W. HUSTRULID, M. KUCHTA AND R. MARTIN

OPEN PIT MINE PLANNING & DESIGN

3RD EDITION

1. FUNDAMENTALS

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OPEN PIT MINE PLANNING & DESIGN
VOLUME 1 – FUNDAMENTALS

OPEN PIT MINE PLANNING & DESIGN

Volume 1 – Fundamentals

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Contents

Preface to the 3rd Edition

The first edition of *Open Pit Mine Planning and Design* appeared in 1995. Volume 1, the "Fundamentals", consisted of six chapters

1. Mine Planning
2. Mining Revenues and Costs
3. Orebody Description
4. Geometrical Considerations
5. Pit Limits
6. Production Planning

totaling 636 pages. Volume 2, the "CSMine Software Package" was written in support of the student- and engineer-friendly CSMine pit generation computer program included on a CD enclosed in a pocket inside the back cover. This volume, which contained six chapters and 200 pages, consisted of (1) a description of a small copper deposit in Arizona to be used for demonstrating and applying the mine planning and design principles, (2) the CSMine tutorial, (3) the CSMine user's manual, and (4) the VarioC tutorial, user's manual and reference guide. The VarioC microcomputer program, also included on the CD, was to be used for the statistical analysis of the drill hole data, calculation of experimental variograms, and interactive modeling involving the variogram. The main purpose of the CSMine software was as a learning tool. Students could learn to run it in a very short time and they could then focus on the pit design principles rather than on the details of the program. CSMine could handle 10,000 blocks which was sufficient to run relatively small problems.

We were very pleased with the response received and it became quite clear that a second edition was in order. In Volume 1, Chapters 1 and 3 through 6 remained largely the same but the reference lists were updated. The costs and prices included in Chapter 2 "Mining Costs and Revenues" were updated. Two new chapters were added to Volume 1:

7. Reporting of Mineral Resources and Ore Reserves
8. Responsible Mining

To facilitate the use of this book in the classroom, review questions and exercises were added at the end of Chapters 1 through 8. The "answers" were not, however, provided. There were several reasons for this. First, most of the answers could be found by the careful reading, and perhaps re-reading, of the text material. Secondly, for practicing mining engineers, the answers to the opportunities offered by their operations are seldom provided in advance. The fact that the answers were not given should help introduce the student to the real world of mining problem solving. Finally, for those students using the book under the guidance of a professor, some of the questions will offer discussion possibilities. There is no single "right" answer for some of the included exercises.

In Volume 2, the CSMine software included in the first edition was written for the DOS operating system which was current at that time. Although the original program does work in the Windows environment, it is not optimum. Furthermore, with the major advances in computer power that occurred during the intervening ten-year period, many improvements could be incorporated. Of prime importance, however, was to retain the user friendliness of the original CSMine. Its capabilities were expanded to be able to involve 30,000 blocks.

A total of eight drill hole data sets involving three iron properties, two gold properties and three copper properties were included on the distribution CD. Each of these properties was described in some detail. It was intended that, when used in conjunction with the CSMine software, these data sets might form the basis for capstone surface mine designs. It has been the experience of the authors when teaching capstone design courses that a significant problem for the student is obtaining a good drillhole data set. Hopefully the inclusion of these data sets has been of some help in this regard.

The second edition was also well received and the time arrived to address the improvements to be included in this, the 3rd edition. The structure and fundamentals have withstood the passage of time and have been retained. The two-volume presentation has also been maintained.

However, for those of you familiar with the earlier editions, you will quickly notice one major change. A new author, in the form of Randy Martin, has joined the team of Bill Hustrulid and Mark Kuchta in preparing this new offering. Randy is the "Mother and Father" of the very engineer-friendly and widely used MicroMODEL open pit mine design software. As part of the 3rd edition, he has prepared an "academic" version of his software package. It has all of the features of his commercial version but is limited in application to six data sets:

- Ariz_Cu: the same copper deposit used with CSMine (36,000 blocks)
- Andina_Cu: a copper deposit from central Chile (1,547,000 blocks)
- Azul: a gold deposit from central Chile (668,150 blocks)
- MMdemo: a gold deposit in Nevada (359,040 blocks)
- Norte_Cu: a copper deposit in northern Chile (3,460,800 blocks)
- SeamDemo: a thermal coal deposit in New Mexico (90,630 blocks).

Our intention has been to expose the student to more realistic applications once the fundamentals have been learned via the CSMine software (30,000 block limitation). The MicroMODEL V8.1 Academic version software is included on the CD together with the 6 data sets. The accompanying tutorial has been added as Chapter 16. Our idea is that the student will begin their computer-aided open pit mine design experience using CSMine and the Ariz_Cu data set and then progress to applying MicroMODEL to the same set with help from the tutorial.

The new chapter makeup of Volume 2 is

14. The CSMine Tutorial
15. CSMine User's Guide
16. The MicroMODEL V8.1 Mine Design Software
17. Orebody Case Examples

Volume 1, "Fundamentals", has also experienced some noticeable changes. Chapters 1 and 3 through 8 have been retained basically as presented in the second edition. The prices and costs provided in Chapter 2 have been revised to reflect those appropriate for today (2012). The reference list included at the end of each chapter has been revised. In the earlier editions, no real discussion of the basic unit operations was included. This has now been corrected with the addition of:

9. Blasting
10. Rotary Drilling
11. Shovel Loading
12. Truck Haulage
13. Equipment Availability and Utilization

Each chapter has a set of "Review Questions and Exercises".

The authors would like to acknowledge the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) for permission to include their 'Estimation of Mineral Resources and Mineral Reserves: Best Practices Guidelines' in Chapter 7. The Australasian Institute of Mining and Metallurgy (AusIMM) was very kind to permit our inclusion of the 'JORC-2004 Code' in Chapter 7. The current commodity prices were kindly supplied by Platt's Metals Week, the Metal Bulletin, Minerals Price Watch, and Skillings Mining Review. The Engineering News-Record graciously allowed the inclusion of their cost indexes. The CMJ Mining Sourcebook, Equipment Watch (a Penton Media Brand), and InfoMine USA provided updated costs. Thomas Martin kindly permitted the inclusion of materials from the book "Surface Mining Equipment". The authors drew very heavily on the statistics carefully compiled by the U.S. Department of Labor, the U.S. Bureau of Labor Statistics, and the U.S. Geological Survey. Mining equipment suppliers Atlas Copco, Sandvik Mining, Komatsu America Corporation, Terex Inc., Joy Global (P&H), Siemens Industry, Inc., and Varel International have graciously provided us with materials for inclusion in the 3rd edition. Ms. Jane Olivier, Publications Manager, Society for Mining, Metallurgy and Exploration (SME) has graciously allowed inclusion of materials from the 3rd edition, Mining Engineering Handbook. Otto Schumacher performed a very thorough review of the materials included in chapters 9 through 13. Last, but not least, Ms. Arlene Chafe provided us access to the publications of the International Society of Explosive Engineers (ISEE).

The drill hole sets included in Chapter 17 were kindly supplied by Kennecott Barneys Canyon mine, Newmont Mining Corporation, Minnesota Department of Revenue, Minnesota Division of Minerals (lronton Office), Geneva Steel and Codelco.

Finally, we would like to thank those of you who bought the first and second editions of this book and have provided useful suggestions for improvement.

The result is what you now hold in your hands. We hope that you will find some things of value. In spite of the changes that have taken place in the content of the book over the years, our basic philosophy has remained the same – to produce a book which will form an important instrument in the process of learning/teaching about the engineering principles and application of them involved in the design of open pit mines.

Another important "consistency" with this 3rd edition is the inclusion of the Bingham Pit on the cover. Obviously the pit has also changed over the years but this proud lady which was first mined as an open pit in 1906 is still a remarkable beauty! Kennecott Utah Copper generously provided the beautiful photo of their Bingham Canyon mine for use on the cover.

Important Notice – Please Read

This book has been primarily written for use as a textbook by students studying mining engineering, in general, and surface mining, in particular. The focus has been on presenting the concepts and principles involved in a logical and easily understood way. In spite of great efforts made to avoid the introduction of mistakes both in understanding and presentation, they may have been inadvertently/unintentionally introduced. The authors would be pleased if you, the reader, would bring such mistakes to their attention so that they may be corrected in subsequent editions.

Neither the authors nor the publisher shall, in any event, be liable for any damages or expenses, including consequential damages and expenses, resulting from the use of the information, methods, or products described in this textbook. Judgments made regarding the suitability of the techniques, procedures, methods, equations, etc. for any particular application are the responsibility of the user, and the user alone. It must be recognized that there is still a great deal of 'art' in successful mining and hence careful evaluation and testing remains an important part of technique and equipment selection at any particular mine.

About the Authors

William Hustrulid studied Minerals Engineering at the University of Minnesota. After obtaining his Ph.D. degree in 1968, his career has included responsible roles in both mining academia and in the mining business itself. He has served as Professor of Mining Engineering at the University of Utah and at the Colorado School of Mines and as a Guest Professor at the Technical University in Luleå, Sweden. In addition, he has held mining R&D positions for companies in the USA, Sweden, and the former Republic of Zaire. He is a Member of the U.S. National Academy of Engineering (NAE) and a Foreign Member of the Swedish Royal Academy of Engineering Sciences (IVA). He currently holds the rank of Professor Emeritus at the University of Utah and manages Hustrulid Mining Services in Spokane, Washington.

Mark Kuchta studied Mining Engineering at the Colorado School of Mines and received his Ph.D. degree from the Technical University in Luleå, Sweden. He has had a wide-ranging career in the mining business. This has included working as a contract miner in the uranium mines of western Colorado and 10 years of experience in various positions with LKAB in northern Sweden. At present, Mark is an Associate Professor of Mining Engineering at the Colorado School of Mines. He is actively involved in the education of future mining engineers at both undergraduate and graduate levels and conducts a very active research program. His professional interests include the use of high-pressure waterjets for rock scaling applications in underground mines, strategic mine planning, advanced mine production scheduling and the development of user-friendly mine software.

Randall K. "Randy" Martin studied Metallurgical Engineering at the Colorado School of Mines and later received a Master of Science in Mineral Economics from the Colorado School of Mines. He has over thirty years of experience as a geologic modeler and mine planner, having worked for Amax Mining, Pincock, Allen & Holt, and Tetratech. Currently he serves as President of R.K. Martin and Associates, Inc. His company performs consulting services, and also markets and supports a variety of software packages which are used in the mining industry. He is the principal author of the MicroMODEL® software included with this textbook.

CHAPTER 1

Mine planning

1.1 INTRODUCTION

1.1.1 *The meaning of ore*

One of the first things discussed in an Introduction to Mining course and one which students must commit to memory is the definition of 'ore'. One of the more common definitions (USBM, 1967) is given below:

Ore: A metalliferous mineral, or an aggregate of metalliferous minerals, more or less mixed with gangue which from the standpoint of the miner can be mined at a profit or, from the standpoint of a metallurgist can be treated at a profit.

This standard definition is consistent with the custom of dividing mineral deposits into two groups: metallic (ore) and non-metallic. Over the years, the usage of the word 'ore' has been expanded by many to include non-metallics as well. The definition of ore suggested by Banfield (1972) would appear to be more in keeping with the general present day usage.

Ore: A natural aggregate of one or more solid minerals which can be mined, or from which one or more mineral products can be extracted, at a profit.

In this book the following, somewhat simplified, definition will be used:

Ore: A natural aggregation of one or more solid minerals that can be mined, processed and sold at a profit.

Although definitions are important to know, it is even more important to know what they mean. To prevent the reader from simply transferring this definition directly to memory without being first processed by the brain, the 'meaning' of ore will be expanded upon.

The key concept is 'extraction leading to a profit'. For engineers, profits can be expressed in simple equation form as

$$\text{Profits} = \text{Revenues} - \text{Costs} \tag{1.1}$$

The revenue portion of the equation can be written as

$$\text{Revenues} = \text{Material sold (units)} \times \text{Price/unit} \tag{1.2}$$

The costs can be similarly expressed as

$$\text{Costs} = \text{Material sold (units)} \times \text{Cost/unit} \tag{1.3}$$

Combining the equations yields

$$\text{Profits} = \text{Material sold (units)} \times (\text{Price/unit} - \text{Cost/unit}) \tag{1.4}$$

As has been the case since the early Phoenician traders, the minerals used by modern man come from deposits scattered around the globe. The price received is more and more being set by world wide supply and demand. Thus, the price component in the equation is largely determined by others. Where the mining engineer can and does enter is in doing something about the unit costs. Although the development of new technology at your property is one answer, new technology easily and quickly spreads around the world and soon all operations have the 'new' technology. Hence to remain profitable over the long term, the mining engineer must continually examine and assess smarter and better site specific ways for reducing costs at the operation. This is done through a better understanding of the deposit itself and the tools/techniques employed or employable in the extraction process. Cost containment/reduction through efficient, safe and environmentally responsive mining practices is serious business today and will be even more important in the future with increasing mining depths and ever more stringent regulations. A failure to keep up is reflected quite simply by the profit equation as

$$\text{Profits} < 0 \tag{1.5}$$

This, needless to say, is unfavorable for all concerned (the employees, the company, and the country or nation). For the mining engineer (student or practicing) reading this book, the personal meaning of ore is

$$\text{Ore} \equiv \text{Profits} \equiv \text{Jobs} \tag{1.6}$$

The use of the mathematical equivalence symbol simply says that 'ore' is equivalent to 'profits' which is equivalent to 'jobs'. Hence one important meaning of 'ore' to us in the minerals business is jobs. Probably this simple practical definition is more easily remembered than those offered earlier. The remainder of the book is intended to provide the engineer with tools to perform even better in an increasingly competitive world.

1.1.2 *Some important definitions*

The exploration, development, and production stages of a mineral deposit (Banfield & Havard, 1975) are defined as:

Exploration: The search for a mineral deposit (prospecting) and the subsequent investigation of any deposit found until an orebody, if such exists, has been established.

Development: Work done on a mineral deposit, after exploration has disclosed ore in sufficient quantity and quality to justify extraction, in order to make the ore available for mining.

Production: The mining of ores, and as required, the subsequent processing into products ready for marketing.

It is essential that the various terms used to describe the nature, size and tenor of the deposit be very carefully selected and then used within the limits of well recognized and accepted definitions.

Over the years a number of attempts have been made to provide a set of universally accepted definitions for the most important terms. These definitions have evolved somewhat as the technology used to investigate and evaluate orebodies has changed. On February 24, 1991, the report, 'A Guide for Reporting Exploration Information, Resources and Reserves' prepared by Working Party No. 79 – 'Ore Reserves Definition' of the Society of Mining, Metallurgy and Exploration (SME), was delivered to the SME Board of Directors (SME, 1991). This report was subsequently published for discussion. In this section, the 'Definitions' and 'Report Terminology' portions of their report (SME, 1991) are included. The interested reader is encouraged to consult the given reference for the detailed guidelines. The definitions presented are tied closely to the sequential relationship between exploration information, resources and reserves shown in Figure 1.1.

With an increase in geological knowledge, the exploration information may become sufficient to calculate a resource. When economic information increases it may be possible to convert a portion of the resource to a reserve. The double arrows between reserves and resources in Figure 1.1 indicate that changes due to any number of factors may cause material to move from one category to another.

Definitions
Exploration information. Information that results from activities designed to locate economic deposits and to establish the size, composition, shape and grade of these deposits. Exploration methods include geological, geochemical, and geophysical surveys, drill holes, trial pits and surface underground openings.

Resource. A concentration of naturally occurring solid, liquid or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible. Location, grade, quality, and quantity are known or estimated from specific geological evidence. To reflect varying degrees of geological certainty, resources can be subdivided into measured, indicated, and inferred.

– Measured. Quantity is computed from dimensions revealed in outcrops, trenches, workings or drill holes; grade and/or quality are computed from the result of detailed sampling. The sites for inspection, sampling and measurement are spaced so closely and the geological character is so well defined that size, shape, depth and mineral content of the resource are well established.

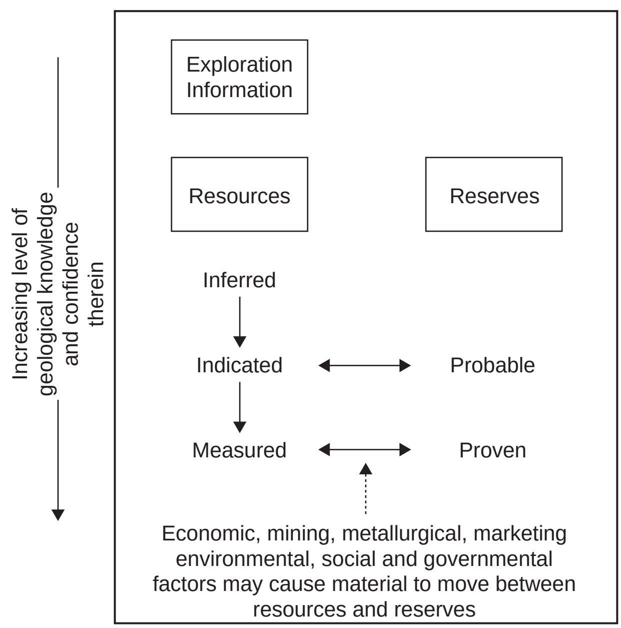


Figure 1.1. The relationship between exploration information, resources and reserves (SME, 1991).

– Indicated. Quantity and grade and/or quality are computed from information similar to that used for measured resources, but the sites for inspection, sampling, and measurements are farther apart or are otherwise less adequately spaced. The degree of assurance, although lower than that for measured resources, is high enough to assume geological continuity between points of observation.

– Inferred. Estimates are based on geological evidence and assumed continuity in which there is less confidence than for measured and/or indicated resources. Inferred resources may or may not be supported by samples or measurements but the inference must be supported by reasonable geo-scientific (geological, geochemical, geophysical, or other) data.

Reserve. A reserve is that part of the resource that meets minimum physical and chemical criteria related to the specified mining and production practices, including those for grade, quality, thickness and depth; and can be reasonably assumed to be economically and legally extracted or produced at the time of determination. The feasibility of the specified mining and production practices must have been demonstrated or can be reasonably assumed on the basis of tests and measurements. The term reserves need not signify that extraction facilities are in place and operative.

The term economic implies that profitable extraction or production under defined investment assumptions has been established or analytically demonstrated. The assumptions made must be reasonable including assumptions concerning the prices and costs that will prevail during the life of the project.

The term 'legally' does not imply that all permits needed for mining and processing have been obtained or that other legal issues have been completely resolved. However, for a reserve to exist, there should not be any significant uncertainty concerning issuance of these permits or resolution of legal issues.

Reserves relate to resources as follows:

– Proven reserve. That part of a measured resource that satisfies the conditions to be classified as a reserve.

– Probable reserve. That part of an indicated resources that satisfies the conditions to be classified as a reserve.

It should be stated whether the reserve estimate is of in-place material or of recoverable material. Any in-place estimate should be qualified to show the anticipated losses resulting from mining methods and beneficiation or preparation.

Reporting terminology

The following terms should be used for reporting exploration information, resources and reserves:

1. Exploration information. Terms such as 'deposit' or 'mineralization' are appropriate for reporting exploration information. Terms such as 'ore,' 'reserve,' and other terms that imply that economic extraction or production has been demonstrated, should not be used.

2. Resource. A resource can be subdivided into three categories:
   (a) Measured resource;
   (b) Indicated resource;
   (c) Inferred resource.

The term 'resource' is recommended over the terms 'mineral resource, identified resource' and 'in situ resource.' 'Resource' as defined herein includes 'identified resource,' but excludes 'undiscovered resource' of the United States Bureau of Mines (USBM) and United

States Geological Survey (USGS) classification scheme. The 'undiscovered resource' classification is used by public planning agencies and is not appropriate for use in commercial ventures.

3. Reserve. A reserve can be subdivided into two categories:
   (a) Probable reserve;
   (b) Proven reserve.

The term 'reserve' is recommended over the terms 'ore reserve,' 'minable reserve' or 'recoverable reserve.'

The terms 'measured reserve' and 'indicated reserve,' generally equivalent to 'proven reserve' and 'probable reserve,' respectively, are not part of this classification scheme and should not be used. The terms 'measured,' 'indicated' and 'inferred' qualify resources and reflect only differences in geological confidence. The terms 'proven' and 'probable' qualify reserves and reflect a high level of economic confidence as well as differences in geological confidence.

The terms 'possible reserve' and 'inferred reserve' are not part of this classification scheme. Material described by these terms lacks the requisite degree of assurance to be reported as a reserve.

The term 'ore' should be used only for material that meets the requirements to be a reserve.

It is recommended that proven and probable reserves be reported separately. Where the term reserve is used without the modifiers proven or probable, it is considered to be the total of proven and probable reserves.

1.2 MINE DEVELOPMENT PHASES

The mineral supply process is shown diagrammatically in Figure 1.2. As can be seen a positive change in the market place creates a new or increased demand for a mineral product.

In response to the demand, financial resources are applied in an exploration phase resulting in the discovery and delineation of deposits. Through increases in price and/or advances in technology, previously located deposits may become interesting. These deposits must then be thoroughly evaluated regarding their economic attractiveness. This evaluation process will be termed the 'planning phase' of a project (Lee, 1984). The conclusion of this phase will be the preparation of a feasibility report. Based upon this, the decision will be made as to whether or not to proceed. If the decision is 'go', then the development of the mine and concentrating facilities is undertaken. This is called the implementation, investment, or design and construction phase. Finally there is the production or operational phase during which the mineral is mined and processed. The result is a product to be sold in the marketplace. The entrance of the mining engineer into this process begins at the planning phase and continues through the production phase. Figure 1.3 is a time line showing the relationship of the different phases and their stages.

The implementation phase consists of two stages (Lee, 1984). The design and construction stage includes the design, procurement and construction activities. Since it is the period of major cash flow for the project, economies generally result by keeping the time frame to a realistic minimum. The second stage is commissioning. This is the trial operation of the individual components to integrate them into an operating system and ensure their readiness

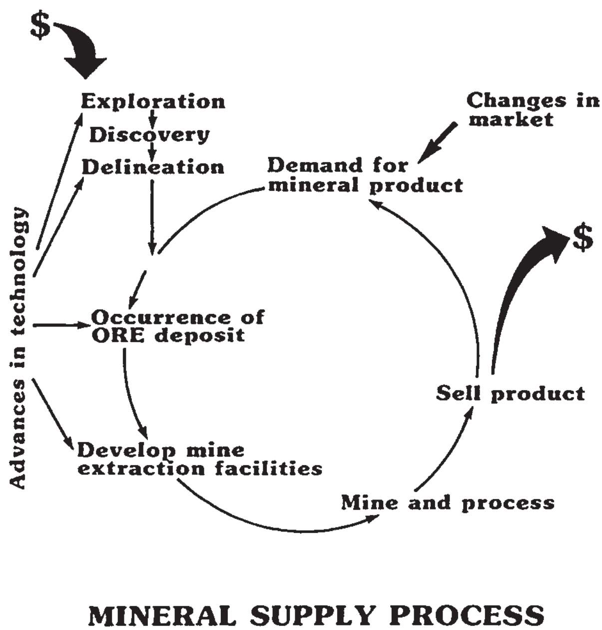


Figure 1.2. Diagrammatic representation of the mineral supply process (McKenzie, 1980).

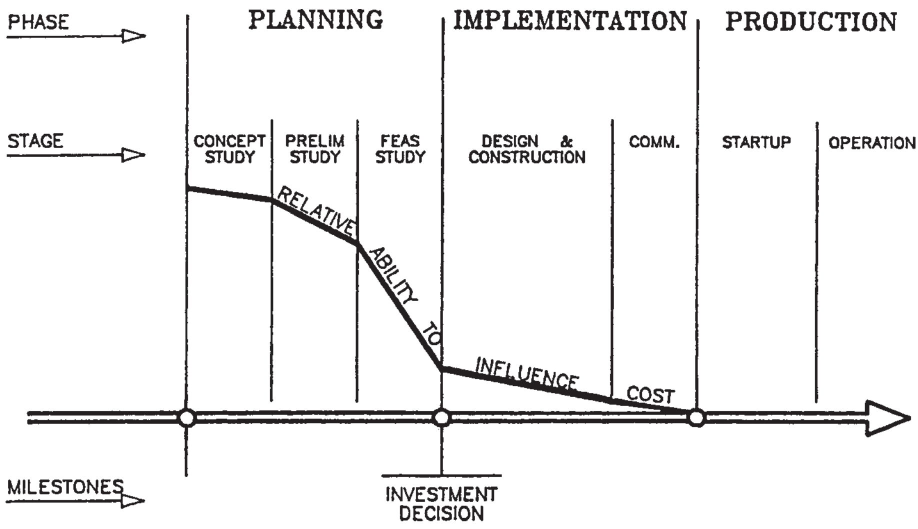


Figure 1.3. Relative ability to influence costs (Lee, 1984).

for startup. It is conducted without feedstock or raw materials. Frequently the demands and costs of the commissioning period are underestimated.

The production phase also has two stages (Lee, 1984). The startup stage commences at the moment that feed is delivered to the plant with the express intention of transforming it into product. Startup normally ends when the quantity and quality of the product is sustainable at the desired level. Operation commences at the end of the startup stage.

As can be seen in Figure 1.3, and as indicated by Lee (1984),

the planning phase offers the greatest opportunity to minimize the capital and operating costs of the ultimate project, while maximizing the operability and profitability of the venture. But the opposite is also true: no phase of the project contains the potential for instilling technical or fiscal disaster into a developing project, that is inherent in the planning phase. . . .

At the start of the conceptual study, there is a relatively unlimited ability to influence the cost of the emerging project. As decisions are made, correctly or otherwise, during the balance of the planning phase, the opportunity to influence the cost of the job diminishes rapidly.

The ability to influence the cost of the project diminishes further as more decisions are made during the design stage. At the end of the construction period there is essentially no opportunity to influence costs.

The remainder of this chapter will focus on the activities conducted within the planning stage.

1.3 AN INITIAL DATA COLLECTION CHECKLIST

In the initial planning stages for any new project there are a great number of factors of rather diverse types requiring consideration. Some of these factors can be easily addressed, whereas others will require in-depth study. To prevent forgetting factors, checklist are often of great value. Included below are the items from a 'Field Work Program Checklist for New Properties' developed by Halls (1975). Student engineers will find many of the items on this checklist of relevance when preparing mine design reports.

Checklist items (Halls, 1975)

1. Topography
   - (a) USGS maps
   - (b) Special aerial or land survey
     - Establish survey control stations
     - Contour
2. Climatic conditions
   - (a) Altitude
   - (b) Temperatures
     - Extremes
     - Monthly averages
   - (c) Precipitation
     - Average annual precipitation
     - Average monthly rainfall
     - Average monthly snowfall
     - Run-off
       - Normal
       - Flood
     - Slides – snow and mud
   - (d) Wind
     - Maximum recorded
     - Prevailing direction
     - Hurricanes, tornados, cyclones, etc.

   (e) Humidity
       Effect on installations, i.e. electrical motors, etc.
   (f) Dust
   (g) Fog and cloud conditions
3. Water – potable and process
   (a) Sources
       Streams
       Lakes
       Wells
   (b) Availability
       Ownership
       Water rights
       Cost
   (c) Quantities
       Monthly availability
       Flow rates
       Drought or flood conditions
       Possible dam locations
   (d) Quality
       Present sample
       Possibility of quality change in upstream source water
       Effect of contamination on downstream users
   (e) Sewage disposal method
4. Geologic structure
   (a) Within mine area
   (b) Surrounding areas
   (c) Dam locations
   (d) Earthquakes
   (e) Effect on pit slopes
       Maximum predicted slopes
   (f) Estimate on foundation conditions
5. Mine water as determined by prospect holes
   (a) Depth
   (b) Quantity
   (c) Method of drainage
6. Surface
   (a) Vegetation
       Type
       Method of clearing
       Local costs for clearing
   (b) Unusual conditions
       Extra heavy timber growth
       Muskeg
       Lakes
       Stream diversions
       Gravel deposits

7. Rock type – overburden and ore
   (a) Submit sample for drillability test
   (b) Observe fragmentation features
       Hardness
       Degree of weathering
       Cleavage and fracture planes
       Suitability for road surface
8. Locations for concentrator – factors to consider for optimum location
   (a) Mine location
       Haul uphill or downhill
   (b) Site preparation
       Amount of cut and/or fill
   (c) Process water
       Gravity flow or pumping
   (d) Tailings disposal
       Gravity flow or pumping
   (e) Maintenance facilities
       Location
9. Tailings pond area
   (a) Location of pipeline length and discharge elevations
   (b) Enclosing features
       Natural
       Dams or dikes
       Lakes
   (c) Pond overflow
       Effect of water pollution on downstream users
       Possibility for reclaiming water
   (d) Tailings dust
       Its effect on the area
10. Roads
   (a) Obtain area road maps
   (b) Additional road information
       Widths
       Surfacing
       Maximum load limits
       Seasonal load limits
       Seasonal access
       Other limits or restrictions
       Maintained by county, state, etc.
   (c) Access roads to be constructed by company (factors considered)
       Distance
       Profile
       Cut and fill
       Bridges, culverts
       Terrain and soil conditions

11. Power
    - (a) Availability
      - Kilovolts
      - Distance
      - Rates and length of contract
    - (b) Power lines to site
      - Who builds
      - Who maintains
      - Right-of-way requirements
    - (c) Substation location
    - (d) Possibility of power generation at or near site
12. Smelting
    - (a) Availability
    - (b) Method of shipping concentrate
    - (c) Rates
    - (d) If company on site smelting – effect of smelter gases
    - (e) Concentrate freight rates
    - (f) Railroads and dock facility
13. Land ownership
    - (a) Present owners
    - (b) Present usage
    - (c) Price of land
    - (d) Types of options, leases and royalties expected
14. Government
    - (a) Political climate
      - Favorable or unfavorable to mining
      - Past reactions in the area to mining
    - (b) Special mining laws
    - (c) Local mining restrictions
15. Economic climate
    - (a) Principal industries
    - (b) Availability of labor and normal work schedules
    - (c) Wage scales
    - (d) Tax structure
    - (e) Availability of goods and services
      - Housing
      - Stores
      - Recreation
      - Medical facilities and unusual local disease
      - Hospital
      - Schools
    - (f) Material costs and/or availability
      - Fuel oil
      - Concrete
      - Gravel
      - Borrow material for dams

   (g) Purchasing
       Duties
16. Waste dump location
   (a) Haul distance
   (b) Haul profile
   (c) Amenable to future leaching operation
17. Accessibility of principal town to outside
   (a) Methods of transportation available
   (b) Reliability of transportation available
   (c) Communications
18. Methods of obtaining information
   (a) Past records (i.e. government sources)
   (b) Maintain measuring and recording devices
   (c) Collect samples
   (d) Field observations and measurements
   (e) Field surveys
   (f) Make preliminary plant layouts
   (g) Check courthouse records for land information
   (h) Check local laws and ordinances for applicable legislation
   (i) Personal inquiries and observation on economic and political climates
   (j) Maps
   (k) Make cost inquiries
   (l) Make material availability inquiries
   (m) Make utility availability inquiries

1.4 THE PLANNING PHASE

In preparing this section the authors have drawn heavily on material originally presented in papers by Lee (1984) and Taylor (1977). The permission by the authors and their publisher, The Northwest Mining Association, to include this material is gratefully acknowledged.

1.4.1 *Introduction*

The planning phase commonly involves three stages of study (Lee, 1984).

Stage 1: *Conceptual study*
A conceptual (or preliminary valuation) study represents the transformation of a project idea into a broad investment proposition, by using comparative methods of scope definition and cost estimating techniques to identify a potential investment opportunity. Capital and operating costs are usually approximate ratio estimates using historical data. It is intended primarily to highlight the principal investment aspects of a possible mining proposition. The preparation of such a study is normally the work of one or two engineers. The findings are reported as a preliminary valuation.

Stage 2: *Preliminary or pre-feasibility study*
A preliminary study is an intermediate-level exercise, normally not suitable for an investment decision. It has the objectives of determining whether the project concept justifies a detailed

analysis by a feasibility study, and whether any aspects of the project are critical to its viability and necessitate in-depth investigation through functional or support studies.

A preliminary study should be viewed as an intermediate stage between a relatively inexpensive conceptual study and a relatively expensive feasibility study. Some are done by a two or three man team who have access to consultants in various fields others may be multi-group efforts.

Stage 3: *Feasibility study*

The feasibility study provides a definitive technical, environmental and commercial base for an investment decision. It uses iterative processes to optimize all critical elements of the project. It identifies the production capacity, technology, investment and production costs, sales revenues, and return on investment. Normally it defines the scope of work unequivocally, and serves as a base-line document for advancement of the project through subsequent phases.

These latter two stages will now be described in more detail.

1.4.2 *The content of an intermediate valuation report*

The important sections of an intermediate valuation report (Taylor, 1977) are:

- Aim;
- Technical concept;
- Findings;
- Ore tonnage and grade;
- Mining and production schedule;
- Capital cost estimate;
- Operating cost estimate;
- Revenue estimate;
- Taxes and financing;
- Cash flow tables.

The degree of detail depends on the quantity and quality of information. Table 1.1 outlines the contents of the different sections.

1.4.3 *The content of the feasibility report*

The essential functions of the feasibility report are given in Table 1.2.

Due to the great importance of this report it is necessary to include all detailed information that supports a general understanding and appraisal of the project or the reasons for selecting particular processes, equipment or courses of action. The contents of the feasibility report are outlined in Table 1.3.

The two important requirements for both valuation and feasibility reports are:

1. Reports must be easy to read, and their information must be easily accessible.
2. Parts of the reports need to be read and understood by non-technical people.

According to Taylor (1977):

There is much merit in a layered or pyramid presentation in which the entire body of information is assembled and retained in three distinct layers.

Layer 1. Detailed background information neatly assembled in readable form and adequately indexed, but retained in the company's office for reference and not included in the feasibility report.

Layer 2. Factual information about the project, precisely what is proposed to be done about it, and what the technical, physical and financial results are expected to be.

Layer 3. A comprehensive but reasonably short summary report, issued preferably as a separate volume.

The feasibility report itself then comprises only the second and third layers. While everything may legitimately be grouped into a single volume, the use of smaller separated volumes makes for easier reading and for more flexible forms of binding. Feasibility reports always need to be reviewed by experts in various specialities. The use of several smaller volumes makes this easier, and minimizes the total number of copies needed.

Table 1.1. The content of an intermediate valuation report (Taylor, 1977).

Aim: States briefly what knowledge is being sought about the property, and why, for guidance in exploration spending, for joint venture negotiations, for major feasibility study spending, etc. Sources of information are also conveniently listed.

Concept: Describes very briefly where the property is located, what is proposed or assumed to be done in the course of production, how this may be achieved, and what is to be done with the products.

Findings: Comprise a summary, preferably in sequential and mainly tabular forms, of the important figures and observations from all the remaining sections. This section may equally be termed Conclusions, though this title invites a danger of straying into recommendations which should not be offered unless specially requested.

Any cautions or reservations the authors care to make should be incorporated in one of the first three sections. The general aim is that the non-technical or less-technical reader should be adequately informed about the property by the time he has read the end of Findings.

Ore tonnage and grade: Gives brief notes on geology and structure, if applicable, and on the drilling and sampling accomplished. Tonnages and grades, both geological and minable and possibly at various cut-off grades, are given in tabular form with an accompanying statement on their status and reliability.

Mining and production schedule: Tabulates the mining program (including preproduction work), the milling program, any expansions or capacity changes, the recoveries and product qualities (concentrate grades), and outputs of products.

Capital cost estimate: Tabulates the cost to bring the property to production from the time of writing including the costs of further exploration, research and studies. Any prereport costs, being sunk, may be noted separately.

An estimate of postproduction capital expenditures is also needed. This item, because it consists largely of imponderables, tends to be underestimated even in detailed feasibilities studies.

Operating cost estimate: Tabulates the cash costs of mining, milling, other treatment, ancillary services, administration, etc. Depreciation is not a cash cost, and is handled separately in cash flow calculations. Postmine treatment and realization costs are most conveniently regarded as deductions from revenues.

Revenue estimate: Records the metal or product prices used, states the realization terms and costs, and calculates the net smelter return or net price at the deemed point of disposal. The latter is usually taken to be the point at which the product leaves the mine's plant and is handed over to a common carrier. Application of these net prices to the outputs determined in the production schedule yields a schedule of annual revenues.

Financing and tax data: State what financing assumptions have been made, all equity, all debt or some specified mixture, together with the interest and repayment terms of loans. A statement on the tax regime specifies tax holidays (if any), depreciation and tax rates, (actual or assumed) and any special

(Continued)

Table 1.1. (Continued).

features. Many countries, particularly those with federal constitutions, impose multiple levels of taxation by various authorities, but a condensation or simplification of formulae may suffice for early studies without involving significant loss of accuracy.

Cash flow schedules: Present (if information permits) one or more year-by-year projections of cash movements in and out of the project. These tabulations are very informative, particularly because their format is almost uniformly standardized. They may be compiled for the indicated life of the project or, in very early studies, for some arbitrary shorter period.
Figures must also be totalled and summarized. Depending on company practice and instructions, investment indicators such as internal rate of return, debt payback time, or cash flow after payback may be displayed.

Table 1.2. The essential functions of the feasibility report (Taylor, 1977).

1. To provide a comprehensive framework of established and detailed facts concerning the mineral project.
2. To present an appropriate scheme of exploitation with designs and equipment lists taken to a degree of detail sufficient for accurate prediction of costs and results.
3. To indicate to the project's owners and other interested parties the likely profitability of investment in the project if equipped and operated as the report specifies.
4. To provide this information in a form intelligible to the owner and suitable for presentation to prospective partners or to sources of finance.

Table 1.3. The content of a feasibility study (Taylor, 1977).

General:
- Topography, climate, population, access, services.
- Suitable sites for plant, dumps, towns, etc.

Geological (*field*):
- Geological study of structure, mineralization and possibly of genesis.
- Sampling by drilling or tunnelling or both.
- Bulk sampling for checking and for metallurgical testing.
- Extent of leached or oxidized areas (frequently found to be underestimated).
- Assaying and recording of data, including check assaying, rock properties, strength and stability.
- Closer drilling of areas scheduled for the start of mining.
- Geophysics and indication of the likely ultimate limits of mineralization, including proof of non-mineralization of plan and dump areas.
- Sources of water and of construction materials.

Geological and mining (*office*):
- Checking, correcting and coding of data for computer input.
- Manual calculations of ore tonnages and grades.
- Assay compositing and statistical analysis.
- Computation of mineral inventory (geological reserves) and minable reserves, segregated as needed by orebody, by ore type, by elevation or bench, and by grade categories.
- Computation of associated waste rock.
- Derivation of the economic factors used in the determination of minable reserves.

Mining:
- Open pit layouts and plans.
- Determination of preproduction mining or development requirements.
- Estimation of waste rock dilution and ore losses.

(Continued)

Table 1.3. (Continued).

- Production and stripping schedules, in detail for the first few years but averaged thereafter, and specifying important changes in ore types if these occur.
- Waste mining and waste disposal.
- Labor and equipment requirements and cost, and an appropriate replacement schedule for the major equipment.

Metallurgy (*research*):
- Bench testing of samples from drill cores.
- Selection of type and stages of the extraction process.
- Small scale pilot plant testing of composited or bulk samples followed by larger scale pilot mill operation over a period of months should this work appear necessary.
- Specification of degree of processing, and nature and quality of products.
- Provision of samples of the product.
- Estimating the effects of ore type or head grade variations upon recovery and product quality.

Metallurgy (*design*):
- The treatment concept in considerable detail, with flowsheets and calculation of quantities flowing.
- Specification of recovery and of product grade.
- General siting and layout of plant with drawings if necessary.

Ancillary services and requirements:
- Access, transport, power, water, fuel and communications.
- Workshops, offices, changehouse, laboratories, sundry buildings and equipment.
- Labor structure and strength.
- Housing and transport of employees.
- Other social requirements.

Capital cost estimation:
- Develop the mine and plant concepts and make all necessary drawings.
- Calculate or estimate the equipment list and all important quantities (of excavation, concrete, building area and volume, pipework, etc.).
- Determine a provisional construction schedule.
- Obtain quotes of the direct cost of items of machinery, establish the costs of materials and services, and of labor and installation.
- Determine the various and very substantial indirect costs, which include freight and taxes on equipment (may be included in directs), contractors' camps and overheads plus equipment rental, labor punitive and fringe costs, the owner's field office, supervision and travel, purchasing and design costs, licenses, fees, customs duties and sales taxes.
- Warehouse inventories.
- A contingency allowance for unforeseen adverse happenings and for unestimated small requirements that may arise.
- Operating capital sufficient to pay for running the mine until the first revenue is received.
- Financing costs and, if applicable, preproduction interest on borrowed money.

A separate exercise is to forecast the major replacements and the accompanying provisions for postproduction capital spending. Adequate allowance needs to be made for small requirements that, though unforeseeable, always arise in significant amounts.

Operating cost estimation:
- Define the labor strength, basic pay rates, fringe costs.
- Establish the quantities of important measurable supplies to be consumed – power, explosives, fuel, grinding steel, reagents, etc. – and their unit costs.
- Determine the hourly operating and maintenance costs for mobile equipment plus fair performance factors.
- Estimate the fixed administration costs and other overheads plus the irrecoverable elements of townsite and social costs.

(Continued)

Table 1.3. (Continued).

Only cash costs are used thus excluding depreciation charges that must be accounted for elsewhere. As for earlier studies, post-mine costs for further treatment and for selling the product are best regarded as deductions from the gross revenue.

Marketing:
- Product specifications, transport, marketing regulations or restrictions.
- Market analysis and forecast of future prices.
- Likely purchasers.
- Costs for freight, further treatment and sales.
- Draft sales terms, preferably with a letter of intent.
- Merits of direct purchase as against toll treatment.
- Contract duration, provisions for amendment or cost escalation.
- Requirements for sampling, assaying and umpiring.

The existence of a market contract or firm letter of intent is usually an important prerequisite to the loan financing of a new mine.

Rights, ownership and legal matters:
- Mineral rights and tenure.
- Mining rights (if separated from mineral rights).
- Rents and royalties.
- Property acquisitions or securement by option or otherwise.
- Surface rights to land, water, rights-of-way, etc.
- Licenses and permits for construction as well as operation.
- Employment laws for local and expatriate employees separately if applicable.
- Agreements between partners in the enterprise.
- Legal features of tax, currency exchange and financial matters.
- Company incorporation.

Financial and tax matters:
- Suggested organization of the enterprise, as corporation, joint-venture or partnership.
- Financing and obligations, particularly relating to interest and repayment on debt.
- Foreign exchange and reconversion rights, if applicable.
- Study of tax authorities and regimes, whether single or multiple.
- Depreciation allowances and tax rates.
- Tax concessions and the negotiating procedure for them.
- Appropriation and division of distributable profits.

Environmental effects:
- Environmental study and report; the need for pollution or related permits, the requirements during construction and during operation.
- Prescribed reports to government authorities, plans for restoration of the area after mining ceases.

Revenue and profit analysis:
- The mine and mill production schedules and the year-by-year output of products.
- Net revenue at the mine (at various product prices if desired) after deduction of transport, treatment and other realization charges.
- Calculation of annual costs from the production schedules and from unit operating costs derived previously.
- Calculation of complete cash flow schedules with depreciation, taxes, etc. for some appropriate number of years – individually for at least 10 years and grouped thereafter.
- Presentation of totals and summaries of results.
- Derived figures (rate of return, payback, profit split, etc.) as specified by owner or client.
- Assessment of sensitivity to price changes and generally to variation in important input elements.

1.5 PLANNING COSTS

The cost of these studies (Lee, 1984) varies substantially, depending upon the size and nature of the project, the type of study being undertaken, the number of alternatives to be investigated, and numerous other factors. However, the order of magnitude cost of the technical portion of studies, excluding such owner's cost items as exploration drilling, special grinding or metallurgical tests, environmental and permitting studies, or other support studies, is commonly expressed as a percentage of the capital cost of the project:

Conceptual study:	0.1 to 0.3 percent
Preliminary study:	0.2 to 0.8 percent
Feasibility study:	0.5 to 1.5 percent

1.6 ACCURACY OF ESTIMATES

The material presented in this section has been largely extracted from the paper 'Mine Valuation and Feasibility Studies' presented by Taylor (1977).

1.6.1 *Tonnage and grade*

At feasibility, by reason of multiple sampling and numerous checks, the average mining grade of some declared tonnage is likely to be known within acceptable limits, say ±5%, and verified by standard statistical methods. Although the ultimate tonnage of ore may be known for open pit mines if exploration drilling from surface penetrates deeper than the practical mining limit, in practice, the ultimate tonnage of many deposits is nebulous because it depends on cost-price relationships late in the project life. By the discount effects in present value theory, late life tonnage is not economically significant at the feasibility stage. Its significance will grow steadily with time once production has begun. It is not critical that the total possible tonnage be known at the outset. What is more important is that the grade and quality factors of the first few years of operation be known with assurance.

Two standards of importance can be defined for most large open pit mines:

1. A minimum ore reserve equal to that required for all the years that the cash flows are projected in the feasibility report must be known with accuracy and confidence.

2. An ultimate tonnage potential, projected generously and optimistically, should be calculated so as to define the area adversely affected by mining and within which dumps and plant buildings must not encroach.

1.6.2 *Performance*

This reduces to two items – throughput and recovery. Open pit mining units have well established performance rates that can usually be achieved if the work is correctly organized and the associated items (i.e. shovels and trucks) are suitably matched. Performance suffers if advance work (waste stripping in a pit) is inadequate. Care must be taken that these tasks are adequately scheduled and provided for in the feasibility study.

The throughput of a concentrator tends to be limited at either the fine crushing stage or the grinding stages. The principles of milling design are well established, but their application requires accurate knowledge of the ore's hardness and grindability. These qualities must therefore receive careful attention in the prefeasibility test work. Concentrator performance is part of a three way relationship involving the fineness of grind, recovery, and the grade of concentrate or product. Very similar relations may exist in metallurgical plants of other types. Again, accuracy can result only from adequate test-work.

1.6.3 *Costs*

Some cost items, notably in the operating cost field, differ little from mine to mine and are reliably known in detail. Others may be unique or otherwise difficult to estimate. Generally, accuracy in capital or operating cost estimating goes back to accuracy in quantities, reliable quotes or unit prices, and adequate provision for indirect or overhead items. The latter tend to form an ever increasing burden. For this reason, they should also be itemized and estimated directly whenever possible, and not be concealed in or allocated into other direct cost items.

Contingency allowance is an allowance for possible over expenditures contingent upon unforeseen happenings such as a strike or time delaying accident during construction, poor plant foundation conditions, or severe weather problems. To some extent the contingency allowance inevitably allows for certain small expenditures always known to arise but not foreseeable nor estimable in detail. Caution is needed here. The contingency allowance is not an allowance for bad or inadequate estimating, and it should never be interpreted in that manner.

The accuracy of capital and operating cost estimates increases as the project advances from conceptual to preliminary to feasibility stage. Normally acceptable ranges of accuracy are considered to be (Lee, 1984):

Conceptual study:	±30 percent
Preliminary study:	±20 percent
Feasibility study:	±10 percent

It was noted earlier that the scope of work in the conceptual and preliminary studies is not optimized. The cost estimate is suitable for decision purposes, to advance the project to the next stage, or to abort and minimize losses.

1.6.4 *Price and revenue*

The revenue over a mine's life is the largest single category of money. It has to pay for everything, including repayment of the original investment money. Because revenue is the biggest base, measures of the mine's economic merit are more sensitive to changes in revenue than to changes of similar ratio in any of the expenditure items.

Revenue is governed by grade, throughput, recovery, and metal or product price. Of these, price is: (a) by far the most difficult to estimate and (b) the one quantity largely outside the estimator's control. Even ignoring inflation, selling prices are widely variable with time. Except for certain controlled commodities, they tend to follow a cyclic pattern.

The market departments of major metal mining corporations are well informed on supply/demand relationships and metal price movements. They can usually provide forecasts of average metal prices in present value dollars, both probable and conservative, the latter being with 80% probability or better. Ideally, even at the conservative product price, the proposed project should still display at least the lowest acceptable level of profitability.

1.7 FEASIBILITY STUDY PREPARATION

The feasibility study is a major undertaking involving many people and a variety of specialized skills. There are two basic ways through which it is accomplished.

1. The mining company itself organizes the study and assembles the feasibility report. Various parts or tasks are assigned to outside consultants.
2. The feasibility work is delegated to one or more engineering companies.

Contained on the following pages is an eleven step methodology outlining the planning (Steps 1–4) organizing (Steps 5–10) and execution (Step 11) steps which might be used in conducting a feasibility study. It has been developed by Lee (1984, 1991).

Phase A. Planning
Step 1: *Establish a steering committee*. A steering committee consisting of managers and other individuals of wide experience and responsibility would be formed to overview and evaluate the direction and viability of the feasibility study team. One such steering committee might be the following:

– Vice-President (Chairman);
– General Manager, mining operations;
– Vice-President, finance;
– Chief Geologist, exploration;
– Vice-President, technical services;
– Consultant(s).

Step 2: *Establish a project study team.* The criteria for selection of the study team members would emphasize these qualities:

– Competent in their respective fields.
– Considerable experience with mining operations.
– Complementary technical abilities.
– Compatible personalities – strong interpersonal qualities.
– Commitment to be available through the implementation phase, should the prospect be viable.

The team members might be:

– Project Manager;
– Area Supervisor, mining;
– Area Supervisor, beneficiation;
– Area Supervisor, ancillaries.

Step 3: *Develop a work breakdown structure*. The Work Breakdown Structure (WBS) is defined by the American Association of Cost Engineers (AACE) as:

a product-oriented family tree division of hardware, software, facilities and other items which organizes, defines and displays all of the work to be performed in accomplishing the project objectives.

The WBS is a functional breakdown of all elements of work on a project, on a geographical and/or process basis. It is a hierarchy of work packages, or products, on a work area basis. The WBS is project-unique, reflecting the axiom that every project is a unique event.

A WBS is a simple common-sense procedure which systematically reviews the full scope of a project (or study) and breaks it down into logical packages of work. The primary challenge is normally one of perspective. It is imperative that the entire project be visualized as a sum of many parts, any one of which could be designed, scheduled, constructed, and priced as a single mini-project.

There are a number of categories which can be used to construct a work breakdown structure. These include:

(1) Components of the product;
(2) Functions;
(3) Organizational units;
(4) Geographical areas;
(5) Cost accounts;
(6) Time phases;
(7) Configuration characteristics;
(8) Deliverables;
(9) Responsible persons;
(10) Subpurposes.

It is not a rigid system. WBS categories can be used in any sequence desired, including using the same category several times. A sample WBS is shown in Figures 1.4 and 1.5.

An alternative to this is the Work Classification Structure (WCS). This commodity-based classification of goods and services is commonly used by construction contractors and consulting engineering firms as the primary cost-collection system. The specific intent of the WCS is to provide a consistent reference system for storage, comparison and evaluation of technical, man-hour and cost data from work area to work area within a project; and from project to project; and from country to country. The WCS may have different names in different organizations, but it is the 'original' costing system. It is the basis for virtually all of the estimating manuals and handbooks which identify unit costs for commodities such as concrete, or piping, or road construction, or equipment installation. The WCS provides a commodity based method to estimate and control costs. The key to the success of the WCS system within an organization is the absolute consistency with which it is used.

The WBS is of primary interest to owners and project managers – both of whom are interested in tracking cost and schedule on a work area basis. The WCS is primarily of interest to construction contractors and engineering consultants, who measure actual performance against forecast performance on a commodity basis.

Professional project managers and cost engineers normally use cost coding systems which encode both the commodity and the work package. This allows them to evaluate job-to-date performance, then forecast cost or productivity trends for the balance of the project.

Step 4: *Develop an action plan for the study.* An action plan in its simplest form, is just a logical (logic-oriented) time-bar plan listing all of the activities to be studied. Figure 1.6 is one example of such a time-bar graph. A more general action plan would have these characteristics:

1. Purpose: the action plan serves as a control document during the execution of the feasibility study. It functions as a master reference, against which change can be measured and resolved. It provides a visual communication of the logic and progress of the study.

2. Methodology: it may be possible for one person, working in isolation, to develop an action plan. However, it is substantially more desirable to have the project study team develop their plan on a participative, interactive basis. (Texas Instruments' Patrick Haggerty insisted that 'those who implement plans must make the plans'). This interaction

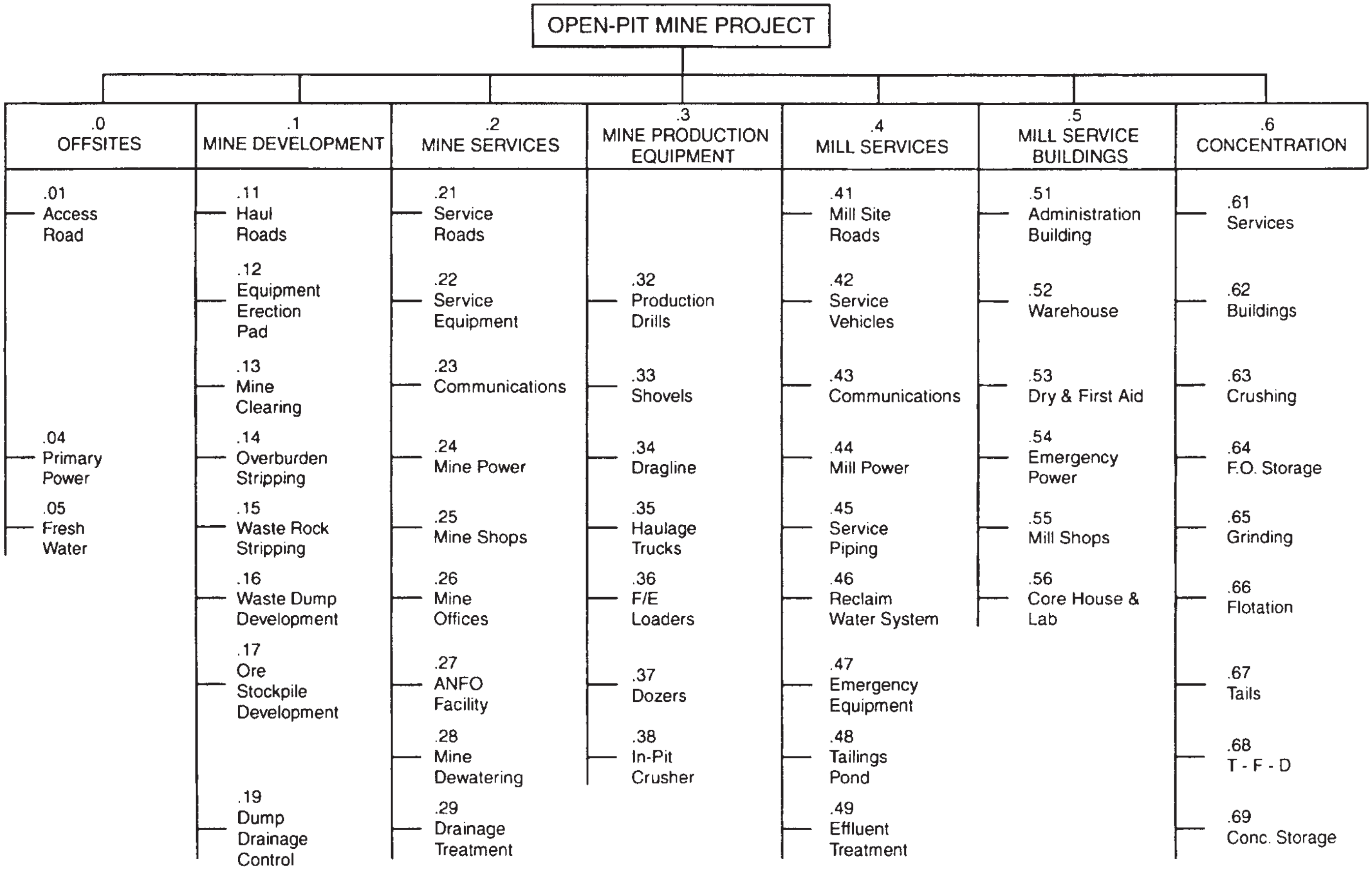


Figure 1.4. Typical work breakdown structure (WBS) directs for an open pit mining project (Lee, 1991).

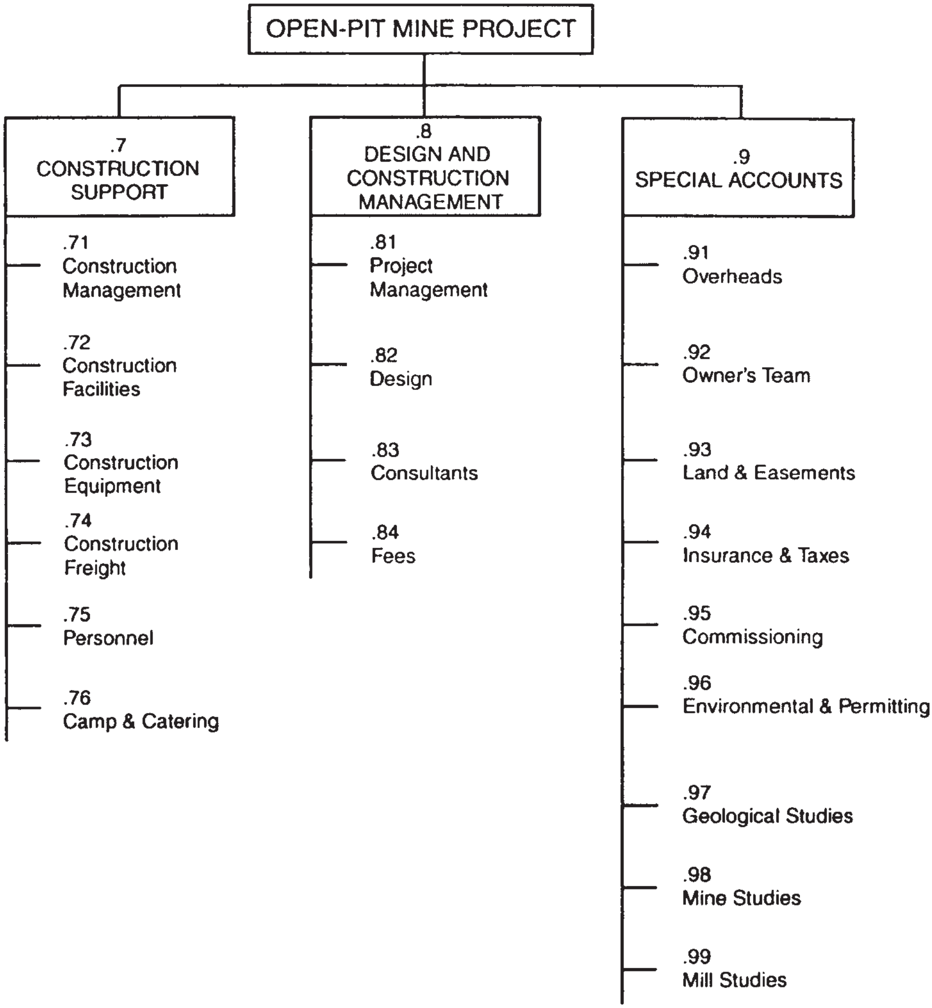


Figure 1.5. Typical work breakdown structure (WBS) indirects for an open pit mining project (Lee, 1991).

fosters understanding and appreciation of mutual requirements and objectives; even more importantly, it develops a shared commitment.

3. Format: a simple master time-bar schedule would be produced, displaying the study activities in a logic-oriented fashion. Brief titles and a reference number would be attached to each activity. For a simple in-house job, an operating company would probably stop at this point. However, for a major study on a new mining operation, the activity reference numbers and titles would be carried into a separate action plan booklet. Each activity would be described briefly, and a budget attached to it.

4. WBS reference: the most convenient way to organize these activities is by referencing them to the first and second levels of the WBS.

5. Number of activities: the practical limitation on the number of individual study activities would be of the order of one hundred.

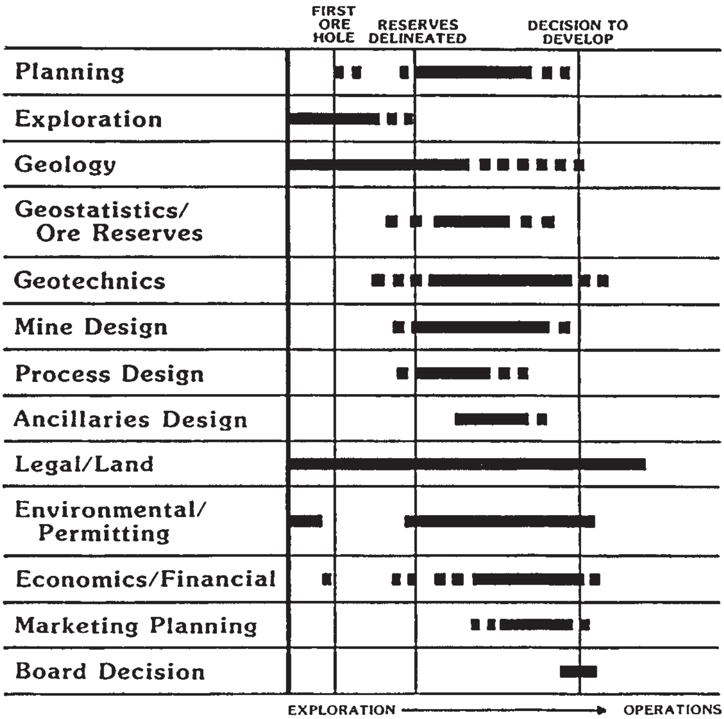


Figure 1.6. Bar chart representation for a mine feasibility/decision-making sequence (McKelvey, 1984).

Phase B. Organizing
Step 5: *Identify additional resource requirements*. While developing a comprehensive action plan, needs for additional resources normally become apparent.

Step 6: *Identify secondary project team members*.

Step 7: *Develop organization chart and responsibilities*. There are a number of ways to organize a project study team for a large study. A separate task force can be established by removing personnel from existing jobs and developing a project-oriented hierarchy, military style. This can work effectively, but can discourage broad participation in the evolution of the project. In a large company, a matrix system can be used very successfully, if used very carefully and with understanding. The management of a matrix organization is based on the management of intentional conflict; it works exceedingly well in a positive environment, and is an unequivocal disaster in an unfavorable environment.

Step 8: *Develop second-level plans and schedules*. Using the master time-bar, the action plan and the WBS as primary references, the enlarged project study team develops second-level plans and schedules, thus establishing their objectives and commitments for the balance of the study. These schedules are oriented on an area-by-area basis, with the primary team members providing the leadership for each area.

Step 9: *Identify special expertise required*. The project study team after reviewing their plan, with the additional information developed during Step 8, may identify a number of areas of the job which require special expertise. Such items may be packaged as separate Requests For Proposals (RFP's), and forwarded to pre-screened consultants on an invitation basis. The scope of work in each RFP should be clearly identified, along with the objectives for the work. A separate section provides explicit comments on the criteria for selection of the successful bidder; this provides the bidder with the opportunity to deliver proposals which can be weighted in the directions indicated by the project team.

Step 10: *Evaluate and select consultants*. Evaluation of the consultant's bids should be thorough, objective, and fair. The evaluations and decisions are made by the use of spread sheets which compare each bidder's capability to satisfy each of the objectives for the work as identified in the RFP. The objectives should be pre-weighted to remove bias from the selection process.

Phase C. Execution
Step 11: *Execute, monitor, control*. With the project study team fully mobilized and with the specialist consultants engaged and actively executing well-defined contracts, the primary challenge to the project manager is to ensure that the study stays on track.

A number of management and reporting systems and forms may be utilized, but the base-line reference for each system and report is the scope of work, schedule and cost for each activity identified in the action plan. The status-line is added to the schedule on a bi-weekly basis, and corrections and modifications made as indicated, to keep the work on track.

1.8 CRITICAL PATH REPRESENTATION

Figure 1.7 is an example of a network chart which has been presented by Taylor (1977) for a medium sized, open pit base metal mine. Each box on the chart contains:

– activity number,
– activity title,
– responsibility (this should be a person/head of section who would carry the responsibility for budget and for progress reports),
– starting date,
– completion date,
– task duration.

The activities, sequential relationships and critical/near critical paths can be easily seen.

Figure 1.8 is the branch showing the basic mining related activities. This progression will be followed through the remainder of the book.

1.9 MINE RECLAMATION

1.9.1 *Introduction*

In the past, reclamation was something to be considered at the end of mine operations and not in the planning stage. Today, in many countries at least, there will be no mine without first thoroughly and satisfactorily addressing the environmental aspects of the proposed project. Although the subject of mine reclamation is much too large to be covered in this brief chapter, some of the factors requiring planning consideration will be discussed. In the western United States, a considerable amount of mineral development takes place on federal and Indian lands. The Bureau of Land Management (BLM) of the U.S. Department of the Interior has developed the *Solid Minerals Reclamation Handbook* (BLM, 1992) with the objective being 'to provide the user with clear guidance which highlights a logical sequence for managing the reclamation process and a summary of key reclamation principles.'

The remaining sections of this chapter have been extracted from the handbook. Although they only pertain directly to those lands under BLM supervision, the concepts have more general application as well. Permission from the BLM to include this material is gratefully acknowledged.

1.9.2 *Multiple-use management*

Multiple-use management is the central concept in the Federal Land Policy and Management Act (FLPMA) of 1976. FLPMA mandates that 'the public lands be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource and archeological values.' Multiple-use management is defined in FLPMA (43 USC 1702(c)) and in regulations (43 CFR 1601.0-5(f)) as, in part, the 'harmonious and coordinated management of the various resources without permanent impairment of the productivity of the lands and the quality of the environment with consideration being given to the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return or the greatest unit output.' In addition, FLPMA mandates that activities be conducted so as to prevent 'unnecessary or undue degradation of the lands' (43 USC 1732 (b)).

The Mining and Minerals Policy Act of 1970 (30 USC 21(a)) established the policy for the federal government relating to mining and mineral development. The Act states that it is policy to encourage the development of 'economically sound and stable domestic mining, minerals, metal and mineral reclamation industries.' The Act also states, however, that the government should also promote the 'development of methods for the disposal, control, and reclamation of mineral waste products, and the reclamation of mined land, so as to lessen any adverse impact of mineral extraction and processing upon the physical environment that may result from mining or mineral activities.'

In accordance with the National Environmental Policy Act (NEPA), an environmental document will be prepared for those mineral actions which propose surface disturbance. The requirements and mitigation measures recommended in an Environmental Assessment (ERA) or Environmental Impact Statement (EIS) shall be made a part of the reclamation plan.

It is a statutory mandate that BLM ensure that reclamation and closure of mineral operations be completed in an environmentally sound manner. The BLM's long-term reclamation goals are to shape, stabilize, revegetate, or otherwise treat disturbed areas in order to provide a self-sustaining, safe, and stable condition that provides a productive use of the land which conforms to the approved land-use plan for the area. The short-term reclamation goals are to stabilize disturbed areas and to protect both disturbed and adjacent undisturbed areas from unnecessary or undue degradation.

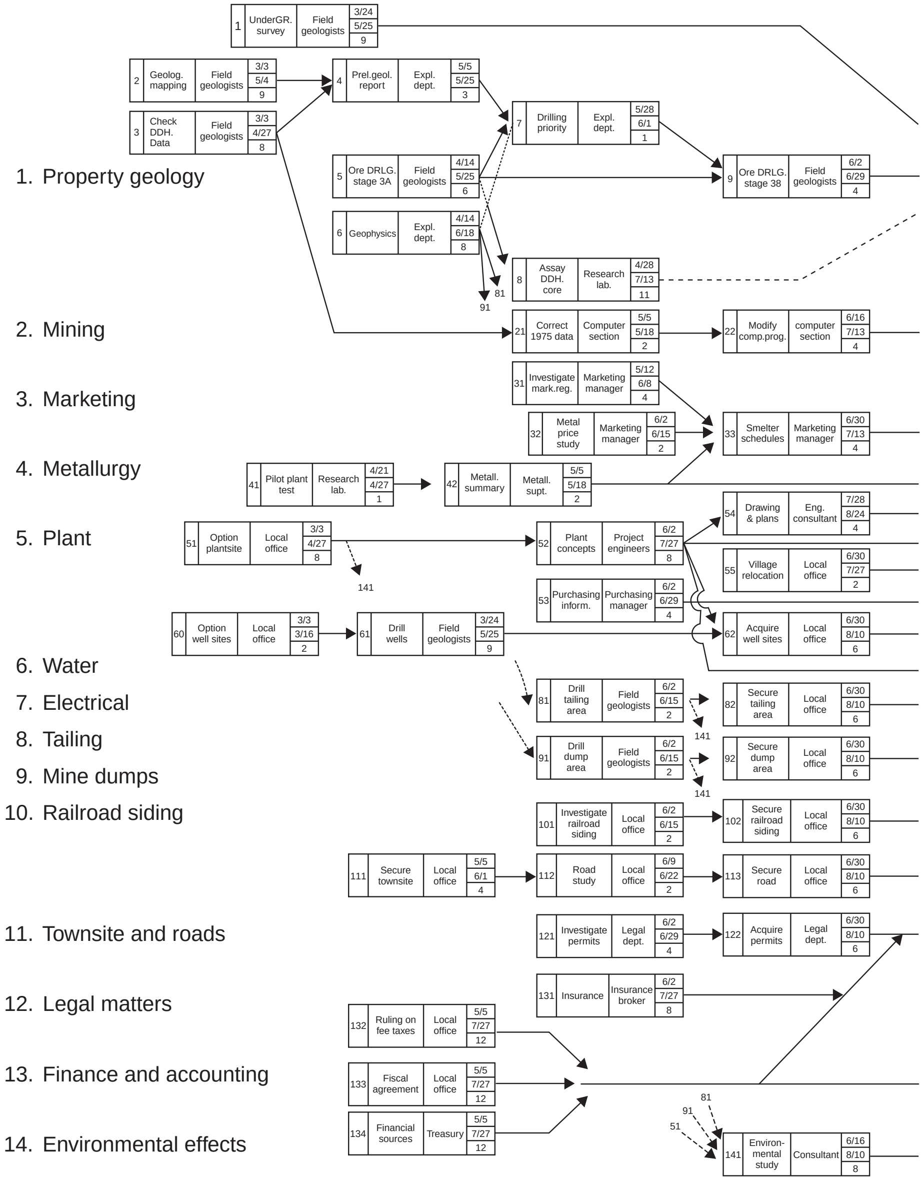
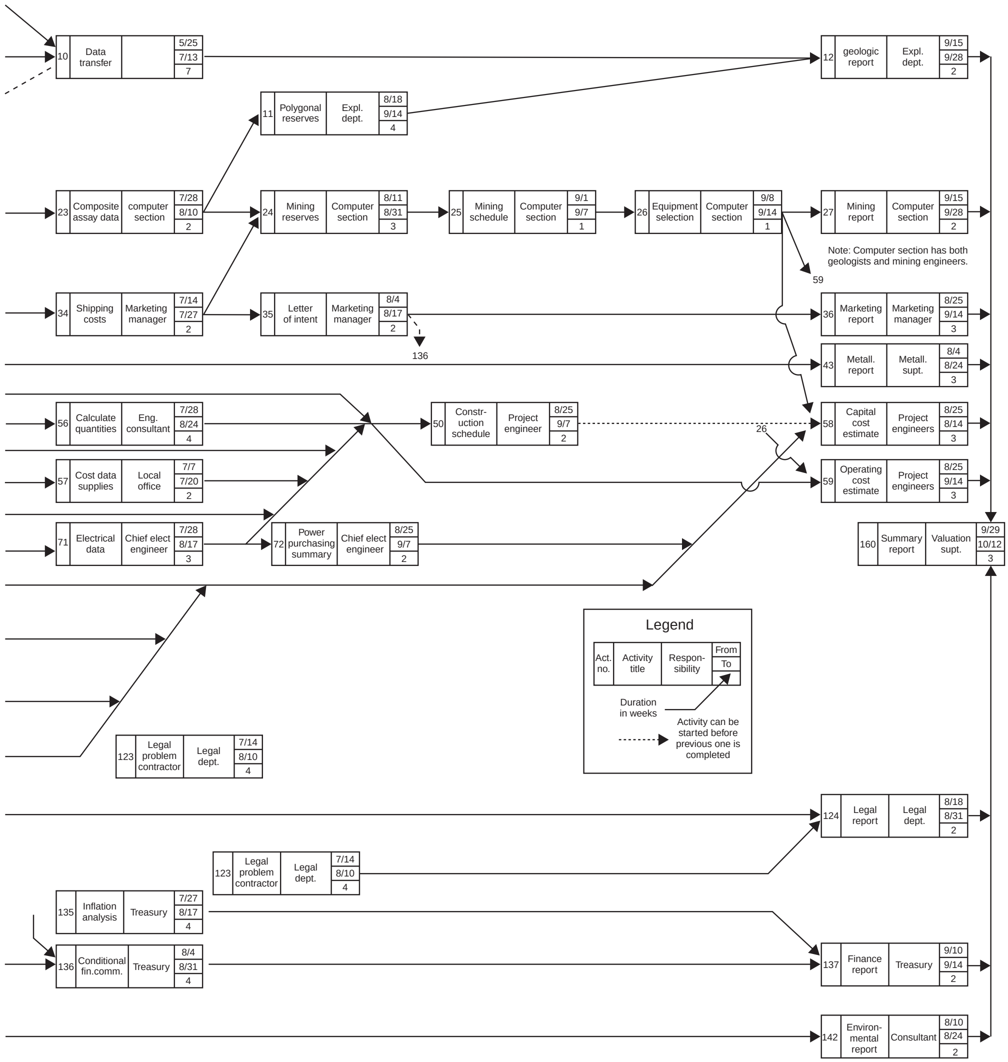


Figure 1.7. Activity network for a feasibility study (Taylor, 1977).



Feasibility report
Volumes:

1. Geology, ore reserves & mining
2. Metallurgy
3. Capital & operating cost estimates
4. Legal, finance & marketing
5. Summary & economic analysis

Figure 1.8. Simplified flow sheet showing the mining department activities.

1.9.3 *Reclamation plan purpose*

The purposes of the reclamation plan are as follows:

1. Reclamation plans provide detailed guidelines for the reclamation process and fulfill federal, state, county and other local agencies requirements. They can be used by regulatory agencies in their oversight roles to ensure that the reclamation measures are implemented, are appropriate for the site, and are environmentally sound.

2. Reclamation plans will be used by the operator throughout the operational period of the project and subsequent to cessation of exploration, mining, and processing activities. In turn, responsible agencies, including the BLM, will use the reclamation plan as a basis to review and evaluate the success of the reclamation program.

3. Reclamation plans should provide direction and standards to assist in monitoring and compliance evaluations.

1.9.4 *Reclamation plan content*

The reclamation plan should be a comprehensive document submitted with the plan of operations notice, exploration plan, or mining plan. A reclamation plan should provide the following:

1. A logical sequence of steps for completing the reclamation process.
2. The specifics of how reclamation standards will be achieved.
3. An estimate of specific costs of reclamation.
4. Sufficient information for development of a basis of inspection and enforcement of reclamation and criteria to be used to evaluate reclamation success and reclamation bond release.

The reclamation plan shall guide both the operator and the BLM toward a planned future condition of the disturbed area. This requires early coordination with the operator to produce a comprehensive plan. The reclamation plan will serve as a binding agreement between the operator and the regulatory agencies for the reclamation methodology and expected reclamation condition of the disturbed lands and should be periodically reviewed and modified as necessary.

Although the operator will usually develop the reclamation plan, appropriate pre-planning, data inventory, and involvement in the planning process by the regulatory agencies, is essential to determine the optimum reclamation proposal. Most determinations as to what is expected should be made before the reclamation plan is approved and implemented.

It is expected that there will be changes to planned reclamation procedures over the life of the project. Any changes will generally be limited to techniques and methodology needed to attain the goals set forth in the plan. These changes to the plan may result from oversights or omissions from the original reclamation plan, permitted alterations of project activities, procedural changes in planned reclamation as a result of information developed by on-site revegetation research undertaken by the operator and studies performed elsewhere, and/or changes in federal/state regulations. Specific requirements are given in the next section.

In preparing and reviewing reclamation plans, the BLM and the operator must set reasonable, achievable, and measurable reclamation goals which are not inconsistent with the established land-use plans. Achievable goals will ensure reclamation and encourage operators to conduct research on different aspects of reclamation for different environments. These goals should be based on available information and techniques, should offer incentives to both parties, and should, as a result, generate useful information for future use.

1.9.5 *Reclamation standards*

An interdisciplinary approach shall be used to analyze the physical, chemical, biological, climatic, and other site characteristics and make recommendations for the reclamation plan. In order for a disturbed area to be considered properly reclaimed, the following must be complied with:

1. Waste management. All undesirable materials (e.g. toxic subsoil, contaminated soil, drilling fluids, process residue, refuse, etc.) shall be isolated, removed, or buried, or otherwise disposed as appropriate, in a manner providing for long-term stability and in compliance with all applicable state and federal requirements:

(a) The area shall be protected from future contamination resulting from an operator's mining and reclamation activities.

(b) There shall be no contaminated materials remaining at or near the surface.

(c) Toxic substances that may contaminate air, water, soil, or prohibit plan growth shall be isolated, removed, buried or otherwise disposed of in an appropriate manner.

(d) Waste disposal practices and the reclamation of waste disposal facilities shall be conducted in conformance to applicable federal and state requirements.

2. Subsurface. The subsurface shall be properly stabilized, holes and underground workings properly plugged, when required, and subsurface integrity ensured subject to applicable federal and state requirements.

3. Site stability.

(a) The reclaimed area shall be stable and exhibit none of the following characteristics:

- Large rills or gullies.
- Perceptible soil movement or head cutting in drainages.
- Slope instability on or adjacent to the reclaimed area.

(b) The slope shall be stabilized using appropriate reshaping and earthwork measures, including proper placement of soils and other materials.

(c) Appropriate water courses and drainage features shall be established and stabilized.

4. Water management. The quality and integrity of affected ground and surface waters shall be protected as a part of mineral development and reclamation activities in accordance with applicable federal and state requirements:

(a) Appropriate hydrologic practices shall be used to protect and, if practical, enhance both the quality and quantity of impacted waters.

(b) Where appropriate, actions shall be taken to eliminate ground water co-mingling and contamination.

(c) Drill holes shall be plugged and underground openings, such as shafts, slopes, stopes, and adits, shall be closed in a manner which protects and isolates aquifers and prevents infiltration of surface waters, where appropriate.

(d) Waste disposal practices shall be designed and conducted to provide for long-term ground and surface water protection.

5. Soil management. Topsoil, selected subsoils, or other materials suitable as a growth medium shall be salvaged from areas to be disturbed and managed for later use in reclamation.

6. Erosion prevention. The surface area disturbed at any one time during the development of a project shall be kept to the minimum necessary and the disturbed areas reclaimed as soon as is practical (concurrent reclamation) to prevent unnecessary or undue degradation resulting from erosion:

(a) The soil surface must be stable and have adequate surface roughness to reduce run-off, capture rainfall and snow melt, and allow for the capture of windblown plant seeds.

(b) Additional short-term measures, such as the application of mulch or erosion netting, may be necessary to reduce surface soil movement and promote revegetation.

(c) Soil conservation measures, including surface manipulation, reduction in slope angle, revegetation, and water management techniques, shall be used.

(d) Sediment retention structures or devices shall be located as close to the source of sediment generating activities as possible to increase their effectiveness and reduce environmental impacts.

7. Revegetation. When the final landform is achieved, the surface shall be stabilized by vegetation or other means as soon as practical to reduce further soil erosion from wind or water, provide forage and cover, and reduce visual impacts. Specific criteria for evaluating revegetation success must be site-specific and included as a part of the reclamation plan:

(a) Vegetation production, species diversity, and cover (on unforested sites), shall approximate the surrounding undisturbed area.

(b) The vegetation shall stabilize the site and support the planned post-disturbance land use, provide natural plant community succession and development, and be capable of renewing itself. This shall be demonstrated by:

- Successful on-site establishment of the species included in the planting mixture and/or other desirable species.
- Evidence of vegetation reproduction, either spreading by rhizomatous species or seed production.
- Evidence of overall site stability and sustainability.

(c) Where revegetation is to be used, a diversity of vegetation species shall be used to establish a resilient, self-perpetuating ecosystem capable of supporting the postmining land use. Species planted shall includes those that will provide for quick soil stabilization, provide litter and nutrients for soil building, and are self-renewing. Except in extenuating circumstances, native species should be given preference in revegetation efforts.

(d) Species diversity should be selected to accommodate long-term land uses, such as rangeland and wildlife habitat, and to provide for a reduction in visual contrast.

(e) Fertilizers, other soil amendments, and irrigation shall be used only as necessary to provide for establishment and maintenance of a self-sustaining plant community.

(f) Seedlings and other young plants may require protection until they are fully established. Grazing and other intensive uses may be prohibited until the plant community is appropriately mature.

(g) Where revegetation is impractical or inconsistent with the surrounding undisturbed areas, other forms of surface stabilization, such as rock pavement, shall be used.

8. Visual resources. To the extent practicable, the reclaimed landscape should have characteristics that approximate or are compatible with the visual quality of the adjacent area with regard to location, scale, shape, color, and orientation of major landscape features.

9. Site protection. During and following reclamation activities the operator is responsible for monitoring and, if necessary, protecting the reclaimed landscape to help ensure reclamation success until the liability and bond are released.

10. Site-specific standards. All site-specific standards must be met in order for the site to be properly and adequately reclaimed.

1.9.6 *Surface and ground water management*

The hydrologic portion of the reclamation plan shall be designed in accordance with all federal, state, and local water quality standards, especially those under the Clean Water Act National Pollutant Discharge Elimination System (NPDES) point source and non point source programs.

The baseline survey should be conducted to identify the quantity and quality of all surface and subsurface waters which may be at risk from a proposed mineral operation. All aspects of an operation which may cause pollution need to be investigated, so that every phase of the operation can be designed to avoid contamination. It is better to avoid pollution rather than subsequently treat water. The diversion of water around chemically reactive mining areas or waste dumps must be considered during the planning stage. Site selection must be considered during the planning stage. Site selection for waste dumps should be conducted to minimize pollution.

Reclamation plans should be prepared to include a detailed discussion of the proposed surface water run-off and erosion controls including how surface run-off will be controlled during the ongoing operations, during interim shutdowns, and upon final closure.

Reclamation plans should also include a properly designed water monitoring program to ensure operator compliance with the approved plan. The purpose of the monitoring program is to determine the quantities and qualities of all waters which may be affected by mineral operations.

Operators should consider controlling all surface flows (i.e. run-on and run-off) with engineered structures, surface stabilization and early vegetative cover. Where the threat to the downstream water quality is high, the plan should provide for total containment, treatment, or both, if necessary, of the surface run-off on the project site. Sediment retention devices or structures should be located as near as possible to sediment source.

The physical control of water use and routing is a major task for mining projects.
The analysis includes the need to:

- Minimize the quantity of water used in mining and processing.
- Prevent contamination and degradation of all water.
- Intercept water so that it does not come in contact with pollutant generating sources.
- Intercept polluted water and divert it to the appropriate treatment facility.

Control may be complicated by the fact that many sources of water pollution are non point sources and the contaminated water is difficult to intercept.

1.9.7 *Mine waste management*

Handling of the waste materials generated during mining has a direct and substantial effect on the success of reclamation. Materials which will comprise the waste should be sampled and characterized for acid generation potential, reactivity, and other parameters of concern. Final waste handling should consider the selective placement of the overburden, spoils, or waste materials, and shaping the waste disposal areas. Creating special subsurface features (rock drains), sealing toxic materials, and grading or leveling the waste dumps are all waste handling techniques for enhancing reclamation. Any problems with the placement of waste discovered after the final handling will be very costly to rectify. Therefore, the selective placement of wastes must be considered during the mine plan review process in order to mitigate potential problems. Waste materials generated during mining are either placed in external waste dumps, used to backfill mined out pits, or used to construct roads, pads, dikes, etc. The design of waste management practices must be conducted in cooperation with the State, the Environmental Protection Agency (EPA), the BLM, other involved federal agencies and the operator.

The most common types of waste dumps include: (1) head of valley fills, (2) cross valley fills, (3) side hill dumps, and (4) flat land pile dumps. In the design and construction of large waste dumps it is important to consider appropriate reclamation performance standards for stability, drainage, and revegetation. Some guidance to consider during the mine plan review process includes the following:

1. Waste dumps should not be located within stream drainages or groundwater discharge areas unless engineered to provide adequate drainage to accommodate the expected maximum flow.

2. Waste dumps will be graded or contoured and designed for mass stability. Design criteria should include a geotechnical failure analysis. It is also recommended that prior to the construction of large waste dumps, a foundation analysis and geophysical testing be conducted on the dump site to ensure basal stability, especially on side hill dump locations. The effects of local groundwater conditions and other geohydrologic factors must be considered in the siting and designing of the dump.

3. Cross valley fills should provide for stream flow through the base of the dump. This is usually done using a rubble drain or french drain. At a minimum, the drain capacity should be capable of handling a design storm flow. To be effective, the drain must extend from the head of the upstream fill to the toe of the downstream face and should be constructed of coarse durable rock which will pass a standard slake test. Toxic or acid-producing materials should not be placed in valley fills.

4. Drainage should be diverted around or through head of valley and sidehill dumps.

5. Drains must be constructed of durable, nonslaking rock or gravel.

6. Topsoil or other suitable growth media should be removed from the proposed dump site and stockpiled for future use in reclamation.

7. Placement of coarse durable materials at the base and toe of the waste dump lowers the dump pore pressure and provides for additional internal hydrologic stability. An exception to this guidance would be in the case where the spoils materials exhibit high phytotoxic properties and the spoils must be sealed to prevent water percolation.

8. The finer textured waste materials which are more adaptable for use as a growing medium should be placed on the outside or mantel of the waste dump.

9. After the waste dump has been shaped, scarified, or otherwise treated to enhance reclamation, available topsoil or other selected subsoils should be spread over the surfaces of the dump as a growing medium. Grading and scarification may be required.

10. The dump should be designed to provide for controlled water flow which minimizes erosion and enhances structural stability.

11. Control erosion on long face slopes by requiring some form of slope-break mitigation, such as benches to intercept the flow of water or rock/brush terraces to slow down the velocity of the run-off.

12. Waste dump benches should be bermed or constructed wide enough to handle the peak design flows and to prevent overflowing onto the face of the dump in the event of freezing conditions. Dump benches should be constructed to allow for mass settling of the dump.

Safety requirements must be calculated for large waste dumps or waste embankments.

1.9.8 *Tailings and slime ponds*

Tailings and slime ponds consist of impounded mill wastes. Slime ponds are tailings ponds with high percentages of silts and clays, which cause very slow sediment drying conditions. Slime ponds are commonly associated with phosphate and bauxite processing operations. Reclamation of slime ponds is complicated by the slow dewatering.

Tailings impoundments are typically placed behind dams. Dams and the impounded wastes may require sealing on a case-by-case basis to avoid seepage below the dam or contamination of the groundwater. This measure only may be done before emplacement of the wastes. Long-term stability of the structure must be assured in order to guarantee ultimate reclamation success.

The nature of the tailings to be impounded should be determined as early as possible during the development of any plan. Tailings exhibiting phytotoxic or other undesirable physical or chemical properties will require a more complex reclamation plan. Analysis should include a thorough review of groundwater flow patterns in the area and a discussion of potential groundwater impacts. An impermeable liner or clay layer may be required to avoid contamination of groundwater. Where tailings include cyanide, final reclamation may include either extensive groundwater monitoring or pumpback wells and water treatment facilities to assure (ensure) groundwater quality is protected. The presence of cyanide in the tailings will not normally complicate reclamation of the surface.

1.9.9 *Cyanide heap and vat leach systems*

Dilute solutions of sodium cyanide (NaCN) or potassium cyanide (KCN) are used to extract precious metals from ores. Concentrations of cyanide solution utilized range from 300 to 500 ppm for heap leach operations to 2000 ppm (0.2%) for vat leach systems.

Low-grade ores can be economically leached in heaps placed on impermeable pads where a cyanide solution is sprinkled onto the ore. The solution preferentially collects the metals as it percolates downward and is recovered at the bottom of the heap through various means. Other metals besides gold and silver are mobilized by cyanide solutions.

Higher grade ores may be crushed, ground and agitated with cyanide solution in vats or tanks. The solids are then separated from the gold or silver-bearing (pregnant) solution. The precious metals are recovered from the pregnant solution and the solids are transferred to a tailings impoundment. The tailings are often deposited in a slurry form and may contain several hundred parts per million of cyanide.

Part of the overall mine reclamation plan includes cyanide detoxification of residual process solutions, ore heaps, tailings impoundments, and processing components.

A key to reclamation of cyanide facilities is planning for the solution neutralization process. The first step is to set a detoxification performance standard. This will have to be site specific dependent on the resources present and their susceptibility to cyanide and metal contamination. A minimum requirement would have to be the specific state standard. BLM may need to require more stringent standards if sensitive resources are present. Other considerations include the health advisory guideline used by EPA of 0.2 mg/l for cyanide in drinking water; and the freshwater chronic standard of 0.0052 mg/l for aquatic organisms. Some species of fish are especially sensitive to cyanide. Likewise metals, and other constituent levels, should be specified for detoxification of cyanide solutions.

There are a variety of methods for achieving detoxification of cyanide solutions. These range from simple natural degradation, to active chemical or physical treatment of process waters. A thorough understanding of the metallurgical process generating the waste, and of the chemistry of the waste stream is necessary to select the most effective cyanide destruction technique.

1.9.10 *Landform reclamation*

Shaping, grading, erosion control, and visual impact mitigation of an affected site are important considerations during review of the reclamation plan. The review process not only ensures that the topography of the reclaimed lands blend in as much as possible with the surrounding landforms, natural drainage patterns, and visual contrasts, but also enhances the success of revegetation.

The final landform should:

- be mechanically stable,
- promote successful revegetation,
- prevent wind and water erosion,
- be hydrologically compatible with the surrounding, landforms, and
- be visually compatible with the surrounding landforms.

Pit backfilling provides an effective means for reclamation of the disturbed lands to a productive post-mining land use. However, development of some commodities and deposit types may not be compatible with pit backfilling.

Open pit mine optimization is achieved by extending the pit to the point where the cost of removing overlying volumes of unmineralized 'waste' rock just equal the revenues (including profit) from the ore being mined in the walls and bottom of the pit. Because there is usually mineralization remaining, favorable changes in an economic factor (such as an increase in the price of the commodity or new technology resulting in a reduced operating cost) can result in a condition where mining can be expanded, or resumed at a future time. This economically determined pit configuration is typical of the open pit metal mining industry and is of critical importance in efforts to maximize the recovery of the mineral resource. To recover all the known ore reserves the entire pit must remain exposed through progressively deeper cuts. Backfilling where technologically and economically feasible, can not begin until the ore reserves within the specific pit are depleted at the conclusion of mining. Additionally, some waste material is not suitable for use as backfilling material.

Depending upon the size of the open pit, backfilling can extend the duration of operations from a few months to several years.

Final highwall configuration, including consideration of overall slope angle, bench width, bench height, etc., should be determined during the review of the plan. The maximum height of the highwall should be determined using site-specific parameters such as rock type and morphology. In most cases, the maximum height is regulated by various state agencies.

The normal procedures are to either leave the exposed highwall or to backfill and bury the highwall either totally or partially. Appropriate fencing or berming at the top of the highwall is necessary to abate some of the hazards to people and animals.

It is important that the backfill requirements be determined during the plan review process and included in the approved plan.

1.10 ENVIRONMENTAL PLANNING PROCEDURES

As described by Gilliland (1977), environmental planning consists of two distinct phases:

- Initial project evaluation,
- The strategic plan.

The components involved in each of these as extracted from the Gilliland paper will be outlined below.

1.10.1 *Initial project evaluation*

1. Prepare a detailed outline of the proposed action. This should include such items as drawings of land status, general arrangement of facilities, emission points and estimates of emission composition and quantities, and reclamation plans. It is also helpful to have information on the scope of possible future development and alternatives that might be available which could be accommodated within the scope of the proposed action.

For example, are there other acceptable locations for tailings disposal if the initial location cannot be environmentally marketed? A schedule for engineering and construction of the proposed action and possible future development should also be available.

2. Identify permit requirements. Certain permits can take many months to process and must be applied for well in advance of construction. Further, some permits will require extensive data, and very long lead times may be encountered in the collection of such data.

For example, biotic studies for environmental impact statements require at least a year, and sometimes longer, to evaluate seasonal changes in organisms. Are there points of conflict between permit requirements and the nature of the proposed action? Can the proposed action be altered to overcome these discrepancies or to avoid the need for permits that could be particularly difficult or significantly time-consuming to obtain? For example, a 'zero' effluent discharge facility could well avoid the Federal Water Pollution Control Action requirement for an Environmental Impact Statement (EIS).

3. Identify major environmental concerns. This includes potential on-site and off-site impacts of the proposed action and from possible future development. Land use and socio-economic issues as well as those of pollutional character must be taken into account. Although there may be little concern about the impacts of an exploratory activity itself, when bulldozers and drill rigs begin to move onto a property, it becomes apparent to the public that there may indeed ultimately be a full development of the property. Public concern may surface from speculation about the possible impacts of full development, and this could result in considerable difficulty in obtaining even the permits necessary to proceed with the proposed activity.

4. Evaluate the opportunity for and likelihood of public participation in the decision-making process. Recent administrative reforms provide for expanded opportunity for public participation in the decision-making process. Projects to be located in areas of minimal environmental sensitivity may stir little public interest and permits will not be delayed beyond their normal course of approval. A project threatening material impact to an area where the environmental resources are significant, however, will probably receive careful public scrutiny and may be challenged every step in the permit process.

5. Consider the amount and effect of delay possibly resulting from public participation during each state of the project. This could also be called intervention forecasting. When can a hearing be requested? When would it be possible for a citizen to bring suit? How long would it take to secure a final court action? Could the plaintiffs enjoin work on the project during the pendency of litigation? Can the project tolerate such delays? Can the project schedule be adjusted to live with such delays?

6. Evaluate the organization and effectiveness of local citizens groups. Attitudes are also part of this evaluation. Local citizen groups can be a powerful ally in positive communications with the public. They can also be effective adversaries. This evaluation should be extended to all groups which could have a significant voice in opinion making within a community. The working relationship of local groups with state or national counterpart groups should also be assessed.

7. Determine the attitudes and experience of governmental agencies. Identify any inter-agency conflicts. New ventures face an intricate web of federal, state, and local laws and regulations which are often complicated by inconsistencies in the policy goals which underlie these laws, and overlapping jurisdiction of the regulatory agencies.

Sometimes you must deal with personnel who have little knowledge of the business world or of the nature of operations being proposed. A company must be prepared, therefore, to dedicate considerable time and effort in promoting and understanding of the project.

Further, it is imperative for a company to recognize that government agency personnel have a public responsibility to see that the various laws and regulations within their jurisdiction are complied with. They may not always agree that the requirements of the law are practical, fair or equitable, but it is their job to ensure their applicability. Sometimes areas of apparent frustration or conflict will resolve themselves by re-evaluating your position with regard to the role that must be performed by regulatory personnel.

8. Consider previous industry experience in the area. This involves a determination of public attitudes toward previous or existing industry in the area and the posture and performance of these industries as a responsible member of the community. It is extremely helpful to the cause of your project if industry enjoys the status of being a good citizen. Where negative attitudes prevail, is there something about your project that could invite similar censure or could it be so designed to change these public attitudes?

9. Consider recent experience of other companies. Have new industries located or tried to locate within the area? Were there any issues involved relative to their success or failure to locate that might also be issues of concern to the proposed activity?

10. Identify possible local consultants and evaluate their ability and experience. Local consultants can be invaluable in assisting the company in many areas of inquiry. Their familiarity with the local scene on environmental, legal, socioeconomic, land use and other matters can enhance the credibility of a company's planning efforts and acceptability within a community.

11. Consider having a local consultant check the conclusions of the initial evaluation.

This initial project evaluation is essentially an identification procedure which in many instances can be largely produced in-house with possibly some modest assistance from outside consultants. Correspondingly, the cost could range from a thousand dollars or less to several thousand dollars depending upon the familiarity of personnel with this type of work and the amount of outside consultant help needed.

1.10.2 *The strategic plan*

Following the initial project evaluation the next step is to prepare a strategy or game plan for dealing with the identified issues. The elements would include:

1. Outline of technical information needed to obtain permits and to address legitimate environmental, land use and socioeconomic concerns. There are good reasons for the reluctance of planners to develop hard data before they are sure that they will be permitted to proceed with a project.

However, if a project is worthwhile, every practical effort must be made to develop information that demonstrates impacts have been carefully assessed, legitimate environmental concerns have been addressed, and controls and mitigation measures will be adequate to meet all existing standards and to protect the environment. In cases where standards are stringent and controls are not demonstrated technology, substantial extra effort may have to be made to develop predictions of performance. In case where better data cannot be developed without delaying construction, plans may have to include a proposal for eventually securing such data and adjusting permit requirements before operations begin.

Where predictive data are not practically obtainable, a plan might provide for operational monitoring with post-startup alteration of permit requirements if problems arise. This plan element, therefore, provides a specific checklist for the information gathering system.

2. Categorically assign responsibilities for the acquisition of the technical information and hire necessary consultants. Coordinate this work with governmental agencies when appropriate.

The primary responsibility for each element of data collection should be clearly designated so that misunderstandings do not arise. Governmental agencies can be an important source of background information on air quality, water quality and other pertinent data. Further, government studies may be intended or in progress which in scope would include the location and environmental concerns of the company's proposed action. Data collection by the company could complement these studies and vice versa.

3. Prepare a schedule for obtaining information and data and for submitting permit applications to the appropriate agencies. Firm target dates must be established for the finalization of reports, permit applications or other necessary authorizations. Interim reporting periods should also be set to ascertain the status of progress and to provide whatever adjustments are necessary to keep on the appropriate schedule. A critical path chart would include a display of this sequence. If a project is properly planned, its proponents require nothing more from government except even handed operation of the approval mechanism.

4. Select local legal, technical and public relations consultants. Sometimes the local consultants may be those who will be directly involved in the data development. In other instances, these consultants would have more of a role in planning, data evaluation and public communications.

5. Avoid hostile confrontations with environmental groups. There is nothing to be gained from a shouting match where both sides become so highly polarized that reason and credibility cannot be maintained. No-growth advocates will probably continue to be unyielding in their opposition no matter how much progress is made in devising effective environmental controls.

Project planners who view citizen opposition as monolithic and implacable miss, however, an opportunity to reduce the risks of intervention and delay. Citizen attitudes are subject to change, and many citizen activists are sincerely, and very properly, seeking to secure for themselves and others the maintenance of a quality environment.

If the proposed activity is demonstrably sound, both industrially and environmentally, and the public has access to all the facts, it is likely that people will make sound judgements and that mineral development will be permitted.

6. Develop a consistent program for the generation of credible factual information. Good factual information needed to refute or substantiate concerns regarding possible impacts of the proposed action or future development is not always available. Such deficiencies are not uncommon or unacceptable if they are honestly faced and a program is designed to acquire the necessary information. Many projects have been seriously delayed or stopped because of a company's failure to admit that a concern exists. This can become a focal point for attacking the credibility of a company's entire program.

1.10.3 *The environmental planning team*

The environmental planning effort, due to the wide diversity of tasks involved requires the participation of many specialists drawn from various functional areas of mining organizations and from outside consulting firms. To coordinate this effort there must be a team leader who has the perspective to understand the requirements of the disciplines involved and the eventual use of the information evolved. This team leader must also have the acknowledged responsibility and authority for the performance of this coordinating role.

Table 1.4. Types of permits and approvals which may be required for the Kensington Gold Project (Forest Service, 1990).

1. *Federal government*

Forest Service
1. NEPA compliance and record of decision on EIS
2. Plan of operations
3. Special use permits

Environmental Protection Agency
1. National Pollutant Discharge Elimination System (NPDES)
2. Spill Prevention Control and Countermeasure (SPCC) plan
3. Review of section 404 Permit
4. Notification of hazardous wages activity
5. NEPA compliance and record of decision on EIS (cooperating agency)

Army Corps of Engineers
1. Section 404 Permit – Clean Water Act (dredge and fill)
2. Section 10 Permit – Rivers and Harbor Act
3. NEPA compliance and record of decision on EIS (cooperating agency)

Coast Guard
1. Notice of fueling operations
2. Permit to handle hazardous materials
3. Application for private aids to navigation

Federal Aviation Administration
1. Notice of landing area and certification of operation
2. Determination of no hazard

Federal Communications Commission
1. Radio and microwave station authorizations

Treasury Department (Dept of Alcohol, Tobacco & Firearms)
1. Explosives user permit

Mine Safety and Health Administration
1. Mine I.D. number
2. Legal identity report
3. Miner training plan approval

U.S. Fish and Wildlife Service
1. Threatened and endangered species clearance
2. Bald Eagle Protection Act clearance

National Marine Fisheries Services
1. Threatened and endangered species clearance

2. *State of Alaska*

Alaska Division of Government Coordination
1. Coastal project questionnaire
2. Coastal management program certification

Alaska Department of Environmental Conservation
1. Air quality permit
2. Burning permit
3. Certification of reasonable assurance
4. Solid Waste Management permit
5. Oil facilities approval of financial responsibility
6. Oil facilities discharge contingency plan
7. Water and sewer plan approval
8. Food service permit

Alaska Department of Natural Resources
1. Water rights permits
2. Tidelands lease
3. Right-of-way permit
4. Permit to construct or modify a dam
5. Land use permit

Alaska Department of Fish and Game
1. Fishway or fish passage permit
2. Anadromous fish protection permit

Alaska Department of Public Safety
1. Life and fire safety plan check

Alaska Department of Labor
1. Fired and unfired pressure vessel certificate
2. Elevator certificate of operation

Alaska Department of Revenue
1. Affidavit for non-resident business taxation
2. Alaska business license
3. Alaska mining license

Alaska Department of Health and Social Services
1. Health care facilities construction license
2. Certificate of need (townsite with health care facilities)

3. *Local government*

City and Bureau of Juneau
1. Mining permit
2. Grading permit
3. Building permits
4. Burning permits
5. Explosive permits

The team members include such personnel as the project manager, project engineers, attorneys, environmental specialists, technical and public relations experts.

1.11 A SAMPLE LIST OF PROJECT PERMITS AND APPROVALS

The 'Final Scoping Document, Environmental Impact Statement' for the Kensington Gold Project located near Juneau, Alaskawas published by the U.S. Forest Service (Juneau Ranger District) in July 1990 (Forest Service, 1990). To provide the reader with an appreciation for the level of effort involved just in the permitting process, a listing of the various federal, state, and local government permits/approvals which may be required for this underground gold mine/mill, is given in Table 1.4.

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REVIEW QUESTIONS AND EXERCISES

1. What is meant by ore?
2. Express the meaning of 'profit' in your own words. How does it relate to your future opportunities?
3. Define
   – Exploration
   – Development
   – Production

4. Discuss the changes that have occurred between the SME 1991 and SME 1999 guidelines regarding the 'Reporting of Exploration Information, Resources and Reserves.' See the Reference section of this chapter.
5. Distinguish the meanings of 'Resource' and 'Reserve.'
6. Using Figure 1.1 discuss the basis upon which 'Resources' and 'Reserves' change category.
7. The U.S. Securities and Exchange Commission (SEC) have their own guidelines regarding the public reporting of resources and reserves. Referring to the website provided in the References, summarize their requirements. How do they compare to the SME 1991 guidelines? To the 1999 guidelines?
8. The most recent version of the USGS/USBM classification system is published as USGS Circular 831. Download the Circular from their website (see References). What was the main purpose of these guidelines? Who was the intended customer?
9. What is meant by 'Hypothetical Resources'?
10. What is meant by 'Undiscovered Resources'?
11. In the recent Bre-X scandal, the basis for their resource/reserve reporting was indicated to be USGS Circular 831. In which of the classification categories would the Bre-X resources/reserves fall? Explain your answer. See the References for the website.
12. Compare the 1999 SME guidelines with those provided in the JORC code included in Chapter 7.
13. Compare the 1999 SME guidelines with those provided in the CIM guidelines included in Chapter 7.
14. Discuss the relevance of the Mineral Supply Process depicted in Figure 1.2 to iron ore for the period 2002 to 2005.
15. Discuss the relevance of the Mineral Supply Process depicted in Figure 1.2 to molybdenum for the period 2002 to 2005.
16. Discuss the relevance of the Mineral Supply Process depicted in Figure 1.2 to copper for the period 2002 to 2005.
17. Figure 1.3 shows diagrammatically the planning, implementation and production phases for a new mining operation. What are the planning stages? What are the implementation stages? What are the production stages?
18. Does the 'Relative Ability to Influence Cost' curve shown in Figure 1.3 make sense? Why or why not?
19. What is the fourth phase that should be added to Figure 1.3?
20. In the initial planning stages for any new project there are a great number of factors of rather diverse nature that must be considered. The development of a 'checklist' is often a very helpful planning tool. Combine the items included in the checklist given in section 1.3 with those provided by Gentry and O'Neil on pages 395–396 of the SME Mining Engineering Handbook (2nd edition, Volume 1).
21. How might the list compiled in problem 20 be used to guide the preparation of a senior thesis in mining engineering?
22. What is the meaning of a 'bankable' mining study?
23. Summarize the differences between a conceptual study, a pre-feasibility study and a feasibility study.
24. Assume that the capstone senior mine design course extends over two semesters each of which is 16 weeks in duration. Using the information provided in Tables 1.3 and 1.4 regarding the content of an intermediate valuation report (pre-feasibility study) and a

feasibility study, respectively, develop a detailed series of deliverables and milestones. It is suggested that you scan the two tables and cut-and-paste/edit to arrive at your final product.

25. Assume that the estimated capital cost for an open pit project is $500 million. How much would you expect the conceptual study, the preliminary study and the feasibility study to cost?
26. Section 1.6 concerns the accuracy of the estimates provided. These are discussed with respect to tonnage and grade, performance, costs, and price and revenue. Summarize each.
27. Discuss what is meant by the contingency allowance. What is it intended to cover? What is it not meant to cover?
28. In section 1.6.4 it is indicated that both probable and average metal prices expressed in present value dollars need to be provided. The 'conservative' price is considered to be that with an 80% probability of applying. Choose a mineral commodity and assign a probable price and a conservative price for use in a pre-feasibility study. Justify your choices.
29. What are the two common ways for accomplishing a feasibility study?
30. Summarize the steps involved in performing a feasibility study. What is the function of the steering committee? Who are the members?
31. Who are the members of the project teams?
32. What is meant by a Work Breakdown Structure? What is its purpose?
33. What is the difference between a Work Breakdown Structure and a Work Classification Structure?
34. Construct a bar chart for the activities listed in the project schedule developed in problem 24. It should be of the type shown in Figure 1.6.
35. What is meant by an RFP? How should they be structured?
36. What is the goal of a Critical Path representation?
37. Section 1.9 deals with mine reclamation. What is the rationale for including this material in Chapter 1 of this book and not later?
38. What is the concept of multiple use management? What is its application to minerals?
39. What is the practical implication of the statement from the Mining and Minerals Policy act of 1970?
40. What is the U.S. National Materials and Mineral Policy, Research and Development Act of 1980 (Public Law 96-479)? Is it being followed today?
41. Define the following acronyms:
    a. BLM
    b. FLPMA
    c. CFR
    d. NEPA
    e. EA
    f. EIS
    g. NPDES
    h. EPA
42. Summarize the purposes of a reclamation plan.
43. What should a reclamation plan contain?
44. For a disturbed area to be properly reclaimed, what must be achieved? Summarize the major concepts.

45. Discuss the most important concepts regarding surface and ground water management.
46. Discuss the important concepts regarding mine waste management.
47. Tailings and slime ponds. What is the difference between them? What are the engineering concerns?
48. What means are available for the detoxification of cyanide heap and vat leach systems?
49. What is meant by landform reclamation?
50. Do open pit mines have to be refilled? Discuss the pro's and con's regarding the backfilling of open pit mines.
51. In section 1.10 'Environmental Planning Procedures' Gilliland divided environmental planning into two distinct phases: (1) Initial project evaluation and (2) The strategic plan. Summarize the most important aspects of each.
52. What members would be part of an environmental planning team?
53. In section 1.11 a list of the project permits and approvals required for the Kensington Gold project in Alaska has been provided. List the permits and approvals required for a new mining project in your state/country.

CHAPTER 2

Mining revenues and costs

2.1 INTRODUCTION

For one to know whether the material under consideration is 'ore' or simply 'mineralized rock', both the revenues and the costs must be examined. It is the main objective of this chapter to explore in some detail each of these topics.

2.2 ECONOMIC CONCEPTS INCLUDING CASH FLOW

In Chapter 6, the production planning portion of this text, an economic basis will be used to select production rate, mine life, etc. This section has been included to support that chapter. It is not intended to be a textbook complete in itself but rather to demonstrate some of the important concepts and terms.

2.2.1 *Future worth*

If someone puts \$1 in a savings account today at a bank paying 10% simple interest, at the end of year 1 the depositor would have \$1.10 in his account. This can be written as

$$\text{FW} = \text{PV}(1 + i) \tag{2.1}$$

where FW is the future worth, PV is the present value, i is the interest rate.

If the money is left in the account, the entire amount (principal plus interest) would draw interest. At the end of year 2, the account would contain \$1.21. This is calculated using

$$\text{FW} = \text{PV}(1 + i)(1 + i)$$

At the end of year n, the accumulated amount would be

$$\text{FW} = \text{PV}(1 + i)^n \tag{2.2}$$

In this case if $n = 5$ years, then

$$FW = \$1(1 + 0.10)^5 = \$1.61$$

2.2.2 *Present value*

The future worth calculation procedure can now be reversed by asking the question 'What is the present value of \$1.61 deposited in the bank 5 years hence assuming an interest rate of 10%?' The formula is rewritten in the form

$$PV = \frac{FW}{(1+i)^n} \tag{2.3}$$

Substituting FW = \$1.61, $i = 0.10$, and $n = 5$ one finds as expected that the present value is

$$PV = \frac{\$1.61}{(1+0.10)^5} = \$1$$

2.2.3 *Present value of a series of uniform contributions*

Assume that \$1 is to be deposited in the bank at the end of 5 consecutive years. Assuming an interest rate of 10%, one can calculate the present value of each of these payments. These individual present values can then be summed to get the total.

Year 1: Payment

$$PV_1 = \frac{\$1}{(1.10)^1} = \$0.909$$

Year 2: Payment

$$PV_2 = \frac{\$1}{(1.10)^2} = \$0.826$$

Year 3: Payment

$$PV_3 = \frac{\$1}{(1.10)^3} = \$0.751$$

Year 4: Payment

$$PV_4 = \frac{\$1}{(1.10)^4} = \$0.683$$

Year 5: Payment

$$PV_5 = \frac{\$1}{(1.10)^5} = \$0.621$$

The present value of these 5 payments is

$$PV = \$3.790$$

The general formula for calculating the present value of such equal yearly payments is

$$PV = FW\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \tag{2.4}$$

Applying the formula in this case yields

$$\text{PV} = \$1\left[\frac{(1.10)^5 - 1}{(0.10)(1.10)^5}\right] = \$3.791$$

The difference in the results is due to roundoff.

2.2.4 *Payback period*

Assume that \$5 is borrowed from the bank today (time = 0) to purchase a piece of equipment and that a 10% interest rate applies. It is intended to repay the loan in equal yearly payments of \$1. The question is 'How long will it take to repay the loan?' This is called the payback period. The present value of the loan is

$$\text{PV (loan)} = -\$5$$

The present value of the payments is

$$\text{PV (payments)} = \$1\left[\frac{(1.10)^n - 1}{0.10(1.10)^n}\right]$$

The loan has been repaid when the net present value

$$\text{Net present value (NPV)} = \text{PV (loan)} + \text{PV (payments)}$$

is equal to zero. In this case, one substitutes different values of n into the formula

$$\text{NPV} = -\$5 + \$1\left[\frac{(1.10)^n - 1}{0.10(1.10)^n}\right]$$

For $n = 5$ years NPV = −\$1.209; for $n = 6$ years NPV = −\$0.645; for $n = 7$ years NPV = −\$0.132; for $n = 8$ years NPV = \$0.335.

Thus the payback period would be slightly more than 7 years ($n \cong 7.25$ years).

2.2.5 *Rate of return on an investment*

Assume that \$1 is invested in a piece of equipment at time = 0. After tax profits of \$1 will be generated through its use for each of the next 10 years. If the \$5 had been placed in a bank at an interest rate of i then its value at the end of 10 years would have been using Equation (2.2).

$$\text{FW} = \text{PV}(1 + i)^n = \$5(1 + i)^{10}$$

The future worth (at the end of 10 years) of the yearly \$1 after tax profits is

$$\text{FW} = A_m\left[\frac{(1 + i)^n - 1}{i}\right] \tag{2.5}$$

where A_m is the annual amount and $[(1+i)^n - 1]/i$ is the uniform series compound amount factor.

The interest rate i which makes the future worths equal is called the rate of return (ROR) on the investment.

In this case

$$\$5(1+i)^{10} = \$1\left[\frac{(1+i)^{10}-1}{i}\right]$$

Solving for i one finds that

$$i \cong 0.15$$

The rate of return is therefore 15%. One can similarly find the interest rate which makes the net present value of the payments and the investment equal to zero at time $t = 0$.

$$\text{NPV} = -\$5 + \$1\left[\frac{(1.10)^{10} - 1}{i(1+i)^{10}}\right] = 0$$

$$i \cong 0.15$$

The answer is the same.

The process of bringing the future payments back to time zero is called 'discounting'.

2.2.6 *Cash flow (CF)*

The term 'cash flow' refers to the net inflow or outflow of money that occurs during a specific time period. The representation using the word equation written vertically for an elementary cash flow calculation is

Gross revenue
– Operating expense
= Gross profit (taxable income)
– Tax
= Net profit
– Capital costs
———————————
= Cash flow

A simple example (after Stermole & Stermole, 1987) is given in Table 2.1.

In this case there is a capital expense of \$200 incurred at time $t = 0$ and another \$100 at the end of the first year. There are positive cash flows for years 2 through 6.

Table 2.1. Simple cash flow example (Stermole & Stermole, 1987).

Year	0	1	2	3	4	5	6
Revenue			170	200	230	260	290
– Operating cost			−40	−50	−60	−70	−80
– Capital costs	−200	−100					
– Tax costs			−30	−40	−50	−60	−70
Project cash flow	−200	−100	+100	+110	+120	+130	+140

2.2.7 *Discounted cash flow (DCF)*

To 'discount' is generally used synonymously with 'to find the present value'. In the previous example, one can calculate the present values of each of the individual cash flows. The net present value assuming a minimum acceptable discount rate of 15% is

$$
\begin{array}{lllr}
\text{Year 0} & \text{NPV}_0 = -200 & = & -200.00 \\[1ex]
\text{Year 1} & \text{NPV}_1 = \dfrac{-100}{1.15} & = & -86.96 \\[1ex]
\text{Year 2} & \text{NPV}_2 = \dfrac{100}{(1.15)^2} & = & 75.61 \\[1ex]
\text{Year 3} & \text{NPV}_3 = \dfrac{110}{(1.15)^3} & = & 73.33 \\[1ex]
\text{Year 4} & \text{NPV}_4 = \dfrac{120}{(1.15)^4} & = & 68.61 \\[1ex]
\text{Year 5} & \text{NPV}_5 = \dfrac{130}{(1.15)^5} & = & 64.63 \\[1ex]
\text{Year 6} & \text{NPV}_6 = \dfrac{140}{(1.15)^6} & = & 60.53 \\
\hline
 & \text{Discounted cash flow} & = & \$55.75
\end{array}
$$

The summed cash flows equal $55.75. This represents the additional capital expense that could be incurred in year 0 and still achieve a minimum rate of return of 15% on the invested capital.

2.2.8 *Discounted cash flow rate of return (DCFROR)*

To calculate the net present value, a discount rate had to be assumed. One can however calculate the discount rate which makes the net present value equal to zero. This is called the discounted cash flow rate of return (DCFROR) or the internal rate of return (ROR). The terms DCFROR or simply ROR will be used interchangeably in this book. For the example given in Subsection 2.2.6, the NPV equation is

$$\text{NPV} = -200 - \frac{100}{1+i} + \frac{100}{(1+i)^2} + \frac{110}{(1+i)^3} + \frac{120}{(1+i)^4} + \frac{130}{(1+i)^5} + \frac{140}{(1+i)^6} = 0$$

Solving for i one finds that

$$i \cong 0.208$$

In words, the after tax rate of return on this investment is 20.8%.

2.2.9 *Cash flows, DCF and DCFROR including depreciation*

The cash flow calculation is modified in the following way when a capital investment is depreciated over a certain time period.

  Gross revenue
− Operating expense
− Depreciation
= Taxable income
− Tax
= Profit
+ Depreciation
− Capital costs

= Cash flow

In this book no attempt will be made to discuss the various techniques for depreciating a capital asset. For this example it will be assumed that the investment (Inv) has a Y year life with zero salvage value. Standard straight line depreciation yields a yearly depreciation value (Dep) of

$$\text{Dep} = \frac{\text{Inv}}{Y} \tag{2.6}$$

The procedure will be illustrated using the example adapted from Stermole & Stermole (1987).

Example. A \$100 investment cost has been incurred at time $t = 0$ as part of a project having a 5 year lifetime. The salvage value is zero. Project dollar income is estimated to be \$80 in year 1, \$84 in year 2, \$88 in year 3, \$92 in year 4, and \$96 in year 5. Operating expenses are estimated to be \$30 in year 1, \$32 in year 2, \$34 in year 3, \$36 in year 4, and \$38 in year 5. The effective income tax rate is 32%.

The cash flows are shown in Table 2.2.

The net present value (NPV) of these cash flows assuming a discount rate of 15% is \$43.29

$$\begin{aligned} \text{NPV} &= -100 - \frac{40.4}{1.15} + \frac{41.8}{(1.15)^2} + \frac{43.1}{(1.15)^3} + \frac{44.5}{(1.15)^4} + \frac{45.8}{(1.15)^5} \\ &= \$43.29 \end{aligned}$$

Table 2.2. Cash flow example including depreciation (Stermole & Stermole, 1987).

Year	0	1	2	3	4	5	Cumulative
Revenue		80.0	84.0	88.0	92.0	96.0	440.0
− Oper costs		−30.0	−32.0	−34.0	−36.0	−38.0	−170.0
− Depreciation		−20.0	−20.0	−20.0	−20.0	−20.0	−100.0
= Taxable		30.0	32.0	34.0	36.0	38.0	170.0
− Tax @ 32%		−9.6	−10.2	−10.9	−11.5	−12.2	−54.4
= Net income		20.4	21.8	23.1	24.5	25.8	115.6
+ Depreciation		20.0	20.0	20.0	20.0	20.0	100.0
− Capital costs	−100.0	–	–	–	–	–	−100.0
Cash flow	−100.0	40.4	41.8	43.1	44.5	45.8	115.6

The DCFROR is the discount rate which makes the net present value equal to zero. In this case

$$\text{NPV} = -100 - \frac{40.4}{1+i} + \frac{41.8}{(1+i)^2} + \frac{43.1}{(1+i)^3} + \frac{44.5}{(1+i)^4} + \frac{45.8}{(1+i)^5} = 0$$

The value of i is about

$$i \cong 0.315$$

2.2.10 *Depletion*

In the U.S. special tax consideration is given to the owner of a mineral deposit which is extracted (depleted) over the production life. One might consider the value of the deposit to 'depreciate' much the same way as any other capital investment. Instead of 'depreciation', the process is called 'depletion'. The two methods for computing depletion are:

(1) cost depletion,
(2) percentage depletion.

Each year both methods are applied and that which yields the greatest tax deduction is chosen. The method chosen can vary from year to year. For most mining operations, percentage depletion normally results in the greatest deduction.

To apply the cost depletion method, one must first establish the cost depletion basis. The initial cost basis would normally include:

– the cost of acquiring the property including abstract and attorney fees.
– exploration costs, geological and geophysical survey costs.

To illustrate the principle, assume that this is \$10. Assume also that there are 100 tons of reserves and the yearly production is 10 tons. The \$10 cost must then be written off over the 100 total tons. For the calculation of cost depletion the cost basis at the end of any year (not adjusted by the current years depletion) is divided by the estimated remaining ore reserve units plus the amount of ore removed during the year. This gives the unit depletion. In this simple case, for year 1

$$\text{Unit depletion} = \frac{\$10}{100} = \$0.10$$

The unit depletion is then multiplied by the amount of ore extracted during the year to arrive at the depletion deduction,

$$\text{Depletion deduction} = 10 \text{ tons} \times \$0.10 = \$1$$

The new depletion cost basis is the original cost basis minus the depletion to date. Thus for the year 2 calculation:

$$\begin{aligned} \text{Depletion cost basis} &= \$10 - \$1 = \$9 \\ \text{Remaining reserves} &= 90 \text{ tons} \end{aligned}$$

The year 2 unit depletion and depletion deduction are:

$$\text{Unit depletion} = \frac{\$9}{90} = \$0.10$$

$$\text{Depletion deduction} = 10 \times \$0.10 = \$1$$

Table 2.3. Percentage depletion rates for the more common minerals. A complete list of minerals and their percentage depletion rates are given in section 613(b) of the Internal Revenue Code.

Deposits	Rate
Sulphur, uranium, and, if from deposits in the United States, asbestos, lead ore, zinc ore, nickel ore, and mica	22 %
Gold, silver, copper, iron ore, and certain oil shale, if from deposits in the United States	15 %
Borax, granite, limestone, marble, mollusk shells, potash, slate, soapstone, and carbon dioxide produced from a well	14 %
Coal, lignite, and sodium chloride	10 %
Clay and shale used or sold for use in making sewer pipe or bricks or used or sold for use as sintered or burned lightweight aggregates	7½ %
Clay used or sold for use in making drainage and roofing tile, flower pots, and kindred products, and gravel, sand, and stone (other than stone used or sold for use by a mine owner or operator as dimension or ornamental stone)	5 %

IRS 2011. Depletion.
Ref: www.irs.gov/publications/p535/ch09.html

Once the initial cost of the property has been recovered, the cost depletion basis is zero. Obviously, the cost depletion deduction will remain zero for all succeeding years.

The percent depletion deduction calculation is a three step process. In the first step, the percent deduction is found by multiplying a specified percentage times the gross mining income (after royalties have been subtracted) resulting from the sale of the minerals extracted from the property during the tax year. According to Stermole & Stermole (1987):

'Mining' includes, in addition to the extraction of minerals from the ground, treatment processes considered as mining applied by the mine owner or operator to the minerals or the ore, and transportation that is not over 50 miles from the point of extraction to the plant or mill in which allowable treatment processes are applied. Treatment processes considered as mining depend upon the ore or mineral mined, and generally include those processes necessary to bring the mineral or ore to the stage at which it first becomes commercially marketable; this usually means to a shipping grade and form. However, in certain cases, additional processes are specified in the Internal Revenue Service regulations, and are considered as mining. Net smelter return or its equivalent is the gross income on which mining percentage depletion commonly is based. Royalty owners get percentage depletion on royalty income so companies get percentage depletion on gross income after royalties.

As shown in Table 2.3, the percentage which is applied varies depending on the type of mineral being mined.

In step 2, the taxable income (including all deductions except depletion and carry forward loss) is calculated for the year in question. Finally in step 3, the allowable percentage depletion deduction is selected as the lesser of the percent depletion (found in step 1) and 50% of the taxable income (found in step 2).

With both the allowable cost depletion and percentage depletion deductions now calculated, they are compared. The larger of the two is the 'allowed depletion deduction'. The overall process is summarized in Figure 2.1.

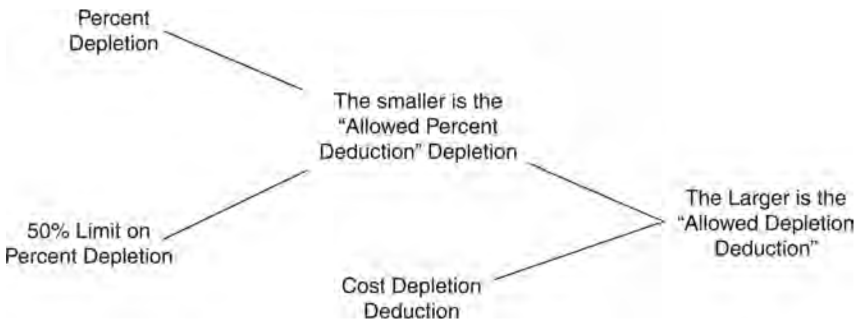

Figure 2.1. Flow sheet for determining the depletion deduction (Stermole & Stermole, 1987).

2.2.11 *Cash flows, including depletion*

As indicated the depletion allowance works exactly the same way in a cash flow calculation as depreciation. With depletion the cash flow becomes:

Gross revenue
− Operating expense
− Depreciation
− Depletion
− Taxable income
− Tax
= Profit
+ Depreciation
+ Depletion
− Capital costs

= Cash flow

The following simplified example adapted from Stermole & Stermole (1987) illustrates the inclusion of depletion in a cash flow calculation.

Example. A mining operation has an annual sales revenue of $1,500,000 from a silver ore. Operating costs are $700,000, the allowable depreciation is $100,000 and the applicable tax rate is 32%. The cost depletion basis is zero. The cash flow is:

(*1*) *Preliminary*. Calculation without depletion.

Gross revenue	$1,500,000
− Operating expense	−700,000
− Depreciation	−100,000
= Taxable income before depletion	$700,000

(*2*) *Depletion calculation*. Since the depletion basis is zero, percentage depletion is the only one to be considered. One must then choose the smaller of:
(a) 50% of the taxable income before depletion and carry-forward-losses
(b) 15% of the gross revenue

In this case the values are:

(a) 0.50 × $700,000 = $350,000

(b) 0.15 × $1,500,000 = $225,000

Hence the depletion allowance is $225,000.

(*3*) *Cash flow calculation.*

Gross revenue	$1,500,000
− Operating expense	−700,000
− Depreciation	−100,000
− Depletion	−225,000
= Taxable income	$475,000
− Tax @ 32%	−152,000
= Profit	$323,000
+ Depreciation	+100,000
+ Depletion	+225,000
= Cash flow	$648,000

The cash flow calculation process is expressed in words (Laing, 1976) in Table 2.4.

Laing (1976) has summarized (see Table 2.5) the factors which should be considered when making a cash flow analysis of a mining property.

The distinction between the 'exploration' and 'development' phases of a project is often blurred in actual practice. However from a tax viewpoint a sharp distinction is often made. The distinction made by the U.S. Internal Revenue Service (1988a) is paraphrased below.

1. The exploration stage involves those activities aimed at ascertaining the existence, location, extent or quality of any deposit of ore or other mineral (other than oil or gas). Exploration expenditures paid for or incurred before the beginning of the development stage of the mine or other natural deposit may for tax purposes be deducted from current income. If, however, a producing mine results, these expenditures must be 'recaptured' and capitalized. These are later recovered through either depreciation or cost depletion.

2. The development stage of the mine or other natural deposit will be deemed to begin at the time when, in consideration of all the facts and circumstances, deposits of ore or other mineral are shown to exist in sufficient quantity and quality to reasonably justify exploitation. Expenditures on a mine after the development stage has been reached are treated as operating expenses.

For further information concerning the economic models the interested reader is referred to Stermole & Stermole (2012).

2.3 ESTIMATING REVENUES

2.3.1 *Current mineral prices*

Current mineral prices may be found in a number of different publications. *Metals Week, Mining Magazine, Metal Bulletin* and *Industrial Minerals* are four examples. Spot prices

Table 2.4. Components of an annual cash flow analysis for a mining property (Laing, 1976).

Calculation	Component
	Revenue
less	Operating costs
equals	Net income before depreciation and depletion
less	Depreciation and amortization allowance
equals	Net income after depreciation and amortization
less	Depletion allowance
equals	Net taxable income
less	State income tax
equals	Net federal taxable income
less	Federal income tax
equals	Net profit after taxes
add	Depreciation and amortization allowances
add	Depletion allowance
equals	Operating cash flow
less	Captial expenditures
less	Working capital
equals	Net annual cash flow

Table 2.5. Factors for consideration in a cash flow analysis of a mining property (Laing, 1976).

Preproduction period	
Exploration expenses	Land and mineral rights
Water rights	Environmental costs
Mine and plant capital requirements	Development costs
Sunk costs	Financial structure
Working capital	Administration
Production period	
Price	Capital investment-replacement and expansions
Processing costs	Royalty
Recovery	Mining cost
Post concentrate cost	Development cost
Reserves and percent removable	Exploration cost
Grade	General and administration
Investment tax credit	Insurance
State taxes	Production rate in tons per year
Federal taxes	Financial year production begins
Depletion rate	Percent production not sent to processing plant
Depreciation schedule	Operating days per year
Post production period	
Salvage value	Contractual and reclamation expenditures

for the major metals are listed in the business sections of many daily newspapers together with futures prices. Tables 2.6 through 2.8 contain 1992–93 prices for certain:

– metals
– nonmetallic minerals
– miscellaneous metals
– ferro alloys
– ores and concentrates.

In reviewing the tables it is seen that there is considerable variation in how the prices are quoted. In general, the prices depend upon:

– quality
– quantity
– source
– form
– packaging.

The units in which the prices are expressed also vary. Some examples in this regard are presented below.

1. For many minerals, the 'ton' is unit of sale. There are three different 'tons' which might be used. They are:

$$
\begin{aligned}
\text{1 short ton (st)} &= \text{2000 lbs} = \text{0.9072 metric tons} \\
\text{1 long ton (lt)} &= \text{2240 lbs} = \text{1.01605 metric tons} \\
\text{1 metric ton (mt or tonne)} &= \text{2204.61 lbs} \\
&= \text{1000 kilograms} \\
&= \text{0.9842 long tons} \\
&= \text{1.1023 short tons}
\end{aligned}
$$

Iron ore, sulfur, and manganese ore are three materials normally sold by the long ton. The prices for iron ore and manganese ore are expressed in X dollars (or cents) per long ton unit (ltu). A 'unit' refers to the unit in which the quality of the mineral is expressed. For iron ore the quality is expressed in $Y\%$ Fe. Therefore one unit means 1%.

If 1 long ton (2240 lbs) of iron ore contained 1% iron (22.40 lbs), then it would contain 1 long ton unit (1 ltu) of iron. If the long ton assayed at 65% iron then it would contain 65 ltu. If the quoted price for pellets is 70¢/ltu, then the price of 1 long ton of pellets running 65% iron would be:

$$
\begin{aligned}
\text{price/long ton} &= 65 \times 70\,¢ = 4550\,¢/\text{lt} \\
&= \$45.50/\text{lt}
\end{aligned}
$$

Metric ton units (mtu) and short ton units (stu) are dealt with in the same way.

The reason for using the 'unit' approach is to take into account varying qualities.

2. For most metals, the unit of weight is the pound (lb) or kilogram (kg).
3. Gold, silver, platinum, palladium, and rhodium are sold by the troy ounce.

Table 2.6. Metal prices (*E/MJ*, 1993).

Aluminum, ¢/lb	
Used beverage cans, 12/24/92	40–42
Comex, 99.7% closing, Mar.	58.00
May	58.00
N.Y. merchant, 99.7%, 1/11/93	57.00–57.25
Antimony, $/lb	
Merchant, 3/1/90	0.85–0.92
Antimony oxide, 3/1/90	1.10–1.20
Beryllium copper, 9/17/90	
Strip (No. 25)	9.25
Rod, bar, and wire (No. 25)	10.24
Bismuth, $/lb, ton lots	
Merchant, 3/1/92	2.40–2.45
Cadmium, $/lb, ton lots	
Producers, 6/1/92	1.80–2.00
Chromium, $/lb, 1/1/91	
Electrolytic metal, standard	3.75
Cobalt, 99%, $/lb	
Afrimet, F.O.B. New York	
Cathodes, etc., 1/1/92	13.00
Powder, 1/27/89	NQ
Extra fine, 1/27/89	NQ
Sherritt Gordon	
'S' power, 12/31/90	NQ
Copper, ¢/lb	
LME, grade A, closing	
cash bid	100.26
3 mo	100.58
Comex, high grade, Jan. closing	98.35
U.S. producers, cathode	100.00
Warrenton refining, wirebar	110.35
N.Y. merchant, cathodes, Mar.	101.00
Gold, $/tr oz	
Zurich avg., opg	328.00
Paris, p.m.	329.21
London, 3:00 p.m.	327.65
Handy & Harman, N.Y.	327.65
Engelhard bullion	328.86
Engelhard fabricated	345.30
Lead, ¢/lb	
U.S. and Canadian producers, 11/6/92	32.00–35.00
Secondary fabricated, 11/9/92	36.00–40.00
London fix, $/mt	
Rudolf Wolff, spot	434.18
Rudolf Wolff, 3 mo	445.88
Lithium, $/lb	
99.9%, 1,000 lb lots, 11/2/92	31.80–32.45
Carbonate tech., 11/2/92	1.91–1.96
Magnesium, ¢/lb, 5-st lots	
Ingots, 99.8%, 11/16/91	143–153
Grinding slab, 1/1/91	143
Sticks, 1.3-in.-dia, 1/2/91	223
Manganese, ¢/lb	
Electrolytic, 99.9%, 11/15/90	105
Mercury, 99.9%, $/flask	
New York prompt, 8/26/92	205–210
C.I.F. European port, 12/8/92	115–130
Molybdic oxide, $/lb	
Producer, 1/6/92	3.35
Nickel, $/lb	
Melting briquettes, 10/10/91	3.48–3.52
N.Y. merchant, spot, 1/14/93	2.64–2.68
Platinum, $/tr oz	
London p.m. fix 1/14/93	358.75
Comex, 99.9%, Apr.	355.50
Engelhard fabricated	459.00
U.S. merchant, 1/14/93	358.00–359.00
Silver, ¢/tr oz	
Engelhard bullion	368.00
Handy & Harman, N.Y.	397.00
London fix, spot	369.15
3 mo	371.95
6 mo	374.95
12 mo	383.00
Zurich fix	369.70
Tin	
Kuala Lumpur spot, ringgit/kilo	14.81
Spot exchange, $/ringgit	0.3843
AMM N.Y. ex-dock, $/lb	2.76
Uranium, $/lb U_3O_8	
Nuexco, 12/31/92	7.85
Zinc, ¢/lb	
U.S. and foreign producers, slab, delivered in U.S., 1/14/93	
High grade	53.76–54.74
Special high grade	51.00–55.24
CGG	51.75–54.49
U.S. producers, die casting alloys	
No. 3, 7/30/91	NQ
No. 5, 7/30/91	NQ

Table 2.7. Prices for some common non-metallic minerals (*Industrial Minerals*, December 1992). Copyright 1992. Industrial Minerals, reproduced with permission.

Asbestos		
All prices quoted are F.O.B. mine		
Canadian chrysotile		
Group No. 3	C$1,450–1,750	
Group No. 4	C$1,080–1,400	
Group No. 5	C$645–850	
Group No. 6	C$525–575	
Group No. 7	C$180–350	
South African chrysotile		
Group No. 5	$360–410	
Group No. 6	$300–390	
Group No. 7	$180–220	
South African amosite		
Long	$660–1,000	
Medium	$610–700	
Short	$425–625	
South African crocidolite		
Long	$720–880	
Medium	$645–715	
Short	$640–695	
Bentonite		
Wyoming, foundry grade, 85% 200 mesh, bagged, 10 ton lots, del U.K.	£120–130	
F.O.B. plants, Wyoming rail hopper cars, bulk st	$18.00–35.00	
F.O.B. plants, Wyoming, bagged, rail cars, st	$33.00–45.00	
Fullers' Earth, soda ash-treated, del, U.K. foundry grade, bagged	£85–95	
Civil engineering grade, bulk	£60–70	
OCMA, bulk del U.K.	£65–70	
API, F.O.B. plant, Wyoming, rail cards, bagged, st	$34.50	
Feldspar		
Ceramic grade, powder, 300 mesh, bagged, ex-storage U.K.	£140	
Sand, 28 mesh, glass grade, ex-store U.K.	£65	
Ceramic grade, bulk, st		
F.O.B. Spruce Pine, NC, 170-250 mesh	$50.00	
F.O.B. Monticello, Ga, 200 mesh high potash	$82.50	
F.O.B. Middleton, Con, 200 mesh	$67.50	
Glass grade, bulk, st		
F.O.B. Spruce Pine, NC, 97.8% > 200 mesh	$33.50	
F.O.B. Monticello, Ga, 92% > 200 mesh, high potash	$64.75	
F.O.B. Middleton, Con, 96% > 200 mesh	$45.50	
Fluorspar		
Metallurgical, min 70% CaF_2, ex-U.K. mine	£85–90	
Acidspar, dry basis 97% CaF_2 bagged ex-works	£140–150	
Acidspar, dry, bulk ex-works tankers	£125–135	
Acidspar Chinese dry bulk, C.I.F. Rotterdam	$100–110	
Mexican, F.O.B. Tampico,		
Acidspar filtercake	$122–127	
Metallurgical	$90–95	
South African acidspar dry basis, F.O.B. Durban	$110–115	
USA, Illinois district, bulk, st acidspar	$190–195	
Iodine		
Crude iodine crystal, 50 kg drums 99.5% min, per kg del U.K.	$15–16	
Phosphates		
Florida, land pebble, run of mine, st dry basis, unground, bulk, ex-mine, avg.	Domestic	Export
60–66% BPL	$34.99	$30.36
66–70% BPL	$25.99	$34.67
70–72% BPL	$27.84	$37.38
72–74% BPL	$36.24	$41.80
74% BPL	$35.10	$50.20
Morocco, 75–77% BPL, FAS Casablanca	$48.50	
70–72% BPL, FAS Casablanca	$46	
Tunisia, 65–68% BPL, FAS Sfax	$32–38	
Nauru, 83% BPL, lt, F.O.B.	–	
Potash		
Muriate of potash, bulk, 60% K_2O		
Std, C.I.F. UP port	£71–74	
Granular, C.I.F. U.K. port	£81–84	
Std, F.O.B. Vancouver	$90–100	
F.O.B. Saskatchewan, bulk per, st		
Standard	$83	
Coarse	$87	
Granular	$89	
F.O.B. Carlsbad, bulk, per ton,		
Coarse	$90–100	
Granular	$95	
Salt		
Ground rocksalt, 15–20 tonne lots, avg. price del U.K.	£20	
Soda ash		
US natural, F.O.B. Wyoming, Dense, st	$80	
Sulphur		
US Frasch, liquid, dark ex-terminal, Tampa, lt	$88	
Canadian, liquid, bright, F.O.B. Rotterdam, tonne	$90	
French, Polish, liquid, ex-terminal Rotterdam, tonne	$105.75	
Canadian, solid/slate, F.O.B. Vancouver, spot	$65.75	
Canadian, solid/slate, F.O.B. Vancouver, contract	$65.70	

To accord with trade practices, certain prices are quoted in US$ (sterling now floating at around $1.50–1.70 = £1). All quotations are © *Metal Bulletin* plc 1992.

Table 2.8. Prices* for some common non-ferrous ores (*Metal Bulletin*, 1993). Copyright 1993 Metal Bulletin; reproduced with permission.

Antimony ... Per metric tonne unit Sb. C.I.F.

Clean sulphide conc., 60% Sb ... $14.00–$15.50
Lump sulphide ore, 60% Sb ... $14.50–$16.00
Chinese conc., 60% Sb,
Se typically 60 ppm.

Hg 30 ppm max. ... $12.00–$13.00

Beryl ... Per short ton unit of BeO

Cobbed lump min. 10% BeO C.I.F. ... $75–$80

Chromite ... Per tonne delivered

Transvaal, friably lumpy,
basis 40% Cr_2O_3 F.O.B. ... $55–$65
Albanian, hard lumpy, min. 42% F.O.B. . $70–$80
Albanian, conc., 51% F.O.B. ... $100–$110
Turkish, lumpy, 48% 3:1
(scale pro rata) F.O.B. ... $160–$180
Russian, lumpy, 40% min. 36% F.O.B. ... $75–$95

Columbium ores ... Per lb pentoxide content

Columbite min. 65%
$Cb_2O_5 + Ta_2O_5$, 10:1 C.I.F. ... $2.60–$3.05

Lead conc.

70/80% Pb $500–550 basis C.I.F. ... $170–$180

Lithium ores ... Per tonne

Petalite, 3.5–4.5% C.I.F. ... £135–£140
Spodumene 4–7% Li_2O C.I.F. ... £178–£183

Manganese ore ... Metallurgical per mtu Mn
48/50% Mn Max. 0.1%P C.I.F. ... $3.35–$3.55

Molybdenite ... Per lb Mo in MoS_2

Conc. C.I.F. ... $1.95–$2.05
Conc. C.I.F. U.S. ... $2.80–$3.00

Monazite ... Australian per tonne

Conc. Min.55% REO + Thoria,
F.O.B./Fid ... A$300–A$350

Tantalite ... Per lb Ta_2O_5

25/40% basis 30% Ta_2O_5 C.I.F.,
max 0.5% U_3O_8 and
ThO_2 combined ... $30.00–$33.00
Greenbushes 40% basis ... $40.00

Tin conc. ... T/C per tonne

20/30% Sn (including deduction) ... £400–£530
30/50% Sn (including deduction) ... £350–£500
50/65% Sn (including deduction) ... £300–£600
65/75% Sn (including deduction) ... £400–£525

Titanium ores ... Australian per tonne

Rutile conc.min.95% TiO_2 bagged,
F.O.B./Fid ... A$550–A$600
Rutile bulk conc.min.95% TiO_2
F.O.B./Fid ... A$500–A$560
Limenite bulk conc.min.54%
TiO_2 F.O.B. ... A$83–A$90

Tungsten ore ... Per metric tonne unit WO_3

Min. 65% WO_3 C.I.F. ... $40–$50
Uranium ... Per lb U_3O_8

Nuexco exchange value December ... $7.85
Nuexco restricted American market
penalty ... $2.10
Nukem December restricted spot . $9.90–$10.35
Nukem December unrestricted spot $7.90–$8.00

Vanadium ... Per lb V_2O_5

Highveld, fused min. 98% V_2O_5 C.I.F. ... $1.95
Other sources ... $1.75–$1.85

Zinc conc. ... T/C per metric dry tonne
Sulphide 49/55% Zn basis
$1,000 C.I.F. main port ... $188–$190
Sulphide 56/61% Zn basis
$1,000 C.I.F. main port ... $190–$194

Zircon ... Australian per tonne

Std. min. 65% ZrO_2 F.O.B./Fid . A$230–A$270
Premium max. 0.05% Fe_2O_3
F.O.B./Fid ... A$250–A$325

*Prices expressed C.I.F. Europe unless otherwise indicated.

The relationship between the troy ounce and some other units of weight are given below.

Troy weight (tr)

$$
\begin{aligned}
1\ \text{troz} &= 31.1035\ \text{grams}\\
&= 480\ \text{grains}\\
&= 20\ \text{pennyweights(dwt)}\\
&= 1.09714\ \text{oz avoird}
\end{aligned}
$$

U.S. Standard (avoirdupois)

$$
\begin{aligned}
1\ \text{ozavoird} &= 28.3495\ \text{grams}\\
&= 437.5\ \text{grains}\\
1\ \text{lb} &= 16\ \text{oz}\\
&= 14.5833\ \text{tr oz}\\
&= 453.59\ \text{grams}
\end{aligned}
$$

4. Mercury (quicksilver) is sold by the flask. A ‘flask’ is an iron container which holds 76 lbs of mercury.
5. Molybdenum is sometimes quoted in the oxide (roasted) form (MoO_3) or as the sulfide (MoS_2). The price given is per pound of Mo contained. For the oxide form this is about 67% and for the sulfide 60%.
6. The forms in which minerals are sold include bulk, bags, cathodes, ingots, rods, slabs, etc.
7. The purity of the mineral products often have a substantial effect on price (see for example Feldspar).
8. The fiber length and quality is extremely important to asbestos.

The point of sale also has a considerable effect on the price. Two abbreviations are often used in this regard.

The abbreviation ‘F.O.B.’ stands for ‘free-on-board’. Thus the designation ‘F.O.B. mine’ means that the product would be loaded into a transport vessel (for example, rail cars) but the buyer must pay all transport charges from the mine to the final destination.

The abbreviation ‘C.I.F.’ means that cost, insurance and freight are included in the price.

Table 2.9 illustrates the difference in price depending on delivery point. For USX Corp. pellets, the price of 37.344 ¢/ltu is at the mine (Mountain Iron, Minnesota). The Cleveland-Cliffs price of 59.4 ¢/ltu (also for Minnesota taconite pellets) is at the hold of the ship at the upper lake port. Hence a rail charge has now been imposed. For the Oglebay Norton Co. (Minnesota) pellets, the price of 72.45 ¢/ltu is at the lower lake port. Thus it includes rail transport from the mine to the upper lake port plus ship transport to the lower lake port. Table 2.10 provides freight rates for iron ore and pellets. Lake freight rates are given in Table 2.11.

Many mineral products are sold through long term contracts arranged between supplier and customer. The prices will reflect this shared risk taking. There will often be significant differences between the short term (spot) and long term prices.

Recent prices for metals and industrial minerals are provided in Tables 2.12 and 2.13. Table 2.14 presents the prices for iron ore from various suppliers in 2005.

Table 2.9. Iron ore prices (*Skillings Mining Review*, 1993a).

Lake Superior iron ore prices	
(Per gross ton, 51.50% iron natural, at rail of vessel lower lake port)	
Mesabi non-Bessemer	$30.03-31.53
Cleveland-Cliffs Inc iron ore pellet prices	
(Per iron natural unit, at rail of vessel lower lake port)	
Cleveland-Cliffs Inc	72.45¢
Per gross ton unit at hold of vessel upper lake port	53.40¢
Wabush pellets per gross ton unit F.O.B. Pointe Noire	63.50¢
Cyprus Northshore Mining Corp. pellet price	
(Per gross ton iron unit natural F.O.B. Silver Bay)	
Cyprus Northshore pellets	48.76¢
IOC Ore Sales Co. pellet price	
(Per natural gross ton unit delivered rail of vessel lower lake port)	
Carol pellets	74.65¢
Inland Steel Mining Co. pellet price	
Per gross ton natural iron unit at hold vessel upper lake port	46.84¢
Oglebay Norton Co. pellet prices	
(Per natural gross ton unit, at rail of vessel lower lake port)	
Standard grade	72.45¢
Eveleth special	74.00¢
U.S. Steel pellet price	
Per dry gross ton iron unit at Mtn. Iron	37.344¢

Table 2.10. Rail tariff rates on iron ore and pellets (*Skillings Mining Review,* 1993b).

Rail freight rates ($/gross ton) from mines to Upper Lake Port	
Marquette Range to Presque Isle	
Pellets	$2.50
Natural ore	2.56
Pellets from Marquette Range to Escanaba delivered into vessel	3.39
Mesabi Range plants on BN to:	
Allouez delivered direct into vessel	6.16
When consigned to storage subject to storage charges	6.53
Winter ground storage charges on pellets:	
At Allouez per gross ton per month	16.0¢
At Escanaba: storage per gross ton per month	2.4¢
handling to storage	21.8¢
handling from storage	21.8¢
Dock charges on iron ore per gross ton	
Car to vessel at Duluth and Two Harbors	$1.05
All-rail freight rates to consuming districts	
Mesabi Range to:	
Chicago district	20.42
Geneva, Utah	*46.97
Granite City and East St. Louis, Ill.	19.69
Valley district	40.17
Marquette Range to Detroit	28.60
Marquette & Menominee Ranges to:	
Chicago district	**24.09
Granite City and East St. Louis, Ill.	23.18

*Conditional on tender of not less than 4800 GT nor more than 5200 GT.
**Multiple car rate.

Table 2.11. Lake freight tariff rates on iron ore, pellets and limestone (*Skillings Mining Review,* 1993c).

Lake freight rates from Upper Lake ports to Lower Lake ports	
Iron ore ($/gross ton)	Self unloading vessels
Head of Lakes to Lower Lakes	$6.50
Marquette to Lower Lakes	5.40
Escanaba to Lake Erie	4.88
Escanaba to Lake Michigan	3.90
Limestone ($/gross ton)	
Calcite, Drummond, Cedarville and Stoneport to	
Lower Lake Michigan	3.98
Lake Erie ports	4.10
Note: The above cargo rates apply after April 15 and before December 15, 1993. Winter formulas apply during other periods. Rates are further subject to surcharges, if warranted.	
Dock, handling and storage charges ($/gross ton) on iron ore at Lower Lake ports RCCR X-088C	
Ex self-unloading vessels at Cleveland, Ohio	
Dockage	$0.26
From dock receiving area into cars, via storage	1.60
From dock receiving area to cars	1.05
Rail of vessel receiving area to cars	1.16
At Conneaut, Ohio BLE	
Dockage of self-unloading vessel	$0.15
From receiving bin to storage	0.53
From storage to railcars	0.68
Ex bulk vessels at Cleveland C&P	
From hold to rail of vessel	$1.03
From rail of vessel into car	1.26
From rail of vessel via storage into car	2.25

2.3.2 *Historical price data*

Mineral prices as monitored over a time span of many years exhibit a general upward trend. However, this is not a steady increase with time but rather is characterized by cyclic fluctuations. Table 2.15 shows the average yearly prices for 10 common metals from 1900 through 2011 (USGS, 2012a). The monthly and average prices for 11 common metals for the period January 1997 through July 2012 are given in Table 2.16 (Metal Bulletin, 2012). To provide an indication of the price unpredictability, consider the case of copper. In 1900 for example the copper price was about 16.2 ¢/lb (Table 2.15). In 2000, 100 years later, the price had risen to 82 ¢/lb. The average rate of price increase per year over this period using the end point values is 1.6 percent. The price dropped to a low of 5.8 ¢/lb (1932) and reached a high of 131 ¢/lb (1989) over this period. Using the average price increase over the period of 1900 to 2000, the predicted price in 1950 should have been 36.4 ¢/lb. The actual value was 21.2 ¢/lb.

A mining venture may span a few years or several decades. In some cases mines have produced over several centuries. Normally a considerable capital investment is required to bring a mine into production. This investment is recovered from the revenues generated over the life of the mine. The revenues obviously are strongly dependent upon mineral price. If the actual price over the mine life period is less than that projected, serious revenue shortfalls would be experienced. Capital recovery would be jeopardized to say nothing of profits.

Price trends, for metals in particular, are typically cyclic. Using the metal price data from Table 2.15, Figures 2.2 through 2.6 show the prices for 10 metals over the period 1950 through 2011. The period and amplitude of the cycles varies considerably. For nickel

Table 2.12. Recent weekly metal prices (Platts Metals Week, 2012, April 16). Copyright 2012 Platts Metals Week; reproduced with permission.

Major Metals	
Aluminum	
	cts/lb
MW US Market	101.750/102.750
US Six-Months P1020	9.500
US 6063 Billet Upcharge	10.500/12.500
US UBCs	78.500/80.000
Painted Siding	79.000/80.000
US 6063 press scrap	4.500/5.500
	Eur/mt
Alloy 226 delivered European works	1700.000/ 1750.000
	$/mt
ADC12 FOB China	2310.000/2320.000
	Yuan/mt
ADC12 ex-works China	17400.000/17600.000
Caustic Soda	
	$/mt
FOB NE Asia	422.000/424.000
CFR SE Asia	476.000/478.000
Copper	
	cts/lb
MW No.1 Burnt Scrap Disc	19.000
MW No.1 Bare Bright Disc	3.000
MW No.2 Scrap Disc	39.000
NY Dealer Premium cathodes	5.500/6.500
US Producer cathodes	371.650/379.090
	$/mt
Grade A Cathode CIF R'dam	8253.000/8260.000
Grade A Premium CIF R'dam	75.000/80.000
Grade A CIF Livorno/Salerno	8228.000/8240.000
Grade A Prem CIF Livorno/Salerno	50.000/60.000
Russian Standard CIF R'dam	8178.000/8210.000
Russian Standard Prem CIF R'dam	0.000/30.000
Lead	
	cts/lb
North American Market	98.830/101.643
	$/mt
European dealer	2072.000/2088.000
European 99.985% Prem IW (R'dam)	20.000/35.000
In-Warehouse S'pore Prem	50.000/80.000
Nickel	
	$/lb
NY Dealer/Cathode	8.403/8.555
NY Dealer/Melting	8.403/8.555
NY Dealer/Plating	8.603/8.755
	cts/lb
NY Dealer/Cathode Premium	30.000
NY Dealer/Melting Premium	30.000
NY Dealer/Plating Premium	50.000
	$/mt
Plating Grade IW R'dam	18324.000/18384.000
Plating Grade Prem IW R'dam	200.000/250.000
Russia Full-Plate	18184.000/18214.000
Russia Full-Plate Prem IW R'dam	60.000/80.000
Briquette Premium IW R'dam	200.000/250.000
In-Warehouse S'pore Prem	150.000/160.000
Tin	
	$/mt
Europe 99.85% IW R'dam	22956.000/23094.000
Europe 99.85% Prem IW R'dam	300.000/400.000
Europe 99.90% IW R'dam	23156.000/23244.000
Europe 99.90% Prem IW R'dam	500.000/550.000
Zinc	
	cts/lb
US Dealer SHG	98.921
MW SHG Premium	7.250
MW SHG Galv. Prem.	7.000
MW SHG Alloyer #3 Prem.	17.000
	$/mt
Europe physical SHG IW R'dam	2109.000/2129.000
Europe physical SHG Prem IW R'dam	105.000/125.000
In-Warehouse S'pore Prem	70.000/95.000
Precious Metals	
	All PGM figures in $/tr oz
Iridium	
MW NY Dealer	1050.000/1085.000
Osmium	
MW NY Dealer	350.000/400.000
Palladium	
MW NY Dealer	630.000/655.000

(Continued)

Table 2.12. (Continued).

Platinum	
MW NY Dealer	1580.000/1630.000
Rhodium	
MW NY Dealer	1300.000/1375.000
Ruthenium	
MW NY Dealer	95.000/115.000
Minor Metals	
Antimony	
	cts/lb
MW NY Dealer	590.000/620.000
	$/mt
99.65% FOB China	13000.000/13200.000
Arsenic	
	cts/lb
MW Dealer	60.000/70.000
Bismuth	
	$/lb
MW NY Dealer	10.400/11.250
Cadmium	
	$/lb
MW NY Dealer	0.950/1.150
Free Market HG	1.000/1.200
Indium	
	$/kg
Producer: US Prod Indium Corp	785.000
MW NY Dealer	540.000/570.000
99.99% CIF Japan	560.000/570.000
Mercury	
	$/fl
Free Market International	1750.000/1950.000
U.S. Domestic	1750.000/1950.000
Rhenium	
	$/kg
MW NY Dealer	4200.000/4800.000
Selenium	
	$/lb
MW NY Dealer	61.000/66.000
Light Metals	
Magnesium	
	cts/lb
US Die Cast Alloy: Transaction	200.000/220.000
MW US Spot Western	215.000/230.000
MW US Dealer Import	200.000/210.000
	$/mt
Europe Free Market	3100.000/3200.000
Die Cast Alloy FOB China	3280.000/3340.000
99.8% FOB China	3000.000/3050.000
Silicon	
	cts/lb
553 Grade Delivered US Midwest	127.000/130.000
	$/mt
553 Grade, FOB China	2250.000/2300.000
553 Grade, CIF Japan	2280.000/2340.000
	Eur/mt
553 Grade, In-warehouse EU	1950.000/2050.000
Titanium	
	$/lb
MW US 70% Ferrotitanium	3.600/3.650
	$/kg
Eur. 70% Ferrotitanium	8.000/8.200
	$/lb
MW US Turning 0.5%	2.150/2.300
Eur. Turning .5%	2.300/2.400
Ferroalloys	
Cobalt	
MW 99.8% US Spot Cathode	*$/lb*
99.8% European	15.000/15.750
99.3% Russian	15.000/15.600
99.6% Zambian	14.800/15.200
	14.700/15.000
Ferrochrome	
	cts/lb
Charge Chrome 48–52% in-warehouse US	118.000/122.000
65% High Carbon in-warehouse US	118.000/122.000
Low Carbon 0.05% in-warehouse US	235.000/240.000
Low Carbon 0.10% in-warehouse US	218.000/222.000
Low Carbon 0.15% in-warehouse US	205.000/210.000
Charge Chrome 52% DDP NWE	103.000/110.000
65%–68% High-Carbon DDP NWE	120.000/123.000
Low Carbon 0.10% DDP NWE	215.000/220.000
High Carbon 60% FOB China	100.000/104.000
50–55% Regular CIF Japan	123.000
60–65% Spot CIF Japan	109.000/111.000
Ferromanganese	
	$/gt
High Carbon 76% in-warehouse US	1275.000/1350.000

(Continued)

Table 2.12. (Continued).

	cts/lb	*Molybdenum*	
Medium Carbon 85% Mn in-warehouse US	95.000/96.000		*$/lb*
		MW Dealer Oxide	14.150/14.300
	$/mt	Oxide Trans	14.150/14.300
High Carbon 75% FOB China	1200.000/1210.000	*Silicomanganese*	
Ferromolybdenum			*cts/lb*
	$/lb	65% Mn in-warehouse US	73.000/75.000
MW US FeMo	16.100/16.400		*$/mt*
	$/kg	65% FOB China	1480.000/1500.000
MW Europe FeMo	34.200/34.600	Chinese CIF Japan	1400.000/1500.000
FOB China FeMo	34.400/34.500		*Eur/mt*
Spot CIF Japan	34.900/35.000	65:16 DDP NWE	1020.000/1050.000
Ferrosilicon		*Stainless Scrap*	
	cts/lb		*$/gt*
75% Si in-warehouse US	94.000/96.000	NA FREE MKT 18-8	1792.000/1837.000
	$/mt	*Tantalum*	
Chinese CIF Japan	1420.000/1435.000		*$/lb*
	$/mt	Spot Tantalite Ore	37.000/42.000
75% FOB China	1420.000/1430.000	*Tungsten*	
	Eur/mt		*$/stu*
75% Std DDP NWE	1230.000/1290.000	MW US Spot Ore	320.000/330.000
Ferrovanadium		APT-US	395.000/420.000
	$/lb		*$/mtu*
Free Market V205	5.500/6.000	APT FOB China	400.000/410.000
US Ferrovanadium	14.250/14.750		*$/kg*
	$/kg	MW Ferrotungsten	54.000/55.000
Europe Ferrovanadium	25.700/26.000	Ferrotungsten FOB	53.000/56.500
Manganese			
	$/mt		
Electrolytic 99.7% FOB China	3000.000/3050.000		

consider the period from 1983 through 1998. In 1983, the price began at $2.12/lb, dropped to $1.76/lb in 1986, and rose to a high of $6.25/lb in 1988. It then dropped to $2.40/lb in 1993 before increasing once again to $3.73/lb in 1995 before landing in 1998 at about the same price it started at in 1983. Starting in 2002, the nickel price again began rising dramatically, reaching $16.87/lb in 2007, falling to $6.62/lb in 2009, and then stabilizing somewhat to around 10.00$/lb for the years 2010 and 2011.

In 1975, silver was around $4.50/tr oz. It shot up to nearly $40.00/tr oz (January 1980) due to the buying of the Hunt brothers from Texas. By the end of 1991, the price had dropped back to about $4.50/tr oz. Recently the price of silver has again been rising dramatically, reaching $34.50/tr oz in 2011.

The price performance of iron ore fines over the period 1900–2011 is presented in Table 2.17 (USGS, 2012b). The monthly spot price for China import iron ore fines over the period January 2000 through July 2012 is presented in Table 2.18 (IMF, 2012) and in Figure 2.7. In the past, the iron ore price each year was set in January and was constant throughout the year. Starting in November 2008, the price began varying monthly reflecting that major iron ore production began moving from long term annual contracts to quarterly, monthly, and then pure spot market prices.

Table 2.13. Prices for some common industrial minerals (Industrial Minerals, 2012. Monthly Prices -June) (All prices are in US$ and quoted per tonne unless indicated.).

Alumina	
Calcined 98.5–99.5% Al_2O_3 bulk FOB US refinery	$675–725
Calcined, ground 98.5–99.5% Al_2O_3, bulk FOB US refinery	$750–850
Calcined, medium-soda Al_2O_3, bulk FOB refinery	$800–850
Alumina, fused	
Brown 95% min. Al_2O_3, FEPA F8-220 Grit, FOB China	$800–840
Brown 95.5% Al_2O_3, refractory lump & sized, FOB China	$660–730
White, 25 kg bags, CIF Europe	€850–890
Brown 94% Al_2O_3, FEPA 8-220 mesh refractory (mm) Chinese	$750–850
Andalusite	
57–58% Al_2O_3, 2,000 tonne bulk, FCA Mine-RSA	€235–280
55–59% Al_2O_3, FOB European port	€350–425
Antimony Trioxide	
Typically 99.5% SbO_3, 5 tonne lots, CIF Antwerp/Rotterdam	$11,100–11,200
Typically 99.5% SbO_3, 20 tonne lots FOB China	$11,100–11,200
Typically 99.5% SbO_3, ex-works USA	$11,100–11,200
Ingot, 99.65% min, CIF Rotterdam	$13,500–13,700
Ingot, 99.65% min, FOB China	$13,500–13,600
Baddeleyite	
Contract price, Refractory/abrasive grade, CIF main European port	$2500–3100
Contract price, Ceramic grade (98% $ZrO_2 + HfO_2$), CIF main European port	$3000–3300
Contract price, Ceramic pigment grade, CIF main European port	$3200–3500
Barytes	
Drilling grade	
Unground lump	
OCMA/API bulk, SG 4.20	
FOB Chennai	$146–150
FOB Morocco	$147–150
FOB China	$155–158
C&F North Sea (Moroccan)	$160–167
API, CIF Gulf Coast,	
Chinese	$166–182
Indian	$157–171
Ground	
OCMA bulk, del. Aberdeen	£95–105
OCMA bulk, del. Gt Yarmouth	£110–120
OCMA/API, big bags (1.5t), FOB S. Turkey	$150–155
SG 4.22, bagged, FOB Morocco	$135–147
Paint grade	
Ground white 96–98% $BaSO_4$, 350 mesh, 1–5 lots, del. UK	£195–220
Chinese lump, CIF Gulf Coast	$250–290
Ground, white, 96–98% $BaSO_4$, 325–350 mesh, 1–5 lots, ex-works USA. $/s. ton	$315–400
Chemical grade	
Chinese, CIF Gulf Coast	$170–182
Bauxite	
Refractory grade	
Chinese Al_2O_3/Fe_2O_3/BD, lumps 0–25 mm Shanxi, FOB Xingang	
Round kiln 87/2.0/3.2	$395–430
Round kiln 86/2.0/3.15–3.20	$360–440
Round kiln 85/2.0/3.15	$370–410
Rotary kiln 86/1.8/3.15	$365–435
Rotary kiln 85/1.8/3.15	$350–450
Guizhou, FOB Zhanjiang/ Fangcheng Round kiln 87/2.0/3.2	$470–525
Guyana RASC bauxite, bulk, FOB Linden	$460–510
Abrasive grade	
Chinese FOB Zhanjiang, China	$320–350
Welding grade	
FOB Zhanjiang, China	$470–480
FOB Linden, Guyana	$450–510
Bentonite	
Cat litter, grade 1–5 mm, bulk, FOB main European port	€42–60
Indian, cat litter grade, crushed, dried, loose in bulk, FOB Kandla	$34–38
OCMA/Foundry grades, crude & dried, bulk, FOB Milos	€60–80
API grade, bagged rail-car, ex-works Wyoming, per s.ton	$90–130
Foundry grade, bagged, railcars, ex-works Wyoming, per s.ton	$97–124
IOP grade, crude, bulk, ex-works Wyoming, per s.ton	$66–72
(Dried material in bulk) FOB Greece, €/tonne	€50–75
Cat litter grade, ex-works Wyoming, USA, $/s.ton	$50–60
Fullers' earth, soda ash-treated, Civil eng. grade, ex-works, South Africa	£50–70
Indian, FOB Kandla, crushed and dried, loose in bulk, Civil Engineering grade	$32–40
Indian, FOB Kandla, crushed and dried, loose in bulk, Iron ore pelletising grade	$36–38

(Continued)

Table 2.13. (Continued).

South African., ex-works Fullers' earth, soda ash-treated, Cat litter grade, 1–7 mm	£27–40
South African., ex-works Fullers' earth, soda ash-treated, foundry grade, bagged	£60–85
Foundry grade, bulk, del Japan	$140–215
Borates/Boron minerals	
Boric Acid, FOB Chile	$1250–1309
Colemanite, 40% B2O3, FOB Buenos Aires	$690–730
Decathydrate Borax, FOB Buenos Aires	$947–979
Ulexite, 40% B_2O_3, FOB Buenos Aires	$666–697
Ulexite, 40% B_2O_3, FOB Lima	$620–652
Ulexite, granular 40% B_2O_3, FOB Chile	$692–734
Borax, PP bags (25 kg & 50 kg), Boric acid, gran, tech, FOB Latin America	$1200–1310
Borax, PP bags (25 kg & 50 kg), Decahydrate borax, gran, tech, FOB Latin America	$910–940
Boric acid, FOB Buenos Aires	$1078–1136
Colemanite, 40–42% B_2O_3, ground, bagged, FOB Argentina	$630–690
Ulexite 46–48% B_2O_3, FOB Lima	$650–710
Bromine	
Purified, bulk, 99.95% Br, domestic destination, tonne lot, ex-works USA	$1.6–1.7
Bulk, purified, 99.95% Br, ex works, CIF Europe	$1.6–1.65
Large contract, Bulk, European	$3300–3500
Calcium carbonate	
GCC, coated, fine grade,ex-works UK	£80–103
GCC, 50–22 microns, FOB USA	$21–26
GCC, 22–10 microns, FOB USA	$50–105
GCC, 3 microns (untreated), FOB USA	$170–185
GCC, stearate coated 1.1–0.7 microns, FOB USA	$270–400
GCC, 1.1–0.7 microns (untreated), FOB USA	$200–290
PCC, Fine, surface treated (0.4–1 microns), FOB USA	$275–375
GCC, coated, chalk, ex-works UK	£60–75
PCC, coated, ex-works, UK	£370–550
PCC, uncoated, ex-works, UK	£340–550
Celestite	
Turkish, 96%, $SrSO_4$, FOB Iskenderun	$90–100
Chromite	
Chemical grade, 46% Cr_2O_3, wet bulk, FOB South Africa	$360–410
Refractory grade, 46% Cr_2O_3, wet bulk, FOB South Africa	$425–500
Foundry grade, 46% Cr_2O_3, wet bulk, FOB South Africa	$390–420
South African, Northwest, Metallurgical grade, friable lumpy, 40% Cr_2O_3	$180–210
Sand, moulding grade, 98% <30 mesh, del UK	£390–450
Foundry +47% Cr_2O_3 dried 1 tonne big bags FOB South Africa	$450–500
Foundry, 45.8% min Cr_2O_3, wet bulk, FOB South Africa	$390–420
Metallurgical grade, Conc' 40%, FOB Northwest, South Africa	$180–210
Diatomite	
US, calcined filter-aid grade, FOB plant	$575–640
US, flux-calcined filter-aid grade, FOB plant	$580–825
Feldspar	
Turkish, Na feldspar, Crude, −10 mm size bulk, FOB Gulluk	$22–23
Turkish, Na feldspar, Glass grade, −500 microns, bagged, FOB Gulluk	$70
(−38 micron, FCL's bagged, >90 Brightness) FOB Durban, South Africa	$168
(Na), ceramic grade, 170–200 mesh, bagged, ex-works USA, $/s.ton	$150–180
Na feldspar, floated −150 microns, bagged, FOB Gulluk, Turkey	$53–55
Na feldspar, floated −500 microns, bulk, FOB Gulluk, Turkey	$38–40
Fluorspar	
Acidspar filtercake, bulk	
Mexican, <5 ppm As FOB Tampico	$540–550
Mexican, FOB Tampico	$400–450
Chinese wet filtercake, CIF Rotterdam	$500–530
Chinese, wet filtercake, FOB China	$450–500
South African, dry basis, FOB Durban	$380–450
Chinese dry basis, CIF US Gulf Port	$550–650
Metallurgical	
Chinese, min 85% CaF_2, CIF Rotterdam	$355–375
Mexican, FOB Tampico	$230–270
Chinese, min 80%, wet bulk, FOB China	$305–325
Chinese, min 85% CaF_2, bulk, FOB China	$355–375
Chinese bulk, min. 90% CaF_2, FOB China	$365–385

(Continued)

Table 2.13. (Continued).

Graphite	
Amorphous powder 80–85% Chinese del Europe	\$600–800
Synthetic fine 97–98% CIF Asia	\$950–1450
Synthetic fine 98–99% CIF Asia	\$1000–1500
Crystalline	
Medium flake 90%C, +100–80 mesh	\$1300–1800
Large flake, 90%C, +80 mesh	\$1900–2300
Fine, 94–97%C, −100 mesh	\$1900–2300
Medium, 94–97%C, +100–80 mesh	\$1875–2200
Large flake 94–97% C, +80 mesh CIF	\$2200–2700
Synthetic 99.95%C, \$ per kg, Swiss border	\$7–20
Ilmenite	
Australian, bulk concentrates, min 54% TiO_2, FOB	\$250–350
Australian, spot price, min 54% TiO_2, FOB	\$250–350
Iodine	
Iodine crystal, 99.5% min, drums, spot, \$/kg	\$60–90
Iodine crystal, 99.5% min, drums, contract, \$/kg	\$60–75
Iron Oxide Pigment	
Brown type 868, bagged, FOB China	\$1015–1075
Red type 130 90% Fe_2O_3, bagged, FOB China	\$1434–1637
Kaolin	
No 1 paper coating grade, Ex-Georgia plant, s.ton	\$161–209
No 2 paper coating grade, Ex-Georgia plant, s.ton	\$107.50–166.70
Kyanite	
Ex-works USA, 54–60% Al_2O_3, raw kyanite, s.ton	\$224–320
54–60% Al_2O_3, 22 ton lots, calcined	\$373–439
Leucoxene	
min. 91% TiO_2, max. 1% ZrO_2, bagged, FOB West Australia	A\$1450–1550
Lithium	
Lithium carbonate, del continental, USA large contracts, \$ per lb	\$2.5–3
Lithium hydroxide, 56.5–57.5% LiOH, large contracts, packed in drums or bags, del Europe or USA, \$/kg	\$6.5–7.5
Lithium hydroxide, Chinese, (56.5–57.5% LiOH), packed in drums or bags, large contracts, del Europe \$/kg	\$6–6.6
Petalite, 4.2% LiO_2, FOB Durban	\$165–260
Spodumene concentrate, >7.5% Li_2O, CIF USA, s.ton	\$720–770
Spodumene concentrate, 5% Li_2O, CIF USA, s.ton	\$460–510
Spodumene concentrate, 7.5% Li_2O, CIF Europe	\$750–800
Spodumene concentrate, 5% Li_2O, CIF Europe	\$440–490
Spodumene concentrate, > 7.5% Li_2O, bulk, CIF Asia	\$720–770
Spodumene concentrate, 5% Li_2O, CIF Asia	\$300–400
Magnesia	
Calcined, 90–92% MgO, lump, FOB China	\$320–360
European calcined, agricultural grade, CIF Europe	€240–350
Dead-burned	
Lump, FOB China	
90% MgO	\$350–400
92% MgO	\$430–470
94–95% MgO	\$410–480
97.5% MgO	\$560–600
Fused,	
Lump, FOB China	
96% MgO	\$790–860
97% MgO	\$930–1050
98% MgO	\$1080–1210
Magnesite	
Greek, raw, max 3.5% SiO_2, FOB East Mediterranean	€65–75
Mica	
Indian mine scrap green (Andhra Pradesh) for mica paper, FOB Madras	\$300–400
Indian wet-ground, CIF Europe	\$600–900
Micronised, FOB plant, USA	\$700–1000
Wet-ground, FOB plant, USA	\$700–1300
Flake, FOB plant, USA	\$350–500
Nitrate	
Sodium, about 98%, ex-store Chile	€550–570
Olivine	
Olivine, refractory grade, bulk, US ex-plant/mine	\$75–150
Perlite	
Coarse (filter aid) FOB east Mediterranean, bulk	€70–75
Raw, crushed, grade, big bags FOB Turkey	\$95–100
Raw, crushed, grade, bulk FOB Turkey	\$80–85
Potash	
C&F Western Europe, contract, Std.	\$400–490
Muriate, KCl, granular, bulk, ex-works, North America	\$515–535

(Continued)

Table 2.13. (Continued).

Muriate, KCl, standard, bulk, FOB Vancouver	$460–550
Muriate, KCl, standard, bulk, FOB Baltic $/tonne	$350–370
Rare earth minerals	
Min 99%, large purchases, FOB China, $/kg	$26–32
Cerium oxide	$1170–1370
Dysprosium oxide	$2590–2990
Europium oxide	$26–34
Lanthanum oxide	$120–160
Neodymium oxide	$120–140
Praesodymium oxide	$88–96
Samarium oxide	
Refractory clays/Mullite	
Clay, Mulcoa 47% (sized in bulk bags), for coarse sizing, FOB USA, s.ton	$198
Rutile	
Australian concentrate, min. 95% TiO_2, bagged, FOB	$2500–2800
Australian concentrate, min. 95% TiO_2, large vol. for pigment, FOB	$2050–2400
Salt	
Australian solar salt bulk CIF Shanghai,	$50
Industrial solar salt, ex-works China	$27–29
Industrial vacuum salt, ex-works China	$35–40
Silica sand	
Minus 20 micron, FCL, bagged >92 brightness, FOB Durban	$295
Glass sand, container, ex-works USA	$20–26
Silicon carbide	
SiC, FEPA 8-220, CIF UK, black, about 99% SiC	
SiC Grade 1	€1900–2100
SiC Grade 2	€1500–1650
Refractory grade	
min 98% SiC	€1500–1800
min 95% SiC	€1350–1450
Soda ash	
Chinese synthetic soda ash, dense & light, CIF Far East	$295–330
Chinese synthetic soda ash, dense & light, FOB China	$260–285
Indian synthetic soda ash, dense & light, Domestic ex-works India	$300–348
Indian synthetic soda ash, dense & light, Export C&F India	$210–230
US natural, large contract, FOB Wyoming	$210–230
European synthetic, dense & light, Large Contracts ex-works	€190–210

TiO_2 pigment	
Bulk volume, per tonne	
CFR Asia	$4300–4850
CIF Northern Europe	€3260–3750
CIF USA	$3550–4000
CIF Latin America, per lb	$1.6–1.9
Vermiculite	
South African, bulk, FOB Antwerp	$400–850
Wollastonite	
US ex-works, s.ton Acicular minus	
200 mesh	$210–240
325 mesh	$220–250
Acicular (15:-1–20:1 aspect ratio)	$444
Chinese, FOB, tonne Acicular minus	
200 mesh	$80–90
325 mesh	$90–100
Zircon	
FOB Australia, bulk shipments	
Premium	$2500–2640
Standard	$2400–2600
FOB USA, bulk shipments	
Premium	$2600–3000
Standard	$2550–2750
FOB South Africa, bulk shipments ceramic grade	$2300–2650
Micronised zircon	
99.5% $<4\ \mu$, average particle size $<0.95\ \mu$, C&F Asia	$2750–2800
Fused zirconia	
Monoclinic, refractory/abrasive, contract, CIF main European port	$6500–7800
Monoclinic, Ceramic pigment grade, Contract price, CIF main European port	$3800–4800
Monoclinic, Structural ceramic/ electronic grade, Contract price, CIF main European port	$4600–6000
Monoclinic, Technical ceramic, grade, Contract price, CIF main European port	$15900–21000
Stabilised, Refractory grade, Contract price, CIF main European port	$6500–7800
Stabilised, Technical ceramic grade, Contract price, CIF main European port	$50000–100000
Zircon Opacifiers	
Micronised zircon, 100% <6 microns, average 1–2 microns, bagged, CFR Asia	$2845–3400
Micronised zircon, 100% <6 microns, average 1–2 microns, bagged, ex-works Europe	$2770–3400

The prices in Table 2.13 appeared in the June 2012 issue of Mineral Price Watch. Published by Industrial Minerals Information, a division of Metal Bulletin plc, U.K. Copyright 2012 Industrial Minerals; reproduced with permission.

Table 2.14. Iron ore prices announced for year 2005 (Skillings, August 2005).

Europe (cents/mtu)	
CVRD Carajas Sinter Feed FOB Ponta da Maderia	65.00
CVRD Blast Furnace Pellets (FOB Ponta da Maderia)	118.57
CVRD Direct Reduction Pellets (FOB Ponta da Maderia)	130.43
CVRD Standard Sinter Feed (FOB Tubarao)	62.51
CVRD Blast Furnace Pellets (FOB Tubarao)	115.51
CVRD Direct Reduction Pellets (FOB Tubarao)	127.06
IOC Concentrate (FOB Sept-Iles)	66.71
IOC Pellets (FOB Sept-Iles)	120.06
Japan (cents/ltu)	
BHP Billiton Mt. Newman (DMT) Fines	61.72
BHP Billiton (DMT) Lump	78.77
CVRD Carajas Sinter Feed FOB Ponta da Maderia	57.08
CVRD Blast Furnace Pellets (FOB Ponta da Maderia)	116.86
CVRD Standard Sinter Feed (FOB Tubarao)	56.23
CVRD Blast Furnace Pellets (FOB Tubarao)	113.84
Rio Tinto Hamersley Lump	78.77
Rio Tinto Hamersley Fines	61.72
Rio Tinto Yandicoogina Ore	58.02

Note: The European and Japanese customers have negotiated somewhat different contracts.

The primary use for iron ore is in steel production, and in recent years, the iron ore market has been dominated by the phenomenal growth in steel production in China. Table 2.19 (World Steel Association, 2012) shows the annual steel production for the top twenty steel producing countries for the years 2000 through 2011, and Figure 2.8 shows the production trends for the top five steel producing countries. The annual production variation over the period for all other countries is dwarfed by the approximately sevenfold increase in annual steel production in China. Much of the recent increase in the price of molybdenum oxide (Fig. 2.4) can also be attributed to the growth in the Chinese steel production since a major use of molybdenum is in the production of steel.

The interested reader is encouraged to carefully study the price trends for each of the metals presented and try to explain the fluctuations. In some cases there are clear causes while in others an explanation is difficult to find.

For making the valuation calculations, the first problem is deciding what base price should be used. The second problem is forecasting the future price history.

Figure 2.9 shows a plot of the average price for copper as a function of time over the period of 1935 to 1992. This is based on the data given in Table 2.20. As can be seen, the price exhibits an upward trend but a cyclic variation is observed.

If the year in which the valuation was made was 1980, then the average copper price is 101.42 ¢/lb. If this current price had been selected as the base price, since it was at the peak of a cycle, the average price would never reach this base price again for many years. In this particular case until 1988. The revenue projection would have been very far off. The same would have been true if the base price for 1985 (a local low) had been selected. Here however the revenue projections would be too pessimistic and possibly the proposed project would be shelved. The conclusion is that choosing the current price as the base price for the

Table 2.15. Average annual metal prices 1900–2011 (USGS, 2012a).

Year	Al (¢/lb)	Cu (¢/lb)	Pb (¢/lb)	Zn (¢/lb)	Au ($/tr oz)	Pt ($/tr oz)	Ag ($/tr oz)	Mo ($/lb)	Ni ($/lb)	Sn ($/lb)
1900	32.7	16.2	4.5	4.4	20.67	6	0.62	NA	0.50	0.30
1901	33.0	16.1	4.4	4.1	20.67	20	0.59	NA	0.56	0.17
1902	33.0	11.6	4.1	4.8	20.67	20	0.53	NA	0.45	0.27
1903	33.0	13.2	4.2	5.4	20.67	19	0.53	NA	0.40	0.28
1904	35.0	12.8	4.3	5.1	20.67	21	0.59	NA	0.40	0.28
1905	35.0	15.6	4.5	5.9	20.67	17	0.62	NA	0.40	0.31
1906	35.8	19.3	5.7	6.1	20.67	28	0.68	NA	0.40	0.40
1907	45.0	20.0	5.4	5.8	20.67	NA	0.65	NA	0.45	0.38
1908	28.7	13.2	4.2	4.6	20.67	21	0.53	NA	0.45	0.29
1909	22.0	13.1	4.3	5.4	20.67	25	0.53	NA	0.40	0.30
1910	22.3	12.9	4.4	5.4	20.67	33	0.53	NA	0.40	0.34
1911	20.1	12.6	4.4	5.7	20.67	43	0.53	NA	0.40	0.42
1912	22.0	16.5	4.5	6.9	20.67	45	0.62	0.20	0.40	0.46
1913	23.6	15.5	4.4	5.6	20.67	45	0.61	0.30	0.42	0.44
1914	18.6	13.3	3.9	5.1	20.67	45	0.56	1.02	0.41	0.34
1915	34.0	17.5	4.7	14.2	20.67	47	0.51	1.02	0.41	0.39
1916	60.8	28.4	6.9	13.6	20.67	83	0.67	1.02	0.42	0.43
1917	51.7	29.2	8.6	8.9	20.67	103	0.84	1.43	0.42	0.62
1918	33.5	24.7	7.1	8.0	20.67	106	0.98	1.48	0.41	0.89
1919	32.1	18.2	5.8	7.0	20.67	115	1.12	1.17	0.40	0.64
1920	32.7	17.5	8.2	7.8	20.67	111	1.02	0.51	0.42	0.49
1921	22.1	12.7	4.7	4.7	20.67	75	0.63	0.71	0.42	0.30
1922	18.7	13.6	5.7	5.7	20.67	98	0.68	0.22	0.38	0.33
1923	25.4	14.7	7.4	6.7	20.67	117	0.65	0.77	0.36	0.43
1924	27.0	13.3	8.3	6.3	20.67	119	0.67	0.92	0.30	0.50
1925	27.0	14.3	9.1	7.7	20.67	119	0.69	0.41	0.33	0.58
1926	27.0	14.1	8.4	7.4	20.67	113	0.62	0.71	0.36	0.65
1927	25.4	13.1	6.8	6.3	20.67	85	0.57	0.77	0.35	0.64
1928	24.3	14.8	6.3	6.0	20.67	79	0.58	1.02	0.37	0.50
1929	24.3	18.4	6.8	6.5	20.67	68	0.53	0.51	0.35	0.45
1930	23.8	13.2	5.5	4.6	20.67	44	0.38	0.56	0.35	0.32
1931	23.3	8.4	4.3	3.6	20.67	32	0.29	0.43	0.35	0.24
1932	23.3	5.8	3.2	2.9	20.67	32	0.28	0.51	0.35	0.22
1933	23.3	7.3	3.9	4.0	20.67	31	0.35	0.76	0.35	0.39
1934	23.4	8.7	3.9	4.2	35.00	34	0.48	0.71	0.35	0.52
1935	20.0	8.9	4.1	4.4	35.00	33	0.64	0.71	0.35	0.50
1936	20.5	9.7	4.7	4.9	35.00	42	0.45	0.67	0.35	0.46
1937	19.9	13.4	6.0	6.5	35.00	47	0.45	0.69	0.35	0.54
1938	20.0	10.2	4.7	4.6	35.00	34	0.43	0.71	0.35	0.42
1939	20.0	11.2	5.0	5.1	35.00	36	0.39	0.69	0.35	0.50
1940	18.7	11.5	5.2	6.4	35.00	36	0.35	0.70	0.35	0.50
1941	16.5	12.0	5.8	7.5	35.00	36	0.35	0.69	0.35	0.52
1942	15.0	12.0	6.5	8.3	35.00	36	0.38	0.72	0.32	0.52
1943	15.0	12.0	6.5	8.3	35.00	35	0.45	0.74	0.32	0.52
1944	15.0	12.0	6.5	8.3	35.00	35	0.45	0.79	0.32	0.52
1945	15.0	12.0	6.5	8.3	35.00	35	0.52	0.78	0.32	0.52
1946	15.0	14.1	8.1	8.7	35.00	53	0.80	0.82	0.35	0.54
1947	15.0	21.3	14.7	10.5	35.00	62	0.72	0.83	0.35	0.78
1948	15.7	22.3	18.1	13.6	35.00	92	0.74	0.85	0.36	0.99

(Continued)

Table 2.15. (Continued).

1949	17.0	19.5	15.4	12.2	35.00	75	0.72	0.95	0.40	0.99
1950	17.7	21.6	13.3	13.9	35.00	76	0.74	0.98	0.45	0.96
1951	19.0	24.5	17.5	18.0	35.00	93	0.89	1.05	0.54	1.27
1952	19.4	24.5	16.5	16.2	35.00	93	0.85	1.07	0.57	1.21
1953	20.9	29.0	13.5	10.8	35.00	93	0.85	1.10	0.60	0.96
1954	21.8	29.9	14.1	10.7	35.00	88	0.85	1.16	0.61	0.92
1955	23.7	37.5	15.1	12.3	35.00	94	0.89	1.17	0.66	0.95
1956	24.0	42.0	16.0	13.5	35.00	105	0.91	1.23	0.65	1.02
1957	25.4	30.2	14.7	11.4	35.00	90	0.91	1.29	0.74	0.96
1958	24.8	26.3	12.1	10.3	35.00	66	0.89	1.34	0.74	0.95
1959	24.7	31.0	12.2	11.5	35.00	72	0.91	1.37	0.74	1.02
1960	26.0	32.3	11.9	13.0	35.00	83	0.91	1.38	0.74	1.02
1961	25.5	30.3	10.9	11.6	35.00	83	0.92	1.47	0.78	1.13
1962	23.9	31.0	9.6	11.6	35.00	83	1.09	1.50	0.80	1.15
1963	22.6	31.0	11.2	12.0	35.00	82	1.28	1.50	0.79	1.17
1964	23.7	32.3	13.6	13.6	35.00	90	1.29	1.59	0.79	1.58
1965	24.5	35.4	16.0	14.5	35.00	100	1.29	1.66	0.79	1.78
1966	24.5	36.0	15.1	14.5	35.00	100	1.29	1.65	0.79	1.64
1967	25.0	38.1	14.0	13.8	35.00	111	1.55	1.69	0.88	1.53
1968	25.6	41.2	13.2	13.5	40.12	117	2.14	1.74	0.95	1.48
1969	27.2	47.6	14.9	14.7	41.68	124	1.79	1.80	1.05	1.64
1970	28.7	58.1	15.7	15.3	36.39	133	1.77	1.77	1.29	1.74
1971	29.0	52.2	13.9	16.1	41.37	121	1.55	1.82	1.33	1.67
1972	25.0	51.3	15.0	17.7	58.47	121	1.68	1.77	1.40	1.77
1973	26.4	59.4	16.3	20.7	97.98	150	2.56	1.76	1.53	2.28
1974	43.1	77.1	22.5	36.0	159.87	181	4.71	2.12	1.74	3.96
1975	34.8	64.0	21.5	39.0	161.43	164	4.42	2.83	2.07	3.40
1976	41.2	69.4	23.1	37.0	125.35	162	4.35	3.25	2.25	3.80
1977	47.6	66.7	30.7	34.4	148.36	157	4.62	4.85	2.27	5.35
1978	50.8	65.8	33.7	31.0	193.46	261	5.40	9.21	2.04	6.30
1979	70.8	92.1	52.6	37.3	307.61	445	11.09	23.13	2.66	7.35
1980	76.2	101.2	42.5	37.4	612.74	677	20.63	9.39	2.83	8.48
1981	59.9	84.4	36.5	44.6	460.33	446	10.52	6.40	2.71	7.35
1982	46.7	73.0	25.5	38.5	376.35	327	7.95	4.09	2.18	6.53
1983	68.5	76.7	21.7	41.4	423.01	424	11.44	3.65	2.12	6.53
1984	61.2	66.7	25.6	48.5	360.80	357	8.14	3.56	2.16	6.26
1985	49.0	67.1	19.1	40.4	317.26	291	6.14	3.25	2.26	5.94
1986	55.8	66.2	22.0	38.0	367.02	461	5.47	2.87	1.76	3.83
1987	72.1	82.6	35.9	41.9	478.99	553	7.01	2.90	2.20	4.19
1988	110.2	120.7	37.1	60.3	438.56	523	6.53	3.45	6.26	4.41
1989	88.0	131.1	39.4	82.1	382.57	507	5.50	3.37	6.03	5.22
1990	73.9	122.9	45.8	74.4	385.68	467	4.82	2.85	4.02	3.86
1991	59.4	109.3	33.5	52.6	363.91	371	4.04	2.38	3.70	3.63
1992	57.6	107.5	35.1	58.5	345.25	361	3.94	2.20	3.18	4.02
1993	53.5	91.6	31.7	46.3	360.80	375	4.30	2.34	2.40	3.50
1994	71.2	111.1	37.2	49.4	385.68	411	5.29	4.76	2.88	3.69
1995	85.7	138.3	42.3	55.8	385.68	425	5.15	7.89	3.73	4.15
1996	71.2	108.9	49.0	51.3	388.79	398	5.19	3.78	3.40	4.12
1997	77.1	107.0	46.7	64.4	332.81	397	4.89	4.30	3.14	3.81
1998	65.3	78.5	45.3	51.3	295.17	375	5.54	3.40	2.10	3.73
1999	65.8	75.7	43.7	53.5	279.93	379	5.26	2.65	2.73	3.66
2000	74.4	88.0	43.6	55.8	280.24	549	5.01	2.55	3.92	3.70

(Continued)

Table 2.15. (Continued).

Year	Al (¢/lb)	Cu (¢/lb)	Pb (¢/lb)	Zn (¢/lb)	Au ($/tr oz)	Pt ($/tr oz)	Ag ($/tr oz)	Mo ($/lb)	Ni ($/lb)	Sn ($/lb)
2001	68.9	76.7	43.6	44.0	272.16	533	4.35	2.35	2.70	3.15
2002	64.9	75.7	43.6	38.6	311.03	543	4.60	3.76	3.07	2.92
2003	68.0	85.3	43.8	40.6	363.91	694	4.88	5.35	4.37	3.40
2004	83.9	133.8	55.3	52.6	410.57	849	6.44	16.65	6.26	5.49
2005	91.2	173.7	61.2	67.1	444.78	900	7.34	31.80	6.67	3.61
2006	121.6	314.8	77.6	158.8	606.52	1144	11.60	24.77	10.98	4.19
2007	122.0	327.9	123.8	154.2	696.72	1308	13.44	30.30	16.87	6.80
2008	120.7	319.3	120.2	88.9	874.01	1578	15.02	28.58	9.57	8.66
2009	79.4	241.3	87.1	78.0	973.54	1208	14.68	11.70	6.62	6.40
2010	104.3	348.3	108.9	102.1	1228.59	1616	20.00	15.80	9.89	9.53
2011	120.0	405.0	124.0	106.0	1600.00	1720	34.50	15.83	10.30	16.40

valuation is generally poor due to the cyclic behavior of the prices. The problem is shown diagrammatically in Figure 2.10.

One must decide the base price to be used as well as the trend angle and project the results over the depreciation period as a minimum. Another alternative to the selection of the current price as the base price is to use a recent price history over the past two or perhaps five years. For a valuation being done in July 1989 the price was \$1.15/lb. Averaging this value with those over the past three years would yield

Years	Base value	% change
1989	1.15	0
1988–89	1.18	−4.8
1987–89	1.06	+28.3
1986–89	0.96	+42.5

Inflation has not been accounted for in these figures. The point being that a wide range of base values can be calculated. The same is obviously true for determining the ‘slope’ of the trend line. This can be reflected by the percent change over the period of interest. These values have been added to the above table. They have been calculated by

$$\text{Percent change} = \left(\frac{\text{Price (1989)} - \text{Price Y}}{\text{Price Y}}\right) 100\%$$

The conclusion is that due to the cyclic nature of the prices, several cycles must be examined in arriving at both a representative base price and a trend.

There are two approaches which will be briefly discussed for price forecasting. These are:

- trend analysis,
- use of econometric models.

2.3.3 *Trend analysis*

The basic idea in trend analysis is to try and replace the actual price-time history with a mathematical representation which can be used for projection into the future. In examining

Table 2.16. Monthly Metal Prices (Metal Bulletin, 2012). Copyright 2012 Metal Bulletin; reproduced with permission.

		Al (¢/lb)	Cu (¢/lb)	Pb (¢/lb)	Zn (¢/lb)	Au ($/tr oz)	Pt ($/tr oz)	Ag ($/tr oz)	Pd ($/tr oz)	Mo Oxide ($/lb)	Ni ($/lb)	Sn ($/lb)
1997	Jan.	71	110	31.4	49	355	359	4.77	121	4.51	3.21	2.67
	Feb.	72	109	29.9	53	347	365	5.07	136	4.77	3.51	2.67
	Mar.	74	110	31.5	57	352	380	5.20	149	4.77	3.58	2.68
	Apr.	71	108	29.1	56	344	371	4.77	154	4.77	3.32	2.59
	May	74	114	28.0	59	344	390	4.76	171	4.71	3.39	2.59
	June	71	118	27.9	61	341	431	4.75	204	4.76	3.20	2.52
	July	72	111	28.8	69	324	416	4.37	188	4.73	3.10	2.47
	Aug.	78	102	27.6	75	324	425	4.50	215	4.73	3.07	2.46
	Sept.	73	96	28.8	74	323	425	4.73	191	4.51	2.95	2.49
	Oct.	73	93	27.2	58	325	424	5.03	205	4.23	2.89	2.52
	Nov.	73	87	25.5	53	307	293	5.08	208	3.99	2.79	2.57
	Dec.	69	80	23.9	50	289	367	5.79	199	3.98	2.70	2.50
	Avg.	*73*	*103*	*28.3*	*60*	*331*	*387*	*4.90*	*178*	*4.54*	*3.14*	*2.56*
1998	Jan.	67	77	24.1	50	297	375	5.88	226	3.97	2.49	2.36
	Feb.	66	75	23.4	47	289	386	6.83	237	4.04	2.44	2.38
	Mar.	65	79	25.4	47	296	399	6.24	262	4.49	2.45	2.48
	Apr.	64	82	25.9	50	308	414	6.33	321	4.40	2.45	2.59
	May	62	79	24.6	48	299	389	5.56	354	4.11	2.28	2.66
	June	59	75	23.9	46	292	356	5.27	287	4.09	2.03	2.71
	July	59	75	24.8	47	293	378	5.46	307	3.99	1.96	2.56
	Aug.	59	73	24.3	47	284	370	5.18	288	3.58	1.85	2.58
	Sept.	61	75	23.6	45	289	360	5.00	283	3.11	1.86	2.49
	Oct.	59	72	22.3	43	296	343	5.00	277	2.71	1.76	2.46
	Nov.	59	71	22.4	44	294	347	4.97	277	2.38	1.87	2.48
	Dec.	57	67	22.7	43	291	350	4.88	297	2.75	1.76	2.39
	Avg.	*62*	*75*	*24.0*	*46*	*294*	*372*	*5.55*	*285*	*3.64*	*2.10*	*2.51*
1999	Jan.	55	65	22.3	42	287	355	5.15	322	2.81	1.94	2.32
	Feb.	54	64	23.3	46	287	365	5.53	352	2.85	2.10	2.39
	Mar.	54	63	23.0	47	286	370	5.19	353	2.82	2.27	2.43
	Apr.	58	66	23.5	46	282	358	5.07	362	2.64	2.31	2.45
	May	60	69	24.5	47	277	356	5.27	330	2.61	2.45	2.56
	June	60	65	22.5	45	261	357	5.03	337	2.74	2.36	2.39
	July	64	74	22.5	49	256	349	5.18	332	2.69	2.59	2.37
	Aug.	65	75	22.8	51	257	350	5.27	340	2.73	2.93	2.37
	Sept.	68	79	23.0	54	265	372	5.23	362	2.91	3.19	2.42
	Oct.	67	78	22.5	52	311	423	5.41	387	2.81	3.32	2.46
	Nov.	67	78	21.7	52	293	435	5.16	401	2.72	3.61	2.65
	Dec.	70	80	21.7	54	284	441	5.16	425	2.71	3.67	2.60
	Avg.	*62*	*71*	*22.8*	*49*	*279*	*378*	*5.22*	*359*	*2.75*	*2.73*	*2.45*
2000	Jan.	76	84	21.4	53	284	441	5.19	452	2.67	3.77	2.69
	Feb.	76	82	20.5	50	300	517	5.25	636	2.65	4.38	2.56
	Mar.	72	79	20.0	51	286	481	5.06	667	2.65	4.66	2.48
	Apr.	66	76	19.1	51	280	498	5.06	572	2.65	4.41	2.44
	May	67	81	18.7	52	275	527	4.99	571	2.69	4.59	2.47
	June	68	79	19.0	51	286	560	5.00	647	2.93	3.82	2.48

(Continued)

Table 2.16. (Continued).

		Al (¢/lb)	Cu (¢/lb)	Pb (¢/lb)	Zn (¢/lb)	Au ($/tr oz)	Pt ($/tr oz)	Ag ($/tr oz)	Pd ($/tr oz)	Mo Oxide ($/lb)	Ni ($/lb)	Sn ($/lb)
	July	71	82	20.5	52	281	560	4.97	702	2.94	3.70	2.42
	Aug.	69	84	21.5	53	274	578	4.88	760	2.79	3.63	2.41
	Sept.	73	89	22.1	56	274	593	4.89	728	2.77	3.92	2.48
	Oct.	68	86	22.0	50	270	579	4.83	739	2.69	3.48	2.40
	Nov.	67	81	21.2	48	266	594	4.68	784	2.55	3.33	2.39
	Dec.	71	84	21.0	48	272	611	4.64	917	2.51	3.32	2.37
	Avg.	*70*	*82*	*20.6*	*51*	*279*	*545*	*4.95*	*681*	*2.71*	*3.92*	*2.47*
2001	Jan.	73	81	21.7	47	266	622	4.66	1040	2.33	3.17	2.35
	Feb.	73	80	22.7	46	262	601	4.55	975	2.38	2.96	2.32
	Mar.	68	79	22.6	46	263	586	4.40	782	2.41	2.78	2.29
	Apr.	68	75	21.6	44	261	595	4.37	696	2.41	2.87	2.24
	May	70	76	21.1	43	272	610	4.43	655	2.44	3.20	2.24
	June	66	73	20.1	41	270	580	4.36	614	2.58	3.01	2.19
	July	64	69	20.9	39	268	532	4.25	526	2.63	2.69	1.97
	Aug.	62	66	21.9	38	272	451	4.20	455	2.45	2.50	1.77
	Sept.	61	65	21.0	36	284	458	4.35	445	2.45	2.28	1.68
	Oct.	58	62	21.2	35	283	432	4.40	335	2.45	2.19	1.70
	Nov.	60	65	22.0	35	276	430	4.12	328	2.44	2.30	1.83
	Dec.	61	67	21.9	34	276	462	4.35	400	2.43	2.39	1.82
	Avg.	*65*	*72*	*21.6*	*40*	*271*	*530*	*4.37*	*604*	*2.45*	*2.70*	*2.03*
2002	Jan.	62	68	23.3	36	281	473	4.51	411	2.62	2.74	1.75
	Feb.	62	71	21.8	35	295	471	4.42	374	2.75	2.73	1.69
	Mar.	64	73	21.8	37	294	512	4.53	374	2.86	2.97	1.74
	Apr.	62	72	21.4	37	303	541	4.57	370	2.89	3.16	1.83
	May	61	72	20.5	35	314	535	4.71	357	2.99	3.07	1.88
	June	61	75	20.0	35	322	557	4.89	335	7.05	3.23	1.94
	July	61	72	20.2	36	314	526	4.92	323	6.05	3.24	1.96
	Aug.	59	67	19.2	34	310	545	4.55	324	4.76	3.05	1.74
	Sept.	59	67	19.1	34	319	555	4.55	327	4.78	3.01	1.79
	Oct.	59	67	19.0	34	317	581	4.40	317	4.71	3.09	1.92
	Nov.	62	72	20.0	35	319	588	4.51	286	4.04	3.32	1.92
	Dec.	62	72	20.1	36	333	597	4.63	243	3.44	3.26	1.92
	Avg.	*61*	*71*	*20.5*	*35*	*310*	*540*	*4.60*	*337*	*4.08*	*3.07*	*1.84*
2003	Jan.	63	75	20.1	35	357	630	4.81	255	3.62	3.64	2.01
	Feb.	65	76	21.5	36	360	682	4.65	253	3.75	3.91	2.07
	Mar.	63	75	20.7	36	341	677	4.49	226	4.51	3.80	2.09
	Apr.	60	72	19.8	34	328	625	4.49	163	5.21	3.59	2.07
	May	63	75	21.0	35	355	650	4.74	167	5.21	3.78	2.15
	June	64	76	21.2	36	356	662	4.53	180	5.67	4.03	2.13
	July	65	78	23.3	38	351	682	4.80	173	5.87	3.99	2.15
	Aug.	66	80	22.5	37	360	693	4.99	182	5.61	4.24	2.19
	Sept.	64	81	23.6	37	379	705	5.17	211	5.61	4.52	2.23
	Oct.	67	87	26.6	41	379	732	5.00	202	6.11	5.01	2.38
	Nov.	68	93	28.2	41	389	760	5.18	197	6.25	5.48	2.43
	Dec.	71	100	31.4	44	407	808	5.62	198	6.25	6.42	2.75
	Avg.	*65*	*81*	*23.3*	*38*	*364*	*692*	*4.87*	*201*	*5.31*	*4.37*	*2.22*

(Continued)

Table 2.16. (Continued).

2004	Jan.	73	110	34	46	414	851	6.32	216	7.68	6.96	2.94
	Feb.	76	125	40	49	405	846	6.44	235	8.15	6.87	3.03
	Mar.	75	136	40	50	407	899	7.23	268	8.88	6.22	3.46
	Apr.	78	134	34	47	403	882	7.06	297	12.74	5.83	4.06
	May	74	124	37	47	384	810	5.85	246	14.00	5.05	4.29
	June	76	122	39	46	392	807	5.86	229	14.97	6.14	4.18
	July	78	127	43	45	398	809	6.31	221	15.75	6.82	4.10
	Aug.	77	129	42	44	401	847	6.66	216	16.72	6.21	4.09
	Sept.	78	131	42	44	405	848	6.39	211	18.28	6.02	4.09
	Oct.	83	137	42	48	420	844	7.10	218	19.63	6.54	4.10
	Nov.	82	142	44	50	439	854	7.49	214	22.44	6.37	4.11
	Dec.	84	143	44	54	442	851	7.10	192	25.71	6.25	3.88
	Avg.	*78*	*130*	*40*	*48*	*409*	*846*	*6.65*	*230*	*15.41*	*6.27*	*3.86*
2005	Jan.	83	144	43	57	424	859	6.61	186	33.00	6.58	3.51
	Feb.	85	148	44	60	423	865	7.03	182	30.75	6.96	3.67
	Mar.	90	153	46	62	434	868	7.26	197	32.06	7.34	3.82
	Apr.	86	154	45	59	429	866	7.12	198	35.50	7.32	3.69
	May	79	147	45	56	422	867	7.02	190	35.89	7.68	3.69
	June	79	160	45	58	431	880	7.31	186	37.61	7.33	3.46
	July	81	164	39	54	424	874	7.01	184	32.44	6.61	3.25
	Aug.	85	172	40	59	438	900	7.04	187	30.00	6.76	3.26
	Sept.	83	175	42	63	456	915	7.15	189	31.67	6.45	3.08
	Oct.	87	184	46	68	470	931	7.67	208	32.13	5.63	2.91
	Nov.	93	194	46	73	477	963	7.87	246	31.25	5.50	2.79
	Dec.	102	208	51	83	510	978	8.64	265	29.67	6.09	3.05
	Avg.	*86*	*167*	*44*	*63*	*445*	*897*	*7.31*	*202*	*32.66*	*6.69*	*3.35*
2006	Jan.	108	215	57	95	550	1029	9.15	273	24.14	6.60	3.20
	Feb.	111	226	58	101	555	1041	9.53	289	23.84	6.79	3.55
	Mar.	110	231	54	110	557	1042	10.38	309	23.17	6.76	3.60
	Apr.	119	290	53	140	611	1102	12.61	353	22.93	8.14	4.02
	May	130	365	53	162	675	1264	13.45	369	24.58	9.56	4.01
	June	112	326	44	146	596	1189	10.80	315	26.22	9.41	3.58
	July	114	350	48	151	634	1229	11.23	319	25.96	12.06	3.82
	Aug.	112	349	53	152	633	1233	12.18	329	25.45	13.95	3.86
	Sept.	112	345	61	154	598	1186	11.68	324	27.03	13.67	4.10
	Oct.	120	340	69	173	586	1085	11.56	313	25.89	14.83	4.43
	Nov.	123	319	74	199	628	1183	12.93	325	25.56	14.57	4.57
	Dec.	128	303	78	200	630	1121	13.36	326	25.50	15.68	5.06
	Avg.	*117*	*305*	*59*	*149*	*604*	*1142*	*11.57*	*320*	*25.02*	*11.00*	*3.98*
2007	Jan.	127	257	76	172	631	1147	12.84	337	25.22	16.70	5.15
	Feb.	128	257	81	150	665	1205	13.91	342	25.53	18.68	5.87
	Mar.	125	293	87	148	655	1219	13.18	350	27.88	21.01	6.30
	Apr.	128	352	91	161	679	1278	13.74	369	28.50	22.80	6.37
	May	127	348	95	174	667	1303	13.15	368	30.10	23.67	6.42
	June	121	339	110	163	655	1287	13.14	368	33.63	18.92	6.40
	July	124	362	140	161	665	1304	12.91	366	32.50	15.16	6.69
	Aug.	114	341	141	148	665	1264	12.36	344	31.44	12.54	6.88
	Sept.	108	347	146	131	713	1307	12.83	335	32.00	13.40	6.81
	Oct.	111	363	169	135	755	1410	13.67	365	32.00	14.09	7.29
	Nov.	114	316	151	115	806	1449	14.70	363	32.75	13.88	7.57
	Dec.	108	299	118	107	803	1487	14.30	351	32.75	11.79	7.38
	Avg.	*120*	*323*	*117*	*147*	*697*	*1305*	*13.39*	*355*	*30.36*	*16.89*	*6.59*

(Continued)

Table 2.16. (Continued).

		Al (¢/lb)	Cu (¢/lb)	Pb (¢/lb)	Zn (¢/lb)	Au ($/tr oz)	Pt ($/tr oz)	Ag ($/tr oz)	Pd ($/tr oz)	Mo Oxide ($/lb)	Ni ($/lb)	Sn ($/lb)
2008	Jan.	111	320	118	106	890	1582	15.96	374	32.81	12.56	7.41
	Feb.	126	358	140	111	922	1995	17.57	466	32.88	12.68	7.81
	Mar.	136	383	136	114	968	2058	19.51	492	32.88	14.16	8.98
	Apr.	134	394	128	103	910	1990	17.50	447	32.88	13.05	9.82
	May	132	380	101	99	889	2055	17.05	437	32.88	11.67	10.91
	June	134	375	85	86	889	2041	16.97	449	32.88	10.23	10.08
	July	139	382	88	84	940	1916	18.03	428	32.88	9.14	10.50
	Aug.	125	346	87	78	839	1492	14.69	316	33.20	8.59	9.08
	Sept.	115	317	85	79	830	1225	12.37	250	33.75	8.07	8.33
	Oct.	96	223	67	59	807	914	10.44	191	33.75	5.51	6.53
	Nov.	84	169	59	52	761	842	9.87	207	15.43	4.85	6.19
	Dec.	68	139	44	50	816	845	10.29	177	12.38	4.39	5.10
	Avg.	*117*	*316*	*95*	*85*	*872*	*1580*	*15.02*	*353*	*29.88*	*9.58*	*8.40*
2009	Jan.	64	146	51	54	859	953	11.29	188	10.08	5.13	5.16
	Feb.	60	150	50	50	943	1038	13.41	207	9.63	4.72	5.01
	Mar.	61	170	56	55	924	1082	13.12	203	9.17	4.40	4.84
	Apr.	64	200	63	63	890	1165	12.51	227	8.55	5.06	5.33
	May	66	207	65	67	929	1134	14.03	230	9.08	5.73	6.26
	June	71	227	76	71	946	1221	14.65	246	10.39	6.79	6.80
	July	76	237	76	72	934	1161	13.36	248	11.52	7.25	6.37
	Aug.	88	280	86	83	949	1245	14.35	275	17.25	8.91	6.74
	Sept.	83	281	100	85	997	1290	16.39	293	13.88	7.93	6.74
	Oct.	85	285	102	94	1043	1333	17.24	322	13.26	8.40	6.81
	Nov.	88	303	105	99	1127	1402	17.82	352	10.75	7.71	6.78
	Dec.	99	317	106	108	1135	1448	17.67	374	11.18	7.74	7.05
	Avg.	*76*	*234*	*78*	*75*	*973*	*1206*	*14.65*	*264*	*11.23*	*6.65*	*6.16*
2010	Jan.	101	335	107	110	1118	1564	17.79	434	14.16	8.36	8.04
	Feb.	93	311	96	98	1095	1521	15.87	424	15.84	8.61	7.42
	Mar.	100	339	99	103	1113	1600	17.11	461	17.71	10.19	7.96
	Apr.	105	351	103	107	1149	1718	18.10	534	17.89	11.81	8.47
	May	93	310	85	89	1205	1630	18.42	491	17.44	9.98	7.97
	June	88	295	77	79	1233	1552	18.45	462	14.76	8.79	7.86
	July	90	306	83	84	1193	1527	17.96	456	14.33	8.85	8.25
	Aug.	96	330	94	93	1216	1541	18.36	487	15.29	9.71	9.41
	Sept.	98	350	99	98	1271	1591	20.55	538	16.25	10.27	10.30
	Oct.	106	376	108	108	1342	1689	23.39	592	15.20	10.80	11.95
	Nov.	106	384	108	104	1370	1696	26.54	683	15.66	10.39	11.58
	Dec.	107	415	109	103	1391	1712	29.35	755	16.03	10.94	11.87
	Avg.	*99*	*342*	*97*	*98*	*1225*	*1612*	*20.16*	*526*	*15.88*	*9.89*	*9.26*
2011	Jan.	111	433	118	108	1356	1787	28.40	793	16.76	11.63	12.46
	Feb.	114	448	117	112	1373	1826	30.78	821	17.58	12.82	14.30
	Mar.	116	432	119	107	1424	1768	35.81	762	17.70	12.16	13.94
	Apr.	121	430	124	108	1474	1794	41.97	771	17.36	11.94	14.72
	May	118	405	110	98	1510	1788	36.75	736	17.25	10.98	13.03
	June	116	410	114	101	1529	1772	35.80	771	17.25	10.14	11.60
	July	114	436	122	108	1573	1757	37.92	788	14.94	10.76	12.39

(Continued)

Table 2.16. (Continued).

	Aug.	109	410	109	100	1756	1806	40.30	763	14.83	10.02	11.08
	Sept.	104	377	104	94	1772	1756	38.15	713	14.71	9.25	10.28
	Oct.	99	333	88	84	1665	1535	31.97	616	13.89	8.57	9.88
	Nov.	94	343	90	87	1739	1596	33.08	626	13.26	8.11	9.64
	Dec.	92	343	92	87	1652	1465	30.41	643	13.46	8.23	8.81
	Avg.	*109*	*400*	*109*	*99*	*1569*	*1721*	*35.11*	*733*	*15.75*	*10.38*	*11.84*
2012	Jan.	97	365	95	90	1656	1507	30.77	659	13.76	8.99	9.73
	Feb.	100	382	96	93	1743	1658	34.14	702	14.52	9.28	11.04
	Mar.	99	384	94	92	1674	1658	32.95	685	14.37	8.49	10.44
	Apr.	93	375	94	91	1650	1589	31.55	657	14.22	8.12	10.02
	May	91	359	91	88	1586	1469	28.67	617	14.10	7.72	9.24
	June	85	337	84	84	1597	1447	28.05	612	13.53	7.50	8.74
	July	85	344	85	84	1594	1427	27.43	579	12.81	7.33	8.44

Al – Aluminum Settlement LME Daily Official $ per tonne Monthly Average
Cu – Copper Settlement LME Daily Official $ per tonne Monthly Average
Pb – Lead Settlement LME Daily Official $ per tonne Monthly Average
Zn – Zinc Settlement LME Daily Official $ per tonne Monthly Average
Au – Gold London Afternoon Daily Price $ per troy oz Monthly Average
Pt – Platinum London free market Morning $ per troy oz Monthly average
Ag – Silver Spot London Brokers Official Daily price Cents per troy oz Monthly Average
Pd – Palladium London free market daily price change Morning $ per troy oz Monthly average
Mo – Molybdenum canned molybdic oxide United States Free market $ per lb Mo in warehouse Monthly average
Ni – Nickel Settlement LME Daily Official $ per tonne Monthly Average
Sn – Tin Settlement LME Daily Official $ per tonne Monthly Average.

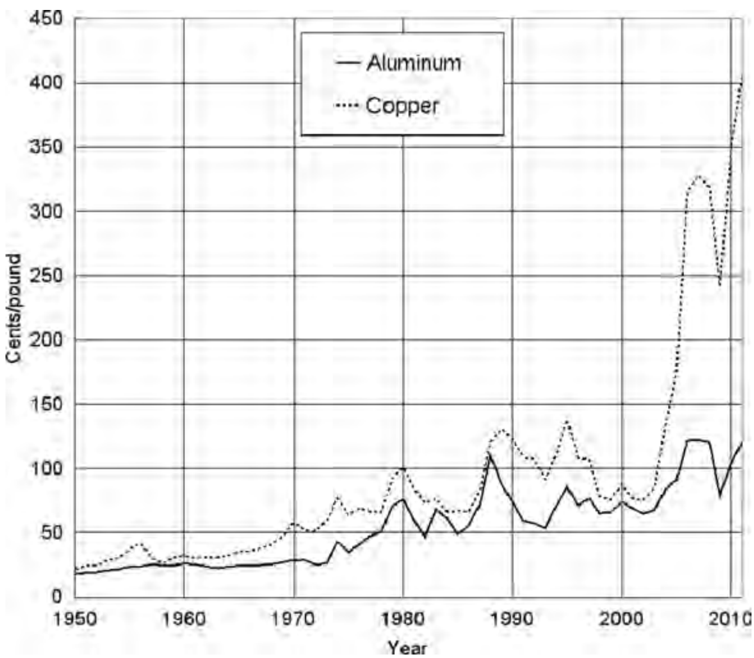

Figure 2.2. Price performance of copper and aluminum over the period 1950–2011.

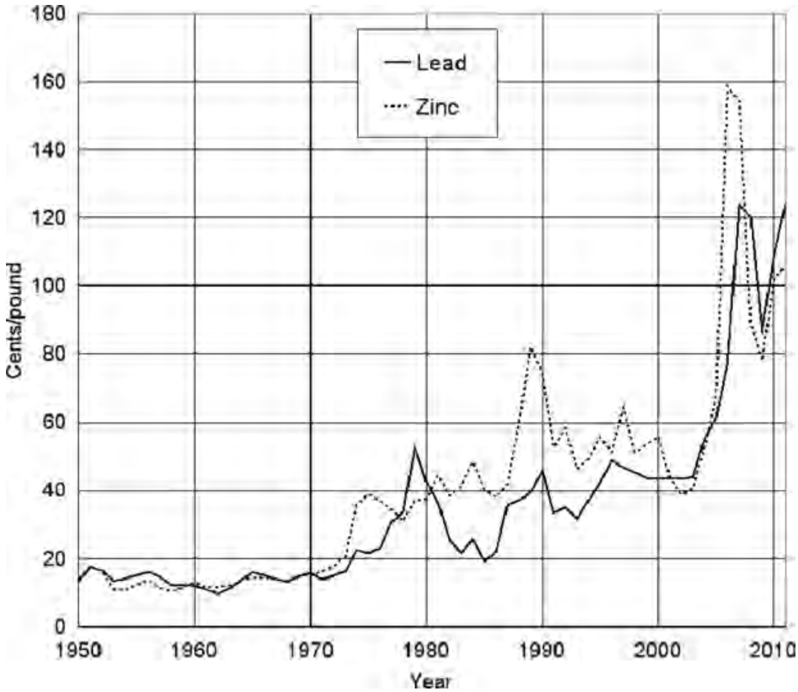

Figure 2.3. Price performance of lead and zinc over the period 1950–2011.

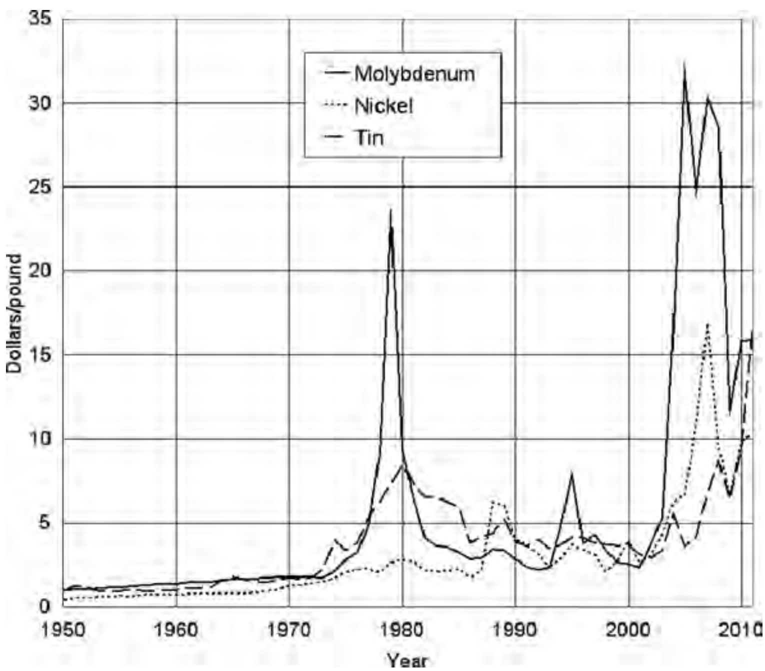

Figure 2.4. Price performance of molybdenum, nickel and tin over the period 1950–2011.

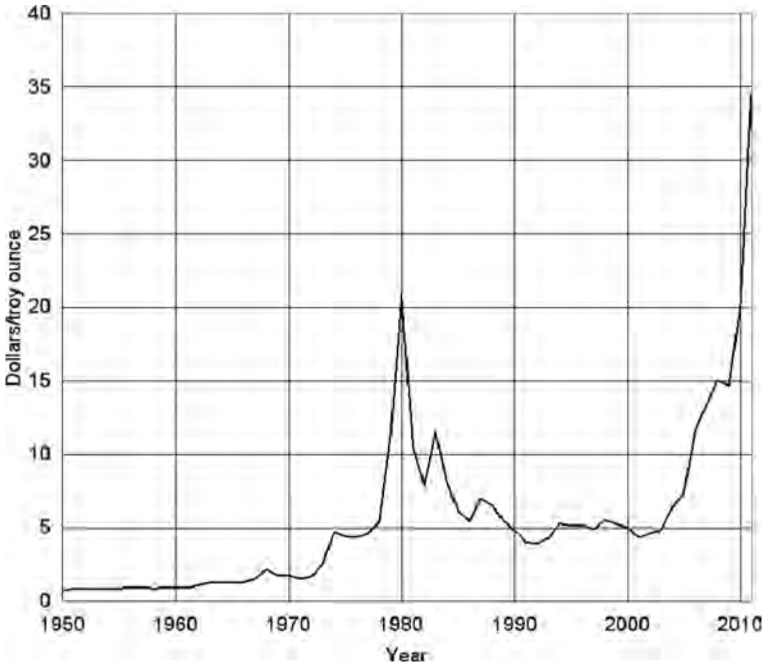

Figure 2.5. Price performance of silver over the period 1950–2011.

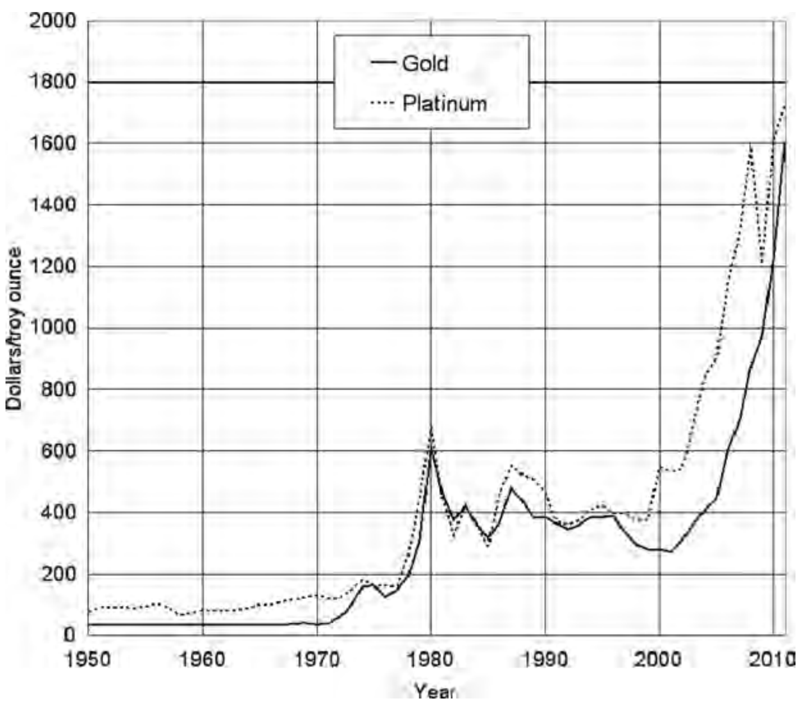

Figure 2.6. Price performance of gold and platinum over the period 1950–2011.

Table 2.17. Annual price of iron ore fines (USGS, 2012b).

Year	$/ton	Year	$/ton	Year	$/ton
1900	2.35	1938	2.56	1976	22.60
1901	1.68	1939	2.99	1977	25.00
1902	1.82	1940	2.52	1978	27.70
1903	1.88	1941	2.65	1979	30.80
1904	1.55	1942	2.61	1980	34.50
1905	1.75	1943	2.62	1981	37.50
1906	2.09	1944	2.69	1982	38.70
1907	2.53	1945	2.72	1983	46.30
1908	2.25	1946	3.01	1984	39.90
1909	2.13	1947	3.44	1985	38.60
1910	2.46	1948	3.88	1986	34.20
1911	1.98	1949	4.46	1987	29.60
1912	1.95	1950	4.92	1988	28.30
1913	2.12	1951	5.40	1989	31.30
1914	1.76	1952	6.21	1990	30.90
1915	1.83	1953	6.81	1991	30.10
1916	2.40	1954	6.76	1992	28.60
1917	3.12	1955	7.21	1993	25.80
1918	3.46	1956	7.68	1994	25.20
1919	3.20	1957	8.10	1995	27.70
1920	4.14	1958	8.27	1996	28.90
1921	3.00	1959	8.48	1997	29.90
1922	3.32	1960	8.35	1998	31.20
1923	3.44	1961	9.13	1999	26.80
1924	2.83	1962	8.82	2000	25.80
1925	2.57	1963	9.22	2001	24.50
1926	2.52	1964	9.46	2002	25.90
1927	2.50	1965	9.25	2003	31.00
1928	2.45	1966	9.50	2004	36.80
1929	2.65	1967	9.64	2005	43.80
1930	2.47	1968	9.78	2006	53.80
1931	2.36	1969	10.20	2007	59.40
1932	1.41	1970	10.40	2008	74.70
1933	3.52	1971	10.90	2009	93.20
1934	2.64	1972	12.10	2010	100.90
1935	2.66	1973	12.80	2011	120.00
1936	2.64	1974	15.50		
1937	2.82	1975	19.40		

a 'typical' curve one can see that it is cyclic and the cycles have different amplitudes. One could try to fit a function describing the behavior quite closely over a given time period using a type of regression analysis which is commonly available on computers as part of a statistical software package.

The general objective is to determine an equation of the form

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + \cdots + a_mx^m \tag{2.7}$$

where a_i are coefficients; y is the price in year x; x is the year relative to the initial year ($x = 0$).

Table 2.18. Monthly spot price for China import iron ore fines 62% FE (CFR Tianjin port), US Dollars per metric ton, (IMF, 2012).

Month	$/metric ton	Month	$/metric ton	Month	$/metric ton
Jan-00	12.45	Jan-08	60.80	Sep-10	140.63
...	...	...	...	Oct-10	148.48
Dec-00	12.45	Nov-08	60.80	Nov-10	160.55
Jan-01	12.99	Dec-08	69.98	Dec-10	168.53
...	...	Jan-09	72.51	Jan-11	179.63
Dec-01	12.99	Feb-09	75.59	Feb-11	187.18
Jan-02	12.68	Mar-09	64.07	Mar-11	169.36
...	...	Apr-09	59.78	Apr-11	179.26
Dec-02	12.68	May-09	62.69	May-11	177.10
Jan-03	13.82	Jun-09	71.66	Jun-11	170.88
...	...	Jul-09	83.95	Jul-11	172.98
Dec-03	13.82	Aug-09	97.67	Aug-11	177.45
Jan-04	16.39	Sep-09	80.71	Sep-11	177.23
...	...	Oct-09	86.79	Oct-11	150.43
Dec-04	16.39	Nov-09	99.26	Nov-11	135.54
Jan-05	28.11	Dec-09	105.25	Dec-11	136.46
...	...	Jan-10	125.91	Jan-12	140.35
Dec-05	28.11	Feb-10	127.62	Feb-12	140.40
Jan-06	33.45	Mar-10	139.77	Mar-12	144.66
...	...	Apr-10	172.47	Apr-12	147.65
Dec-06	33.45	May-10	161.35	May-12	136.27
Jan-07	36.63	Jun-10	143.63	Jun-12	134.62
...	...	Jul-10	126.36	Jul-12	127.94
Dec-07	36.63	Aug-10	145.34		

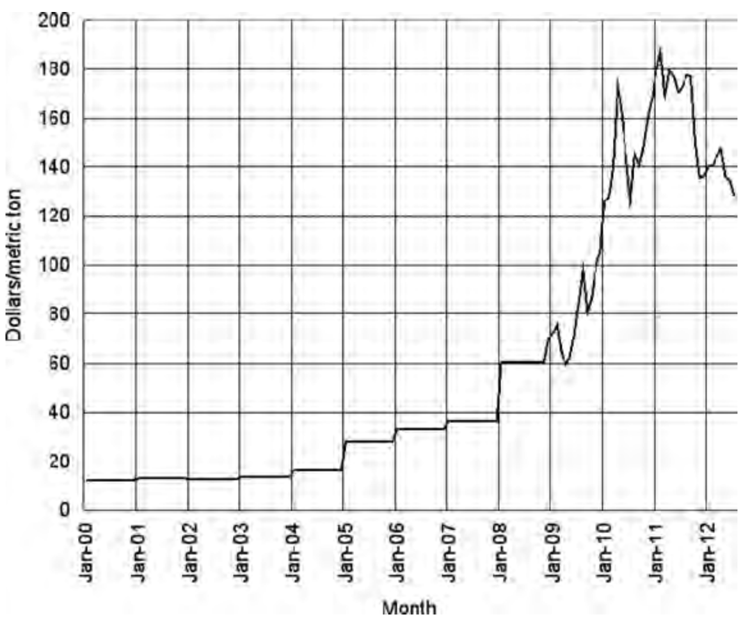

Figure 2.7. Monthly average price Jan-2000 to July-2012 for China import iron ore fines (62% Fe spot, CFR Tianjin port), US Dollars per metric ton (IMF, 2012).

Table 2.19. Annual steel production (in thousand tonnes) for the top twenty steel producing countries for years 2000 to 2011 ranked by year 2011 production, (World Steel Association, 2012).

Rank	Country	Year 2000	2001	2002	2003	2004	2005
1	China	128,500	151,634	182,249	222,336	272,798	355,790
2	Japan	106,444	102,866	107,745	110,511	112,718	112,471
3	United States	101,803	90,104	91,587	93,677	99,681	94,897
4	India	26,924	27,291	28,814	31,779	32,626	45,780
5	Russia	59,136	58,970	59,777	61,450	65,583	66,146
6	South Korea	43,107	43,852	45,390	46,310	47,521	47,820
7	Germany	46,376	44,803	45,015	44,809	46,374	44,524
8	Ukraine	31,767	33,108	34,050	36,932	38,738	38,641
9	Brazil	27,865	26,717	29,604	31,147	32,909	31,610
10	Turkey	14,325	14,981	16,467	18,298	20,478	20,965
11	Italy	26,759	26,545	26,066	27,058	28,604	29,350
12	Taiwan	16,896	17,261	18,230	18,832	19,599	18,942
13	Mexico	15,631	13,300	14,010	15,159	16,737	16,195
14	France	20,954	19,343	20,258	19,758	20,770	19,481
15	Spain	15,874	16,504	16,408	16,286	17,621	17,826
16	Canada	16,595	15,276	16,002	15,929	16,305	15,327
17	Iran	6,600	6,916	7,321	7,869	8,682	9,404
18	United Kingdom	15,155	13,543	11,667	13,268	13,766	13,239
19	Poland	10,498	8,809	8,368	9,107	10,593	8,336
20	Belgium	11,636	10,762	11,343	11,114	11,698	10,420

Rank	Country	Year 2006	2007	2008	2009	2010	2011
1	China	421,024	489,712	512,339	577,070	637,400	683,265
2	Japan	116,226	120,203	118,739	87,534	109,599	107,595
3	United States	98,557	98,102	91,350	58,196	80,495	86,247
4	India	49,450	53,468	57,791	63,527	68,321	72,200
5	Russia	70,830	72,387	68,510	60,011	66,942	68,743
6	South Korea	48,455	51,517	53,625	48,572	58,914	68,471
7	Germany	47,224	48,550	45,833	32,670	43,830	44,288
8	Ukraine	40,891	42,830	37,279	29,855	33,432	35,332
9	Brazil	30,901	33,782	33,716	26,506	32,928	35,162
10	Turkey	23,315	25,754	26,806	25,304	29,143	34,103
11	Italy	31,624	31,553	30,590	19,848	25,750	28,662
12	Taiwan	20,000	20,903	19,882	15,873	19,755	22,660
13	Mexico	16,447	17,573	17,209	14,132	16,870	18,145
14	France	19,852	19,250	17,879	12,840	15,414	15,777
15	Spain	18,391	18,999	18,640	14,358	16,343	15,591
16	Canada	15,493	15,572	14,845	9,286	13,013	13,090
17	Iran	9,789	10,051	9,964	10,908	11,995	13,040
18	United Kingdom	13,871	14,317	13,521	10,079	9,709	9,481
19	Poland	10,008	10,632	9,728	7,128	7,993	8,794
20	Belgium	11,631	10,692	10,673	5,635	7,973	8,114

If one has 10 pairs of data (price, year), then the maximum power of the polynomial which could be fitted is $m = 9$. As the power is increased, the actual behavior of the data could be more and more closely represented. Unfortunately while this is a good procedure for interpolation, that is, defining values for points within the range of the data, the equation

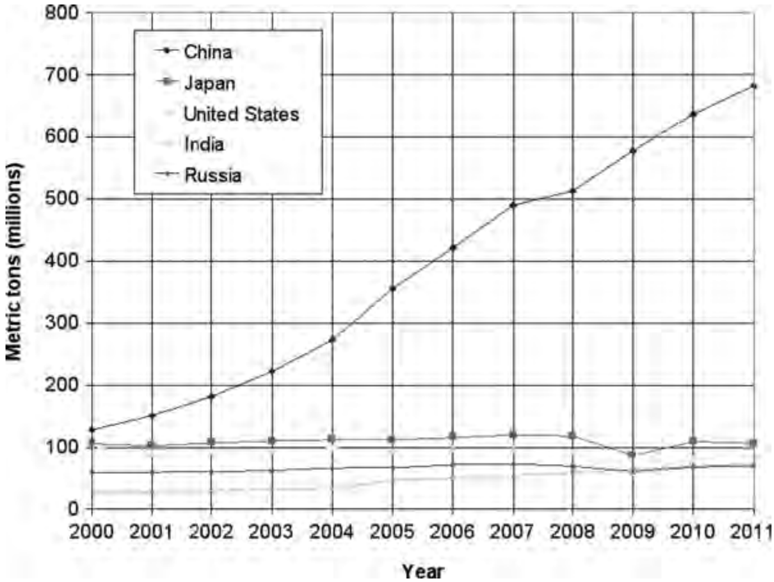

Figure 2.8. Annual steel production for the top five steel producing countries for years 2000 to 2011, (World Steel Association, 2012).

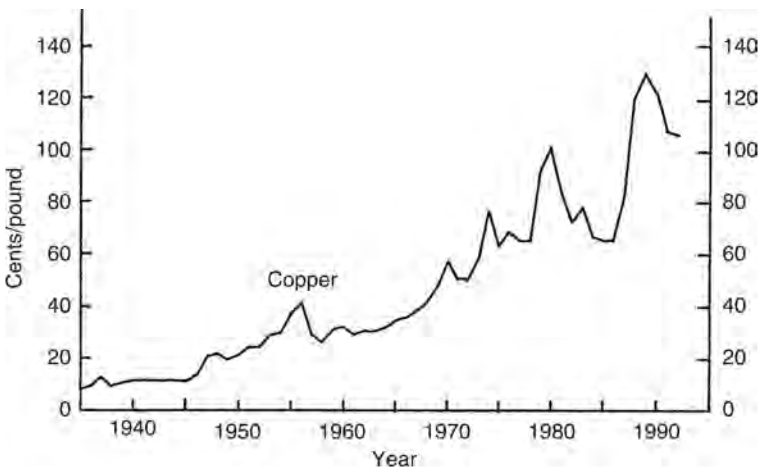

Figure 2.9. Average copper price by year over the time period 1935 to 1992 (Noble, 1979; *E/MJ*, 1992).

cannot be used for determining values beyond the endpoints (extrapolation). This however is what is desired, that of projecting the historical data past the end points into the future. It can be easily demonstrated that some of the terms of power 2 and higher can vary wildly both in sign and magnitude over only one year. Thus such a general power series representation is not of interest. There are some other possibilities however based upon the fitting of the first two terms of a power series. The simplest representation

$$y = a_0 + a_1 x \tag{2.8}$$

Table 2.20. Average annual copper prices 1935-92 (*E/MJ*, 1935–1992).

Calendar year	Relative year	Domestic copper (¢/lb)	Calendar year	Relative year	Domestic copper (¢/lb)
1935	0	8.649	1965	30	35.017
	1	9.474		31	36.170
	2	13.167		32	38.226
	3	10.000		33	41.847
	4	10.965		34	47.534
1940	5	11.296	1970	35	57.700
	6	11.797		36	51.433
	7	11.775		37	50.617
	8	11.775		38	58.852
	9	11.775		39	76.649
1945	10	11.775	1975	40	63.535
	11	13.820		41	68.824
	12	20.958		42	65.808
	13	22.038		43	65.510
	14	19.202		44	92.234
1950	15	21.235	1980	45	101.416
	16	24.200		46	83.744
	17	24.200		47	72.909
	18	28.798		48	77.861
	19	29.694		49	66.757
1955	20	37.491	1985	50	65.566
	21	41.818		51	64.652
	22	29.576		52	81.097
	23	25.764		53	119.106
	24	31.182		54	129.534
1960	25	32.053	1990	55	121.764
	26	29.921		56	107.927
	27	30.600		57	106.023
	28	30.600			
	29	31.960			

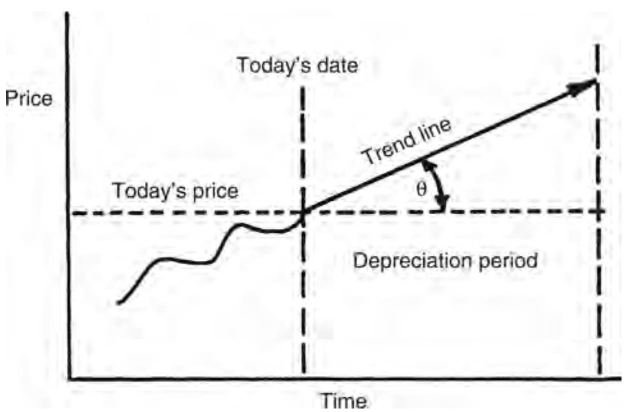

Figure 2.10. Diagrammatic representation of the price projection process.

represents a straight line with intercept a_0 ($x = 0$) and slope a_1. For this to apply the data should plot as a straight line on rectangular graph paper. Figure 2.9 shows such a plot for the copper data over the time period 1935–1992. The average trend over the period 1935 through 1970 might be fitted by such a straight line but then there is a rapid change in the rate of price growth. In examining the average trend it appears as if some type of non-linear function is required. The first approach by the engineer might be to try an exponential function such as

$$y = a\mathrm{e}^{bx} \tag{2.9}$$

Taking natural logs of both sides one finds that

$$\ln y = \ln a + bx \ln \mathrm{e}$$

Since the natural log of e is 1, then

$$\ln y = \ln a + bx \tag{2.10}$$

Letting

$$y^1 = \ln y$$
$$a^1 = \ln a$$

Equation (2.10) becomes

$$y^1 = a^1 + bx \tag{2.11}$$

A straight line should now result when the natural log of the price is plotted versus the year. Such a plot, easily made using semi-log paper, is shown in Figure 2.11. A straight line can be made to fit the data quite well. In 1977, Noble (1979) fitted an equation of the form

$$y = a\mathrm{e}^{bx}$$

to the data in Table 2.20 for the period 1935 to 1976. For the least squares approach employed, the constants a and b are given by

$$b = \frac{\sum (x_i \ln y_i) - \frac{1}{n}\sum x_i \sum \ln y_i}{\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2} \tag{2.12}$$

$$a = \exp\left(\frac{\sum \ln y_i}{n} - b\frac{\sum x_i}{n}\right) \tag{2.13}$$

For the period of 1935 to 1976

$$n = 42$$
$$\sum (x_i \ln y_i) = 3085.521$$
$$\sum x_i = 861$$
$$\sum \ln y_i = 136.039$$

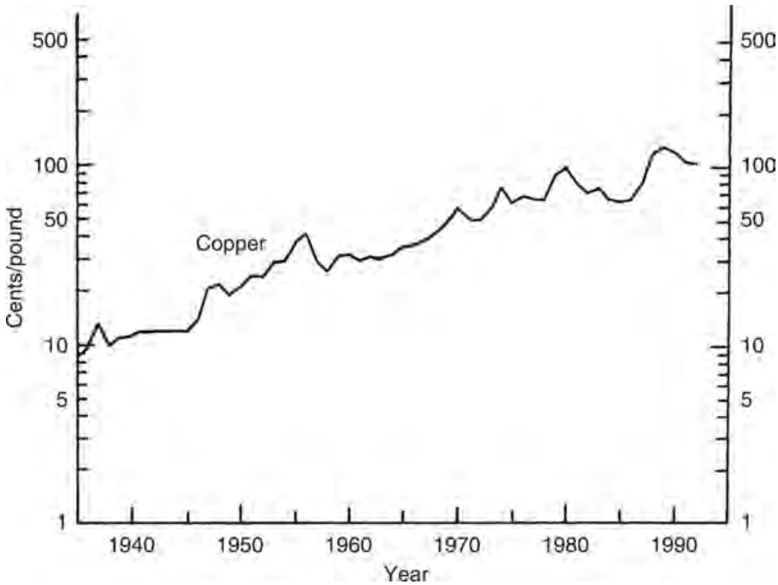

Figure 2.11. Logarithmic plot of copper price versus time for the time period 1935 to 1992.

$$\sum x_i^2 = 23{,}821$$

$$\sum (\ln y_i)^2 = 456.0775$$

Substituting the appropriate values into Equations (2.12) and (2.13) one finds that

$$b = \frac{3085.521 - \frac{1}{42}861 + 136.039}{23821 - \frac{1}{42}(861)^2} = 0.04809$$

$$a = \exp\left(\frac{136.039}{42} - \frac{0.04809}{42}861\right) = 9.5185$$

Hence the price predictor equation becomes

$$y = 9.5185\mathrm{e}^{0.04809x} \tag{2.14}$$

The correlation coefficient r may be calculated using

$$r = \frac{S_{xy}}{\sqrt{S_{xx}S_{yy}}} \tag{2.15}$$

where

$$S_{xx} = n\sum x_i^2 - \left(\sum x_i\right)^2 = 259{,}161 \tag{2.16}$$

$$S_{yy} = n\sum (\ln y_i)^2 - \left(\sum \ln y_i\right)^2 = 648.65 \tag{2.17}$$

$$S_{xy} = n\sum (x_i \ln y_i) - \left(\sum x_i\right)\left(\sum \ln y_i\right) = 12{,}462.30 \tag{2.18}$$

In this case

$$r = 0.961$$

This high correlation coefficient indicates a strong relationship between price and time. Confidence limits (CL) for the estimates may be calculated using

$$\mathrm{CL}(y) = ae^{bx \pm c} \tag{2.19}$$

The constant c is given by

$$c = t_{\alpha/2}(1 - r^2)^{1/2}\left[S_y^2 + \frac{(n - \bar{x})^2}{(n - 2)S_x^2}\right]^{1/2} \tag{2.20}$$

where:
α is the probability (expressed as a decimal) of y being outside the confidence limits;
$t_{\alpha/2}$ is the value read from a Student 't' table for a cumulative probability (P) of $1 - \alpha/2$ and $n - 2$ degrees of freedom;
S_y^2 is the population variance of ln y $(=(\mathrm{SD}_y)^2)$;
S_x^2 is the population variance of x $(=(\mathrm{SD}_x)^2)$;
$\bar{x}$ is the mean (arithmetic value) of x;
(SD_y) is the standard deviation of ln y;
(SD_x) is the standard deviation of x;
r is the correlation coefficient.

The required mean values, variances and standard deviations are given by

$$\overline{\ln y} = \frac{\sum \ln y_i}{n} = 3.2390 \tag{2.21}$$

$$S_y^2 = \frac{\sum (\overline{\ln y} - \ln y_i)^2}{n - 1} = 0.3767 \tag{2.22}$$

$$S_y = \mathrm{SD}_y = \sqrt{S_y^2} = 0.6137 \tag{2.23}$$

$$\bar{x} = \frac{\sum x_i}{n} = 20.5 \tag{2.24}$$

$$S_x^2 = \frac{\sum (\bar{x} - x_i)^2}{n - 1} = 150.5 \tag{2.25}$$

$$S_x = \mathrm{SD}_x = \sqrt{S_x^2} = 12.2678 \tag{2.26}$$

Substitution of these values into Equation (2.20) yields

$$c = t_{\alpha/2}(0.2765)\left[0.3767 + \frac{(x - 20.5)^2}{6020}\right]^{1/2} \tag{2.27}$$

If the probability of y being outside of the confidence limits is $\alpha = 0.20$ (80% probability that the price is within the upper and lower limits), then

$$P = 1 - 0.20/2 = 0.90$$
$$\mathrm{DF} = 42 - 2 = 40$$

Table 2.21. Predicted and actual copper prices (Noble, 1979).

X	Year	Predicted average price (¢/lb)	Predicted range (¢/lb) Low	High	Actual price (¢/lb)
42	1977	71.74	56.28	91.44	65.81
43	1978	75.27	58.94	96.13	65.51
44	1979	78.98	61.72	101.07	92.33
45	1980	82.87	64.63	106.27	101.42
46	1981	86.96	67.66	111.75	83.74
47	1982	91.24	70.84	117.51	72.91
48	1983	95.73	74.16	123.59	77.86
49	1984	100.45	77.63	129.98	66.76
50	1985	105.40	81.26	136.71	65.57
51	1986	110.59	85.05	143.80	66.10
52	1987	116.04	89.01	151.27	82.50
53	1988	121.76	93.16	159.14	120.51
Average		94.75	73.36	122.39	80.09

The value of $t_{\alpha/2}$ as read from the Student 't' table is

$$t_{\alpha/2} = 1.303$$

Equation (2.27) becomes

$$c = 0.3603\left[0.3767 + \frac{(x-20.5)^2}{6020}\right]^{1/2} \tag{2.28}$$

The average trend price value for 1976 ($x = 41$) is

$$y = 68.37 \text{ ¢/lb}$$

This happens to be very close to the actual 1976 price of 68.82 ¢/lb. The predicted average price and price ranges for the time period 1977–1988 ($x = 42$ to 53) are given in Table 2.21.

The actual average prices for the same years are also given. As can be seen for the time period 1982–1987, the actual value was considerably lower than the predicted lower limit. This corresponded to a very difficult time for producers. The conclusion is that it is very difficult to predict future price trends.

2.3.4 *Econometric models*

A commodity model is a quantitative representation of a commodity market or industry (Labys, 1977). The behavioral relationships included reflect supply and demand aspects of price determination, as well as other related economic, political and social phenomena.

There are a number of different methodologies applied to modelling mineral markets and industries. Each concentrates on different aspects of explaining history, analyzing policy and forecasting. The methodologies chosen for a model depend on the particular economic behavior of interest. It could be price determination, reserve and supply effects, or other aspects.

The market model is the most basic type of micro economic structure and the one from which other commodity methodologies have developed. It includes factors such as:

– Commodity demand, supply and prices;
– Prices of substitute commodities;
– Price lags;
– Commodity inventories;
– Income or activity level;
– Technical factors;
– Geological factors;
– Policy factors influencing the supply.

Market models, which balance supply and demand to produce an equilibrium price, are commonly used in the mineral business for: (a) historical explanation, (b) policy analysis decision making, and (c) prediction.

They are also used to simulate the possible effects of stockpiles and/or supply restrictions over time.

2.3.5 *Net smelter return*

For base metals such as copper, lead, and zinc, prices are not quoted for concentrates rather the refined metal price is given. The payment received by the company from the smelter for their concentrates (called the net smelter return (NSR)) (Lewis et al., 1978; Huss, 1984; Werner & Janakiraman, 1980) depends upon many factors besides metal price. The process by which the net smelter return is calculated is the subject of this section.

Assume that a mill produces a copper concentrate containing G percent of copper metal. The amount of contained metal in one ton of concentrate is

$$\mathrm{CM} = \frac{G}{100} 2000 \tag{2.29}$$

where CM is the contained metal (lbs), G is the concentrate grade (% metal), and the ratio lbs/ton is 2000.

Most smelters and refiners pay for the contained metal based upon prices published in sources such as *Metals Week*. If the current market price ($/lb) is P then the contained copper value is

$$\mathrm{CV} = \frac{G}{100} 2000P \tag{2.30}$$

where CV is the contained copper value ($/ton), P is the current market price ($/lb).

It is never possible for smelting and refining operations to recover one hundred percent of the contained metal. Some metal is lost in the slag, for example. To account for these losses, the smelter only pays for a portion of the metal content in the concentrate. The deductions may take one of three forms:

(1) Percentage deduction. The smelter pays only for a percentage (C) of the contained metal.

(2) Unit deduction. The concentrate grade is reduced by a certain fixed amount called the unit deduction. For minerals whose grade is expressed in percent one unit is one percentage point. For minerals whose grade is expressed in troy ounces, one unit is one troy ounce.

(3) A combination of percentage and unit deductions.

The 'effective' concentrate grade (G_e) is thus

$$G_e = \frac{G}{100}(G - u) \tag{2.31}$$

where G_e is the effective concentrate grade (%), u is the fixed unit deduction (%), C is the credited percentage of the metal content (%).

The payable (accountable) metal content in one ton of concentrates is

$$M_e = \frac{C}{100}\frac{G-u}{100}2000 \tag{2.32}$$

where M_e is the payable metal content (lbs).

Smelters sometimes pay only a certain percentage of the current market price. The factor relating the price paid to the market price is called the price factor. If 100% of the market price is paid then the price factor is 1.00. The gross value of one ton of concentrates is thus

$$GV = M_e Pf \tag{2.33}$$

where f is the price factor, GV is the gross value (\$/ton of concentrate).

To obtain the basic smelter return (BSR) the charges incurred during treatment, refining and selling must be taken into account. The basic equation is that given below

$$\text{BSR} = M_e(Pf - r) - T \tag{2.34}$$

where r is the refining and selling cost (\$/pound of payable metal), T is the treatment charge (\$/ton of concentrate).

Often there are other metals/elements in the concentrate. Their presence can be advantageous in the sense that a by-product credit (Y) is received or deleterious resulting in a penalty charge (X).

The net smelter return (NSR) is expressed by

$$\text{NSR} = M_e(Pf - r) - T - X + Y \tag{2.35}$$

where X is the penalty charge due to excessive amounts of certain elements in the concentrate (\$/ton of concentrate) and Y is the credit for valuable by-products recovered from the concentrate (\$/ton of concentrate).

Letting

$$P_e = Pf - r \tag{2.36}$$

where P_e is the effective metal price (after price reductions and refining charges) the NSR expression can be simplified to

$$\text{NSR} = M_e P_e - T - X + Y \tag{2.37}$$

Long-term refining and treatment agreements generally contain cost and price escalation provisions. Escalation of refining charges (e_1) can be grouped into five distinct forms:

(1) No escalation.

(2) Predictive escalation. A specified rate of increase for each year of the contract based upon predictions of cost/price changes.

(3) Cost-indexed escalation. Escalation based upon published cost indices (e.g. wages, fuel and energy).

(4) Price based cost escalation. If the metal price increases above a certain level, the refining cost is increased. This allows the refinery to share in the gain. On the other hand if the price decreases below a certain level, the refining cost may or may not be decreased.

(5) Some combination of (2), (3) and (4).

Escalation of treatment charges (e_2) is generally either by predictive (No. 2) or cost-indexed (No. 3) means. Including escalation, the general NSR equation can be written as

$$\text{NSR} = M_e(Pf - r \pm e_1) - (T \pm e_2) - X + Y \tag{2.38}$$

Smelter contracts must cover all aspects of the sale and purchase of the concentrates from the moment that they leave the mine until final payment is made. Table 2.22 lists the elements of smelter contract and the questions to be addressed. Although the terms of an existing smelter contract are binding upon the contracting parties, supplementary agreements are usually made in respect to problems as they arise.

The net value of the concentrate to the mine is called the 'at-mine-revenue' or AMR. It is the net smelter return (NSR) minus the realization cost (R)

$$\text{AMR} = \text{NSR} - R \tag{2.39}$$

The realization cost covers such items as:

(a) Freight.
(b) Insurance.
(c) Sales agents' commissions.
(d) Representation at the smelter during weighing and sampling.

O'Hara (1980) presented the following formula for freight cost F in \$ Canadian (1979) per ton of concentrates

$$F = 0.17T_m^{0.9} + \$0.26R_m^{0.7} + \$0.80D_o \tag{2.40}$$

where F is the freight cost (\$/ton); T_m are miles by road (truck); R_m are miles by railroad; D_o are days of loading, ocean travel and unloading on a 15,000-ton freighter.

In 1989 US\$, the formula becomes

$$F = 0.26T_m^{0.9} + 0.39R_m^{0.7} + \$1.20D_o \tag{2.41}$$

The relationship between the AMR and the gross value of the metal contained in the concentrate (CV) is called the percent payment (PP)

$$\text{PP} = 100 \times \frac{\text{AMR}}{\text{CV}} \tag{2.42}$$

For base-metal concentrates the percent payment can vary from as little as 50% to more than 95%.

Smelter terms are, therefore, a significant factor in the estimation of potential revenue from any new mining venture.

To illustrate the concepts, an example using the model smelter schedule for copper concentrates (Table 2.23) will be presented. It will be assumed that the copper concentrate contains 30% copper and 30 tr oz of silver per ton. It also contains 2% lead. All other

Table 2.22. The major elements of a smelter contract and the questions addressed (Werner & Janakiraman, 1980).

1. *The parties to the contract.* Who is the seller and who is the buyer?
2. *The material and its quality.* What is the nature of the material; for example, ore or concentrate? What are its assay characteristics and on what basis (wet or dry) are any assays made and reported?
3. *The quantity and duration of the contract.* What are the amounts involved? Are the shipments sent wet or dry? What is the size of a lot? What is the duration of the contract and how are the shipments to be spread out over the period in question?
4. *What is the mode of delivery.* What is the mode of delivery (in bulk or otherwise)? In what manner is the shipment to be made and how is it to be spread over the life of the contract? Is it to be delivered by truck, rail or ship and on what basis; for example, C.I.F. or F.O.B.? Which of the parties to the contract pays the transportation charges?
5. *The price to be paid.* How much of the metal contained in the shipment is to be paid for? Is there any minimum deduction from the reported content of the concentrate? What is the nature of the prices; for example, simple or weighted average? Which particular price or prices are to be used, for example; New York or London Metal Exchange basis, and in what publications are these prices published? What is quotational period involved? How is the price derived averaged over what quotational period?

   In what current is the price to be paid? If it is an average price, what is the basis for the averaging? What forms of weight measurement are to be used: for example, troy, avoirdupois or metric? What premiums, if any, are to be offered? What are the provisions if the quotation ceases to be published or no longer reflects the full value of the metal?
6. *The smelter's charges*. What is the smelter's base charge for treatment? On what grounds might it be increased or decreased, and if so, how might this be done – in relation to the price of metal or to some other change such as a variation in the cost of labour at the smelter? What are the penalties or premiums for excess moisture and for exceeding minimum or maximum limits in content of other elements of mineral constituents?

   What are the associated refining charges, if any?
7. *The quotational period.* What is the quotational period (for example, the calendar month following the month during which the vessel reports to customs at a designated port) and how is this specified?
8. *Settlement.* Whose weights and samples are to be used and what represents a smelter lot?
9. *Mode of payment*. How much is to be paid and when (for example, 80% of the estimated value of each smelter lot shall be paid for at the latest two weeks after the arrival of the last car in each of the lot at buyers' plant)?

   Where, in what form and how are the payments to be made and what are the provisions for the making of the final payment?
10. *Freight allowances*. Which party pays duties, import taxes, etc.?
11. *Insurance*. Which party pays for insurance and to what point? For example, 'alongside wharf'.
12. *Other conditions*. What are the provisions concerning events beyond the control of the buyer or seller? When may 'force majeure' be invoked? What are the conditions under which the contract may be assigned to a third party by the buyer or the seller? What, if any, are the provisions in regard to the presence of specific minor minerals or metals in the concentrate?
13. *Payment conversion rates.* What price quotations and currency conversion rates are to be used and in what publication are they quoted? What are the provisions for the adoption of new bases if those used cease to be published?
14. *Arbitration.* Where are any problems to be arbitrated? How and under what jurisdiction?
15. *Weighing, sampling and moisture determination*. Who does this, where, and who pays for it? Does the seller have the right to be represented at the procedure at his own expense? How are the samples taken to be distributed among buyer, seller and umpire?

Table 2.22. (Continued).

16. *Assaying*. What are the procedures for assaying? What is an acceptable assay for settlement purposes and what are the splitting limits? Which party pays for umpire assaying?
17. *Definitions of terms*. What are the agreed upon definitions of terms? For example: 'Short ton equivalent to 2000 pounds avoirdupois.' Do dollars and cents refer to, for example, Canadian or United States currency?
18. *Insurance*. What insurance coverage is required and which party is to pay for it?
19. *Title*. At what point shall title pass from seller to buyer?
20. *Risk of loss*. At what point shall risk of loss pass from seller to buyer?
21. *Arbitration and jurisdiction*. What are the procedures for settling any disputes that may arise between the parties and which country's law are to govern the parties?

Table 2.23. Model 1989 smelter schedule for copper concentrates (Western Mine Engineering, 1989).

Payments	copper	Pay for 95% to 98% of the copper content at market value, minimum deduction of 1.0 unit per dry ton for copper concentrates grading below 30%. Unit deductions and treatment charges may be higher for concentrates above 30% copper.
	gold	Deduct 0.02 to 0.03 troy ounce per dry ton and pay for 90% to 95% of the remaining gold content at market value.
	silver	Deduct 1.0 troy ounce per dry ton and pay for 95% of the remaining silver content at market value.
Deductions	treatment charge	\$65 to \$100 per dry ton ore or concentrate. Concentrates sold on the spot market are commanding a treatment charge of about \$90 to \$100 per short ton.
	refining charges	\$5.00 to \$6.00 per ounce of accountable gold. \$0.30 to \$0.40 per ounce of accountable silver. \$0.075 to \$0.105 per pound of accountable copper, March, 1989 spot concentrate deals are carrying refining charges of about \$0.11 per pound, long term refining charges are usually \$0.09 to \$0.095 per pound.
	Excessive amounts of some of the following elements may result in rejection	
Deleterious element assessments	lead	Allow 1.0 units free; charge for excess at up to \$10.00 per unit. (No penalty at some plants).
	zinc	Allow 1.0 to 3.0 units free; charge for excess at up to \$10.00 per unit. (No penalty at some plants).
	arsenic	Allow 0.0 units free; charge for excess at \$10.00 per unit.
	antimony	Allow 0.0 units free; charge for excess at \$10.00 per unit.
	bismuth	Allow 0.5 units free; charge for excess at \$20.00 per unit.
	nickel	Allow 0.3 units free; charge for excess at \$10.00 per unit. (No penalty at some plants).
	moisture	Allow 10.0 units free; charge for excess at \$1.00 per unit. (No penalty at some plants).
	alumina	Allow 3.0 units free; charge for excess at \$1.00 per unit.
	other	Possible charges for fluorine, chlorine, magnesium oxide, and mercury.

deleterious elements are below the allowable limits. Assumed prices are \$1/lb for copper, \$6/tr oz for silver and \$0.50/lb for lead. The payments, deductions and assessments are:

Payments

Copper: $C = 98\%$

$f = 1.0$

$u = 1\%$

Silver: $C = 95\%$
$f = 1.0$
$u = 1.0$ tr oz

Deductions
Copper: $T = \$75$/ton
$r = \$0.10$/lb
Silver: $r = \$0.35$/tr oz of accountable silver

Assessments
Lead: 1 unit is free
additional units charged at \$10.00 per unit.

The copper provides the major source of income. Using Equation (2.34) one finds that the basic smelter return is

$$\begin{aligned}\text{BSR} &= M_e(Pf - r) - T\\ &= \frac{C}{100}\frac{G-u}{100}2000(Pf - r) - T\\ &= \frac{98}{100}\frac{30-1}{100}2000(\$1 \times 1 - 0.10) - \$75\\ &= \$436.56\text{/ton of concentrate}\end{aligned}$$

The penalty charge for excess lead is

$$\begin{aligned}X &= \text{is the (Units present} - \text{Units allowable)} \times \text{Charge/unit}\\ &= (2-1)\$10.00 = \$10.00\end{aligned}$$

The by-product credit for silver is

$$\begin{aligned}Y &= \left(\frac{C}{100}\right)(G-u)(Pf-r)\\ &= \left(\frac{95}{100}\right)(30.0-1.0)(\$6 \times 1.0 - 0.35) = \$155.66\text{/ton of concentrate}\end{aligned}$$

Hence the net smelter return is

$$\text{NSR} = \$436.56 - \$10.00 + \$155.66 = \$582.22\text{/ton of concentrate}$$

It will be assumed that the concentrates are shipped 500 miles by rail to the smelter. The transport cost (F) per ton of concentrate is

$$F = 0.39R_m^{0.7} = 0.39(500)^{0.7} = \$30.22$$

The at-mine-revenue becomes

$$\text{AMR} = \$582.22 - \$30.22 = \$552$$

Table 2.24. Model 2011 smelter schedule for copper concentrates (InfoMine USA, 2012).

Payments	copper	Pay for 95% to 98% of the copper content at market value. Minimum deduction of unit (1 % of a ton) per dry tonne for copper concentrates grading below 30%. Unit deductions and treatment charges may be higher for concentrates above 40% copper.
	gold	Deduct 0.03 to 0.05 troy ounces per dry tonne and pay for 90% to 95% of the remaining gold content at market value.
	silver	Deduct 1.0 troy ounce per dry tonne and pay for 95% of the remaining silver content at market value.
Deductions	treatment/ refining charges	Treatment charges in annual contracts for 2011 varied between $56.00 to $90.00 per tonne concentrate with refining charges of $0.056 to 0.090 per pound copper.
	price participation	Prior to mid-2006, contracts often included price participation clauses. Most contracts settled after late 2006 either eliminated price participation clauses or have capped the price participation to $0.04–$0.10 per pound of copper at a basis of $1.20 per pound copper or above. In 2011 none of the contracts reported a price participation clause.
	complex concentrates	Treatment charges for "complex" concentrates are typically $15 to $25 per tonne higher than charges for clean concentrates. In addition, copper concentrates grading over 40% may be charged up to $10 per tonne more for treatment. This extra charge varies depending on the tightness of the concentrate market. Currently, no smelters are imposing this charge on high grade concentrates.
	refining charges	Range from $6.00 to $8.00 per ounce of payable gold and $0.50 to $0.75 per ounce of payable silver.
Penalties	deleterious element assessments	Copper concentrates containing excessive amounts of the following elements may be penalized or rejected: lead, zinc, arsenic, antimony, bismuth, nickel, alumina, fluorine, chlorine, magnesium oxide, mercury. Lead, zinc, and arsenic levels above 2% each often result in rejection. For fluxing ores, iron must be less than 3% and the alumina at low levels so that the available silica fluxing content remains high.
	moisture	High moisture content may also be penalized due to material handling difficulties.
Notes:	Spot treatment charges since 2008 have fluctuated widely from treatment charges between $5 to $120 per tonne and $0.005 to $1.20 per pound refining. Mid-year 2011 spot contracts were reported lower at $42 to $44 per tonne.	

The gross value of the metal contained in one ton of concentrates is

$$\begin{aligned} &\qquad\quad \text{(copper)} \qquad \text{(silver)} \qquad \text{(lead)} \\ \text{GV} &= 2000\frac{30}{100}\$1 + 30 \times \$6 + 2000\frac{2}{100}\$0.50 \\ &= \$600 + \$180 + \$20 = \$800 \end{aligned}$$

The percent payment is

$$\text{PP} = 100\frac{552}{800} = 69\%$$

Table 2.24 is an example of a current model smelter schedule for copper concentrates (Info Mine USA, 2012).

2.3.6 *Price-cost relationships*

Using the net smelter return formula it is possible to calculate the revenue per ton of concentrate. The revenue to the mine every year depends upon the tons of concentrate produced and the price. The costs to the mine on the other hand depend upon the amount of material mined and processed.

If one assumes that K tons of concentrate are produced every year, then the yearly revenue depends directly on the price received for the product.

A large capital investment is required at the start of the mining. As will be discussed later this must be recovered from the yearly profits. If the yearly profits are not as expected, then the payments cannot be made. Therefore it is important that the price projections or price forecasts be made covering at least the depreciation period (that period in which the investment is being recovered).

By examining the simplified net smelter return formula,

$$\text{NSR} = \frac{C}{100} 20(G - u)\frac{P - r}{100} - T \tag{2.43}$$

where P is the price, r is the refining and selling cost, T is the treatment cost, G is the percent of metal, u is the fixed unit deduction (%), one can see that the revenue is equal to

$$k(P - r) - T - F$$

where k is a constant.

Assume for definiteness that

$$\begin{aligned} C &= 100\% \\ r &= 12¢ \\ T &= \$60 \\ u &= 1.3\% \\ G &= 28.5\% \\ P &= 90¢ \end{aligned}$$

Thus

$$\begin{aligned} \text{NSR} &= 1 \times 20(28.5 - 1.3)\left(\frac{P - r}{100}\right) - T = \frac{544}{100}(P - r) - T \\ &= 5.44(90 - 12) - 60 = \$364.32 \end{aligned}$$

Assume that next year both the price and the costs increase by 5% but that C, G and u remain constant

$$\begin{aligned} P &= 90 \times 1.05 = 94.5¢ \\ r &= 12 \times 1.05 = 12.6¢ \\ T &= 60 \times 1.05 = \$63 \end{aligned}$$

Hence

$$\text{NSR} = 5.44 \times 81.9 - 63 = \$382.54$$

The net present value would be

$$\text{NPV} = \frac{382.54}{1.05} = \$364.32$$

If the price however *decreased* by 5% and the costs *increased* by 5%, then

$$NSR = 5.44(85.5 - 12.6) - 63 = \$333.58$$

If the price increased by 10% and the costs increased by 5%, then

$$NSR = 5.44(99 - 12.6) - 63 = \$407.02$$

The conclusion is that the net smelter return depends upon the relative changes of the price and the costs. If the prices and costs *escalate* at the same rate then the expected return remains intact. If however, there is a difference then the return may be significantly more or significantly less than expected. Obviously the problem area is if the costs are significantly more than expected or the price significantly less.

2.4 ESTIMATING COSTS

2.4.1 *Types of costs*

There are a number of different types of costs which are incurred in a mining operation (Pfleider & Weaton, 1968). There are also many ways in which they can be reported.

Three cost categories might be:

- Capital cost;
- Operating cost;
- General and administrative cost (G&A).

The capital cost in this case might refer to the investment required for the mine and mill plant. The operating costs would reflect drilling, blasting, etc. costs incurred on a per ton basis. The general and administrative cost might be a yearly charge. The G&A cost could include one or more of the following:

- Area supervision;
- Mine supervision;
- Employee benefits;
- Overtime premium;
- Mine office expense;
- Head office expense;
- Mine surveying;
- Pumping;
- Development drilling;
- Payroll taxes;
- State and local taxes;
- Insurance;
- Assaying;
- Mine plant depreciation.

The capital and G&A costs could be translated into a cost per ton basis just as the operating costs. The cost categories might then become:

- Ownership cost;
- Production cost;
- General and administrative costs.

The operating cost can be reported by the different unit operations:

- Drilling;
- Blasting;

– Loading;
– Hauling;
– Other.

The 'other category' could be broken down to include dozing, grading, road maintenance, dump maintenance, pumping, etc. Some mines include maintenance costs together with the operating costs. Others might include it under G&A. Material cost can be further broken down into components. For blasting this might mean:

– Explosive;
– Caps;
– Primers;
– Downlines.

The operating cost could just as easily be broken down for example into the categories:

– Labor;
– Materials, expenses and power (MEP);
– Other.

At a given operation, the labor expense may include only the direct labor (driller, and driller helper, for example). At another the indirect labor (supervision, repair, etc.) could be included as well.

There are certain costs which are regarded as 'fixed', or independent of the production level. Other costs are 'variable', depending directly on production level. Still other costs are somewhere in between.

Costs can be charged against the ore, against the waste, or against both.

For equipment the ownership cost is often broken down into depreciation and an average annual investment cost. The average annual investment cost may include for example taxes, insurance and interest (the cost of money).

The bottom line is that when discussing, calculating or presenting costs one must be very careful to define what is meant and included (or not included). This section attempts to present a number of ways in which costs of various types might be estimated.

2.4.2 *Costs from actual operations*

Sometimes it is possible to obtain actual costs from 'similar' operations. However great care must be exercised in using such costs since accounting practices vary widely. For many years the *Canadian Mining Journal* has published its 'Reference Manual and Buyers Guide'. A great deal of useful information is contained regarding both mine and mill. Table 2.25 contains information from the 1986 edition for the Similkameen Mine.

Similar information for eleven open pit operations of different types and sizes as extracted from the 1993 edition of the *Reference Manual* (Southam Mining Group, 1992), is included in Table 2.26. Since Similco Mines Ltd. is the successor of Similkameen Property described in Table 2.25, one can examine changes in the operation and in the costs with time. Information as complete as this is seldom publicly available.

The 2004 edition of the CMJ Mining Source book (CMJ, 2004) has included the detailed cost information for the Huckleberry Mine given in Table 2.27. Operating and cost data for some Canadian open pit mines published in the 2010 Mining Sourcebook (CMJ, 2010) are presented in Table 2.28. The authors understand that the 2010 Mining Sourcebook is the last in a long series. This is unfortunate since it has been a very valuable resource. The authors are grateful to the Canadian Mining Journal for permission to include this valuable set of information.

Table 2.25. Cost information (Canadian \$) for the Simikameen Mine, Newmont Mining Company Mines Limited (*CMI,* 1986).

1. *Location*: Princeton, British Columbia, Canada

2. *Pit geometry*
   (a) Pit size at surface: 3200′ × 1000′
   (b) Pit depth: 330′
   (c) Bench height: 40′
   (d) Bench face angle: 70°
   (e) Berm width: 40′
   (f) Road grade: 10%

3. *Capacity*
   (a) Mining: ore = 22,000 tpd
   Waste = 25,500 tpd
   ore and waste = 5,111,500 tpy (actual)
   (b) Milling: capacity = 20,000 tpd
   ore = 2,945,000 tpy (actual)
   mill heads = 0.43% Cu
   minerals recovered = Cu, Au, Ag
   recovery = 85.5%
   concentrate grade = 30% Cu
   principal processes: primary SAG, secondary cone crusher, ball milling, Cu flotation

4. *Pit equipment*
   (a) Ore and waste loading = 4 P & H 1900A shovels (10 yd^3)
   (b) Ore and waste haulage = 15 Lectra Haul M100 trucks
   (c) Other = 4 Cat D8K dozers
   1 Cat 14E grader
   3 Cat 824 r.t.d.
   1 Dart 600C f.e.l. (15 yd^3)
   2 Komatsu 705A graders

5. *Blasting in ore and waste*
   (a) Explosives 85% bulk Anfo
   15% packaged slurry
   (b) Powder factor (lb/ton) = 0.46
   (c) Loading factor (lb/yd^3) = 0.70

6. *Drilling in ore and waste*
   (a) Drills = 3 Bucyrus-Erie 60R
   (b) Hole diameter = $9^7/_8''$
   (c) Pattern (burden × spacing) = 18′ × 24′
   (d) Feet drilled/shift = 490′
   (e) Tons/foot = 26
   (f) Bit life = 6,000 ft
   (g) Rod life = 320,000 ft

7. *Power requirements*
   (a) Total (all motors) = 53,600 HP
   (b) Peak demand = 35,776 kVA
   (c) Annual mill demand = 255,282,172 kWh
   (d) Total annual demand = 266,573,172 kWh

(Continued)

Table 2.25. (Continued).

8. *Personnel*	
(a) Open pit	
Staff personnel	20
Equipment operators, labor	78
Mechanical, maintenance crew	44
Total open pit workforce	142
(b) Mineral processing plant	
Staff personnel	25
Operators (all classifications)	37
Repair and maintenance crew	45
Total mill workforce	107
(c) Surface plant	
Staff personnel	1
Mechanical and maintenance crew	13
Total surface plant workforce	14
(d) Other	
Office and clerical personnel	22
Warehouse	14
Total other	36
Total employees	299
9. *Mining costs for ore and waste ($/ton)*	
(a) Dozing and grading	0.05
(b) Drilling	0.07
(c) Blasting	0.13
(d) Loading	0.14
(e) Hauling	0.21
(f) Crushing	0.11
(g) Conveying	0.06
(h) Pumping	0.01
(i) Maintenance	0.10
(j) Supervision	0.02
(k) Other	0.02
Total	$0.92
10. *Milling costs ($/ton)*	
(a) Crushing	0.096
(b) Grinding	1.844
(c) Flotation	0.244
(d) Drying	0.075
(e) Assaying	0.015
(f) Conveying	0.091
(g) Power	0.921
(h) Tailings disposal	0.137
(i) Labor	0.437
(j) Supervision	0.094
Total	$3.954

Table 2.26. Operating and cost data from some Canadian open pit mines (Southam Mining Group, 1993).

1. Open pit mines included

Company, mine	Location	Minerals recovered	Pit size at surface Depth	Ore mined Waste removed	Bench height Slope	Berm road Grade
BHP Minerals Canada Ltd., Island Copper	Port Hardy, BC	Cu, Mo	7500′ × 4000′ 1300′	57,500 tpd ore 77,500 tpd waste	40′ 45°	25′ 10%
Equity Silver Mines Ltd.	Houston, BC	Ag, Au, Cu	1100 m × 500 m 240 m	10,000 mtpd ore 8000 mtpd waste	5 m 52°	8 m 12%
Hudson Bay Mining & Smelting Co. Ltd., Chisel Lake	Snow Lake, Man	Zn, Cu, Pb, Ag, Au	805′ × 200′ 200′	1315 tpd ore 656 tpd waste	20′ 90°	11′6″ 9%
Iron Ore Co. of Canada, Carol	Labrador City, Nfld	Fe ore	Avg. size, 5 pits: 1500 m × 500 m 90 m	106,000 mtpd ore 18,500 m^3 waste	13.7 m 40° and 60°	15 m 8%
Mines Selbaie, A1 zone	Joutel, Que	Cu, Zn, Ag, Au	1090 m × 875 m 80 m	6000 mtpd ore 19,000 mtpd waste	8–10 m 45–54°	8–10 m 9%
Placer Dome Inc., Dome	South Porcupine, Ont	Au, Ag	100′ × 500′ 130′	350,000 tpy ore 700,000 tpy waste	40°	20′ 10%
Similco Mines Ltd. No. 1	Princeton, BC	Cu, Au, Ag	1500′ × 1200′ 800′	Total 3 pits: 22,500 tpd ore 22,500 tpd waste	40′ 55°	40′ 8%
Similco Mines Ltd. No. 3	Princeton, BC	Cu, Au, Ag	4000′ × 2500′ 1200′	Total 3 pits: 22,500 tpd ore 22,500 tpd waste	40′ 55°	40′ 8%
Similco Mines Ltd., Virginia	Princeton, BC	Cu, Au, Ag	1350′ × 1200′ 440′	Total 3 pits: 22,500 tpd ore 22,500 tpd waste	40′ 55°	40′ 8%
Stratmin Graphite Inc.	Lac-des-Iles, Que	Graphite	650 m × 350 m 25 m	1000 mtpd ore 3500 mtpd waste	6 m 50°	4 m 10%
Williams Operating Corp., C zone	Hemlo, Ont	Rockfill and some Au	450 m × 350 m 36 m	330 mtpd ore 4500 mtpd waste	10 m 70°	8 m 10%

2. Deposit description

Company, mine	Proven and probable reserves	In situ grade	Ore type	Dimensions ($L \times W \times D$)	Host rock
BHP, Island Copper	95 million tonnes	0.355% Cu 0.017% Mo	Porphyry Cu	$5000' \times 2000' \times 1600'$	Andesite
Equity Silver Mines	6 million tonnes	72 g/t Ag 0.22% Cu 0.83 g/t Au	Disseminated and brecciated Sulphides	2.5 km × 500 m × 250 m	Pyroclastic
Hudson Bay, Chisel Lake	439,384 tonnes	0.056 g/t Au 1.23% g/t Ag 0.29% Cu 9.2% Zn 1.09% Pb	Mainly massive sulphides	$750' \times 100' \times 150'$	Altered felsic volcanics
Iron Ore Co., Carol	3 billion tonnes	39% Fe 19% magnetite	Specular hematite and magnetite in sedimentary iron formation	8 km × 250 m × 300 m	Quartzites and quartz-carbonate sandstones
Mines Selbaie	21.2 million tonnes	0.77% Cu 2.19% Zn 28.15 g/t Ag 0.47 g/t Au	Cu, Zn and pyrite lenses	1090 m × 875 m × 176 m	Welded acitic tuff, rhyodacitic breccia, massive pyrite and pyrite breccia
Placer Dome, Dome	9.3 million tonnes	0.143 Au	Hydrothermal quartz vein	$200' \times 1800'$ open at depth	Volcanic porphyry, conglomerate and ultramatic
Similco Mines	Pvn: 24.9 million tonnes Prb: 121.9 million tonnes stockpile: 13 million tonnes	0.45% Cu 0.40% Cu 0.25% Cu	Bornite, pyrite and chalcopyrite		Ore in adesitic volcanics with barren diorite gabbro intrusive
Stratmin Graphite	4 million tonnes	7.4% Cg	Graphite flakes	2700 m × 1700 m × 350 m	Marble and quartzite

(Continued)

Table 2.26. (Continued).

3. Pit equipment

Company, mine	Ore or waste	Shovels	Loaders	Trucks	Other
BHP, Island Copper	Ore and waste	3 P&H 2100BL, 15 yd^3 2 Marion 191M, 15 yd^3		16 Euclid R170 3 Unit Rig Mark 36, 170-t 2 Euclid R190	4 Cat D10N dozers 1 Cat D9L dozer 3 Cat 824 dozers 5 Cat 16G graders 1 Cat 988 loader 1 Hitachi UH20 backhoe
Equity Silver Mines	Ore and waste	3 P&H 1600, 7 yd^3	1 Cat 992C, 10 m^3	2 Wabco, 80-t 5 Cat 777B, 80-t 3 Cat 773, 45-t	2 Cat D8L dozers 2 Cat 14G graders 2 Cat 824 dozers 1 Cat D6K dozer 4 Cat 16G graders 2 Cat 824C dozers 2 Cat 235 backhoes
Hudson Bay, Chisel Lake	Ore and waste	1 Komatsu PC640, 4.6 yd^3	1 Cat 988B, 7 yd^3	3 Euclid, 35-t	1 Cat D8N dozer 1 Champion 780A grader
Iron Ore Co., Carol	Ore and waste	5 B-E 295bII, 14 m^3 2 P&H 2300, 14 m^3 3 Kubota 280, 9 m^3	1 Letourneau L1100, 11.5 m^3 1 Cat 992C, 7.5 m^3 2 Cat 938B, 6 m^3	22 Titan T2200, 180-t 8 Terex 33-15, 154-t	5 Cat 16G graders 4 Komatsu D375A dozers 2 Cat D10N dozers 6 Cat 834B dozers
Mines Selbaie, A1 zone	Ore Waste	 1 Hitachi VH801, 11 yd^3	1 Cat 992C, 11 yd^3 1 Cat 992C, 11 yd^3	3 Cat 777, 77-t 5 Cat 777, 77-t	3 Cat D8L dozers 2 Cat 16G graders 1 Cat 824 dozer 2 water trucks 1 dewatering truck 1 Anfo truck 2 Cat 235 shovels
Similco Mines	Ore and waste	4 P&H 1900A 1 P&H 1900A1	1 Cat 992 1 Terex 7271, 7 yd^3	4 Cat 785, 120-t 9 Unit Rig, 120-t	2 Cat D8 dozers 2 Cat 16G graders 2 Cat 824 dozers 1 Cat D9N dozer
Stratmin Graphite	Ore and waste	1 Cat 235C	2 Cat 980C, 3.8 m^3 1 Cat 988B, 5.5 m^3	4 Cat 769C, 35-t 2 Cat D25C, 25-t	1 Cat 14G grader
Williams Operating Corp.	Ore and waste	1 P&H 1900A1	1 Cat 992	4 Cat 777	1 Cat 14G grader 1 Cat D7 dozer 1 Cat D9N dozer

4. Drilling equipment and practices

Company, mine	Ore or waste	Drills	Hole diameter Pattern	Feet per shift	Tons per foot	Feet per bit	Feet per shank	Feet per rod
BHP, Island Copper	Ore and waste	2 Bucyrus-Erie 60R2 2 Bucyrus-Erie 60RIII	9 7/8″ 25′ × 25′	828	44	12,600	654,000	292,900
Equity Silver Mines	Ore and waste	3 Bucyrus-Erie 40R	230 mm 5 m × 5 m	625	22	37,400	215,225	269,030
Hudson Bay, Chisel Lake	Ore	1 GD SCH3500BU 1 with HPR 1H hammer	4 1/2″ 7′ × 8′	443	7	69	836	5297
	Waste	1 Copco ROC 812HCSO 2 with 1238ME hammer	4 1/2″ 8′ × 10′	280	5.8	423	871	7405
Iron Ore Co., Carol	Ore and waste	4 Bucyrus-Erie 49RH 3 Gardner Denver 120	381 mm Ore: 8 m × 8 m Waste: 8.5 m × 8.5 m	Ore: 260 Waste: 22	Ore: 65.5 Waste: 55.5	1660		
Mines Selbaire, A1 zone	Ore and waste	2 Driltech D40KII 1 Driltech D60KII 1 Copco ROC 712H (secd)	200 mm Ore: 5.1 m × 5.8 m Waste: var	435	Ore: 70 Waste: 77	1090	14,925	13,355
Placer Dome, Dome	Ore		4″ 10′ × 10′		8			
Similco Mines	Ore and waste	3 Bucyrus-Erie 60R	9 7/8″	540	30	4500		200,000
Stratmin Graphite	Ore and waste	2 Atlas Copco 812HC5001	5″ 4 m × 4 m	340	13.6	13,000	3000	6000
Williams Operating Corp.	Waste	1 Gardner Denver 100	10 5/8″ 5.5 m × 6.5 m	328	23	1804		

(Continued)

Table 2.26. (Continued).

5. Blasting practices

Company, mine	Ore			Waste		
	Explosives	Loading factor	Powder factor	Explosives	Loading factor	Powder factor
BHP, Island Copper	100% emulsion	0.86 lb/yd^3	0.38 lb/ton	Magnafrac	0.86 lb/yd^3	0.38 lb/ton
Equity Silver Mines	60% Anfo 40% slurry	0.53 kg/m^3	0.18 kg/t	60% Anfo 40% slurry		
Hudson Bay, Chisel Lake	Dry holes: Amex Wet holes: Magnafrac	2.4 lb/yd^3	0.53 lb/ton	Dry holes: Amex Wet holes: Magnafrac	1.66 lb/yd^3	0.63 lb/ton
Iron Ore Co., Carol	Magnafrac B9000	1.71 kg/m^3	0.44 kg/t	Magnafrac B9000	1.65 kg/m^3	0.43 kg/t
Mines Selbaie, A1 zone	67% Anfo (column charge) 33% slurry (bottom charge)	0.80–0.86 kg/m^3	0.23–0.32 kg/t	67% Anfo (column charge) 33% slurry (bottom charge)	0.75–0.80 kg/m^3	0.26–0.28 kg/t
Placer Dome, Dome	90% Anfo 10 slurry	1.125 lb/yd^3	0.5 lb/ton	Amex & Detagel	1.125 lb/yd^3	0.5 lb/ton
Similco Mines	95% Fragmax 5% emulsion		0.59 lb/ton	Fragmax NBL 1019		0.59 lb/ton
Stratmin Graphite	90% Anfo 10% slurry	1.35 lb/yd^3	0.06 lb/ton	90% Anfo 10% slurry	1.12 lb/yd^3	0.5 lb/ton
Williams Operating Corp.	95% Anfo 5% packaged			95% Anfo 5% packaged	0.40 kg/m^3	

6. Primary crushing

Company, mine	Crusher site	Transport and distance to crusher	Crusher	Crusher setting	Throughput capacity per hour	Transport and distance to mill
BHP, Island Copper	In pit	170-t trucks, 2000′	A-C gyratory 54″ × 72″	6″	4500 tph	54″ conveyor, 4100′ 54″ conveyor, 800′
	At mill	170-t trucks, 11,200′	A-C gyratory 54″ × 72″	6″	4000 tph	
Equity Silver Mines	At mill	80-t trucks, 1200 m	A-C gyratory 1.1 m × 1.65 m	175 mm	1500 mtph	1.2 m conveyor
Hudson Bay, Chisel Lake	Adjacent to pit	35-t trucks, 2000′	Kue Ken jaw 36″ × 43″	6″	300 tph	Bottom dump rock wagons, 9 miles
Mines Selbaie, A1 zone	Between pit and mill	77-t trucks, 1050 m	A-C gyratory 42″ × 65″	6″	1200 mtph	5 conveyors, 375 m
Placer Dome, Dome	At pit edge	Cat 988 loader, 200′	Piedmont portable jaw 48″ × 60″	6″	250 tph	30″ conveyor, 1000′
Similco Mines		Trucks, 3500′ to 6600′	A-C gyratory 54″ × 72″	8″	120 tph	40″ conveyor, 6600′
Stratmin Graphite	At mill	35-t trucks, 7000 m	915 mm × 1220 mm	150 mm	150 mtph	915 mm conveyor, 150 m
Williams Operating Corp.	Outside pit	4 Cat 777 trucks	A-C gyratory 42″ × 65″	175 mm	100 mtph	1066 mm conveyor (stockpile), 450 m

(Continued)

Table 2.26. (Continued).

7. Mineral processing

Company, mill	Location	Daily throughput	Products	Mill heads	Recovery	Concentrate grade	Principal processes
BHP Minerals Canada Ltd., Island Copper	Port Hardy, BC	57,500 tpd	Cu conc Mo conc	0.39% Cu 0.016% Mo	84% Cu 65% Mo	24.0% Cu 45% Mo	Primary SAG, secondary ball milling, flotation, filtering and drying
Equity Silver Mines Ltd.	Houston, BC	9000 mtpd	Cu-Ag conc Ag-Au dore	0.22% Cu 86 g/t Ag 0.88 g/t Au	69% Cu 62% Ag 59% Au	11.1% Cu 3927 g/t Ag 21.9 g/t Au	Rod and ball milling, flotation, filtering, drying and CIL circuit
Hudson Bay Mining and Smelting Co. Ltd., Flin Flon	Flin Flon, Man	7000 tpd	Cu conc Zn conc	1.8% Cu 6.3% Zn 0.06 g/t Au	94.3% Cu 92.3% Zn 83% Au	21.0% Cu 51.5% Zn	Rod and ball milling, roughing and cleaning for both Cu and Zn conc., thickening and filtering
Mines Selbaie	Joutel, Que	A1 ore: 5800 mtpd	Cu conc Zn conc	0.67% Cu 2.28% Zn	87% Cu 82% Zn	24% Cu 56% Zn	SAG and ball milling, differential flotation and pressure filtering
		A2 & B ore: 1650 mtpd	Cu conc Zn conc	2.93% Cu 0.77% Zn	96% Cu 40% Zn	27% Cu 55% Zn	Rod and ball milling, differential flotation and pressure filtering
Placer Dome Inc., Dome	south Porcupine, Ont	4000 tpd	Au	0.125 g/t Au	95.5%		Crushing, rod and ball milling, jig concentrating, NaCN leaching and CIP
Similco Mines Ltd.	Princeton, BC	25,000 tpd	Cu conc	0.50% Cu	80%	28.5% Cu	SAG, ball milling, Cu flotation, thickening, filtering and drying
Stratmin Graphite Inc.	Lac-des-Iles, Que	1000 mtpd	Natural flake graphite	6.2% Cg	95%	96% Cg	Mechanical processes
Williams Operating Corp.	Hemlo, Ont	6000 mtpd	Au bullion	7.77 g/t	95%	873.7 fine Au	SAG, leaching, CIP, carbon stripping, E/W and refining

8. Personnel numbers and distribution

Company, operation	Underground					Open pit				Mineral processing				Surface plant			Other		
	Staff personnel	Stopping, productions miners	Haulage, hoisting crew	Development, maintenance crew	Total underground workforce	Staff personnel	Equipment operators, labor	Mechanical and maintenance crew	Total open pit workforce	Staff personnel	Operators (all classifications)	Repair and maintenance crew	Total mill workforce	Staff personnel	Mechanical and maintenance crew	Total surface plant workforce	Office and clerical personnel	Others	Total employees
BHP, Island Copper						47	155	135	337	41	60	83	184				34	17[1]	572
Equity Silver Mines Ltd.						12	37		49	15	33		48	8	42	50	12		159
Hudson Bay, Chisel Lake						2	11	2	15										
Iron Ore Co., Carol						80	247	235	562										
Mines Selbaie	12	31	46	43	132	6	58	29	93	15	57	21	93	47	99	146	42	32	538
Placer Dome Inc., Dome	18	54	63	41	176				Note 2	10	17		27	16	70	86	53		342
Similco Mines Ltd.						22	75	42	139	25	43	49	117	1	12	13	25		294
Stratmin Graphite						5	22	6	33	4	21	10	35	3	5	8	12		88
Williams Operating Corp.	25	120	125	50	320	2	13	7	18	19	19	10	48	24	130	124	80		619

[1]Warehouse and safety personnel. [2]Employees of contractor.

(Continued)

Table 2.26. (Continued).

9. Mine operating costs (Canadian $/ton)

Company, mine	Dozing and grading	Drilling	Blasting	Loading	Haulage	Crushing	Conveying	Pumping	Maintenance	Labour	Power	Other	Total
BHP, Island Copper		0.040	0.088	0.345		0.177[1]		0.020	0.044			0.240[2]	0.993
Equity Silver Mines*		0.161	0.161	0.230	0.440			0.033			0.050	0.116	1.189
Hudson Bay, Chisel Lake													
waste		1.640	0.480		0.870[3]	0.050		0.125	1.360		0.840	0.550[4]	5.915
ore		0.950[5]			0.820[3]	0.510		0.125	1.360		0.840	0.550[4]	5.155
Iron Ore Co., Carol													1.887
Mines Selbaie*													
A zone ore	0.137	0.270	0.285	0.090	0.232	0.070			0.955	0.052		0.668[6]	2.759
overburden	0.137			0.090	0.232				0.488			0.097	1.044
waste	0.137	0.270	0.285	0.090	0.232				0.615			0.097	1.726
Placer Dome, Dome													
ore													2.900
waste													3.100
Similco Mines	0.077	0.063	0.118	0.144	0.328	0.090	0.090			0.082		0.015	1.007
Stratmin Graphite*	0.163	0.254	0.308	0.336	0.336			0.082				0.390	1.869
Williams Operating Corp.*	0.073	0.327	0.218	0.308	0.354	0.744					0.136	0.227	2.387

*Amounts reported in metric units have been converted to imperial equivalents. [1]Includes conveying. [2]Includes reclamation $0.055, mine shipping expense $0.096, and other $0.089. [3]Includes loading. [4]Supervision. [5]Includes blasting. [6]Includes engineering and geology.