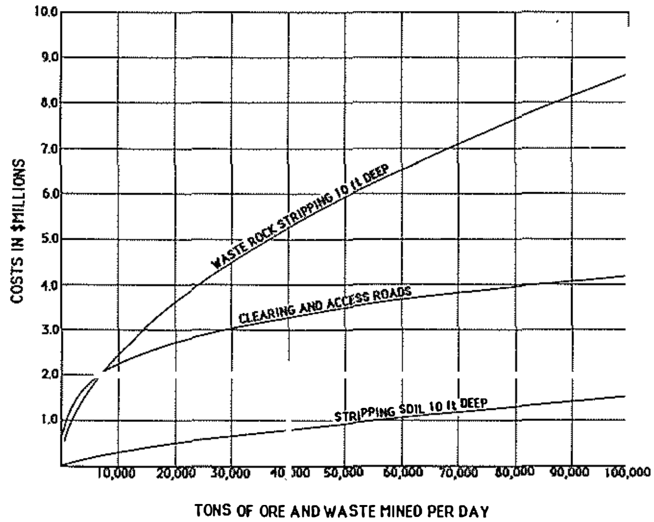

Fig. 6.3.11. Clearing, stripping, and road costs for open pit mines.

substations and power cables underground depends on the average peak load of the mine in kilowatts, as estimated from Eq. 6.3.27 that determines the overall peak load for an underground mine and a surface mill. Since the surface hoist is fed from the surface electrical distribution, the power consumption and peak load of the mine facilities located underground generally will not absorb more than 15% of the total electrical load. Thus if the plant peak load in kilowatts is estimated to be 165 $T^{0.5}$ for a mine and mill producing T tons of ore daily, the portion of this load that is attributable to the underground mining facilities is about 24.75 $T^{0.5}$ in kW.

The cost of installing the underground substations and power cables is estimated to be:

$$\text{Cost} = \$1600\ (\text{kW})^{0.9} \qquad (6.3.111)$$

where kW is the portion of the peak load attributable to the underground facilities.

See Fig. 6.3.10 for costs of mobile equipment, fill, and electrical distribution.

6.3.3.2 Open Pit Mine Projects

The cost formulas for open pit mines were derived from the actual costs of North American mine projects completed since 1980. The weighted average cost for each item of capital cost has been escalated by statistical indices to be appropriate for the third quarter of 1988.

Clearing Costs for Open Pit Mines: The capital cost for clearing the area where the open pit is located depends on the area A in acres (see Eq. 6.3.31) and the clearing cost per acre.

Total clearing cost
$= \$1600\ A^{0.9}$ for 20% slopes with light tree growth (6.3.112)
$= \$300\ A^{0.9}$ for flat land with shrubs and no trees (6.3.113)
$= \$2000\ A^{0.9}$ for 30% slopes with heavy trees (6.3.114)

Clearing, stripping, and road costs for open pit mines are shown in Fig. 6.3.11.

Preproduction Waste Stripping: If T_s is the tons of soil, and T_w is the tons of waste rock that must be stripped to expose an amount of ore to sustain four to six months ore production, then the estimated costs of waste stripping will be

Soil stripping costs $= \$3.20\ T_s^{0.8}$ for soil not more than 20 ft deep (6.3.115)

Waste stripping costs $= \$340\ T_w^{0.6}$ for rock requiring blasting, loading, and haulage (6.3.116)

Cost of Open Pit Drilling Equipment: The cost of drilling equipment depends on the number of drills Nd and the hole diameter d in inches drilled in order to prepare the daily tonnage of ore and waste rock for production (see Eqs. 6.3.64, 6.3.65, and 6.3.66).

$$\text{Drilling equipment cost} = Nd \times \$20{,}000\ d^{1.8} \qquad (6.3.117)$$

This formula includes a 25% allowance for drilling and blasting supplies and accessory equipment.

Cost of Shovels and Loading Equipment: The cost of loading equipment depends primarily on the number Ns and size S in cubic yards of the shovels, as shown by Eqs. 6.3.67 and 6.3.68. The total cost of the fleet of shovels supplemented by auxiliary bulldozers and front end loaders will be

$$\text{Loading equipment cost} = Ns \times \$510{,}000\ S^{0.8} \qquad (6.3.118)$$

Cost of Trucks and Accessory Road Maintenance Equipment: The cost of haulage equipment depends primarily on the number Nt of trucks, and the truck size (t in tons), as shown by Eqs. 6.3.69 and 6.3.70.

$$\text{Haulage equipment cost} = Nt \times \$20{,}400\ t^{0.9} \qquad (6.3.119)$$

Open pit equipment costs are shown in Fig. 6.3.12.

Cost of Open Pit Maintenance Facilities: The cost of constructing and equipping the pit maintenance shop varies with

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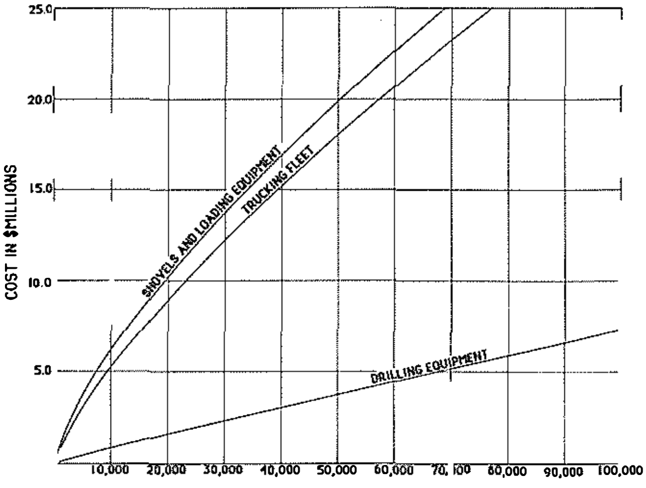

Fig. 6.3.12. Open pit equipment costs.

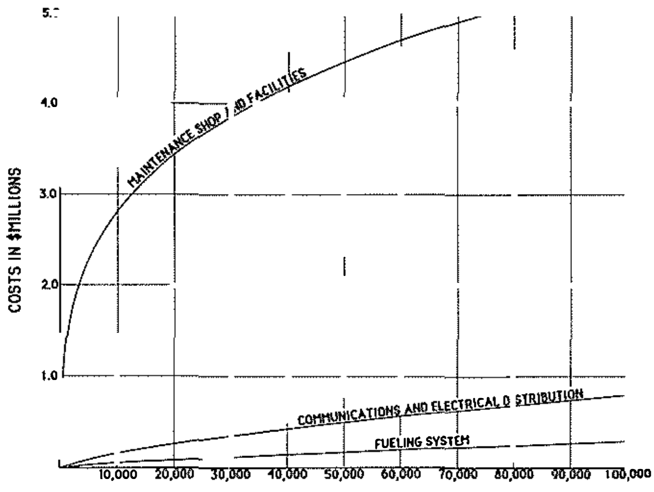

Fig. 6.3.13. Open pit services costs.

the shop area A in square feet as shown by Eq. 6.3.71 and the size t of the trucks in the truck fleet.

$$\text{Cost of pit maintenance facilities} = \$6000\,A^{0.6}\,t^{0.1} \qquad (6.3.120)$$

Cost of Open Pit Communications and Electrical Distribution: This cost includes the installed costs for a surface telephone system with mobile and base radio units with one or more repeaters depending on the size of the mine. The electrical distribution includes the installed costs of primary substations, transmission lines, portable skid-mount transformers, and trailing cables, all of which depend on the size of the open pit mine as measured by the daily tons T_p of ore and waste mined.

$$\text{Cost of communications/electrical} = \$250\,T_p^{0.7} \qquad (6.3.121)$$

Cost of Open Pit Fueling System: This cost includes the storage and services for diesel fuel, gasoline, lubricants, and coolants for the truck haulage fleet and mobile service vehicles

$$\text{Cost of fueling system} = \$28\,T_p^{0.8} \qquad (6.3.122)$$

Open pit services costs are shown in Fig. 6.3.13.

6.3.3.3 Concentrator and Surface Facilities for Mine Projects

It is assumed that the mill operates at three 8-hr shifts for 7 days/week, regardless of the shifts worked by the underground mine or the open pit mine. Some underground mines operate 2 shifts/day, 5 days/week; but other underground mines and most open pit mines operate for 7 days/week. Thus the daily tonnage of ore milled may be the same as the daily tonnage of ore mined, or it may be only 71% of this tonnage.

The crushing plant may operate for 5, 6, or 7 days/week, depending on the mine schedule and whether or not there is adequate fine ore storage capacity to keep the mill supplied with ore when the crusher is shut down for repairs or regular maintenance.

The cost guides in this section are based on the assumption that the mill capacity is 71% of the daily tonnage mined 5 days/week, and that the crushing plant has the same daily capacity as the mine, but will work 6 days/week to ensure that the mill will be supplied with crushed ore if the fine ore bins have insufficient capacity to keep the mill supplied with ore during the two-day mine shutdown. In all cases where costs are presented as a function of T tons of ore daily, the number T is the daily capacity in tons of the facility being costed, regardless of whether the facility works 5, 6, or 7 days/week.

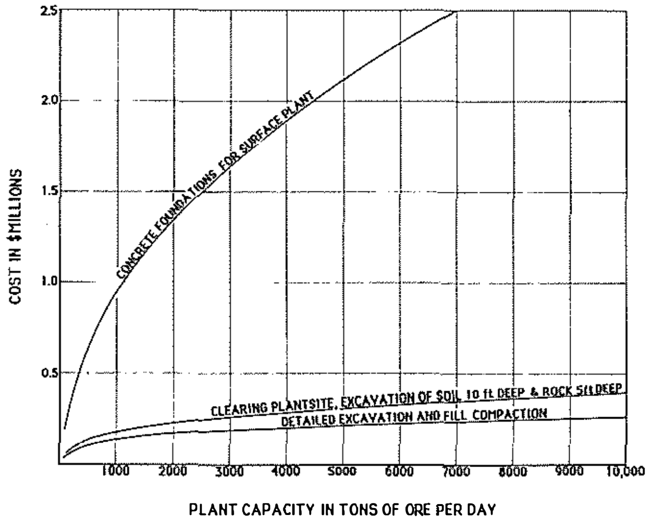

Fig. 6.3.14. Surface plant clearing, excavation, and foundations.

Clearing Costs for Concentrator, Crushing Plant, and Service Facilities: The area A in acres that must be cleared (Fig. 6.3.14) of trees, roots, and shrubs before construction of the concentrator and related facilities can begin is shown in Eq. 6.3.33. In addition to this clearing, roads must be constructed from the nearest existing suitable road to provide access to the site of the concentrator, the hoisting plant, the proposed tailings basin, and the source of water supply.

Costs for clearing and access roads for the surface plant are estimated to be:

Clearing costs $= \$2000\,A^{0.9}$ for lightly treed area with slopes of not more than 20% gradient (6.3.123)

Access roads $= \$280{,}000$ per mile for 30-ft (9-m) wide graveled road in mildly hilly region (6.3.124)

These formulas should be modified ±30% for more adverse or more favorable slope and tree growth conditions.

Excavation of Overburden: Soil overburden must be stripped wherever buildings and facilities are to be sited. The cost of stripping soil overburden *Do* feet deep over an area of *A* acres will be:

$$\text{Cost of soil stripping} = \$1000\,A^{0.8}\,Do \qquad (6.3.125)$$

After the soil overburden is removed and the underlying rock or basal strata is exposed, this rock or strata will require localized removal, probably by drilling and blasting, to establish sound foundation conditions over levelled areas for the plant buildings and plant equipment. If there are *Cu* cubic yards of rock requiring drilling, blasting, and haulage to a dump site, this mass excavation will cost:

$$\text{Cost of mass excavation:} = \$200\,Cu^{0.7} \qquad (6.3.126)$$

for excavations of up to 100,000 yd³ (76 km³)

If the mass excavation is in rock that can be broken by ripping, the mass excavation will cost only 20% of the foregoing costs.

When the mass excavation has been completed, detailed excavation to tailor the rock surface to the exact levels for pouring concrete foundations can be done. At the same time, suitable fill will be placed and compacted over level areas where deep trenches of soft soil have been removed. If there are *Cd* cubic yards of rock to be excavated by detailed excavation and *Fc* cubic yards of compacted fill to be placed, the cost will be:

$$\text{Excavation and fill compaction} = \$850\,Cd^{0.6} + \$75\,Fc^{0.7} \qquad (6.3.127)$$

Concrete Foundations for Concentrator Building: Concrete costs for the foundations of the concentrator building, fine ore bins, and concentrator equipment probably will cost between \$350 and \$900/yd³, depending on whether the concrete pour is for a simple form with little reinforcing steel or for a complex form that is heavily reinforced. The concrete cost may be significantly higher per cubic yard if concrete is scheduled to be poured in winter months when the temperature is below 40°F (4.4 °C) and heating of aggregate and water and heating of concrete forms is required for sound concrete.

It is difficult to estimate the shape and volume of concrete forms before these forms have been designed, and hence concrete costs related to concrete volume are unreliable for preliminary estimation.

$$\text{Approximate concrete foundation costs} = \$30{,}000\,T^{0.5} \qquad (6.3.128)$$

for concentrators milling *T* tons daily (assuming no difficulties).

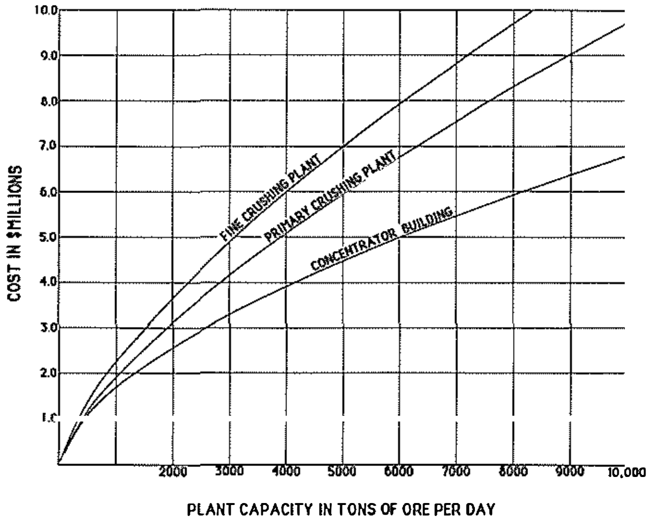

Fig. 6.3.15. Concentrator building and crushing plant costs.

Concentrator Building Costs: The cost of the concentrator building (Fig. 6.3.15) includes all costs of constructing the building above the concrete foundations and enclosing the building, plus the cost of internal offices, laboratories, and changerooms; however, it does not include the cost of process equipment, piping, or electrical wiring, because these items are included in the costs of each functional area. The equipment in operating concentrators generates a substantial amount of heat and comfortable working conditions can be attained with little or no insulation, as long as the concentrator is located in a region with a mild climate.

$$\text{Cost of building} = \$27{,}000\,T^{0.6} \qquad (6.3.129)$$

for flotation mills milling *T* tons of ore daily and located in a mild climate.

A "mild climate" is defined as a region where the degree days are about 7000 (in °F) or 4000 (in °C) per year. Weather stations usually record the "degree days" (°F × *D*, or °C × *D*), which represents the average number of days times the degrees that the temperature is below 65°F or 18°C. In hot climates, where freezing temperatures are not experienced, the building costs may be reduced by only partially enclosing the building and by locating thickeners and other hydrometallurgical equipment outside the building. In cold climates, the additional cost of insulation, heating, and snow loading is likely to increase the building cost by about 10% for each increase of 1800°F × *D* above 7000 (or 1000°C × *D* above 4000).

Primary Crushing Plant with Gyratory Crusher: Although nearly all underground mines place the primary crusher underground to eliminate problems in loading skips and conveyors prior to hoisting the ore, open pit mines generally place the primary crusher on the surface outside the pit, within convenient conveying distance to the coarse ore stockpile and the fine ore crushing plant. Open pit trucks normally discharge ore into a truck dump grizzly mounted over the gyratory crusher, which discharges crushed ore to a conveyor. Because of the headroom required to operate and discharge the crushed ore from a gyratory crusher, a substantial excavation and volume of concrete is required for the primary crusher plant. The cost of the primary crusher depends on the size and capacity of the gyratory crusher selected for an open pit mining *T* tons of ore daily:

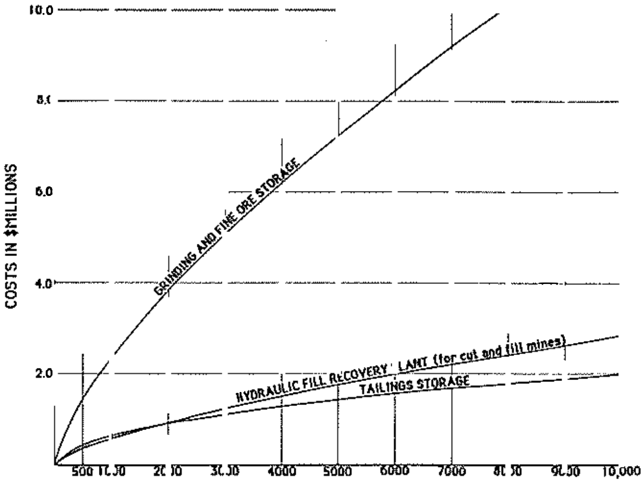

Fig. 6.3.16. Grinding, storage bins, and tailings storage.

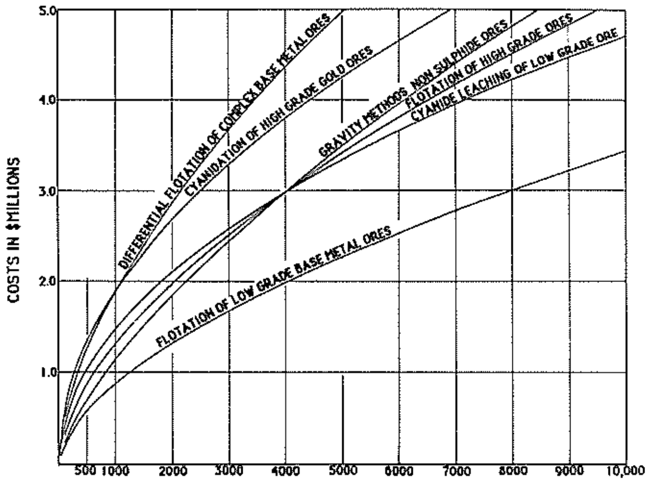

Fig. 6.3.17. Costs of processing section.

$$\text{Cost of gyratory crusher} = \$63\ T^{0.9} \tag{6.3.130}$$

The cost of excavating and concreting the foundations for the primary crusher, installing the crusher, construction of the truck dump and grizzly, plus the coarse ore conveyor and feeder under the crusher is:

$$\text{Cost of primary crushing plant} = \$15{,}000\ T^{0.7} \quad \text{(excluding crusher cost)} \tag{6.3.131}$$

Cost of Fine Ore Crushing and Conveyors: This cost includes the crushing plant building, installed equipment and conveyors.

$$\text{Cost of fine ore crushing plant} = \$18{,}000\ T^{0.7} \tag{6.3.132}$$

Note: Cost may be 12% higher if conveyors must be enclosed and heated.

Grinding Section and Fine Ore Storage Costs: The fine storage bins must have sufficient live capacity to provide mill feed for at least the number of days that the crushing plant is idle per week. The cost of the fine ore bins (Fig. 6.3.16) will be proportional to the weight of steel used in constructing these bins, and the weight of steel will be proportional to $T^{0.7}$, where T is the tons of ore milled daily.

The size and cost of the grinding mills depend on the tons of ore to be ground daily by each mill, but they also depend on the hardness of the ore as measured by the work index and the fineness of grind that is required to attain the desired concentration and recovery of valuable minerals.

Cost of grinding and bins = $\$18{,}700\ T^{0.7}$ for medium hard ore with a work index of 15, ground to 70% passing 200 mesh (6.3.133)

= $\$12{,}500\ T^{0.7}$ for soft ores ground to 55% passing 200 mesh (6.3.134)

= $\$22{,}500\ T^{0.7}$ for hard ores with a work index of higher than 17, ground to 85% passing 200 mesh (6.3.135)

Cost of Processing Section and Related Sections: The capital costs in this section cover the purchase and installation of all equipment required to concentrate or extract valuable minerals from the slurried ground ore, and process the concentrates or extracted minerals into dried solids or impure metals that are directly salable as dry concentrates, ingots of precious metals, uranium yellowcake, or impure metallic gravity concentrates of alloy metals. These capital costs include equipment and tanks for thickening, filtering, precipitation, leaching, solvent extraction, etc., plus all process piping, electrical wiring, and process control.

Process costs (Fig. 6.3.17) for different types of ore by different methods are listed in the following in relation to the tons of ore milled daily T.

1. High-grade gold ores leached by cyanidation, followed by zinc dust precipitation of gold by Merrill Crowe process, filtering, drying, and gold refining:

$$\text{Process capital costs} = \$60{,}200\ T^{0.5} \tag{6.3.136}$$

2. Low-grade ores, cyanide leaching, CIP (carbon-in-pulp) or CIL (carbon-in-leach) adsorption, refining:

$$\text{Process capital costs} = \$47{,}300\ T^{0.5} \tag{6.3.137}$$

3. High-grade gold ores with base metal sulfides; cyanide leaching, secondary flotation, carbon adsorption by CIP or CIL process, filtering, thickening, drying, and refining:

$$\text{Process capital costs} = \$103{,}200\ T^{0.5} \tag{6.3.138}$$

4. Simple low-grade base metal ores of copper with minor content of gold, which can be recovered as smelter credits. Flotation, thickening, filtering, and drying of auriferous copper concentrates:

$$\text{Process capital costs} = \$13{,}700\ T^{0.6} \tag{6.3.139}$$

5. Pyritic gold/silver ores where the precious metals are locked in the pyritic minerals. Differential flotation, selective roasting, recovery of deleterious materials, cyanidation, thickening, precipitation, filtering, and refining.

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$$\text{Process capital costs} = \$180{,}000\ T^{0.5} \tag{6.3.140}$$

6. High-grade Cu/Pb ores, Cu/Zn ores, Pb/Zn ores, Cu/Ni ores. Recovery by differential flotation, thickening, filtering, and drying of separate concentrates:

$$\text{Process capital costs} = \$20{,}600\ T^{0.6} \tag{6.3.141}$$

7. Complex base metal ores containing at least three valuable metals, with recoverable minor amounts of precious metals; Cu/Zn/Pb ores, Pb/Zn/Ag ores, Cu/Pb/Ag ores, Cu/Zn/Au ores. Recovery by differential flotation, separate thickening, filtering, and drying of several concentrates and/or bulk concentrates.

$$\text{Process capital costs} = \$30{,}100\ T^{0.6} \tag{6.3.142}$$

8. Nonsulfide ores containing specialty metals such as columbium (niobium), tantalum, tungsten, and tin in minerals that do not respond to flotation, and which are separated by specialized gravity concentration methods:

$$\text{Process capital costs} = \$5000\ T^{0.7} \text{ to } \$13{,}000\ T^{0.7} \tag{6.3.143}$$

9. Uranium ores: acid leaching, countercurrent decantation, clarification, solvent extraction and yellowcake precipitation:

$$\text{Process capital costs} = \$150{,}000\ T^{0.5} \text{ to } \$200{,}000\ T^{0.5} \tag{6.3.144}$$

Capital Cost of Initial Tailings Storage: There are many aspects of tailings storage such as topography, distance from mill to tailings site, localized environmental concerns, etc., that could drastically alter the costs of tailings storage. If, however, all adverse aspects are absent, and a suitable tailings site is available within two miles of the mill, and the nature of the tailings does not have adverse environmental effects, the minimum cost of tailings storage may be:

$$\text{Minimum tailings storage cost} = \$20{,}000\ T^{0.5} \tag{6.3.145}$$

Very few mines have such favorable conditions, and if the area topography is steep or the environmental constraints are stringent, the tailings storage costs could be several times as high as the foregoing cost guide.

Capital Costs of Hydraulic Fill Recovery/Storage: If the underground mine uses the cut and fill stoping method, the hydraulic fill requirements usually can be attained from the tailings by cyclone recovery of the coarser sizes in the ground tailings. The recovery of suitable fill material is usually imposed on the mill plant personnel, as is the storage and slurrying of the recovered fill. The cost of the fill recovery and storage plant is:

$$\text{Cost of fill recovery and storage} = \$4500\ T^{0.7} \tag{6.3.146}$$

Capital Cost of Water Supply System: The cost of fresh water pumping plants, reclaim water plants, and provision for fire protection water supply, plus potable water supply, varies according to the local topography and the proximity and nature of nearby sources of year-round supplies of water. If there is a suitable source of water within two miles of the mill, and the intervening topography is moderately level, the water supply system would cost:

$$\text{Cost of water supply system} = \$14{,}000\ T^{0.6} \tag{6.3.147}$$

The cost of the water supply system for the mine, mill, and

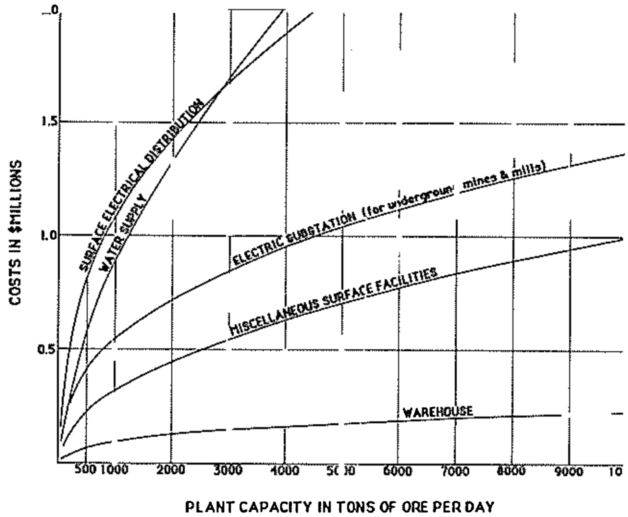

Fig. 6.3.18. Costs of plant service facilities.

plant (but excluding the mine water distribution system) will be much higher if the local topography is steep and rugged or if there are severe constraints on sources of fresh water.

Cost of Electrical Substation and Surface Electrical Distribution: The capital cost of electrical facilities for a mining/milling plant depends primarily on the size of the electrical peak load in kilowatts, which can be estimated by Eqs. 6.3.27 and 6.3.28. The cost of power supply depends on whether the power is generated by an existing electric utility or by a mine diesel-electric plant. Small mines in remote areas may be forced to generate their own electric power, because the cost of a lengthy transmission line from an existing utility may be too high due to the low peak load and low electric power consumption of a small mine.

If the mine is supplied with utility power, the cost of a utility substation with step-down transformers will be

$$\text{Cost of substation} = \$580\ (\text{kW})^{0.8} \tag{6.3.148}$$

where kW is peak load.

The cost of installing low-voltage power distribution to the surface concentrator, crushing plant, and surface facilities, including the mine hoist and compressor plant but excluding the distribution to the surface open pit or the underground mine, is likely to be

$$\text{Cost of surface power distribution} = \$1150\ (\text{kW})^{0.8} \tag{6.3.149}$$

A diesel-electric generating plant may be required for a small mine in a remote area or by a larger mine supplied with utility power that may require a standby electric power plant for protection of vital equipment.

Costs of plant service facilities are shown in Fig. 6.3.18.

$$\text{Cost of diesel-electric plant} = \$6000\ (\text{kW})^{0.8} \tag{6.3.150}$$

Cost of General Plant Services: These costs include the costs of constructing, furnishing, and equipping the general administrative office, general warehouse, electrical and mechanical repair shop (for smaller mill equipment and services equipment), vehicle garages, changehouses, first aid and mine rescue stations, security stations plus general purpose vehicles, parking lots, and yard fencing.

The size of the buildings tends to depend on the number of employees served by each building, which can be estimated by Eqs. 6.3.2 to 6.3.26. It is necessary to estimate the building size in square feet before estimating building cost, which will vary with the area of each type of building.

1. Administrative office. The floor space per person tends to increase as the number of administrative and technical staff *Nat* becomes larger. This reflects the more complex records of accounting and technical staff and the consequent requirement of more space for computer facilities, mining plans, and reference file facilities.

$$\text{Office area } A \text{ required in ft}^2 = 35\ (Nat)^{1.3} \qquad (6.3.151)$$

$$\text{Cost of office} = \$155\ A^{0.9} \qquad (6.3.152)$$

2. Surface plant maintenance shop. Maintenance personnel *Nsv* will require about 85 ft²/person for maintenance and repair of movable equipment from the mill and service departments.

$$\text{Cost of shop} = \$102 \times (85 \times Nsv)^{0.9} \qquad (6.3.153)$$

3. Mine changehouse. The mine changehouse requires about 24 ft²/person on the mine payroll (*Nmn* for underground mines or *Nop* for open pit mines) and includes the first aid station and mine rescue facilities.

$$\text{Changehouse cost} = \$125 \times (24 \times Nmn)^{0.9} \qquad (6.3.154)$$

4. Surface warehouse. This should accommodate all supplies and spare parts for the mine, mill, and service facilities that must be kept indoors. Bulky supplies such as rough lumber, structural steel, etc., can be stored outdoors in most climates.

$$\text{Surface warehouse cost} = \$5750\ T^{0.4} \qquad (6.3.155)$$

where T is tons milled per day.

5. Miscellaneous surface facilities. This includes general purpose vehicles and garages, security stations and fencing, parking lots, and miscellaneous services.

$$\text{Miscellaneous surface facilities} = \$10{,}000\ T^{0.5} \qquad (6.3.156)$$

6.3.3.4 Mine Project Overhead Costs

In addition to the direct costs for specific facilities for a mine project, which may total many millions of dollars, there are substantial costs and expenses involved in project design, general site costs, supervision and administration, and provision of working capital. These overhead costs (Fig. 6.9.19) may be estimated as a function of the total direct costs D in dollars.

Engineering: This includes the costs of feasibility studies, environmental impact studies, design engineering, equipment specifications and procurement, and specialized consulting services:

$$\text{Engineering costs} = \$2.30\ D^{0.8} \qquad (6.3.157)$$

General Site Costs: This includes construction camp costs, specialized construction equipment, and general construction site costs:

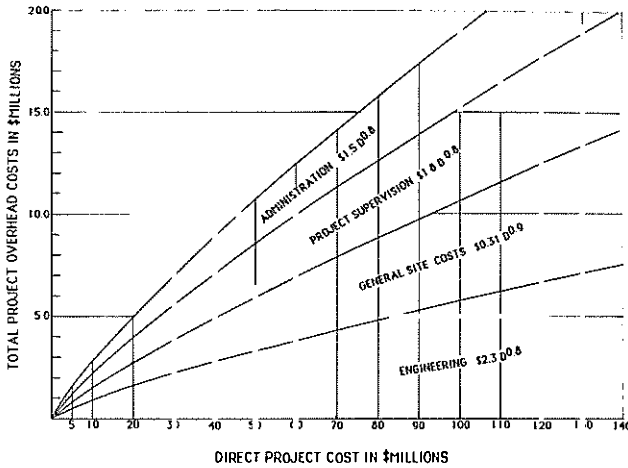

Fig. 6.3.19. Project overhead vs. direct costs.

$$\text{General site costs} = \$0.310\ D^{0.9} \qquad (6.3.158)$$

Project Supervision: This includes project supervision, scheduling and budgeting, and construction management:

$$\text{Project supervision costs} = \$1.80\ D^{0.8} \qquad (6.3.159)$$

Administration: This includes local office administration by corporate owner's representatives, accounting and payment of general contractor, legal costs, plus preproduction employment of key operating staff:

$$\text{Administration costs} = \$1.50\ D^{0.8} \qquad (6.3.160)$$

Project overhead costs as a percentage of direct project costs tend to vary depending on the size and complexity of the project; the lower percentages of 4 to 6% would be typical for $100 million projects and conventional technology, whereas the higher percentages of 8 to 11% would apply to smaller $10 million projects that are technically novel or complex.

Working Capital: The allowance for working capital for a mining project should be sufficient to cover all operating costs plus purchase of the initial inventory of capital spares and parts until revenue is received from smelters or purchasers of metallic products. The time period elapsing before receipt of revenue sufficient to pay imminent operating costs will vary depending on the smelter terms or marketing terms, but the typical allowance is about 10 weeks after the concentrator is operating at full capacity.

Typical working capital allowance
= operating costs for 10 weeks

after commissioning of concentrator plus cost of purchasing initial inventory of capital spares and parts.

Whenever the mine or mill design is based on extensive usage of reconditioned used equipment, there is a higher frequency of equipment downtime that requires additional time allowance of working capital; this will decrease the apparent savings of used equipment.

6.3.4 COST GUIDES FOR OPERATING COSTS OF MINES AND MILLS

The cost guides provided in the form cost $= KT^x$ compute the cost of each mining activity as a function of the tons T of ore mined and express this cost as a cost per day of mining activity. The cost per ton can be derived from the formula by dividing the cost per day by the tons mined per day so that cost per ton = KT^x/T which equals $K/T^{(1-x)}$. Thus if 100 $T^{0.7}$ represents the cost per day, the cost per ton = $100/T^{0.3}$.

When a mine is producing T tons per day from all mining methods, but the mining method being costed produces only t tons of ore per day, then the cost of the mining method per day equals $Kt/T^{(1-x)}$, although the cost per ton remains at K/T^{1-x}.

6.3.4.1 Underground Mine Operating Costs per Day

The cost per day for different mining methods includes the cost of labor and supplies for drilling, blasting, ground support, loading, and haulage of stoped ore from each stope. This cost covers work done by the stoping and mucking crew only and does not include labor and supplies involved in crushing, transport, and hoisting of ore; neither does it include general mine services, supervision, or mine activities that are not specific to the mining methods being used to recover ore from the stopes.

Stoping Costs:

1. Shrinkage stoping costs	= \$146 $T^{0.6}$ per day	(6.3.161)
2. Cut and fill stoping costs	= \$185 $T^{0.6}$ per day	(6.3.162)
3. Fill distribution	= \$22 $T^{0.7}$ per day	(6.3.163)
4. Longhole stoping costs	= \$160 $T^{0.6}$per day	(6.3.164)
5. Fill distribution for bulk filling longhole stopes	= \$12 $T^{0.7}$ per day	(6.3.165)
6. VCR stoping costs	= \$125 $T^{0.6}$ per day	(6.3.166)
7. Room and pillar stoping costs (hard rock)	= \$130 $T^{0.6}$ per day	(6.3.167)
8. Room and pillar stoping costs (soft rock)	= \$85 $T^{0.6}$ per day	(6.3.168)
9. Sublevel caving costs	= \$115 $T^{0.6}$ per day	(6.3.169)
10. Block caving costs	= \$105 $T^{0.6}$ per day	(6.3.170)

These cost guides to stoping costs are based on the presumption that the stope widths (or heights) are as follows: shrinkage 8 ft (2.4 m), cut and fill 15 ft (4.6 m), longhole stoping and VCR stoping 30 ft (9.1 m), room and pillar stoping 12 ft (3.7 m) high, but if the actual width W (or height H) differs from the assumed width Wa (or height Ha), the stoping costs should be corrected by the ratio of the assumed width divided by the actual width with the quotient taken to the 0.4 power.

$$\text{Stoping cost correction} = (Wa/W)^{0.4}, \text{ or } (Ha/H)^{0.4} \quad (6.3.171)$$

Stope Preparation Costs per Day: Stope preparation costs may be estimated as follows:

Preparation costs = \$85 $T^{0.48}$ $W^{0.2}$ for shrinkage stopes (6.3.172)
= \$9.60 $T^{0.7}$ $W^{0.5}$ for cut and fill stopes (6.3.173)
= \$19.20 $T^{1.06}/W^{0.6}$ for blasthole stopes (6.3.174)
= \$29.04 $T^{1.04}/W^{0.6}$ for VCR stopes (6.3.175)
= \$2,200 $T^{0.6}$ $H^{0.2}$ for block caving stopes (6.3.176)

Crushing and Hoisting Costs per Day: When underground ore is crushed and hoisted, the cost per day depends primarily on the tons of ore crushed or hoisted per day. The size of ore fragments to be crushed or hoisted makes little difference to the daily crushing cost or daily hoisting cost; consequently the type of stoping method employed has little effect on crushing costs or hoisting costs.

$$\text{Crushing costs per day} = \$2.00\ T^{0.8} \quad (6.3.177)$$

$$\text{Hoisting costs per day} = \$4.70\ T^{0.8} \quad (6.3.178)$$

Cost of Mine General Services: This cost includes all labor and supplies required to maintain all direct mine services, including ventilation, pumping of drainage water, repair and maintenance of mine equipment, maintenance of development levels and ground support, plus mine supervisory staff. This cost includes all cost items that are not already costed previously and that are directly supervised by mine supervision; it should not include any "distributive costs," which are allocated and supervised by staff other than the mine supervision.

General service costs should be retained in the department that has supervisory responsibility over the activity that incurred these costs. Thus the cost of electric power utilized by the mine, concentrator, and general services should not be allocated to each department on some expedient basis, unless each departmental usage of electric power is metered directly and for which the departmental supervision is to be held accountable.

Thus the cost formulas shown in the following for mine general services apply only for those costs that are committed by personnel under the supervision of mine staff.

$$\text{Cost of mine general services} = \$75\ T^{0.8} \quad (6.3.179)$$

$$\text{Cost of mine supervision} = \$12\ T^{0.7} \quad (6.3.180)$$

6.3.4.2 Open Pit Operating Costs per Day

The operating costs of open pit mines depends on the size and numbers of drills, shovels, and trucks, which in turn is dependent on the tons per day of ore and waste. In most open pit mines mining low grade ore, there is little if any difference in the specific gravities, blasting characteristics, and drillabilities of ore or waste, and the haulage distance to the ore dump usually does not differ very much from the waste haulage distance. Consequently, the cost of mining a ton of ore will be virtually the same as the cost of mining a ton of waste.

The cost of open pit mining can be assessed against the total ore and waste tonnage (T_p) mined daily.

Drilling cost per day	= \$ 1.90 $T_p^{0.7}$	(6.3.181)
Blasting cost per day	= \$ 3.17 $T_p^{0.7}$	(6.3.182)
Loading cost per day	= \$ 2.67 $T_p^{0.7}$	(6.3.183)
Haulage cost per day	= \$18.07 $T_p^{0.6}$	(6.3.184)
General services cost per day	= \$ 6.65 $T_p^{0.7}$	(6.3.185)

The open pit general services cost includes the cost of pit maintenance, road grading, waste dump grading, pumping, and open pit supervision, but it does not include the cost of primary crushing or electric power.

6.3.4.3 Concentrator and Services Operating Costs per Day

The operating costs per day for the crusher, concentrator, and general surface facilities are grouped together, because these costs are generally interrelated in terms of sequential activities applied to the run-of-mine ore as received from the mine to convert this ore into a salable product shipped from the plant to the purchaser. Thus, although the gyratory crusher may be located at the edge of the open pit, the costs of operating it are grouped under milling costs, rather than as open pit operating costs, as the first stage of ore treatment. Conversely, the cost of operating an underground jaw crusher is usually considered a mining cost because it is operated and repaired by the mine crew.

The cost of treatment of tailings in storage, or the cost of recovery of coarse tailings for mine backfill, and the cost of gold refining, or the contract trucking of concentrates from the mill to the purchaser, can be regarded as the final stages of ore treatment.

Operating costs that apply to the complete mining and milling plant, such as electric power consumption, which is metered only at the main electric substation, is grouped with concentrator costs. This results because the concentrator is usually the largest consumer of power in the mining and milling complex, and because most attempts to allocate power costs to different sections of the plant are uncertain at best, unless the power distribution to each section of the plant is separately metered.

The design of the milling flowsheet is usually optimized after extensive testwork on the types of processes tailored to the characteristics of the ore; at the preliminary feasibility stage however, the optimum processing requirements are not known with accuracy, and the costs of processing can only be approximately estimated.

The following cost guides are offered as rough estimates of crushing and concentrating costs per day.

Primary Crushing Costs per Day: This cost includes the cost of primary crushing, the cost of conveying the primary crushed ore to the coarse ore stockpile, plus operating costs of the coarse ore stockpile.

Crushing costs per day = \$7.90 $T^{0.6}$ for open pits and mills (6.3.186)

= \$2.00 $T^{0.8}$ for underground mines and mills (usually included in mining costs) (6.3.187)

Fine Crushing and Conveying Costs per Day: This includes fine crushing, conveying from coarse ore storage, and conveying to the fine ore bins.

Fine crushing costs per day = \$12.60 $T^{0.6}$ (6.3.188)

Grinding and Fine Ore Bins Cost per Day: This cost includes the fine ore bin storage and the rod mills, ball mills, and/or SAG (semiautogenous grinding) mills:

Grinding section costs per day = \$4.90 $T^{0.8}$ (6.3.189)

Process Section Costs per Day: This includes the operating costs of all sections that involve concentration of ore by flotation or by gravity, leaching of metals from ore, thickening of slurries, ion exchange, precipitation, filtering, drying, and recovery of metallic concentrates, or deleterious materials that would otherwise penalize smelter revenue.

Processing costs per day = \$65.00 $T^{0.6}$ for cyanidation of gold/silver ores (6.3.190)

= \$54 $T^{0.6}$ for flotation of simple base metal ores (6.3.191)

= \$34 to \$41 $T^{0.7}$ for complex base metal ores varying in complexity (6.3.192)

= \$65 $T^{0.7}$ for uranium ores by leaching, CCD, solvent extraction, and precipitation (6.3.193)

= \$45 $T^{0.7}$ for nonflotable nonsulfide ores responding to gravity separation (6.3.194)

Tailings costs per day = \$0.92 $T^{0.8}$ for all concentrators (6.3.195)

Assaying costs per day = \$1.27 $T^{0.8}$ for all concentrators (6.3.196)

Supervision, maintenance, and general costs per day = \$40.80 $T^{0.6}$ for all concentrators (6.3.197)

Processing costs should be decreased to 55% of those shown by the foregoing formulas when low-grade ore, typically mined by open pit mining, is being treated by a concentrator that rejects tailings at an early stage.

Electrical Power Costs per Day: The peak load and daily electric power consumption of the mine plant, consisting of an underground mine or open pit, crushing plant and concentrator, plus surface services and general administration office can be estimated from Eqs. 6.3.27, 6.3.28, 6.3.29, and 6.3.30. These equations indicate that a small underground mine and plant processing 500 tpd (454 t/day) of ore will have a peak load of about 3700 kW, and a daily consumption of about 62,000 kWh.

Under these conditions, the unit cost of power is typically about 8¢/kWh, and the unit cost is normally reduced for larger mines that use larger quantities of electric power. Usually, the unit cost of electric power is reduced in stages by about 4.3% each time the power consumption is doubled, and by using these typical assumptions, it is possible to estimate the daily cost of electric power for mines and mills larger than 500 tpd.

Cost of electric power = \$ 164 $T^{0.56}$/day for underground mines and plants processing T tons of ore/day (6.3.198)

= \$145 $T^{0.56}$/day for open pit mines and plants processing T tons of ore/day (6.3.199)

Surface Services Cost per Day: The daily cost of each person in the surface maintenance and general services departments is estimated to be \$141 in wages and fringe benefits, plus an average cost of \$16 in supplies consumed. If the number of maintenance and general services personnel is Nsv as estimated from Eqs. 6.3.22, 6.3.23, and 6.3.24, then the daily costs of maintenance and general services departments is

Services cost per day = \$157 Nsv (6.3.200)

Costs of Administration and Technical Staff: The daily costs of the administrative and technical staff, including supplies and services required by them, plus fixed costs for local property taxes and legal fees paid by administrative services, are proportional to the number of staff Nat, as estimated in Eqs. 6.3.25 and 6.3.26.

Each staff person is estimated to cost on the average \$185 in salary per day, and to consume \$37.60 in supplies and services per day.

Total cost per day for administrative and technical staff salaries and supplies = \$222.60 *Nat* (6.3.201)

6.3.5. CONCLUSION

The consequences of inaccurate estimation of capital and operating costs in feasibility studies may include the commitment of major amounts of capital funds before it is realized that the mining project will not be profitable, or the rejection of a proposed mining project that could be profitable. Accurate cost estimation is possible only after a substantial amount of technical activity has been competently completed. This technical activity should include the following:

General mine planning of all mine development, including scaled maps and drawings from which the lengths, quantities, and unit costs of all mine excavations and openings can be estimated.

Assessment of the sizes, types, numbers, and prices of mine and mill equipment that will be required for the planned rate of production.

Environmental impact studies for the regional area surrounding the proposed mine site and the nature and content of all fluids and gases that will be discharged from the mine and plant.

Metallurgical tests of bulk samples of mine ore treated by the proposed concentrator process.

General plant layout must be completed to show the dimensions of all plant buildings and the depth and amount of excavation required for sound building and equipment foundations. Access roads, transmission lines, water lines, and tailings lines must be mapped and the topography contoured.

Cost formulas can provide some guidance as to the order to magnitude of capital and operating costs, but the accurate estimation of costs depends on measured quantities taken from the design planning, plus unit costs quoted by contractors or derived from unit costs of recently completed projects similar in nature. In general, the accurate estimation of project costs must be entrusted to consulting engineering firms and project management firms with experience in many similar projects.

Most mining engineers employed in operating mines do not have the necessary expertise or training to determine the design features or costs of surface mining plants, and these should be determined by experienced firms employing engineers skilled in civil, structural, mechanical, chemical, metallurgical, and electrical engineering.

Additional assistance in cost estimation may be obtained from the following sources or publications:

1. *General Construction Estimation Standards,* 6 volumes, revised annually, published by Richardson Engineering Services, Inc., P.O. Box 1055, San Marcos, CA 92069.

2. *Means Construction Costs,* revised annually, and published by Robert Snow Means Co. Inc., 100 Construction Pl., Kingston, MA 02364.

3. *US Bureau of Mines Cost Estimating System Handbook,* 2 volumes, Information Circular 9142 (surface and underground mining), and Information Circular 9143 (mineral processing). Mining and milling costs are as of January 1984. The two volumes, IC 9142 and IC 9143, are available from the Superintendent of Documents, US Government Printing Office, Washington, DC 20402

4. *Canadian Construction Costs: Yardsticks for Costing,* revised annually; available from Southam Business Publications, 1450 Don Mills Rd., Don Mills, ON, Canada, M3B 2X7.

5. *Mining and Mineral Processing Equipment Costs and Preliminary Capital Cost Estimations,* Special Vol. 25, 1982; published by The Canadian Institute of Mining and Metallurgy, 1 Place Alexis Nihon, 1210-3400 de Maisonneuve Blvd. W., Montreal, PQ, Canada H3Z 3B8.

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