SUSTAINABLE MANAGEMENT OF MINING OPERATIONS

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Preface

Mining is among humankind's oldest industries, having been essential to improving our quality of life since the Stone Age. Today, mineral resources are at the core of many human activities, from housing, household goods, industrial equipment, and energy to high technology and space exploration. Our quality of life will continue to depend on the availability and extraction of minerals for the foreseeable future.

The minerals industry has been entrusted with the responsibility of meeting this need for minerals without compromising the interests of future generations. Today, mining companies' charters include acting with environmental and social—as well as commercial—responsibility. This presents unique challenges for both today's mining engineers and tomorrow's.

The title, *Sustainable Management of Mining Operations*, refers to the vision and process that effectively integrate economic, environmental, and social considerations aimed at creating sustainable mine operations in the 21st century and beyond.

The book focuses on sustainable management at the operations level and how to integrate sustainability into the organization at all levels. It deals with three management functions that are key for sustainable management: corporate strategy, human resources management, and operations management. We have sought an international perspective from a global array of authors to address these functions.

The book represents a team effort from chapter editors, authors, and mining company representatives and others contributed information, and the guidance of our Project Advisory Board. Any plaudits this work may earn belong to those who have shared their time and knowledge so generously. Special thanks go to my friend and colleague, Dr. Thomas Davis, professor of geophysics at Colorado School of Mines, whose leadership and support made the project possible.

The project has been cohosted by Colorado School of Mines and Universidad Politécnica de Madrid (Escuela de Minas de Madrid, or Madrid School of Mines), my two "alma mater" institutions, which have served the minerals industry for more 150 years.

J.A. Botin

Contents

CHAPTER ONE

Introduction

J. A. Botin

The use of mineral resources has been fundamental to human activity: from housing to household goods, from industrial equipment to energy, and from high technology to space exploration, mining has provided the basics of life to the human race. The mining industry produces energy, metals, and minerals that are essential to economic prosperity and a better quality of life. As important as these benefits are, mining activity produces social and environmental impacts on communities, and requires a more responsible mining practice—it requires *sustainable mine management.*

Today, mining faces unparalleled challenges brought by globalization and increased social and environmental awareness. Many mining companies have acknowledged the challenge and have stated their commitment to the values of sustainability. However, the public perception of the environmental and social performance of the minerals industry remains poor.

Furthermore, significant driving forces are acting on the market, whereby corporate performance in sustainable development issues is becoming increasingly related to measurable economic returns and increased value to shareholders. A better reputation is becoming a competitive advantage through improved control of business risks and increased business opportunities. In this context, mining managers are expected not only to comply with but also to lead in the development of increasingly demanding corporate policies and regulations for environmental control, safety, and social responsibility.

This book characterizes the concept of sustainable management as the management approach that integrates sustainability throughout the organization of the company. Each section of the book focuses on sustainable management from a different perspective, management level, or stage of the mine life cycle.

MINING AND SUSTAINABLE DEVELOPMENT

A discussion of the conceptual meaning of sustainable development and the multiple views and emphasis found in the literature is beyond the scope of this book. A brief description of this concept and what it means in the context of mining is introduced in this section and briefly discussed in Chapter 3. For more detailed analysis on the different meanings of sustainable development, the reader is referred to "The Meaning of Sustainable Development" by Michael Redclift,[1] "Capital Theory and the Measurement of Sustainable Development"[2] by Pearce and Atkinson, and *Sustainable Mineral Resource Management and Indicators: Case Study Slovenia*[3] by Shields and Solar.

An early reference to sustainable development was made in 1980 in a report on renewable resource management by the International Union for Conservation of Nature, where sustainable development was defined as "a strategy framework by which economic development can progress, whilst simultaneously enhancing human development and ensuring the long-term viability of those natural systems on which that development depends."[4] Later, in 1987, the World

Commission on Environment and Development (the Brundtland Commission) issued a report in which sustainable development means "to meet the needs of the present generation without undermining the capacity of future generations to meet their needs."[5]

In most definitions, sustainable development integrates three separate strands of thought about the management of human activities. The economic dimension focuses on the economic needs of society, such as adequate livelihood, productive assets, and systems. The social dimension refers to social and cultural needs, for example, health, education, shelter, cultural institutions, and norms. The third dimension deals with the maintenance of ecosystems and the natural resource base.

In the context of mining, one of the more notable references to sustainable development was made in 2002 by the United Nations Environment Programme in a publication titled *Berlin II Guidelines for Mining and Sustainable Development. Berlin II* stated: "If sustainable development is defined as the integration of social, economic and environmental considerations, then a mining project that is developed, operated and closed in an environmentally and socially acceptable manner could be seen as contributing to sustainable development. Critical to this goal is ensuring that benefits of the project are employed to develop the region in a way that will survive long after the mine is closed."[6]

More recently, mining associations, nongovernmental organizations, and minerals industry groups have attempted to create sustainable development standards or frameworks outlining performance requirements on environmental, human rights, and social issues associated with the minerals industry. Some of these *frameworks* are described in Chapters 3 and 4 and are referred to throughout this book.

SUSTAINABLE MANAGEMENT: THE CHALLENGE

The concept of sustainable management of mining operations or sustainable mine management, as characterized in this book, refers to a management approach that efficiently integrates economic, environmental, and social issues into the mining operations; aims to create long-term benefits to all stakeholders; and tries to secure the support, cooperation, and trust of the local community in which a mine operates (that is, a continuing social license to operate). Among many other issues, sustainable mine management deals with strategy, responsible exploration and project feasibility decisions, and managing for operational efficiency, improved risk management, enhanced stakeholder relationships, and corporate reputation. Overall, it deals with seeking long-term competitive advantages through responsible management of environmental and social issues.

An essential requirement for sustainable mine management is the corporate commitment to the values of sustainability, but this is not sufficient. Also essential is the development of a business culture where sustainability is a high professional and business value. Furthermore, an organizational structure with specific roles and integration mechanisms and adequate management systems is also required.

Regarding business culture, a well-established business code is a necessary but insufficient condition. Sustainable management relies on individual ethical conduct and trust to foster full participation of stakeholders and encourage commitment among them. It allows decision making at appropriate levels in the organization and encourages individual risk-taking for continuous improvement. Without trust, earning and maintaining social license is not achievable.

Therefore, sustainable mine management is a major challenge. This is evidenced by the strong management focus on the "Sustainable Development Framework" published by multiparticipant initiatives offering policy guidance on sustainable development to the minerals

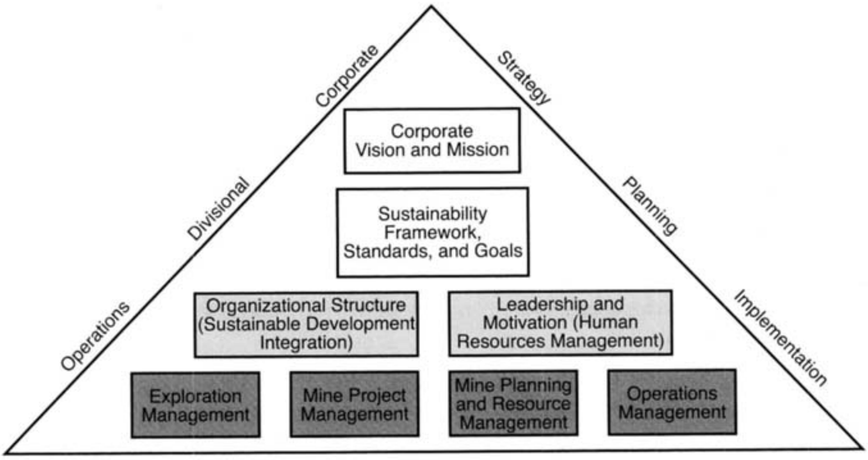

FIGURE 1.1 Sustainable management of mining operations—an integrated model

industry. For example, the International Council on Mining and Metals' principles of sustainable development[7] make references to culture, structural integration, strategy implementation, continual improvement, and other challenging management tasks.

The author's concept of sustainable mine management is that of a management approach that integrates a business culture, strong leadership, and an organizational structure that strives for long-term economics benefits through sustainability. This concept is represented in the graphical model in Figure 1.1. In this model, sustainability must be vertically integrated at three organizational levels (corporate, divisional, and operations) and three functional levels (strategy, planning, and implementation). In addition, the implementation of sustainability goals at the different stages of the mine life cycle (exploration, project, mine planning, and production) requires an organizational structure with adequate integration mechanisms[8] and a business culture in which sustainability is a high professional value.

THE BUSINESS CASE ON SUSTAINABILITY

There is ample evidence of the link between environmental and social performance and company financial performance.[9] However, the question of whether there is a business case for sustainability performance remains open to debate. Ultimately, any business case for sustainability requires that sustainable management practice leads to improved profitability and added value to owners; in this regard, the potential benefits of sustainability need to be quantified.

The quantitative evaluation of the benefits described here and cost concepts may or may not provide a business case. If a business case exists, sustainable management will be driven by business considerations and become fully integrated in the business cycle.

Sustainable management offers a variety of potential benefits:

- Enhanced corporate reputation and lower risk profile
- Higher operational efficiency, derived from sustainable management of safety and health, energy usage, ore resources, and the production processes

- Improved planning and control, derived from the implementation of management systems (e.g., ISO 14001[10], ISO 9001[11]) and the continuous improvement philosophy associated with sustainable management
- Greater advantage in access to mineral resources, resulting in lower resource acquisition cost and reduced project failure rates
- Greater advantage in recruiting and retaining human resources, resulting in improved leadership and motivation, initiative, and decision making at lower levels
- Easier and more economical project financing, derived from investors' perception of the positive financial consequences of social license in financing new mining projects
- Lower project development costs through improved stakeholder relations and a faster permitting process

Achieving these benefits has an associated cost related to a larger company structure, the partnership or sponsorship in community development projects, and, in general, the costs of earning and maintaining the social license.

My personal perception is that, at present, many mining companies are already in the position to substantiate a business case from sustainability performance and are probably achieving the competitive advantages of sustainable management. Looking to the future, the generalization of a "business case" for sustainability[12] will be enhanced by the increased social and political sensitivity on environmental and social issues and the corresponding increase on the prices and the production costs of mineral commodities.

BOOK OVERVIEW

Mining and Mine Management: Historical Background (Chapter 2)

This chapter is intended to provide nonengineers with both a broad and a selective look at a number of historical aspects of mining. These aspects have had an impact not only on management in the industry but on civilizations around the world and on the millions of miners who have made the industry possible. Chapter 2 also looks at two schools that have played a large role in educating mining engineers over the years and that have provided considerable support throughout the research stages of our book project: the Escuela de Minas de Madrid (Madrid School of Mines) and the Colorado School of Mines.

What Sustainability and Sustainable Development Mean for Mining (Chapter 3)

This chapter reviews the ideas underlying sustainability and sustainable development, independent of mineral development and mining. It discusses the implications of these ideas for the minerals sector and for the responsibilities of mining companies. Finally, it reviews what companies have done to put these principles into practice and the project-level tools that have been developed to guide mine managers.

Strategic Issues in the Mining and Metals Industries (Chapter 4)

Sustainability is becoming a fundamental pillar of mining companies' strategy. Not infrequently, operational managers lack sufficient understanding of the rationale for corporate strategic decisions. To address this lack and to help managers comprehend companies' strategic choices, this chapter provides an overview of the main concepts and issues related to the corporate strategy of mining companies. The chapter presents the theoretical basis of the corporate strategy in a simple, comprehensive way, as well as the nature and influence of the external and internal factors affecting mining firms' competitiveness.

Integrating Sustainability into the Organization (Chapter 5)

This chapter discusses the organizational structure of a mining company, focusing on the challenge of integrating the values of sustainable development and sustainability down to the operational levels of mining companies, as well as the organizational structures and the management roles, systems, and tools required for integration. It describes corporate vision and strategy on sustainability and on how to integrate the use of environmental management systems, the management of social stakeholders' expectations, and the concepts and application of the "community partnerships" approach in integrating the expectations of community and local stakeholders at operating levels.

Human Resources Management (Chapter 6)

This discussion of human resources management focuses on the integration of sustainability values in the business culture and ethics in the organization. It describes the processes of recruiting, training, leadership, and recognition as the keys to employee commitment and trust, thus allowing for the integration of decision making down to the lowest possible levels in the organization, a necessary condition for sustainable management.

Management of Exploration (Chapter 7)

Mineral exploration is the technical and management process applied to the search for mineral deposits in the earth's crust. At least in its early stages, exploration does not require changing the use of the land where it is undertaken, so its social and environmental footprint is rather limited. However, the manner in which exploration is conducted is critical to the social license; therefore, it must be conducted in an environmentally responsible manner and in close communications with local stakeholders. Chapter 7 presents an overview of corporate exploration strategy and highlights a sustainable approach to exploration management based on conducting exploration activities in a responsible and transparent manner, aiming to achieve the license to operate at early stages of the mine life cycle.

Managing Project Feasibility and Construction (Chapter 8)

Chapter 8 deals with the sustainable management challenges at the preproduction stages of mining projects. It presents an approach to project management in which the focus is placed on the sustainable feasibility evaluation of economic performance, safety and health, and environmental and social responsibility as the key management issues involved in ensuring long-term benefits throughout the mine life cycle. The chapter compiles the authors' personal experiences as project managers. It aims to share the authors' perspectives without attempting a systematic approach to project management systems and techniques.

Mine Planning and Production Management (Chapter 9)

This chapter outlines the main management issues concerning responsible management in mine production activities. The focus is on various units of operation such as planning, excavations, processing, ground control, material handling, maintenance, waste disposal, and waste management. These topics will be discussed in relation to responsible management for a sustainable mining operation.

INFORMATION SOURCES

Some material in this book has been drawn from publications, sustainable development institutions, mining companies' Web sites, and personal communications. In all cases, these contributions are acknowledged and referenced in endnotes, tables, or figures. We gratefully acknowledge the permissions given to us by these companies, individuals, publishers, and organizations.

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CHAPTER TWO

Mining and Mine Management: Historical Background

W. Eckley

INTRODUCTION

I swear there is no greatness or power that does not emulate those of the earth.
—Walt Whitman, *Leaves of Grass*

When the poet Walt Whitman penned that line, he was no doubt thinking of both the physical and metaphysical relationship between Man and Nature. Moreover, in a more practical sense, he was surely aware of the greatness and power of the mineral resources lying beneath the earth's surface, resources used over the ages by human curiosity and ingenuity in the growth and development of the world's civilizations. For early miners of such minerals as gold, copper, tin, and iron, the relationship with the earth was clear enough: they had to find the minerals, take them from the earth, and put them to use. Although these miners are lost to past ages, their legacy lives on in today's dynamic mining industries, which provide the world with comfort, convenience, and achievement.

Primitive though their activities were, the early miners had to be concerned with the tensions of management. Over the millennia, these tensions became more complex to recognize and more difficult to orchestrate. Like management in any of today's business ventures, mining management has itself become a science—to be studied, developed, and followed. In short, it has become a profession. Economic theories, political conflicts, human relations, and environmental questions—just to name a few—are constant concerns of modern mining management. Moreover, the future offers little if any diminution in the plethora of management problems, which get more complicated and challenging as time passes.

While the past is seldom considered relevant in a world primarily concerned with the present, a glance at history can occasionally prove valuable. This chapter of *Sustainable Management of Mining Operations* offers nonengineers an informative, detailed introduction to some of the many challenges facing the mining industry in a rapidly changing world. It looks both broadly and selectively at a number of historical aspects of mining that have not only had an impact on mining industry management but also on the civilizations of the world and the millions of miners who have made it all possible.

FROM THE BEGINNINGS

Early man, nomad that he was, relied on hunting, fishing, and gathering for his subsistence, a way of life that was time-consuming and precarious. Even in those primitive times, however, recognizable forms of cooperation were evolving to maintain and increase longevity. With no writing skills and little more than grunts and child-like pictures scraped on cave walls for communication, this early man was establishing simple forms of management that, through the millennia, would ultimately lead to the settling of lands suitable for planting and harvesting crops. Agriculture and the permanency it brought gave impetus to the first civilizations, particularly in the fertile valleys of the Nile and Euphrates rivers. This early period, in which man was using various stones and flints for weapons as well as for crude farming implements, set the stage for the Age of Metals, a new and creative chapter in human development, with hammering giving way to melting.

Gold was found in many areas of the world, and, because of its peculiar qualities of malleability and longevity, was used extensively for decorative jewelry and coins. In the search for gold, other metals were discovered and used, among them silver, copper, tin, and iron. Melting led to smelting, and smelting led to new dimensions and uses of these basic minerals. Copper and tin became bronze, while zinc and copper became brass. The curtain was indeed being raised on what was to become the modern age of minerals. The Ages of Copper and Bronze were succeeded by the Iron Age. Abundant and relatively cheap to mine, iron was the strongest and most magnetic of the heavy metals. Iron's ubiquitous properties eventually made it the most indispensable of metals, particularly with the emergence of wrought iron, cast iron, and the many types of steel. Iron was widely used by the Assyrians and the Egyptians, as well as by those who followed them in biblical times.

Because history is a continuum with overlapping timelines, it is difficult to label any period or endeavor accurately. This is certainly true when trying to reach a workable division of ages that cover thousands of years. The Age of Metals, for example, covers only 1% of the five hundred thousand years of human existence. So how does one pinpoint when mining became modern with any accuracy? The only way is with a broad brush. T. A. Rickard, in his *Man and Metals,*[1] points to the medieval years (450–1450) as a time when the recognition of the true value of metals brought considerable attention to the search for them and to the improvement of mining technology—the beginnings, as he put it, of the real art of mining. Mining for the ancients had been little more than a grubbing in the ground, carried out mostly by slaves or near slaves with little incentive to improve their craft. Because of limited space, these miners often had to work on their backs, using hammers, picks, and shovels, with the broken ore passed from man to man in bags weighing 100 to 200 pounds. Plutarch complained that "one cannot much approve of gaining riches by working mines, the greatest part of which is done by malefactors and barbarians."[2] These often-brutal working conditions in mines were not to be ameliorated for some time.

Columbus's voyages of discovery unleashed a host of adventurers seeking their fortunes in what was aptly called New Spain. In the relatively short period of 60 years, a myriad of gold, silver, copper, tin, and mercury mines appeared in the areas that would one day become Mexico, Peru, Chile, Columbia, and Bolivia—mines that served the industrial and coinage needs of a booming Europe unable to provide its own resources. Spain alone imported more than 200 metric tons of gold and almost 20,000 metric tons of silver from New Spain between 1520 and 1560. Carlos Prieto, in *Mining in the New World,*[3] points out that, in addition to the welcome economic impetus in Europe, the mines of New Spain led to the development of agriculture and trade, as well as the building of roads and ports, the formation of cities, and the establishment of educational institutions throughout the area. New Spain was indeed on the road to becoming the Latin American nations that exist today. The economic and political roles of the Conquistadors were accompanied by the efforts of the Catholic missionaries who did their part in spreading Christianity to the natives and turning them into a valuable and obedient workforce in the mines.

With the value of metals increasing and the need to find new sources of ore, efforts to improve mining technology increased to the point that mining itself was becoming a legitimate industry in both the new and the old worlds. The areas of Cornwall in Britain and Saxony on the Continent, for example, did much to bring mining out of the dark ages.[4,5] Not only did they exchange miners and mining techniques, they also organized miners' associations that did much to raise the status of individual miners, even if it was minimally. It would not, moreover, be long before mining schools were founded throughout New Spain. Then, too, the mining industry was attracting men of superior ability and of sufficient capital, who were willing to assume the risks that could lead them to fortune or misfortune. One such risk-taker was Jacob Fugger, the grandson of a German weaver, who moved the family's assets into mining interests in 1473. By 1495, the Fuggers had a fortune based on copper and silver mines, which enabled them to become the bankers for many European kingdoms. Fugger also had a positive role, according to Rickard, in turning mining in Germany into a respected industry, firmly established as a prime factor in the conquest of nature and an essential agent in the advancement of humankind.

Another key figure of the period, though not in a monetary sense, was George Bauer, better known as Georgius Agricola, the author of *De Re Metallica*,[6] a work that in the view of its translators, Herbert and Lou Hoover, speaks for itself as a masterful, systematic treatment of the sciences of mining and metallurgy. It also stands as a work of art for the artistic woodcuts that illustrate various aspects of mining. Born in 1494 in Glauchau, Saxony, Agricola was swept up in the Protestant Reformation and the age of exploration that was part of it. Graduating from the University of Leipzig in 1518, he went to Italy to taste the beginnings of the Renaissance, studying philosophy, medicine, and the natural sciences. Although his career combined that of physician, university professor, and holder of several public offices, his primary fascination lay in observing and studying mineralogy and mining. Interestingly enough, it was his investment in a mine, appropriately named God's Gift, that made him a wealthy man. At this time, the arguments over advances in technology, particularly in the use of minerals, and what they might mean to humankind had been common over the centuries.

Although Agricola certainly knew there was no going back, he nevertheless defends the use of iron, copper, and lead in weapons. If such were done away with, he points out, men would quickly turn to hand-to-hand combat, poison, starvation, and all manner of horrible means of torture to do away with an enemy. Moreover, he argues, wars are not caused by products of mines in themselves, but from man's own vices—anger, cruelty, discord, passion for power, avarice, and lust. "For my part," he says, "I see no reason why anything that is in itself of use should not be placed in the class of good things." To the argument that agriculture was more stable than mining, Agricola responds that in the long run "mining would be more productive and profitable than that land which, if you sow, it does not yield crops, but if you dig, it nourishes many more than if it had borne fruit." He admits that none of the arts is older than agriculture, but that of the metals is not less ancient. In fact, they are at least equal and coeval, he argues, "for no mortal man ever tilled a field without implements."

In answer to the view that mining is a dangerous occupation for the miners on its cutting edge, Agricola notes simply that occurrences that killed or injured miners "are of exceeding gravity, and moreover fraught with terror and peril, so that I should consider that the metals should not be dug up at all, if such things are to happen very frequently to the miners, or if they could not safely guard against such risks by any means." He also puts much of the blame for mining accidents on the carelessness of the miners themselves. Yet, he had great respect for the miner: "For, trained to vigilance and work by night and day, he has great powers of endurance when occasion demands, and easily sustains the fatigues and duties of a soldier."

The footnotes that Hoover, the translator, supplied are valuable by-products of Agricola's monumental work. In one of the more interesting notes, Hoover discusses how from early periods to modern times, mining laws have favored four groups with certain proprietary rights regarding mining claims and the actual mining carried out on them. These were the overlord, the state, the landowner, and the mine operator and discoverer. Time and place, of course, made for variations in the power and structure of these agencies. During the Middle Ages, for example, the stronger of the potentates were quick to interpret early Roman mining law in affirming their right to dispossess the weaker. The growth of individualism in the 19th century gave landlords and miners wider rights at the expense of the state. Sentiment since then, however, has been to grant greater restrictions on mineral ownership in favor of the state.

MINING AND THE INDUSTRIAL REVOLUTION

With the dawn of the 19th century, Europe was on the threshold of a new kind of revolution—the Industrial Revolution. While it had been on its way for some years, it arrived with a force that was to be felt first in Europe and eventually throughout the civilized world. Using iron, coal, coke, and steam, this revolution was marked by steam locomotives, steam ships, rolling mills, mass-production factories, urbanized industrial centers, and some rather horrifying working conditions for the common laborer. For two centuries, European nations, particularly those with overseas empires, had been practicing mercantilism, the general goal of which was to export more products than were imported and to accumulate as much bullion as possible. Adam Smith in his widely read *Wealth of Nations*[7] argues that mercantilism had essentially run its economic course and should be replaced with increased industry undergirded by free trade. Britain was the first to realize the implications of steam power and mass production in redefining economic strength. As William Willcox and Walter Arnstein point out in *The Age of Aristocracy*,[8] Britain had the prerequisites to meet this new economic challenge: a supply of natural resources, agriculture to feed a population that doubled between 1750 and 1821, a large-scale division of labor, sufficient capital to finance new industries, a demand for consumer goods, and technological innovation. Coal, coke, and iron were the key resources needed, and Britain had sizeable deposits of all three, as did central Europe for that matter. Britain led the way in coal mining, followed by Belgium, France, and Germany. Steam took over from water to run machines that were constantly growing larger and more complex, and the flap of belts that ran them became a common sound in British and European factories and would remain so until the middle of the 20th century.

The nations of Europe found that it was cheaper to get base metals from New Spain than from their own mines, which in some areas were showing signs of depletion. The Cerro de Paso mine in Peru, for example, produced ore containing copper, silver, and gold from a single mine. Mexico, moreover, struck a bonanza in 1762 that produced 31 million dollars worth of silver from a single mine. Mines of Cerro de Potosi in Bolivia produced silver valued at more than a billion dollars between 1505 and 1801. So productive were these mines that Potosi was at once a luxurious and splendid city, notes Prieto, that imported not only European merchandise, but silks and carpets from Africa; perfumes from Arabia; diamonds from Ceylon; crystal, ivory, and precious stones from East India; and spices, aromatics, and porcelain from Ternate, Malacca, and Goa. Indeed, Potosi was so famous that in every language the phrase "worth a Potosi" became a symbol for wealth.[9]

It is interesting to note that as the Industrial Revolution was moving toward its zenith, gold was discovered in California and other western areas of America, setting off the rush to riches that thousands hoped they would find at the end of a rainbow of gold and silver. For one brief instant, the miner was truly his own boss. Equipped with little more than a pick and pan, he made or lost, usually the latter, his fortune. If this was the miner's apotheosis, it was a short one to be sure. As Rickard laments, "The free miner, the heroic youth of the Golden Age, was succeeded by the hired mechanic; the increasing complexity of the civilization that he himself had helped so largely to build by his gift of metals, proved his undoing. The democratic ideal was submerged beneath the industrial complex."[10] As romantic as this view might seem, it is basically true. The Industrial Revolution spawned considerable social and political change in both Europe and the Americas. If the miner, or any worker for that matter, was ever his own boss, mass production pretty much made him a cog in a machine that he himself did not fully understand. What he came quickly to learn, however, was that in widely developed unity there could be significant strength. Thus was unionism born, and thus was the strike to become the basic weapon used in the perennial conflict between labor and management.

As the Industrial Revolution progressed, pressures on mining grew rapidly. Production of coal in Britain, for example, grew from 10 million metric tons in 1810 to 200 million metric tons in 1875. Miners employed increased from 69,000 in 1801 to more than a million and a half in 1914 in some three thousand mines. While mining procedures were improving to some degree, basically they were not much different from what they were in the 16th century. According to Bernard Cook, in Victorian Britain, between 1850 and 1914, approximately one thousand miners were killed annually. He also notes that work in the mines was still strenuous, disagreeable, and ultimately debilitating, with miners still having to work on their knees in coal seams half a meter high. There was some effort to improve conditions in the mines with Shaftesbury's Mines Act of 1842, which outlawed work by women and children under the age of 10 in the mines. During the first half of the19th century, it was common for miners to be paid monthly and that any advances in pay had to be spent in the Tommy shop, a store run by the mine, whose prices were 20% more than those of the average market. This was a pattern that soon found its way into company mining towns of North America.

Accompanying the Industrial Revolution were insurgent movements in Spanish and Portuguese America. As Prieto notes, independence in Spanish America was an inevitable consequence of the maturing of the people who made up the empire.[11] The American and French revolutions were also having considerable influence. Between 1810 and 1814, such insurgent movements were carried out in the Spanish kingdoms and provinces of Argentina, Chile, Ecuador, Paraguay, Peru, and Venezuela, as well as in Portuguese Brazil. Of these, Mexico and Peru were the most valuable to Spain. The independence achieved did not signal any significant democratic overtones in governmental struggles that would plague most of Latin and South America for almost two centuries. Whatever the forms of government, however, these areas were, and still are, major players in the mining of minerals needed by the industrial world.

A fascinating story that actually begins long before the Industrial Revolution and continues to this day is that of Rio Tinto, a sulfur and copper mine in the area of Huelva, some 30 kilometers inland from the gulf of Cadiz. In June 1556, at the order of King Philip II, a group of Spaniards were searching for some ancient mining diggings in this area. First used by the Phoenicians and later by the Romans, these mines had faded from history for some centuries. Because of Spain's financial problems, Philip was eager to increase the country's mining interests. The searchers found a great pile of slag, from which they garnered some ore samples that assayed positively for copper. Because of the expense involved in building a seaport and a railroad to get minerals to the coast, the area was not developed significantly until 1723, when the Rio Tinto mines were reborn to become one of the greatest, if not the greatest, copper mining centers of the world. Rio Tinto Company Limited, an international consortium led by the British, purchased the mine from Spain for four million pounds and succeeded in bringing the mine on line.

The story of Rio Tinto during this period reads very much like a movie script. The mine grew rapidly by the 1880s with more than eight thousand workers from Spain and Portugal laboring in the mines. The British managers lived in their rather posh compound, while the miners lived in more primitive dwellings—not an unusual division in mining towns of the world. It was not long before social tensions arose between miners and managers. The former, discontented with wages, crowded living conditions, and rules limiting the drinking of alcohol, were mobilized in late 1887 by Maximiliano Tornet, who organized them into secret groups resembling the Molly Maguires, who were operating in the anthracite mining areas of Pennsylvania at about the same time. Civil guards, called the blacklegs, came on the scene to quell demonstrations by striking miners, with the result that on February 4, 1888, shots were fired that killed or wounded 48 demonstrators.

David Avery,[12] in his excellent history of Rio Tinto, *Not on Queen Victoria's Birthday*, describes the impact of this tragedy on both the British and the Spaniards. For the former, it "represented a crystallization of all the fears and all the uneasiness which lay beneath the surface life at Rio Tinto." For the latter, it was a marked break with the past and a symbol of the present, "in which they were subjected without any right of participation, to the decrees of authority which could in the last resort depend on armed might to enforce its rule." In short, this violent episode brought both sides to a reality that neither wanted nor could escape. The idea that opposites generate each other held true for each side. The British were the demons for the Spaniards, and the Spaniards were the demons for the British. Simply put, the British cared more for a profitable mine while the miners cared more for better living and working conditions.

The years of World War I and World War II were difficult for Spain. Rio Tinto, even though it needed new blood in management and considerable repair, played a significant role in helping the nation get back to normal. Since 1954, Rio Tinto has been reorganized on the international economic scene a number of times. Indeed, at this writing, Chinese steelmakers are competing with BHP Billiton, the world's largest mining company, with headquarters in Melbourne, Australia, to take over London-based Rio Tinto Limited. Thus does a fascinating mining story continue.

DIGGING FOR KING COAL

Underground mining, whatever the mineral in question, has many common characteristics, and it has always been of significant interest to the general public. Yet, it may well be that the underground coal miner has captured more of the imagination of that general public than any other. Arguably, his job has always been the dirtiest, the hardest, and the most dangerous in the occupation of mining. Moreover, it is carried out deep in an unforgiving netherworld that in itself seems almost supernatural. It is not surprising that many miners, hard rock or coal, still hold to the folklore belief that mines of any kind are the home of the little people—ghosts, gremlins, gnomes, or what have you—that can have both good and evil motives. Cedric Gregory, in *A Concise History of Mining*,[13] points to one of the more interesting of these beliefs, held by the early coal miners of Cornwall, in creatures called the Tommy Knockers who teased the miners and mimicked the sound of their picks. The miners believed that the Knockers were the souls of departed spirits drifting between heaven and hell and wandering about the mines. There are, however, more realistic problems facing coal miners of today.

At the beginning of the 20th century, 344 thousand of the 30 million workers in the United States were coal miners, most in the anthracite mines of eastern Pennsylvania and the bituminous mines of southern West Virginia.[14,15] Once it was learned in the mid-1800s that there was coal in these areas, speculators grabbed whatever land they could and began seeking labor to mine coal.

Because of the scarcity of the native Pennsylvania Dutch (German background) and the native Scotch-Irish laborers of West Virginia, mine owners sought and welcomed immigrants from such places as Cornwall, Italy, Serbia, Slovenia, Slovakia, and Hungary. These immigrants, along with a number of southern African Americans, joined the native labor to provide a varied but effective workforce, even if its members did not always get along well with each other.

The larger coal companies began construction of towns around their mines to house miners and their families. It has been said that miners belonged to the company because they were treated by the company doctor, lived in a company house that might be taken from them without notice, shopped at the company store where prices were high, and were eventually buried in the company graveyard. While there were advantages for both company and miner, it was without doubt an economic boon for the company to keep the miner in debt to the store. Some companies built churches and hired ministers to provide "acceptable" religious services. David Corbin, in his excellent study, *Life, Work, and Rebellion in the Coal Fields,*[16] tells of a mine owner advising his superintendent "to never lose sight of the fact that the sole purpose of the company was to make money for the stockholders, and that matters of conduct tending to produce a contradictory result should be promptly squelched with a heavy hand."

As it is with all miners, the coal miner's basic concern is the number of loads that he produces, while that of the manager is the overseeing of an operation that will produce a positive bottom line. Each of these concerns touches on the very core of human needs and values of the individual holder. While they no doubt bring inherently different life views in terms of culture and education, miner and manager must fashion a working relationship that will have a chance at solving the conflicts that have been instrumental in the shaping of the mining industry.

The underground mine itself is in many respects the miner's world, the one where he makes his living and risks his life in the process. It is in fact a world that the mining manager, who spends the majority of his time on the top, may not fully understand. In a newspaper interview,[17] one West Virginia miner described a telling incident regarding his uncle's first day at the No. 9 mine: "When he got to the bottom of the elevator and the doors opened up and he looked back in the heading (tunnel), he went right back up and said, 'I quit.'" Yet, most miners do not quit as long as the job is there. In his private, almost secret world, he lives for the moment or for the tenor of the whistle that ends the shift and leads to a double shot and a beer.

Though difficult to explain, the lure of the mine that is a theme for a number of folk ballads and country songs is real enough. It is highly doubtful that anyone has made up a song about mine managers. Miners across the world have a pride and a respect regarding their jobs, perhaps even a touch of arrogance. After all, it is the miner who goes back into a mine to rescue his mates in time of disaster. The manager who does not understand and appreciate this "other" culture of the mines will never fully succeed in his own job.

Advocates of social Darwinism, mine owners, and other industrialists saw unionism as the forerunner of socialism and a threat to the very core of business, and they were prepared to fight it as often and as hard as necessary. Anxious to enlarge its influence, the United Mine Workers of America sent labor organizers into the coal-mining areas to awaken miners to the value of a union. John Mitchell, who had worked in a mine at the age of 12, eventually became president of the United Mine Workers in 1898. He led two strikes in the anthracite region of Pennsylvania, one in 1900 and one in 1902. The latter lasted 23 weeks and garnered a 10% increase in pay, a 9-hour work day, the right of miners to name overseers of the weighing of coal produced daily by a miner, and a conciliation board to hear grievances.

Two other strikes in American coalfields reflect the vehemence and violence that could result when mine owner and striking miner faced each other. The first occurred in 1914 in the mining towns of southern Colorado. The strikers wanted recognition of the United Mine Workers union and improved working conditions. Realizing that they were going to be evicted from their company houses, they moved into tents. On April 20, after some 7 months of the strike, 200 company guards attacked and burned the main miner camp at Ludlow, killing 21, including 11 children, and wounding 100. The second major strike occurred in the coalfields of southern West Virginia in 1920. Suffice it to say that West Virginia was a battlefield in which thousands of miners fought against scabs, Baldwin-Felts detectives, state police, and National Guard troops. Lon Savage, in his penetrating study, *Thunder in the Mountains*, describes one day's battle (May 12, 1920) at the town of Matewan, across the river from Kentucky:

> As if on schedule, fighting erupted in the rainy morning hours . . . when the bullets peppered down from the West Virginia mountains on a half dozen mining towns near Matewan. Immediately, nonunion miners returned fire from the Kentucky mountains. By mid-morning, fighting was general, and shots rang out from every mountain. No one could tell who was shooting at whom. Nonunion miners in the valley shot blindly back, and deputies opened fire with machine guns. Hundreds, then thousands of shots boomed and echoed until in places they became a continuous roar.[18]

Only after the federal government declared martial law and sent in the Army did the fighting stop. The mines of southern West Virginia were not unionized until the 1930s.

The coal-mining industry of Britain, too, had its labor problems, including strikes and political conflicts that helped bring down the Heath government in 1974. The industry had been nationalized in 1947 in an attempt resuscitate it. Between that year and 1982, however, the number of British coal miners declined from 700 thousand to 200 thousand. The fate of British coal mining was essentially sealed. One rather interesting example of the impact of the Industrial Revolution and the later reduction in coal mining in Britain are the Rhondda Valleys, which until the 1850s were thinly populated. With the discovery of vast amounts of coal, migration to the area resulted in population growth from less than a thousand in 1851 to 169,999 in 1924. The valleys were packed with some 53 collieries and hundreds of houses. Upwards of five thousand men were employed in the five pits of the Lewis Merthyr colliery, producing nearly a million metric tons of coal each year. Cheap coal from overseas eventually made mining in the valleys a losing proposition. Lewis Merthyr stopped mining in 1983, and the last of the valley pits closed in 1990. The same fate awaited Wylam, a former collier village whose mining days began in the 11th century when the monks of Tynemouth mined both coal and iron. At one time, the village supported five coal mines and two iron works. Following the closure of the mines in the mid-20th century, the area became rough grassland with scattered trees and is now the Wylam Haughs Nature Reserve, a fitting grave for the miners who toiled beneath it.

A TALE OF TWO SCHOOLS

It is appropriate here to look for a moment at two schools that have played a large role in educating mining engineers over the years and have provided considerable support throughout the research stages of our book project: the Escuela de Minas de Madrid (Madrid School of Mines) and the Colorado School of Mines.

Having both established international reputations for excellence as institutions of higher learning in mining and engineering, the Madrid School of Mines and the Colorado School of Mines have not only prepared students in the practical aspects of mining but have also carried out significant research projects. These projects have opened new avenues in mining, mineralogy, stewardship of the earth, and mine management.

The Academy of Mining in Almadén was founded in 1777 by Charles III, King of Spain. Several years earlier, the strategic mercury mine in Almadén had suffered a long-burning fire that necessitated closing it for a considerable time. Two other mercury mines were unable to produce the amount of mercury needed to process the silver being mined not only in Spain, but also in New Spain (Peru and Mexico), so the Spanish economy was suffering. To answer the need, the king set up the academy and brought a number of professors from Freiberg to aid in its organization. The Underground Geometry and Mineralogy Chair, under the direction of Don Enrique Cristobal Storr, was the first to be established and followed the Germanic way of teaching.

The academy was moved to Madrid in 1836 and became the Madrid School of Mines (Figure 2.1), and its educational mission began to grow dramatically. The degree of mining engineer was established in 1857 with a program based on scientific and experimental education replacing the older practical approach. This 5-year degree program encompassed 2 years of basic sciences, 2 years of applied sciences, and a fifth year of specialization.

In 1896, the School of Mines moved to its present campus in Madrid, a handsome new main building designed by Velazquez Bosco and decorated by Daniel de Zuloaga. Subjects added to the curriculum have included steel production, microscopy, petrography, mineral micrography, liquid fuels, groundwater geology, geophysics, industrial engineering, computer sciences, and management and environmental engineering. Two new degrees include geological engineering and energy, fuels, and explosive engineering.

The Colorado School of Mines (Figure 2.2), established roughly a century after the Madrid School, was a creation of the developing American frontier as it moved across the West. Unofficially founded by an Episcopalian missionary in Golden, Colorado, it was one of a trio of schools: a preparatory school, a divinity school, and a mining school. The embryonic mining school that would eventually become the Colorado School of Mines was the only survivor of the three. From the beginning, its role was obvious: to educate and train engineers, who were sorely needed to guide and develop the hard-rock mining that was such a large part of the American West. So important was it that the State of Colorado took control of the fledgling school in 1874. Thanks to the academic leadership of such early presidents as Regis Chuavenet, Victor Alderson, and Melville Coolbaugh, the Colorado School of Mines was able to continue with some confidence on its educational journey.

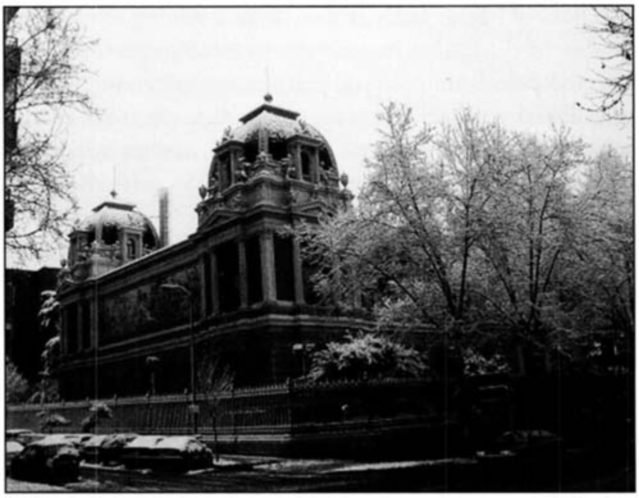

FIGURE 2.1 **Escuela de Minas de Madrid (Madrid School of Mines)**

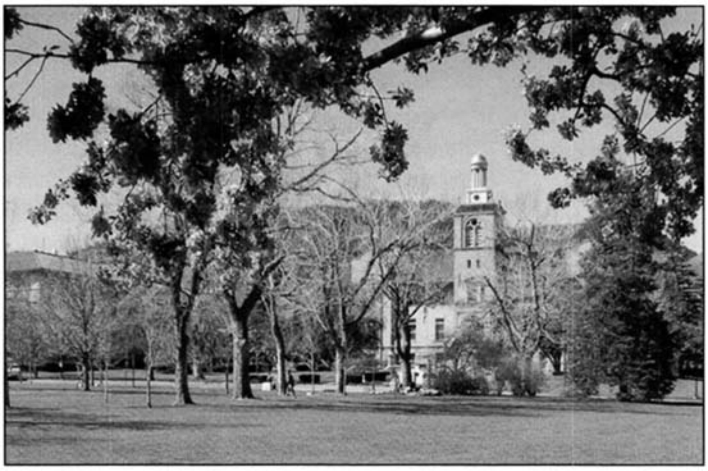

FIGURE 2.2 Colorado School of Mines

Through the last half of the 19th century and the early part of the 20th in America, mining was key to the development of the lands west of the Platte River. The discovery of gold in California in 1848 drew thousands of Americans and foreigners alike to try their luck at becoming rich overnight. Indeed, mining became the largest nonagricultural source of jobs in the West. Ten years later, gold was found in Clear Creek Canyon near Golden, Colorado. Although Colorado did not experience the same frenzy that California did, it was surely on the map for the gold and silver mining, just as it would be later for coal and uranium mining.

Mining was caught in the process of change. The romanticized days of the prospector were coming to a close if they had ever existed. Going underground and demanding more technology and capital, mining would soon be a bonanza of big business and millionaires who would build opera houses and shoe their horses in silver.

The Colorado School of Mines today is more than a mining school. Its roots have spurred the growth of a number of disciplines in addition to mining: geology, metallurgy, chemistry, chemical engineering and petroleum refining, petroleum engineering, geophysics, physics, economics and business, liberal arts and international studies, electrical engineering, mechanical engineering, civil engineering, environmental engineering, mathematics, and computer science. All of these degree programs at the Colorado School of Mines, with the exception of liberal arts and international studies, offer PhD programs.

THE TOUCHSTONE OF MINING

Just as the Greeks had their misgivings about minerals and their uses, so too do various groups today. The latter, of course, have no illusions that the mining of minerals or the drilling for oil can, or should be, eliminated or even diminished. Each age has offered its costs and its gifts, its problems and its solutions regarding the advances of technology and the minerals required for those advances. In a world that's, ironically, growing smaller in terms of communication and interaction as it grows larger in terms of population, competition has become the insidious by-product of that conundrum. When the economic factors of cost and profit are taken into consideration, the level of complexity rises dramatically. For mining, the line between these two factors is fine indeed and requires that management come into play early and strongly. In addition to the broader concerns mentioned earlier, the physical activities of mining involve risk and capital. Finding, evaluating, digging, loading, and hauling of minerals and coal are the physical activities of mining, whether it's done underground or at the surface. These activities all require various levels of skilled labor, as well as capable managers to plan and oversee them.

Since prehistoric times, management of one fashion or another has run the world's affairs, from household to religion, from government to the largest of corporations. And it has not been an easy task at any level. Confucius had it right when he said that if you would set government in order, you must first set your family in order; if you would set your family in order, you must set yourself in order; if you would set yourself in order, you must first call things by their right names. The last, of course, is the most difficult to do. Like all management, mining management at any level is never easy. Successful mining, then, needs a touchstone, and that touchstone is capable and imaginative management carried out by individuals and teams who recognize and accept their professional, moral, and ethical responsibilities.

Just as technology has more often than not outpaced the making of war, so has it often outpaced the organizing of business and industry, with the result that managers face constant growth and change. In this race, as it were, Frederick Turner's rules of efficiency[19] and William Whyte's *Organization Man*[20] have been left in the dust of that growth and change. Mining certainly has had to change its own methods of operation and management over the years. Profit, of course, still remains the hoped-for bottom line, but the challenges and conflicts inherent in that quest are numerous and show no evidence of riding off into the sunset. It is impossible here to rank these challenges and conflicts, but undoubtedly, labor relations, mine safety, and environmental questions are of perennial importance. In an ideal mine, of course, the mineral would be plentiful and easily accessible; the relationship between miner and manager would be mutually rewarding; and there would be no environmental problems to muddy the waters. Reality, however, more often presents a different scenario.

Mine safety has been a constant concern throughout the history of mining, particularly in recent times. Although Agricola is right when he says that many mining accidents are the result of carelessness on the part of the miner, many more are the result of insufficient regulations or the failure to follow established ones. While this chapter was in development, three tragic coal-mine accidents occurred: one in the state of Utah in which nine miners were killed, another in Ukraine in which scores of miners were killed, and a third in China in which 96 were reported killed. During the 45 years of communist control in Russia and Eastern Europe, many mine disasters were not reported to the rest of the world. Both Ukraine and China presently rank high in mining accidents. Since the fall of communism in 1991, 4,700 Ukrainian miners have been killed, the worst single accident occurring in 2000, when 80 miners died in a dust explosion. China averages approximately five thousand deaths from mining accidents each year. One of the worst mining disasters in the United States occurred in the anthracite fields in 1869, when a firedamp explosion killed 108 men and boys. This, of course, is not the place simply to point the finger of responsibility. Suffice it to say that of all mining, coal mining in particular, has to be examined more carefully regarding safety; moreover, it is the mining manager who must play a significant role in that effort.

Environmental damage is a worldwide problem that is probably even more significant and more difficult to solve than mine safety problems. Although mining has contributed its share of this damage, directly or indirectly, it is certainly not alone in polluting the environment or in contributing to the warming of the earth. China, with its dynamic population growth and industrial expansion, again finds itself as a leader in damaging the environment. As one might expect, however, China points to other nations that should bear some of the guilt. An article in the *New*

York Times of August 26, 2007, notes that Britain, the United States, and Japan polluted their way to prosperity and worried about environmental damage only after their economies had matured and their citizens were demanding blue skies and safe drinking water. One Chinese climate expert complains that China has to deal with environmental problems while it is still poor and with no model to follow.

At this writing, the Colorado legislature is debating a bill that would impose new restrictions on mining in Colorado, especially uranium mining. Hard-rock miners have expressed concern that such restrictions would force them to curtail existing operations at the very time that they want to reopen mines. Some Colorado mountain communities that suffered environmental damage as a result of earlier mining operations and whose economies have suffered because of mine closures are now interested in having mining resumed.

The mining manager, to be sure, has much to worry about. Along with concern for the productivity and safety of miners, he or she must satisfy owners, stockholders, governmental regulators, banks, accountants, environmentalists, politicians, and the miners digging and loading the tonnage. He or she must, moreover, keep up with technological advances that sometimes must seem like the mechanical rabbit at a dogtrack: they never get caught. The mining manager must wear many hats and bear heavy responsibility but with few absolute answers. Fortunately, the greatness and power of the earth remains as a beacon.

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CHAPTER THREE

What Sustainability and Sustainable Development Mean for Mining

R. G. Eggert

INTRODUCTION

The index of the two-volume, 2,400-page *SME Mining Engineering Handbook*[1] does not contain the words *sustainability* and *sustainable development.* The world certainly has changed. Today, one would expect these words and the underlying concerns about mining's environmental and social challenges, and how they relate to economic and commercial considerations, to be prominent in any new edition of this landmark publication. Sustainability and sustainable development have taken on heightened—some would say paramount—importance since publication of this book in the early 1990s.

Despite the prominence of sustainability and sustainable development in current discussions about mining, these terms are prone to hyperbole, confusion, and disagreement over what they mean and imply for mining.

This chapter seeks to clarify the concepts of sustainability and sustainable development and what they imply for mine management. It begins by reviewing the ideas behind sustainability and sustainable development, independent of mineral development and mining, then defines four implications (or principles) for the mineral sector and discusses what they mean for the responsibilities of mining companies. And finally, it reviews what companies have done to put these principles into practice and what project-level tools have been developed to guide mine managers.

BROAD CONCEPTS

Sustainability and sustainable development emerged as key social concepts out of concern that many current, commercial activities are *unsustainable*—that is, these activities may result in such significant environmental damage and social disruption that future generations will be worse off than the current generation. There is general agreement—and who could disagree with the goal or ideal?—that decisions today not make future generations worse off than the present generation and, more specifically, that commercial decisions not only reflect the quest for profits but also result in appropriate protection of the natural environment and in social justice.

The concept of sustainability originated in the field of renewable resource management. The idea is that a forest, fishery, or other renewable resource be managed such that the rate of harvest does not exceed the rate of regeneration—thus sustaining indefinitely the stock of the natural resource. This original idea can be applied to other environmental and natural resource issues, such as managing an ecosystem so that the stock of natural resources that make up an ecosystem is sustained, maintaining a desired degree of biodiversity, or maintaining a desired level of air or water quality.

Think of sustainability, in this sense, as *environmental sustainability*. It also can be viewed as physical sustainability in that the unit of measure is physical (e.g., number of species, or parts per billion of a specific air pollutant). Environmental sustainability emphasizes maintaining the ability of the natural environment to provide the life-sustaining services and the aesthetic qualities it provides to humans (e.g., clean air and water, or scenic vistas). This view of sustainability also embodies the belief that the natural environment should be maintained or sustained for its own sake, independent of how human beings interact with and use the environment.

Economic sustainability, a second form of sustainability, emphasizes sustaining or enhancing human living standards. A starting point for assessing economic sustainability is a measure of well-being at present, such as per capita income. Broader starting points incorporate other, less purely economic determinants of human well-being, such as education levels, life expectancy, and income distribution. The United Nations Human Development Index (http://hdr.undp.org/statistics) is one example. Sustainability requires that these indicators of well-being be at least sustained if not enhanced. At a national level and more conceptually, the concept of green accounting goes a step further and attempts to assess whether a given level of well-being today is, in fact, sustainable in the future.

Traditional gross domestic product (GDP) is the estimated value of goods and services produced by an economy, which at a national level is equivalent to income, in turn, a first approximation of human well-being. Traditional GDP, however, will not be sustainable if today's economic activities diminish our ability create goods and services (i.e., human well-being) in the future—as would happen if today's activities completely wore out existing manufacturing and other productive equipment and facilities. The solution is to adjust traditional GDP estimates to account for net investment in productive facilities (investment purchases minus depreciation), yielding a measure of the level of production (and analogously income) that is sustainable because it leaves the capital stock intact. Similarly, our overall level of human well-being will not be sustainable if current activities "wear out" natural resources and the environment. So-called green GDP takes traditional GDP as a starting point but includes the following adjustments: (a) net investment in human-made productive facilities as noted previously (which can be a positive or negative adjustment, depending on the balance between investment and depreciation), (b) net changes to the stock of mineral and energy resources (which can be subtracted from or added to GDP, depending on the net effect of reserve depletion from ongoing mineral and energy production and reserve additions during the same period), and (c) the estimated value of the net effect of improvements to environmental quality due to pollution-control expenditures and of environmental damage caused by current economic activities. To be sure, valuation is not simple, but considerable work has been done investigating how to assign economic value to natural resources and the environment.[2]

Social and cultural sustainability is the third major form of sustainability. It focuses on social justice. It emphasizes how the benefits and burdens of economic activities are distributed; is a specific distribution fair? Most commercial activities yield benefits and burdens that are not shared equally across society. For example, a new manufacturing facility may bring net benefits to a national or provincial economy but may leave the local, host community worse off on balance if the facility brings in workers from outside the local economy and leaves local unemployment unchanged, creates significant environmental damage for which the local community is uncompensated, or leads to social problems because the influx of workers strains the local infrastructure of housing, schools, and medical facilities. Concerns such as these raise the question of the extent to which parties affected by a new commercial development have or should have a role in deciding whether the development occurs and under what terms. In what circumstances is an affected party entitled to compensation? To what extent are affected parties entitled to share in the net benefits or profits of an activity? The process through which issues such as these are resolved is an important aspect of social and cultural sustainability.

Note that each form of sustainability—environmental, economic, sociocultural—can be thought of as one-dimensional in that the objective is to maintain or sustain something that is either environmental (e.g., maximum allowable rate of pollution), economic (e.g., per capita income or some other measure of human living standards), or social (e.g., a fair distribution of wealth). Each form of sustainability gives priority—either explicitly or implicitly—to an objective in one dimension (e.g., environmental quality) at the potential expense of alternative objectives in the other dimensions (e.g., economic and social justice).

Sustainable development, in contrast, is inherently multi-dimensional. Development that is sustainable will appropriately balance and integrate environmental, economic, and social aspects of an activity. Sustainable development, in other words, strives to *simultaneously* sustain or even enhance environmental quality, human (economic) living standards, and the fairness of the distribution of the burdens and benefits of development (social justice). Sustainable development represents economic development that is consistent with society's preferences for environmental quality and social justice. There is no single measure of sustainable development; rather, progress toward this goal is less prone to quantification and instead is indicated only by looking at a variety of environmental, economic, and sociocultural indicators. Given that pursuing goals in one dimension (say, environmental) may come at the expense of goals in another dimension, progress toward sustainable development requires careful attention to the social institutions and processes that facilitate the resolution of conflicts and the simultaneous pursuit of multiple objectives.

In translating these broad concepts into actual decisions, the issue of scale is important. Is our priority the sustainability or sustainable development of a local community? A province or subnational region of a country? A nation? Or the world as a whole? What is sustainable for a local community may not be sustainable or optimal for a nation or the world as a whole. In other words, there may be and are conflicts between what sustainability and sustainable development mean for different people, organizations, and social and political groups.

Four Implications or Principles for Mining

What do these broad concepts of sustainability and sustainable development mean for the mining sector? What they certainly do *not* mean is that we should strive to sustain forever the life of an individual mine, which of course is impossible—although the life of an individual mine can be sustained to some degree through development of additional reserves adjacent to existing reserves and through technological innovation that makes it technically and commercially feasible to extract previously uneconomic rock. Furthermore, these concepts do not mean that we should strive to sustain forever and at all costs the life of an individual community; there are some mines in sufficiently remote locations that there are no viable (commercial) opportunities that do not revolve around mining.

Instead, this author's view is that the concepts of sustainability and sustainable development suggest the following principles or social goals associated with mining:

1. Facilitate the creation of mineral wealth;
2. Ensure that mineral development occurs in an economically (socially) efficient manner;
3. Distribute the surpluses from mining fairly; and
4. Sustain the benefits of mining even after a mine closes.

Facilitate the Creation of Mineral Wealth

Before minerals can contribute to sustainability or sustainable development, mineral wealth needs to be created. To be sure, minerals themselves will not be created in the earth's crust over time periods relevant for human beings. The creation of mineral wealth, in contrast, requires human activities to acquire sufficient knowledge of a mineral occurrence (or the chance of occurrence) that someone is willing to purchase exploration, development, or mining rights.

Ensure That Mineral Development Occurs in an Economically (Socially) Efficient Manner

The key idea or goal of economic efficiency is to maximize net benefits, in this case from mining. The definitions of benefits and costs need to be broad enough to include full social benefits and costs. Starting points for estimating benefits and costs are the revenues received and costs incurred by profit-seeking mining companies. In addition, and significantly when evaluating sustainability or sustainable development, one needs to consider the possible spillover benefits and costs associated with mining. Spillover benefits could include local purchases of inputs (e.g., food, fuel, spare tires) by a mining company that otherwise would not occur, local spending of mine-worker wages that otherwise would not occur, health improvements experienced by local communities from clinics a mining company funds, and roads or other infrastructure a mining company builds for a mine that also are useful for a local community. Spillover costs could include environmental damage, cultural impacts on indigenous peoples, and social disruptions often associated with mining development, such as increased rates of alcoholism or prostitution. Economic efficiency requires that decision-makers acknowledge and recognize the unpaid nature of spillover costs—in other words, unpaid costs need to be paid. More specifically, local communities should be compensated for spillover costs they bear from mining. Overall, economic efficiency, defined here as maximizing the net social benefits of an activity, incorporates at least conceptually the environmental and social problems that lead to concern that these activities are unsustainable.

Distribute the Surpluses from Mining Fairly

Mining often generates surpluses (economic profits or, as they sometimes are called, rents) even after mining companies pay the spillover costs referred to previously, either by compensating local communities or others for bearing these costs or through activities such as expenditures on environmental protection that reduce or eliminate the creation of these costs. How these surpluses are distributed—among the owners and workers of private mining companies, national governments, local governments, communities, and other organizations—is a key issue in social and cultural sustainability and sustainable development. This issue is a critical aspect of the quest for social justice.

The core conceptual question is: What is fair? As noted by Young,[3] the Aristotelian approach emphasizes proportionality—for a fair distribution, allocate surpluses according to each party's contribution to creation of the surplus. For mining, proportionality suggests that business partners should share in profits in proportion to their financial contributions to a project. Other allocations based on proportionality are less easily quantifiable—government's fair share when it funds infrastructure used by the mine (but usually also by other members of the community) or society's share if it is argued that a mineral deposit is a gift of nature and thus contributed by society at large to the project. A second approach to fairness, associated with the philosopher Jeremy Bentham, emphasizes utility—distribute surpluses such that their use leads to the greatest good. For mining, it is difficult to know how to put this into practice. Which party has the ability to put mining's surpluses to best use? A mining company, through reinvestment in mineral development? A local government, though investment in schools and public infrastructure? A national government, which might take surpluses from the region of a mine and invest them in public infrastructure in a poorer region of the country? A third approach, attributed to the philosopher John Rawls, emphasizes helping the least well-off groups in society. For mining, such an approach might emphasize directing surpluses to activities that alleviate poverty.

Sustain the Benefits of Mining Even After a Mine Closes

Investing an appropriate portion of the revenues from mining in sustainable assets can, in effect, make the benefits from mining permanent. This principle is perhaps the key lesson from the concept of economic sustainability. The idea is simple: save and invest a portion of current income each period, spend at most the investment's income each period and in so doing sustain the ability of the investment's corpus to fund spending indefinitely into the future. This principle can be implemented in various ways. As Hanneson[4] notes, there are a number of important investment issues to consider:

- *How much to save and invest:* The answer depends on what a society wants to sustain—the current level of well-being, growth in the level of well-being, or some other goal? The higher the goal, the higher the savings rate must be.
- *By whom:* Governments on behalf of a local community or national society? The mining companies themselves, which presumably would emphasize investments in sustaining a mine's life or in developing other mineral deposits?
- *In what:* Financial assets? Or public investment in roads, schools, electric power, schools, hospitals, scientific and technical research and development?
- *Where:* In the mining community, region, or nation? Wherever the potential investment returns are highest given the riskiness of an investment?

Implications for Corporate Responsibility and Mine Management

The previous section, articulating principles for the mineral sector, ignored the important issue of who is responsible for pursuing the objectives these principles represent. Just what the appropriate roles and responsibilities of governments, private companies, and other nongovernmental organizations are in mineral development and in pursuit of these principles depends, of course, on one's view of how social activities should be organized. To most economists and in market economies, production of most goods and services—including minerals and mineral products—is left to private enterprises because, in well-functioning markets, private enterprises have the incentive to create wealth in an economically efficient manner (satisfying the environmental and social requirements for sustainable development described previously). In the process of striving to maximize profits for their owners, mining enterprises provide employment for workers, purchase inputs from suppliers, and so forth. As part of the process, these enterprises have the incentive to minimize costs for a given level of output, maximizing the creation of surplus or net benefits (profits from the perspective of private enterprises).

In an ideal world, governments—acting on behalf of society at large—would establish appropriate legal and regulatory frameworks that facilitate achievement of the four principles of sustainable mineral development identified previously. In particular, most economists argue that government intervention in specific markets, including mining, be limited to activities that facilitate market activity, promote fairness in the distribution of burdens and benefits, and promote economic efficiency by correcting imperfections in actual markets that would prevent them from being "well functioning" or economically efficient. In mining, governments would facilitate mineral exploration, mine development, and mining through policies that, among other things, define property rights, create processes for private companies to obtain approvals for exploration and development, and outline and describe the rights and responsibilities of private companies during extractive activities and after mining ceases. Government would define mechanisms to define what a fair distribution of benefits and burdens is and then to achieve this fair distribution. Governments would intervene more directly in mineral activities to correct the inefficiencies that otherwise would occur when environmental damages and social disruptions receive inadequate consideration in decisions about mineral exploration, mine development, and mining.

In such an ideal world, private mining companies would strive to maximize profits based on their evaluations of the commercial attractiveness of the various investment and operational options they face in mineral exploration, mine development, and mining. Private companies would not need to consider their "responsibility" to local communities beyond striving to maximize profits in ways consistent and compliant with social norms as codified in laws and regulations. Companies would *not* find it advantageous or appropriate to go beyond complying with existing rules for environmental protection, worker health and safety, and investments in the communities in which they operate.

This ideal or conventional view of a company's responsibilities can be questioned on at least three grounds. First, mining companies might find it more profitable over the longer term to go beyond compliance if such activities develop goodwill with workers and in the community in which they operate—even if existing laws and regulations clearly define the framework for mining, and government institutions are capable of implementation and enforcement. In this case, companies would consider whether an investment in goodwill today fosters higher profitability in the future, even if it sacrifices current profits. Second, companies may find it more profitable over the longer term than otherwise to go beyond what is minimally required when comprehensive laws and regulations do not exist or when government and social institutions for implementing rules are weak, leading to inconsistent or spotty enforcement or when the political, legal, and regulatory environment is in a state of flux. In this case, mining companies would go beyond what is minimally required to avoid or minimize future conflicts. Companies in effect would become surrogate governments or development agencies in choosing how much environmental protection to build into a mine, how much engagement to have with local communities in ensuring fairness in the distribution of benefits and burdens, and how much attention they should give to developing mechanisms to sustain the benefits of mining after mining ceases through trust funds, investment in other economic sectors to promote diversification, and other activities. The third way the ideal or conventional view of a company's responsibilities can be questioned is more controversial—that companies have a moral responsibility to go beyond mere compliance with rules regarding the natural environment, worker health and safety, and how they interact with and support the communities in which they operate—even if going beyond mere compliance leads to lower profits.

In the first two cases, companies would act in their own self-interest, undertaking activities that reduce profits today in exchange for expected higher profits in the future. In this sense, the first two situations are variations on the ideal or conventional view of a company's social responsibilities rather than entirely different perspectives. The third case, however, when companies would sacrifice profits over the longer term in the public interest, is controversial. A detailed assessment of whether companies *should* undertake profit-reducing activities for moral reasons is beyond the scope of this paper. For such an assessment and review of the important issues, see Vogel,[5] Hay, Stavins, and Vietor,[6] and Yakovleva.[7] Suffice it to say that private companies do undertake activities in the first two categories out of necessity.

PUTTING CONCEPTS INTO PRACTICE IN MINING

Whether motivated by requirements of public policy or company decisions to go beyond simple compliance, most private mining companies undertake a variety of activities aimed at one aspect or another of sustainability or sustainable development. Yakovleva[8] groups these activities into three categories: the natural environment, worker health and safety, and community development and stakeholder engagement. Yakovleva reviewed annual reports and other information published by the ten largest gold mining companies during the period 1998–2001 and found that the majority of companies made public commitments and disclosures in all three categories. For the environment, the majority of companies commit to meet established rules and regulations, to improve environmental performance, to meet the standards of sustainable development, and to minimize environmental impacts and effects; they have environmental management plans and systems for, for instance, environmental monitoring, tailings management, water management, air quality, revegetation, assessment of ecological risk and environmental impacts, independent environmental audits, and reporting of environmental performance.

Similarly, in the area of worker health and safety, the majority of large gold mining companies have formal health and safety policies, a commitment to improve performance in this area, dedicated health and safety offices, training programs, monitoring of all workers, HIV/AIDS policies or programs, and health and safety audits and reports. Finally, in the category of community development and stakeholder engagement, the majority of large gold mining companies have formal social and community policies and consult with stakeholders; offer education and training to members of the local community; contribute to community activities such as schools and clinics; cooperate with nongovernmental organizations, industry associations, and government on social programs; and have established philanthropic foundations. To be sure, some of these activities are required by existing government policies and regulations. But many go beyond mere compliance. Key approaches are disclosure of policies, independent audits of performance, and public reporting.

To this point, this chapter has discussed general principles and concepts. The rest of the chapter describes several specific initiatives aimed at putting sustainability and sustainable development into practice in the mining sector.

Broad, Multi-Participant Initiatives

Between 2000 and 2002, a group of large mining companies undertook the Global Mining Initiative (GMI), dedicated to understanding the relationship between sustainable development, on the one hand, and mining, on the other. GMI had two lasting outputs. The first is the final report of the Mining, Minerals and Sustainable Development (MMSD) project, an independent review of the key issues, initiated through the World Business Council for Sustainable Development and then performed by the International Institute for Environment and Development. The review involved regional partnerships focusing on issues specific to southern Africa, South America, Australia, and North America; 23 global workshops and expert-group meetings; and more than 150 commissioned studies. The final report appeared as the book *Breaking New Ground* (International Institute for Environment and Development, 2002).[9] It identifies nine key challenges, which broadly speaking encompass the four principles articulated earlier in this chapter. The second lasting output is the creation of the International Council on Mining and Metals (ICMM)[10] based in London. ICMM is an industry association charged with carrying out the work investigated by MMSD and more generally to promote mining that is both viable for companies and that contributes to broader sustainable development.

Between 2001 and 2003, the Extractive Industries Review was performed. The review, commissioned by the World Bank and conducted independently, examined the role of the World

Bank in the extractive industries, including oil, natural gas, and mining. It was prompted by strong external criticism of the bank's role in financing and promoting these sectors, particularly that the extractive industries were *not* consistent with sustainable development and poverty alleviation precisely because of the environmental damage and social disruption caused by extraction. The review found that the World Bank does have a role to play in the extractive sectors but only if its activities promote sustainable development and poverty alleviation, which in turn require that three enabling conditions be met: that pro-poor public and corporate governance exists, that extractive projects have stronger environmental and social requirement than at present, and that there be respect for human rights as verified by third parties. The detailed findings of the review are available at the World Bank Web site,[11] and the World Bank's response can be viewed at the International Finance Corporation Web site.[12]

Three other international initiatives relate to mining, even though they are not targeted directly at sustainability and sustainable development. First, the Equator Principles are a voluntary set of guidelines for banks and other financial institutions to use in managing environmental and social issues that arise in lending to investment projects. The principles[13] were developed in 2003 and revised in 2006. As of early 2008, 59 institutions had become signatories. Second, the Global Compact,[14] initiated in 2000, is a voluntary network of businesses and other organizations committing to adhere to practices consistent with appropriate corporate behavior in the areas of human rights, labor practices, the environment, and corruption reduction and prevention. Third, the Extractive Industries Transparency Initiative[15] promotes full disclosure and independent verification of company payments and government revenues from oil, gas, and mining. Launched in 2003, the initiative aims to improve private and public governance in resource-rich nations by making it more difficult for companies and governments to undertake activities that the public at large finds inappropriate.

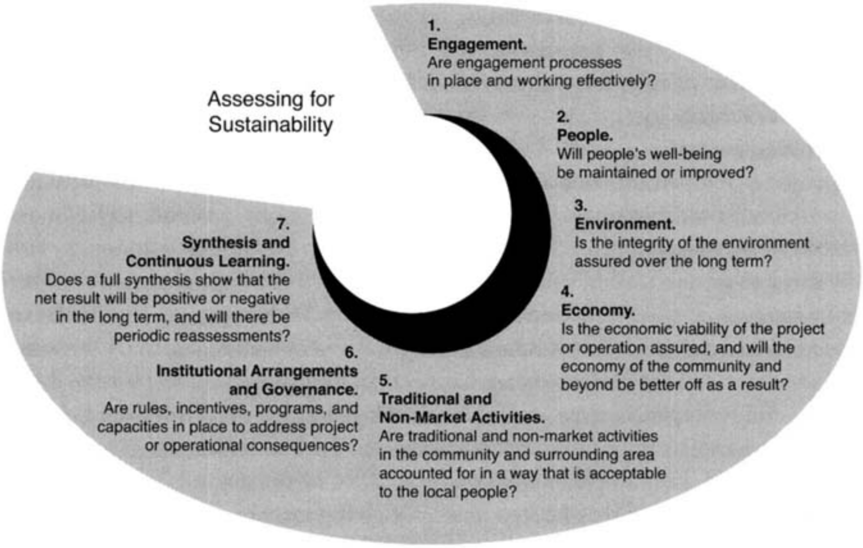
Project-Level Tools

At the scale of an individual mine, community, or region, implementing any of the principles described to this point in the chapter typically is not simple or straightforward. Developing appropriate processes to consider and, when necessary, balance economic, environmental, and social considerations is essential.

The Seven Questions Framework

One approach is the Seven Questions framework[16] for assessing sustainability (Figure 3.1). The Seven Questions help answer the overall question: Is a project or operation and its net contributions to sustainability positive over the longer term?[17] Developed as part of the MMSD project described previously, the questions are the product of two workshops, one in Canada and the other in the United States, involving some 30 participants and experts from academia, First Nations/Native Americans, government, industry, organized labor, and other nongovernmental organizations. The Seven Questions are broad and serve as starting points for more detailed examinations of specific issues:

1. *Engagement:* Are engagement processes in place and working effectively?
2. *People:* Will people's well-being be maintained or improved?
3. *Environment:* Is the integrity of the environment assured over the longer term?
4. *Economy:* Is the economic viability of the project or operation assured, and will the economy of the community and beyond be better off as a result?



Source: International Institute for Environment and Development, 2002

FIGURE 3.1 Seven Questions to Sustainability

5. *Traditional and Non-Market Activities:* Are traditional and non-market activities in the community and surrounding area accounted for in a way that is acceptable to the local people?
6. *Institutional Arrangements and Governance:* Are rules, incentives, programs, and capacities in place to address project or operational consequences?
7. *Synthesis and Continuous Learning:* Does a full synthesis show that the net result will be positive or negative in the long term, and will there be periodic reassessments?

Each broad question is answered through assessment of a hierarchy of more specific questions, indicators, and measures. For example, an affirmative answer to the first question (engagement) requires that all interested parties have the opportunity to participate in decisions that affect their futures and that engagement processes are understood and agreed upon by the interested parties, consistent with legal, institutional, and cultural characteristics of the community and country. Appropriate processes need to have dispute resolution mechanisms, reporting and verification, adequate resources, and informed and voluntary consent. There are similar requirements for affirmative answers to the other questions.

Seven Questions is a framework for discussion, aimed at helping identify issues important to the various interested parties. It is a mechanism for evaluating these issues and the trade-offs that sometimes are inevitable among economic, environmental, and sociocultural considerations and objectives associated with mining. It is a mechanism for finding solutions to conflict that are mutually beneficial to all parties.

The Seven Questions framework was applied to the experience of the Tahltan people with mining.[18] The Tahltan people are a First Nation in northwestern British Columbia, Canada. Over the last 50 years, a number of gold mines have operated in Tahltan traditional territory. Since the middle 1990s, Barrick Gold's Eskay Creek gold mine has operated there.

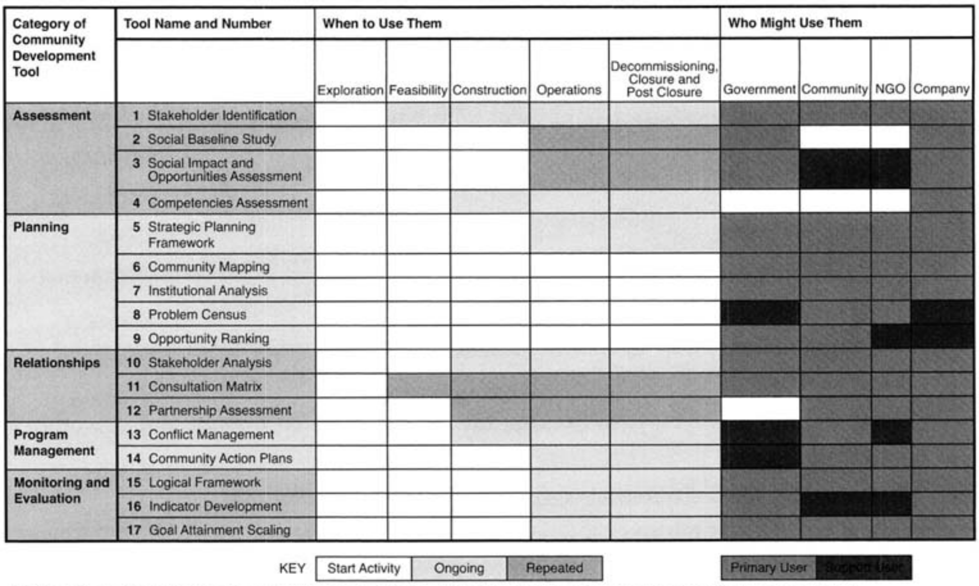
The goals of the Seven Questions review were to evaluate the experiences of the Tahltan people and develop a strategy to guide future relationships between the Tahltan people and the mining industry. The review was carried out through a 3-day workshop in 2003, involving twenty-eight Tahltan people, five industry participants, four government representatives, and a facilitator. The Tahltan assessment consisted of separate evaluations of mineral exploration, operating mines, and mine closure. The assessments contributed to a mining strategy that the Tahltan people developed for themselves, with three objectives: first, to communicate that the Tahltan people support mining on their lands if it is done "right"; second, to facilitate Tahltan participation in mining and mineral activities; and third, to ensure that community concerns—especially those related to health, society, and culture—receive adequate attention. The strategy identified a number of potential, specific actions that the Tahltan people could take to achieve these objectives and that the mining industry and government could take, too. One would like to write that the Seven Questions framework has been an unqualified success for the Tahltan people and the mining companies active on Tahltan lands. Although the framework helped facilitate interactions among the various interested parties in the Tahltan region, it has not eliminated all tensions. In 2005, 35 Tahltan elders occupied the office of the elected Tahltan chief for more than 3 weeks and demanded that he step down for giving inadequate attention to consultation with communities in negotiating on behalf of the Tahltan people for a number of new mining projects.[19]

The Community Development Toolkit

The World Bank and ICMM jointly developed another similar but more detailed framework to guide interactions between mining companies and communities, the *Community Development Toolkit*.[20] This toolkit is aimed primarily at mining companies, although it can be used also by communities, governments, and other nongovernmental organizations. The existence of such a toolkit might suggest that mining companies in the past have not paid attention to communities. Such is not the case. As the toolkit notes, companies frequently funded schools, clinics, and other facilities in communities in which they operated. Unfortunately, in many cases these projects—although well intentioned—were not as successful as they might have been and were not long lasting (i.e., sustainable). The reasons were many: the companies or local elites chose the projects without broad community involvement; outsiders built or ran the project; only the affluent community members, and not the poor, had access to the project; or the local community did not have the capacity to manage the project, especially after the mine closed. It was against this backdrop that the toolkit was developed. It consists of 17 tools to facilitate community development over the mining-project life cycle, including exploration, feasibility, construction, operations, decommissioning and closure, and postclosure (Figure 3.2):

Assessment:

1. Stakeholder identification: to identify all the people with an interest or who might be affected by a project
2. Social baseline study: to profile a community and its regional and national setting
3. Social impact and opportunities assessment: to identify and assess the impacts of a project, positive and negative, and to evaluate how to manage them
4. Competencies assessment: to determine the adequacy of your team's skills, knowledge, and understanding and, if deficient, evaluate what other cometencies may be necessary



Category of Community Development Tool	Tool Name and Number	When to Use Them					Who Might Use Them			
		Exploration	Feasibility	Construction	Operations	Decommissioning, Closure and Post Closure	Government	Community	NGO	Company
Assessment	1 Stakeholder Identification	□	░	░	░	░	▓	▓	▓	▓
	2 Social Baseline Study	□	□	□	▒	▒	▓			▓
	3 Social Impact and Opportunities Assessment	□	□	□	▒	▒	▓	█	█	▓
	4 Competencies Assessment	□	□	░	░	░				▓
Planning	5 Strategic Planning Framework	□	□	□	░	░	▓	▓	▓	▓
	6 Community Mapping	□	□	□	□	□	▓	▓	▓	▓
	7 Institutional Analysis	□	□	□	□	□	▓	▓	▓	▓
	8 Problem Census	□	□	□	□	□	█	▓	▓	█
	9 Opportunity Ranking	□	□	□	□	□	▓	▓	█	█
Relationships	10 Stakeholder Analysis	□	□	░	░	░	▓	▓	▓	▓
	11 Consultation Matrix	□	▒	▒	▒	▒	▓	▓	▓	▓
	12 Partnership Assessment	□	□	▒	▒	▒		▓	▓	▓
Program Management	13 Conflict Management	□	□	░	░	░	█	▓	█	▓
	14 Community Action Plans	□	□	□	░	░	█	▓	▓	▓
Monitoring and Evaluation	15 Logical Framework	□	□	□	░	░	▓	▓	▓	▓
	16 Indicator Development	□	□	□	░	░	▓	█	█	▓
	17 Goal Attainment Scaling	□	□	□	░	░	▓	▓	▓	▓

KEY □ Start Activity ░ Ongoing ▒ Repeated ▓ Primary User █ Support User

NOTE: This matrix provides a general guide to the tools including who might use them and when during the project cycle.

Source: ESMAP, World Bank, and ICMM.

FIGURE 3.2 Overview of ICMM's Community Development Toolkit

Planning tools:

5. Strategic planning framework: to assess why you want to contribute to community development, what your development objectives are, how you will achieve these objectives, and how you will know when you have succeeded
6. Community map: to facilitate the local people's planning of their community's physical layout
7. Institutional analysis: to evaluate the variety, strength, and linkages among institutions in the community
8. Problem census: to facilitate identification and prioritization of development issues in the community, involving all interested parties
9. Opportunity ranking: to help decide what projects to start first by considering both priority and feasibility

Relationships tools:

10. Stakeholder analysis: to evaluate the level of interest of the various stakeholders in the project
11. Consultation matrix: to develop a system for consulting with stakeholders that is appropriate both in frequency and detail
12. Partnership assessment: to analyze potential partners in community development

Program management tools:

13. Conflict management: to identify, understand, and manage conflicts through to resolution so that these conflicts do not disrupt activities of any of the stakeholders
14. Community action plans: to implement solutions to problems identified in the planning process

Monitoring and evaluation tools:

15. Logical framework: to develop clear outputs and outcomes using verifiable measures of progress toward goals
16. Indicator development: to choose indicators that are transparent and can stand up to external scrutiny
17. Goal attainment strategy: to measure the degree to which outputs and outcomes are being met

The toolkit contains detailed questions and templates for each tool.

Finally, at the stage of mineral exploration, Environmental Excellence in Exploration publishes an online toolkit of good practices and examples of environmental and social corporate responsibility in topics such as community engagement, land acquisition and access, camps, and drilling. It also has checklists and case histories. It is a consortium of companies and coordinated by the Prospectors and Developers Association of Canada.[21]

CONCLUSIONS

So, what do sustainability and sustainable development mean for mineral development and mine management? At a minimum, they mean that mining companies and mine managers will continue to work with local communities and local and national governments to integrate environmental and social issues into technical and commercial decisions about mining. They mean that processes will continue to be important—the processes through which companies and all other interested parties to mine development identify, discuss, and resolve issues that require integrating the technical, commercial, environmental, and social aspects of mining.

One hopes, more broadly, that the growing experience of companies and communities interacting with one another will lead to broader agreement about what is to be sustained, for whom, and through what process. To date, there has been little consensus on how to put the broad concepts of sustainability and sustainable development into practice. Nevertheless, there are limits to the extent that we should expect worldwide agreement to emerge. What is sustainable to a community in one part of the world may not be sustainable in another community in another part of the world. Sustainability and sustainable development are all about social preferences for the appropriate balance among the economic, environmental, and sociocultural dimensions of human activity.

Suggested Readings

This chapter draws significantly on four earlier writings by the author.[22–25] In addition to the publications cited in the text, the following papers and books are recommended. For more on the broad concepts of sustainability and sustainable development, see *Our Common Future,*[26] referred to as the Brundtland report and credited with initiating discussion of sustainable development, Jamieson,[27] Pezzey and Toman,[28] National Research Council,[29] and World Bank.[30]

For more on how sustainability and sustainable development relate to the mining sector, see Auty and Mikesell[31] and Otto and Cordes.[32]

For more on managing the range of sustainability issues at the mine site, see Rajaram, Dutta, and Parameswaran[33] and the various publications prepared by the International Council on Mining and Metals,[34] the Minerals Council of Australia,[35] and other industry professional associations.

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CHAPTER FOUR

Strategic Issues in the Mining and Metals Industries

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INTRODUCTION

Sustainability is becoming a fundamental pillar of any mining or metals company's strategy. That's because today's society has a much better understanding of the consequences of the interaction between human activity and the ecosystem, and people have become increasingly conscious of the importance of this issue for both present and future generations. As a consequence, the social license to operate is becoming more difficult to obtain, forcing companies to better integrate the concept and the values of sustainability into their strategy.

The dictionary[1] defines *strategy* as "the science and art of using all the forces of a nation to execute approved plans as effectively as possible during peace or war." If this definition were translated into business terms, it would be "the science and art of using all the forces of a company to create and execute plans as effectively as possible in order to reach its objectives." The adjective *strategic* is defined as "highly important to an intended objective." As a corollary, the strategy of a company is the science of dealing with its more important issues.

Regardless of the skills of its managers, no company can conduct business by improvising decisions. Mining is no exception; managing a mining business requires exhaustive internal and competitive analysis, which results in a set of guiding principles that constitute the strategic plan.

The conception of the company's strategy is the highest-level task that managers can perform. Although the broad objectives are fixed by the shareholders, management is in charge of identifying the actions and means to allow the corporation to get as close to these objectives as possible.

Designing a company's strategy includes a permanent redefinition of its business geometry: its size, markets, geographical implementation, technologies, and human resources, as well as social and political attitude. Strategy is intrinsically dynamic; it can be said that an excessively static strategy is always a poor one.

All too frequently, operational managers lack sufficient understanding of the rationale for strategic corporate decisions. The goal of this chapter is to aid in the comprehension of these strategic choices, presenting the theoretical basis of the corporate strategy in a simple, comprehensive way, as well as the nature and influence of the external and internal factors affecting the competitiveness of mining companies.

The work of many authors has contributed to the creation of the modern methodology for corporate strategy and strategic planning. However, Michael E. Porter[2] and Alfred Humphrey merit special mention because of the relevance of their contributions; their ideas have inspired some elements of this chapter.

BASICS OF BUSINESS STRATEGY: SPECIAL CHARACTERISTICS OF THE MINERALS INDUSTRY

This section presents the basic principles governing the most important function of management: the strategy. It starts with some basic ideas and concepts, then continues with a description of the main external and internal factors and their roles in a company's life. It focuses specifically on the more relevant issues for the mining and metals industries.

The Corporation and Its Interfaces

Corporations are open systems interfacing actively with their environments. There is a continuous flow of information between corporations and their shareholders, employees, clients, suppliers, banks, financial analysts, media, and authorities, as well as with their political and social neighborhoods. The quality and intensity of these flows are not the same for every sector or for every company within each sector.

A corporation's development of its strategic plan must take into consideration the dissimilar interactions with these stakeholders. The importance to the company of the different interfaces differs with the kind of business and its environment. For example, the mining sector will give more importance to environmental issues than will the banking or retailing sectors, which will put more emphasis on suppliers' issues.

An essential condition for successful strategies, in all companies and all sectors, is their elaboration as a complex, multivariable exercise, integrating the potential influence of each one of the factors that may affect a company's business.

The mining and metals business, because of its specificity, requires a particular kind of relationship with its stakeholders. Any mining company needs what is called "social license to operate." Although the feeling of mistrust that has often obstructed the relationship between mining companies and some of their stakeholders is less present today, a certain degree of caution still remains. It is evident that mining activities are still regarded by the public as threatening and hazardous. Few citizens will object to the installation of a research center in their neighborhood, but it will be a hard task to convince them to accept a mine near their homes. It is obvious that a strategic plan for developing such a mine can't be limited to the geological, operational, market, and financial considerations. It must include an exhaustive analysis of the social, political, and environmental implications that could be crucial for the feasibility of the project.

The management structure of a company must reflect these external interfaces, so it is increasingly common in mining companies for the senior executive in charge of sustainability matters to occupy a seat on the board of directors, along with the technical, marketing, and financial executives. This was seldom the case in the past.

The interaction between a corporation and its stakeholders must respond to a well-established, coherent, and consensual plan aligned with the corporate strategy. In addition to the marketing communication that aims to improve the commercialization of products or services, corporate communication must build an appropriate image of the company itself, creating the best possible reputation among all stakeholders. It must be professionally and efficiently designed and executed, because operational and functional managers do not necessarily have the appropriate skills to perform such a task.

Crisis communication is a particularly important element of this communication function for the minerals industry. Because of the nature of its activities, the minerals industry is especially exposed to sudden unplanned events that can have serious repercussions on a company's image and threaten its equilibrium. Industrial accidents, casualties, effluent spills, and similar incidents need to be handled and communicated in a very professional manner. Although these events are, by their nature, unpredictable, the reaction of the company can and must be prearranged. A crisis cell, perfectly trained for this task, must be put in place immediately. It must be in charge, not only of taking the first measures to cope with the crisis, but also of arranging and executing the internal and external communication to minimize the negative repercussions of the event.

Another important element, although less specific to the mining sector, is financial communication. Apart from the institutional reports (e.g., annual financial report, sustainability reports), the company should institute a set of contacts with its financial stakeholders, analysts, and shareholders. Data supplied must be truthful, clearly expressed, and consistent with previous communications. The key expression of this consistency is the coherence of the units and references used. There is a strong temptation to change the time references or the summarizing schemes in order to hide unsatisfactory performance from view and make time series analysis difficult. This would be a mistake; in the long run, it will surely provoke a negative perception of the entire business, as well as a reaction of mistrust that will have a serious effect on the credibility of the company.

Reputation is an important intangible asset in mining companies. It can be improved in the framework of an intelligent strategy or degraded by wrong policies and poor communication. It is not only a matter of prestige. It allows companies to be better accepted by their environment and, as a consequence, increase their competitiveness in many fields.

Methodology of Strategic Planning

It was stated previously that strategy is the science and art of dealing proactively with the important issues of a company. It is basically an empirical science, built more on practical experience than on theory. Years of practicing this science by thousands of corporations, together with the analysis of the results of the application of diverse principles, have consolidated a methodology that can be used to develop successful strategies. Numerous authors have worked on compiling and synthesizing these experiences, but special mention should be given to Michael E. Porter,[3] one of the most innovative and pertinent authors in this field.

The strategic planning process sets the principles and guidelines that have to be applied to achieve the company's objectives and to determine how these objectives will be reached.

The first step consists of analyzing the present situation: "Where are we now?" This asks for an unbiased analysis of today's situation, identifying the strengths and weaknesses of all the components of the company: markets, technologies, human resources, political background, environmental issues, financial situation, and so forth. It is in reality a very classical exercise. In the 1970s, business theorist Alfred Humphrey developed the SWOT (strengths, weaknesses, opportunities, and threats) method at Stanford Research Institute; this method can be very helpful in systematizing this analysis.

The second step is a bit more complicated: "Where do we want to go?" Do we want to be the biggest company in the sector? Do we want to maximize the return to our shareholders? Do we want to help the society through clean, sustainable operations? Or, perhaps, do we want a weighted mix of all of these? We must define how we ideally want the company to be in the future. The answers to these questions often lie with the shareholders, but management can and must provide quantified options. It is extremely important, although it is not always the case in practice, to integrate macroeconomic information into strategy design,[4] especially in the commodities industry.

The third step defines the strategic plan: "How do we get there and with what timing?" Depending on the nature of the business, companies can take either of two approaches to strategic management. The first approach is the industrial organization approach, which is based on economic principles like competitiveness and costs and resources allocation. The second, the sociological approach, is based on human interactions, like behavior or customer satisfaction. The industrial organization approach is suitable for companies with activities that are more material, like the mining, automobile, food, machinery, or electronics industries. The sociological approach is appropriate for companies producing and selling more immaterial goods, like software, medical services, and media.

Generally, both approaches are used together, with a preponderance of one or the other. In the case of the mining and metals industries, the industrial organization approach predominates.

Dimensions of the Strategy

The strategic planning domain has two dimensions: time and degree of generality. On the time dimension, the strategy can be short or long term.

The short-term strategy portrays the measures needed to run the business in a time horizon of less than 1 year. Thus, it manages the present. Its main goal is maximizing value by establishing decisions tailored to the observed situation and conditioning factors. It is set up within the framework of the long-term strategy and is generally driven by opportunistic considerations. It is usually set up within the framework of a task force involving a number of specific competences: marketing, operations, human resources, financial, legal, and so forth.

The long-term strategy prepares the future, is essentially structural, and seeks to maximize the long-term value of the company. It is oriented to the development of sustainable competitive advantages. It usually results from a deep analysis carried out by a multidisciplinary team led by the company's top executives and the chief executive officer (CEO). It often involves profound changes in the company's structure, spread over several years, and has low reversibility. As Gary Hamel expressed acutely, "a company that cannot imagine its industry's future may not survive to see it."[5] In practice, changes to the long-term strategy of a company need the approval of the board and must be submitted to the shareholders' assembly.

On the other dimension, the "degree of generality," strategic planning involves different levels, from high to low: corporate, business, and functional. These levels are correlated with the organizational structure:

- The corporate-level plan is the most general, conclusive, and essential plan a company can establish. It provides the necessary guidance for all the activities of the company and defines the financial and geographical geometry of the corporation, through mergers, acquisitions, divestitures, and spin-offs.
- The business-level plan defines the technological and commercial strategy, product policy, and human resources development.
- The functional-level plan deals with the most operational issues of the company: work organization, production planning, maintenance, and so forth.

Figure 4.1 illustrates the two conceptual dimensions of the strategy. The sizes and positions of the defined areas depend on the specific circumstances of each company.

The strategic plan must extend over all domains of the company—functional, business, and corporate—with the overall goal of "being better than competitors" for every option adopted. All options shall be generated through a process of creative thinking,[6] getting away from routine, and traditional, well-known alternatives. They must be challenged, checking that all assumptions are realistic and feasible, answering all "what if. . ." questions, and cautiously taking into consideration the probabilities and consequences of the worst-case scenario.

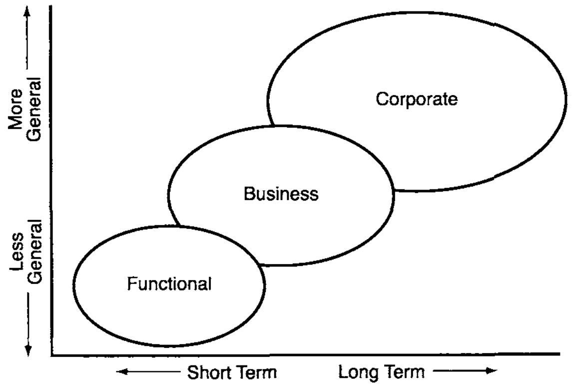


FIGURE 4.1 Two conceptual dimensions of strategy

Operational Effectiveness Versus Strategy

It is important to differentiate between operational effectiveness and strategy. A company can reach high levels of operational effectiveness through the application of modern management tools (reengineering, benchmarking, outsourcing, total quality), but this does not necessarily lead to value creation and sustainable profits, unless these actions are well inserted in the framework of an adequate strategy.

Because of the importance that costs have in the minerals industry's competitiveness, management frequently immerses itself in an intensive exercise of improving operational efficiency and costs, neglecting the strategic agenda. Management techniques often take the place of sound strategy. Operational effectiveness is necessary but not sufficient. In the early 1900s, although some lead producers made substantial investments in order to increase the production of bismuth (a by-product of lead concentrates) as a way to increase their competitiveness, the U.S. Food and Drug Administration was considering banning its use in pharmaceutical products, then its main use. The result was an overproduction that was not at all in line with market demand. Once again, productivity considerations took the place of strategic thinking.

The search for competitive advantages as a way to create value is the main goal of the corporate strategy. These advantages must be sustainable and long lasting, without degrading the existing ones, and developed in the framework of a sound long-term strategy. For example, reducing the premiums over the London Metal Exchange (LME) prices of a metal will allow increasing sales and reducing stocks in a tough market scenario. But this advantage is only temporary because competitors will quickly imitate the move with equivalent results. The final consequence is shrinking margins for the entire industry. This strategy does not create a permanent, sustainable advantage, so it is not a good one. A much better alternative would be to reduce the amount of impurities in the metal ingots, through research and investments, differentiating the product from the competitor's. The dominance of benchmarking over real strategies leads to imitation and ultimately to strategic convergence.

The maximum possible operational efficiency that a company can ideally reach using the best technologies, human capital, and external resources has been called the "productivity frontier" (Figure 4.2).[7]

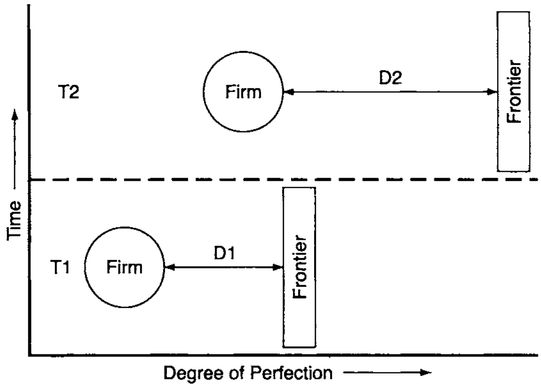


FIGURE 4.2 Productivity frontier

Some companies try to create competitive advantages by moving forward their operational efficiency toward the productivity frontier (Figure 4.2). As the production factors (education, technologies, external supplies, etc.) progress continuously, the frontier moves forward, neutralizing part of the progress. Except for the ones that manage to create differentiation, the result is an exhausting race that does not create competitive advantage for anyone. The search for operational excellence is necessary but not sufficient. It must be performed in the framework of a competitive, value-creating strategy.

Generic Strategies

Among the multiple strategies that a company can implement, Michael Porter[8] has identified three generic ones as common factors for most successful businesses: cost, differentiation, and focus.

Cost Strategy

The first generic strategy is reducing costs. It is obvious that if a company is able to produce an equivalent good or service at a lower cost than its competitors, it gains a competitive advantage because its margins will be higher for a given market price. This generic strategy is by far the most important for the mining and metals industries. Reducing costs is sometimes contradictory with other functions that may be essential to a good competitive situation. It is easy to reduce research, development, or training costs, but the consequences over the long term can be catastrophic. However, there is an optimal equilibrium to be found between cost reductions and long-term competitiveness.

The cumulative cost curve (Figure 4.3) is a strategic analysis tool that represents the unit cost by company in a given sector, related to the cumulative production. The cost usually represented is the *net cash cost*, defined as the total production cash cost credited with the value of the by-products produced per ton. The width of the columns is proportional to the amount of units produced per year. If the market price of the metal is Q_y, the margin of company D will be positive (P). For this price, all companies in the sector except J and K have positive margins. If the market price is Q_x, then company D will have a negative margin (L). At this market price, only companies A and B have positive margins.

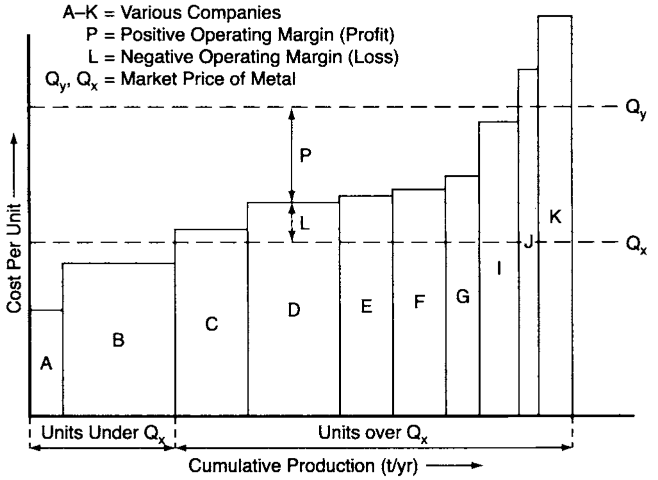


FIGURE 4.3 Cumulative cost curve

The curve allows the companies to evaluate their cost position versus that of their competitors. It also allows for estimating the total amount of production in the sector with associated costs lower than those of a given company. The shape of the curve fluctuates with time. It is then possible to assess changes in competitiveness for the different actors.

These curves are largely used in the minerals industry to carry out competitive analyses. They are published and made available to the industry by several specialized consulting firms for the most important metals.[9]

Another instrument commonly used in prospective cost analysis is the "experience curve" (Figure 4.4). It has been demonstrated that the average manufacturing cost per unit of a product decreases regularly with the cumulated number of units produced. This is due to the "learning experience," which makes the production process more efficient as a consequence of the improvements introduced over time. It has been suggested that the relative reduction in cost each time that the cumulated production doubles is constant and specific for each industry, product, or process, going from 10% to 30%. In the late 1970s, the Boston Consulting Group (www.bcg.com) stressed the link between this fact and the strategy formulation: companies should capitalize on the situation within the life cycle of a product to gain the competitive advantage arising from lower costs. The curves can be drawn empirically for each product or process.

Differentiation Strategy

The second generic strategy is differentiation. Although more important in other businesses, it has a certain weight in the minerals industry. Differentiation consists of doing business in a way that's distinct from that of the competitors. Although some metal producers would choose to specialize in low-cost mass production of a few basic metals, others may decide to transform some impurities contained in the concentrates in minor or precious metals. Differentiation can be a way to overcome the negative effect of some external factors, like high labor costs, by taking advantage of other favorable ones, like a highly qualified labor force. Because of the traditional interchange of technical and organizational information between mining companies, best practices are rapidly imitated. In addition to the data interchanged by bilateral benchmarking exercises,

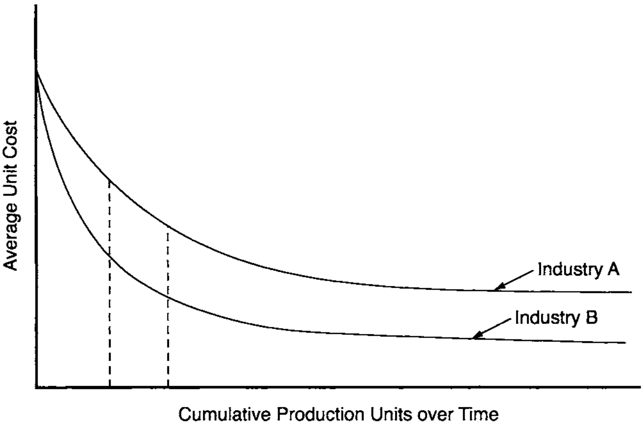


FIGURE 4.4 Experience curve

strategic knowledge may be diffused through visits, institutional communication, or even informal exchanges. Competitors tend to copy successful strategies, and finally most players end by having the same ones. A good strategic analysis will recognize the competitors carrying out similar strategies and identify different paths that may be the key for success. The paths to be followed for the companies to get competitive advantages are not always obvious. The fight to create value is sometimes fierce; therefore, it is not surprising that a frequent motivation for mergers and acquisitions is the opportunity to surpass a competitor, following this strategy: "if you can not beat it, buy it."

Focus Strategies

The third generic strategy is focus, which means concentrating the activity on a particular market segment, product group, or geographical area. After the analysis is done and the decisions are made, management should not be distracted with secondary options. Consistency is an essential quality necessary to implement any strategy. All the resources of the company must be put at the service of its main objectives. The cost of "management distraction" is not only the amount of the labor costs but also the loss of value creation over the main strategic objectives. Consistency is a great virtue for a corporate strategy. It is, most of the time, the consequence of strong and intelligent leadership.

Mining companies often face this question: "Where do we position the business in the value chain?" Because it can only mine ores and sell metal concentrates, more questions develop: "Or should we get the smelting process integrated, producing ingots and alloys? Or go further and fabricate derivate products like sheets, pipes, die casting pieces, packaging items, or chemical byproducts? How large should the spectrum of activities be? Should it be reduced to a few metals? Fabricated in a broader variety? Should we enlarge its mining activities to products like bricks, clay, kaolin, refractory products? Include some energy commodities like uranium or coal and so forth? Why not oil, tar sands, natural gas...?"

Rather frequently, companies implement strategies based mainly on growth. Growth by itself is not a good strategy. The growth approach may lead to fundamental errors that may damage the value-creating function. On the other hand, a sound strategy can also lead to growth when used in addition to value creation.

Dynamics of the Strategy Formulations

Although an efficient strategy must be consistent, it should not be rigid. As the factors affecting a company's performance change with time, the strategy needs to be adapted to these changes. This flexibility ought to be higher for the short-term (functional) strategy and lower for the long-term (corporate) strategy. Middle-term strategy must be adapted to the market and environmental changes (e.g., variation in production output as a function of the prices, raw materials supply, competitor's commercial policy).

Only drastic and permanent changes in the fundamental parameters should lead to modifications of the long-term strategy. For the minerals industry, the main factors that would justify this would be substantial changes in metals' end uses and markets, environmental regulations, social and political changes, or significant adjustments of competitors' roles.

Consistency is a great virtue of winning strategies in the long term. It is a common factor among the most successful mining companies that have constantly created shareholder value and survived crises. It is also an indicator of good strategic analysis. Long-term equilibrium may appear to be challenged temporarily in the middle and short term, which sometimes induces unnecessary strategy changes in companies whose business analysis lacks rigor and pertinence.

Strategy and Leadership

Strategy is not an exact science. Although some of the elements of good strategic planning come from a scientific analysis of data, other variables, like sociological and psychological elements, are more difficult to quantify. Forecasting market data, technology evolution, or sociopolitical trends and constraints is not always an easy exercise. For the fuzziest areas of the subject, intuition becomes a useful tool. With such a complex set of forces intervening, strong personalities with solid intellectual frameworks are necessary.

The percentage of time that managers actually devote to looking at the company's future, on average, has been estimated at 1% to 3%.[10] This figure is probably lower for the minerals industry. Building the future in mining means knowing how the markets will be and understanding the trends in metal uses, the threats of product substitution, and the evolution of the social license for its activities. It also means comprehending the progression of the energy and labor markets, the main components of its costs. Producing 1 t of aluminum from bauxite requires 12,000 kW·h of electricity. An ingot of aluminum is in fact a concentrate of energy. It is obvious that a long-term strategy for this metal (and many others) can't be disconnected from the energy facts.

Managers need to have a vision and be able to transmit it to the organization. Each company has its cultural "genes," the evolution of which is neither easy nor fast. Long-term strategies need to be followed by "genetic mutations" that can only be forced by strong leadership.

Someone has to do the job of building the future concept of the corporation. This task should be an essential element of the top executive's job description. A CEO must "see the future," create the necessary competences (human, technological, financial), and build the way to it. Most of the abrupt changes presently seen in companies' top management are not motivated by a lack of capacity for managing the present but because of insufficiencies in building the future of the corporation. Strong, intelligent chiefs are a rare species, expensive and not easy to find, but indispensable. They should be able not only to design the future but to decide at what pace the company should reach it.

Corporations are complex, dynamic systems in which the cause/effect relationship is not always evident or intuitive. Massachusetts Institute of Technology professor Jay Forrester[11] has developed models that attempt to quantify the effect on performance of the multiple internal and external factors. But in practice its application is not simple and most of the time managers must compensate for the lack of a rigorous approach by pragmatic experience/intuition-based decisions, built on team-developed foundations, as well as on experience and a deep knowledge of markets and competitors. The results are often surprisingly good, which proves that, once again, a manager's personality and leadership are essential conditions for winning strategies.

The same qualities are necessary for managers to obtain the loyalty of their employees and to implement the strategy successfully. When the turnaround of the company is evident, the employees find themselves happy and motivated.

Special Characteristics of the Minerals Industry

The concepts exposed are applicable to a broad range of activities, although the ones that are more significant for the minerals industry have been emphasized. Some characteristics of the minerals industry are special and not shared with many other sectors.

Contrary to most activities, a mine's geographical location is imposed. A mine cannot be moved as a factory or a commercial unit can. When the orebody has been discovered, some of the parameters of the future business are already locked: geographical location, political environment, availability of energy and water, transportation conditions, climate, and so forth. Little can be done to change these parameters.

Considering that labor, energy, and transportation are usually the most important components of the cost, it is easy to understand that the location of an orebody is a major element in the strategy of the business. The comparative net present value of two ideally equal mines depends on where they are located.

The mining activity strongly interacts with its social and ecological environments. Probably no government will oppose the existence of a computer research center, but it will have something to say in the case of a new mine or smelter. Even if the apparent economic returns for the host country (or region) constitute a powerful incentive, the drawbacks of the mining activity are considerable. The conditions imposed will surely be constraining, sometimes not counterbalancing the benefits expected from the operation.

Another particularity of the minerals industry is the relatively small number of actors. Mining production involves relatively few companies. The consolidations that have taken place lately reduced this number even more. Smelter activity is even more concentrated, with a smelter typically having sufficient capacity to process the production of several mines.

The products of mines and smelters (concentrates, materials, metals, alloys) are not always sold to end users. This particularity, together with the long cycle between the extraction of the ore from the mine and the use of the metal by the manufacturing companies, introduces a hysteresis or lag in effect in the transmission of the market signals from the end user to the miner. The miners know their clients, the smelters, well but have little knowledge about the manufacturers' activity and even less of the end users'. This circumstance places additional difficulty on the task of building the strategy of mining companies. The more a mining company is integrated downstream in the value chain, the better its vision will be on the future uses and prices of its products.

Prices for some important mining products are determined daily by organized markets (LME, Commodity Exchange [COMEX], New York Mercantile Exchange [NYMEX], and others) and are applicable to most transactions. These markets provide instruments (derivatives) that allow the sellers and the buyers to operate with future prices, fix prices over a certain period, or limit the range of prices applicable during a given interval of time. The LME, COMEX, and NYMEX markets provide services like pricing, hedging, and physical delivery for most commercial metals. The LME holds a large network of warehouses throughout the world where producers can sell metals at prevailing daily prices and customers can buy them at published, transparent prices.

Although it has other virtues, the existence of physical metal stocks at the LME warehouses brings up delay in companies' reactions, complicating their strategic thinking. A mining company can increase production over the level demanded by its clients and sell the surplus to the LME. Increasing capacity reduces the unit cost immediately, and the products will not augment the companies' stocks because they can be sold to the LME. But in the long term, prices will go down under the pressure of the increase of LME stocks, and the total industry will see decreasing profits (and not only the companies that originated the stocks).

Not all prices of mining products are determined by commodity exchange pricing. Some, like coal, bauxite, iron ore, or minor metals, are negotiated directly between sellers and buyers. These specificities make the strategic planning exercise of mining companies (and, more generally, commodities companies) particularly complex.

EXTERNAL FACTORS INFLUENCING THE STRATEGY

External factors are referred to as those business factors that are imposed on a company by its external interface and which it can do little to change. The legal framework, market structure, financial partners, politics, society, and competitors are external factors, given that they exist and function independently of the will of the company. Although the company can have some leverage on some of them (e.g., lobbying and publicity), they cannot be considered as variable parameters in the strategic equation. Nevertheless, they are essential in the construction of the company strategy.

The Legal Framework

The *legal framework* is probably the external factor that most constrains the strategy of a mining company. Mining operations are linked to a specific geographical region (i.e., country, state, province, and town), and the applicable law within the region establishes the legal framework of the activity, the boundaries of what a company can or cannot do with the different components of the business.

During the exploration and development stages, a mining company must follow a specific regulatory framework (and pay taxes and royalties as required by law) in order to obtain and retain the exploration claims and mining concessions. In this process, the company must interact and subscribe agreements with the appropriate government agencies, evaluate risks and opportunities, and make strategic decisions accordingly. Also, mining companies must negotiate and agree with landowners to gain access to the land required for the exploration and mining activities.

Mining companies require government permits during all stages of the mine life cycle. For example, permits are required during the prefeasibility and construction stages (e.g., project, roads, power lines, water supply, environmental), mining operations (e.g., mine plan, blasting, and ore transportation), and mine closure (e.g., reclamation, decommissioning, postclosure).

Corporate, environmental, labor, commercial taxation, and many other business issues are subject to laws and regulations that are specific to each country or region. Expatriate company executives managing mining operations abroad frequently make the mistake of trying to extrapolate situations that were analyzed under the prism of their country's legislation. In this context, the company, as well as its executives and staff, may incur liabilities in relation to the mining activities. Proper consideration must be given to this, as the associated costs could change the substance of the strategy.

As several chapters in this book discuss, environmental regulations are becoming an increasingly important strategic factor for the mining sector, so they need to be carefully considered before any decision is made.

The main target of any strategy is to maximize the shareholder value. In this regard, the applicable fiscal laws must be considered cautiously because this may become an impediment to reaching the financial goals. It may be advantageous to establish alliances and get the help of local companies or individuals. This is a pragmatic way of coping with country and local regulations.

If the standards and governance rules of the company ask for a universal application of some principles, it shall be necessary to evaluate their impact on the project carefully.

None of this is banal. The feasibility of a mining project often depends on the strategic trade-offs management will take during negotiation with the local authorities. The economic and financial analysis of mining projects must include a realistic estimate of all costs associated with legal issues during all stages of the mine life cycle and consider how far the company can go, integrating the margins of error, and keeping in mind that other competitors may also be candidates for the business.

Shareholders' Role and Influence

Shareholders are the ultimate drivers of a company's strategy. In addition to the ownership of shares of publicly held corporations, shareholders have other rights, among them the right of information and the right to influence and approve certain management decisions. These rights are exercised mainly through voting at the general shareholder meetings.

Principal shareholders are those who own a substantial stake in the company and have significantly more power than small shareholders. Even if their stake is lower than the legal voting majority, principal shareholders may have real power over management, and often, the dispersion of ownership makes it easier for them to achieve formal control of voting and thus decisions.

Small shareholders do not usually have significant influence on the company. However, they can reinforce their influence by creating *shareholder associations* or *shareholder committees*. The shareholder associations work outside the framework of the corporation and are often led by corporate law professionals. Shareholder committees are internal bodies resulting from the cooperation between management and shareholders, aiming to improve communication and transparency.

The by-laws of each company set out the procedures by which certain management decisions (like changes in strategy) must be submitted to the shareholders for approval. Even if it is not legally required, it is a sound management practice to submit the matters concerning long-term strategies for shareholder approval. It is also important that political, social, and environmental issues are included with this information because shareholders are increasingly concerned about the sustainability performance of the company.

From an economic viewpoint, the mining business has two distinctive characteristics: (1) it follows a cyclical pattern, and (2) it requires substantial capital investments with long-term maturity. Evidently, a business with these characteristics calls for solid shareholders, that is, investors willing to commit a considerable amount of capital in volatile ventures and to wait years for a return. For example, the initial capital investments in a mining project must not only pay for the exploration costs but also for development of the mine and plant facilities, site development infrastructure, and overburden waste removal; there may be years of negative operational cash flow. A frequent joke among mining professionals says that the ideal shareholder must have "deep pockets and large shoulders." In this context and in the case of stock or bond issues and other financial operations, a major strategic task for top management is to seek the right investors who will became future shareholders.

Markets

Metals and minerals markets are singular commodity markets. They are global, and the producers (the mining companies) are somewhat disconnected from the end users. Metals and minerals are homogeneous, nonperishable products, traded mainly on the basis of price with a comparatively small number of suppliers and clients. In this context, decisions concerning markets are of strategic importance. Quantities, qualities, costs, and destination are issues that can make the difference between successful and unsuccessful mining companies.

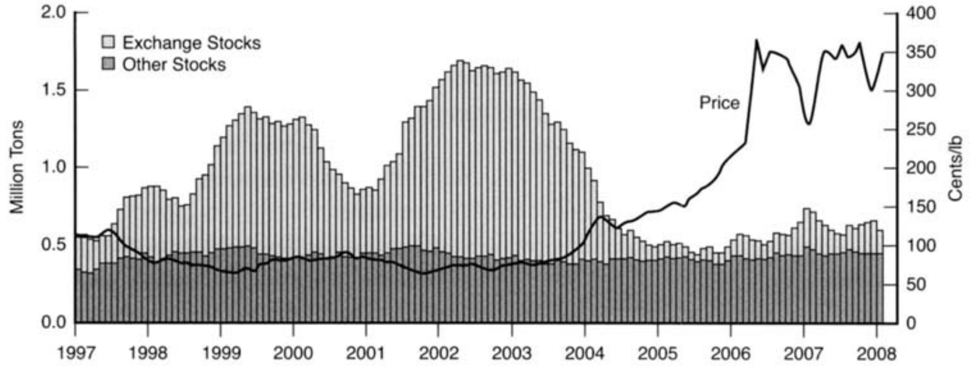
Metal concentrates are nonstandard products and each mine has its own concentrate signature (i.e., differing grades, fluxes, impurities, and by-products' content, grain size, flow moisture point, self-oxidizing behavior). Even concentrates produced at different moments in a mine's life can be fairly dissimilar. Smelters may require a specific flow sheet to process a specific metal concentrate. Therefore, one of the first strategic decisions to be made during the preproduction stages of a mining project is the choice of smelters that may be technically and economically suitable for processing the concentrates. Changes in the flow sheet and capacities are possible, although expensive and technically complex for both mines and smelters. Given the capital investments involved, mistakes at this stage can be fatal. On the other hand, the geographical location plays an essential role, as it affects the transportation and distribution cost of the products.

Another factor requiring careful consideration during the feasibility stage is the effect on the market of the new capacities brought on stream by the project. Critical to this effect are the analysis of consumption trends, the spare capacity of the competitor's facilities, and the impact on prices and markets of the new production. Hence, the price scenario used for the final feasibility study should be established after due consideration of the effect on prices of the increase in supply. This effect will be higher if the production capacity added by the project is higher relative to the total market of the related commodity.

Another strategic issue is the possible convenience of the mine/smelter integration. If production capacity is large enough and local conditions are adequate (i.e., energy cost and supply, transportation infrastructure, labor availability and cost, access to harbors or railways), the construction of an on-site smelter may be a good option. Vertical integration can also be realized when the concentrates are processed in smelters owned by the same company if they are close enough to the mine. Other strategic options for the concentrates are swapping with competitors or selling them in the concentrate markets. In all cases, the factor that weighs most heavily in this strategic decision is cost. The structure to be adopted is often the one that minimizes the total cost of the chain from mine to clients.

If concentrates are to be sold to third parties, an important strategic issue is deciding the number and structure of the agreements with customers (e.g., amounts sold through long-term agreements with smelters versus short-term sales to concentrate traders, swapping conditions for third parties).

The market strategy should integrate the risk of product substitution (which is linked with prices), the quality requirements of potential buyers, and the environmental conditions. There are many examples of product substitution in the metals sector. Aluminum cans are progressively replacing tin-coated steel cans. Plastics can often be substituted for steel in the automobile industry (at least partially). Organic molecules can replace bismuth in pharmaceutical applications. Clay or cement shingles can replace zinc sheets in roofing. Polypropylene plumbing pipes take the place of lead and copper. Lead could be replaced, at least partially, by nickel or cadmium in the battery industry. Metal oxide pigments can be replaced by organic pigments. A prolonged shortage of a specific metal can cause sharp increases of prices, thereby inducing goods manufacturers to substitute more economical raw materials. Negative environmental effects can dramatically reduce the use of some metals, such as is the case with mercury and cadmium.



Source: Rio Tinto 2008 Chart Book

FIGURE 4.5 LME stocks and metal prices

Price Mechanisms

The main characteristic of the metals supply/demand balance is low supply elasticity. Smelters generally operate at close to 100% of nominal capacity and have very little flexibility in changing production rate. This is a requirement to reduce costs: the bigger the production is, the lower the fixed cost per ton. Mines are designed for a given production capacity, and a production increase requires capital investments and time for implementation. It is difficult for a mine operation to cut back on production because unit prices would increase and competitiveness would erode. As a consequence, supply is unable to react rapidly to changes in demand, thus generating stress and price volatility in the market.

Changes in demand generate variations in stocks (very visible through the LME warehouses' stocks) and stresses in supply (Figure 4.5). From the customers' perspective, adjusting to price fluctuations is not easy because product substitutions require changes in technology that only make sense in the long term.

Mines and smelters are also subject to sudden incidents that can cut production (e.g., accidents, breakdowns, strikes, or unforeseen environmental problems). Depending on the amount of production loss, these incidents may have a significant impact on metal prices.

Metal prices are global, established daily at organized market platforms like the LME or the New York–based NYMEX or COMEX exchanges. LME is the world's premier nonferrous metals market.[12] In addition to pricing, LME provides services like hedging future price risks, physical trading, storage, and delivery. Prices are fixed daily as the result of a high volume of trading on the "ring." Producers and consumers can hedge at the LME as well. Hedging allows for managing the risk of price changes by offsetting that risk in the futures markets. Through hedging, the industry can decide on the level of risk it is prepared to accept. The LME can physically buy and deliver approved brands of metals from its authorized warehouses. The level of stocks in these warehouses is published daily, along with the prevailing prices.

The United Nations study groups (copper, lead, zinc, and nickel) are intergovernmental organizations that periodically provide a source of industry statistics about production, consumption, new project status, and other essential information on the metals industries and markets. Their role is to contribute to the transparency and equilibrium of these markets. They also provide forums in which industry and government representatives can exchange information.

A number of professional organizations are financed and steered by the industry. They work on subjects of common interest for all members with respect to the laws of competition. Among other tasks, they develop statistics that help the industry in understanding the market situation.

All these data and facts together help industry strategists gain a better understanding of the future evolution of markets and prices.

LME physical stocks and metal prices are inversely correlated. Figure 4.5 presents the evolution of copper prices and LME stocks of this metal[13] from 1997 to 2007. Although the correlation is not perfect, it can be seen that, in general, higher prices correspond to lower stocks and vice versa. The evolution of stocks (sum of LME "visible" stocks and the ones in the hands of producers, consumers, and traders) is a good indicator of future price trends, which is broadly used by tacticians to forecast short- and mid-term price evolution.

The study of the variations in the LME physical stocks is one of the tools that the industry uses to forecast future prices. Strategic hedging decisions are an important consequence of this.

Regarding risk management policies, there are basically two doctrines: one that maintains that price fluctuation is a normal market phenomenon and companies must live with it and assume the economic consequences, and the other that defends the idea that the intelligent use of derivatives limits the risks and maximizes the margins of the companies. There are companies adopting each of these doctrines and it is difficult to argue for or against them. What is clear is that, given its importance, the issue of price risk management is strategic and companies should publicly state their hedging strategies to allow stakeholders to act accordingly. In fact, the real and difficult issue is the balance between cost and benefits as a consequence of these two strategies.

It is therefore important that management seeks shareholders' approval of their policies on fixing and/or hedging metal prices, exchange rates, or interest rates. Price hedging is generally considered as a conservative strategy, allowing smelters to buy concentrates and sell the metal contained at the same price paid a few months before (independent of the price fluctuations that may have occurred). It limits losses if prices go down but also prevents profits if prices go up. On the other hand, fixing the future prices or exchange rates implies a bet on unknown events. All players, including the shareholders, can have an opinion about this. If things turn out wrong, the financial consequences can be enormous. Shareholders often say, "Managers are paid to run the company, not to gamble with our money."

Finally, regarding the utilization of derivatives, one must consider that their use requires highly specialized knowledge and tight control of these activities by top management. History is full of cases of the misuse of these financial instruments and its catastrophic consequences. Also, the operating cost of the group in charge of these operations within the company's organization can be substantial and may offset potential benefits.

Financial Strategy and Corporate Finance

Financial aspects are among the most important external factors affecting a company's strategy. Financial resources are scarce and often impose limits on the activities of a mining company. Therefore, as the company develops its strategy, the issue of how to finance its activities often arises. Three financing mechanisms are possible: (1) use of internally generated funds, (2) use of debt, and (3) financing by equity. Each one has its own advantages and drawbacks.[14]

A first element of financial strategy is of a fiscal nature. Interest and dividends are both financial costs, but interest is deductible from taxable income, while dividends on common stock are paid out of after-tax income. Therefore, a company pays lower taxes when financed by debt.

Sources on Percentage of the Total Expenditures

	A	B
• Internally generated cash*	72%	52%
• Financial deficit	28%	48%
• Covered by:		
- Net stock issues	4%	34%
- Net increase in long-term debt	20%	10%
- Net increase in short-term debt	4%	4%

*Cash flow from operations less cash dividends paid to stockholders.

FIGURE 4.6 Two examples of sources and uses of funds in mining companies

Issuing securities implies a set of formalities that consumes time and money. It also involves an exercise in transparency and publicity that some companies may not want to go through. On the other hand, a loan implies a deal between the company and its banker; therefore, the facts and strategies of the company are disclosed to a lesser extent.

Those in the financial world (analysts, banks, investors) carefully watch the debt/equity ratio of mining companies. This parameter is considered as one of the indicators of financial health. Too much debt versus equity can be considered as a weakness and might affect the share value. The structure of funds of most mining companies shows that the internally generated cash is preponderant over the stock issues and the short- and long-term debt. In fact, this structure is not exclusive to the minerals industry. The adoption of a scheme for financing the activities is a strategic decision and is part of strategic planning.

Figure 4.6 shows two case examples of sources and uses of funds. Case A refers to a company with high internal cash flow, which implies a low financial deficit, covered mostly by long-term debt. Short-term debt is used mainly to finance current commercial activities and small investments. Case B presents a company with lower internally generated cash flow, which leads to a higher financial deficit. Investments and working capital are covered by stock issues and long-term debt. Companies represented by Case A have a strong actual cash flow and will use it to finance new projects. Companies represented by Case B, although they may have high potential, have low cash flow, so they need to seek investors to finance their projects.

The minerals industry is a cyclical one. There are endless discussions about the structure and interval of these cycles, but it is well known that a period of high prices is always followed by one of low prices and vice versa. The length of these cycles can be tens of years. Managers must know how to deal with this phenomenon, which affects the ability of the company to invest and compete. Intuitively, one might gain the impression that the time after a high activity period is when the company is in the best position to undertake new investments and projects. What happens in reality (Figure 4.7) is quite to the contrary.

When pulling out of a recession, mining companies are not operating at 100% of capacity. They sell from existing stocks, which releases cash, and they do not invest heavily because they have spare capacity. After a peak in the cycle of economic activity, companies are immersed in substantial investments and new projects, so they may have difficulties in adjusting their expenditures to the recession. At the same time, their sales decline and the need for funds increases.

An important component of the strategy of mining companies consists of anticipating the effects of the cycles on their financial equilibrium. The deep ups and downs of prices can shake a company's financial system and force managers to adapt their decisions accordingly.

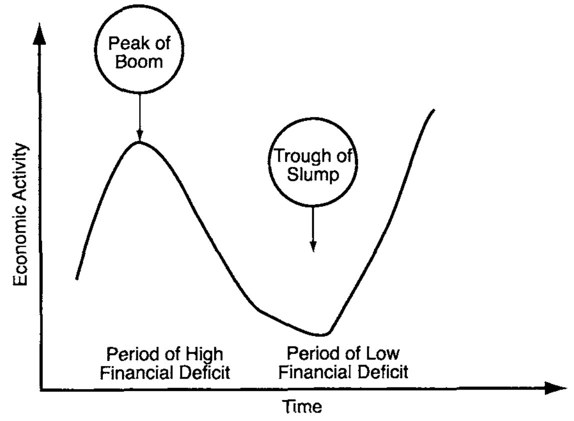


FIGURE 4.7 Financial deficit versus economic activity

Politics, Society, and the Corporation

Today, mining and smelting are controversial activities. The intensity and importance of the political and social interactions are higher than for most other industries. The latent value of a mining asset can only be achieved if the company is able to obtain what has been called "social license" and runs its operations in compliance with the specific conditions of the host country and local communities.

"Know-how" on social and political management represents an important competitive advantage today. Some mining and metals companies have developed specialized skills to operate in specific social and political environments. This is the case with Teck Cominco in the Arctic mines or Umicore in the heart of the most densely populated regions of Europe.

Some years ago, mining companies' activities mainly consisted of finding the best possible orebody, extracting the richest ore as quickly as possible, and moving to another place to start the process all over again. However, as social and environmental sensitivity grew, mining companies became conscious of the environmental and social impacts of their activities. Governments progressively tightened environmental regulations as society became increasingly aware of ecological matters. The notion of sustainability is rapidly gaining importance, but the speed of this process is different among countries. It may take decades for environmental regulations in certain developing countries to reach the level of severity of those already in force in some industrial countries (Sweden, France, Germany, the United States, and Japan). Environmental organizations are gaining importance worldwide. Today, their membership, financial capacity, and influence have reached a considerable level.

This increasing ecological awareness has manifested itself in many countries as a surge of "green parties"—political parties whose programs are for the most part ecological. These parties are gaining strength in many countries, especially in those of the European Union. Their presence in the European Parliament (as of the most recent elections in 2004) is assured by two parliamentary groups, the European Greens/European Free Alliance and the European United Left/Nordic Green Left, which represent 83 members out of a total of 732, for 11% of the total membership. In fact, given that public opinion today is sensitive to sound ecological principles, most of the other political parties include some "green" ideas and projects in their programs. Obviously, these circumstances have a strong influence on national environmental policies and

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regulations. Given the representation of the dominant parties (European People's Party/European Democrats and Party of European Socialists), the "green" parties have a certain role of arbitration, which gives them more effective power than their numerical representation might otherwise indicate.

The laws reflect equilibrium among social forces that defend their own interests. In the specific case of the environmental and sustainability matters, two opposing forces try to influence legislators. They are what Paul B. Downing calls the "emitters lobby" and the "receivers lobby,"[15] where each lobby represents a sector of the society. The former defends the potentially polluting activities while the latter defends the environment. Although the emitters have the strength of monetary resources, the receivers have the strength of the votes. In the context of the minerals industry, the emitters are represented by international professional associations such as the International Council on Mining and Metals (ICMM),[16] European Association of Metals (Euro-Metaux),[17] Independent Petroleum Association of America,[18] American Petroleum Institute,[19] and European Petroleum Industry Association,[20] among others. The receivers are represented by international nongovernmental organizations (NGOs) like the International World Union for Conservation of Nature,[21] World Wide Fund for Nature,[22] Friends of the Earth International,[23] and Greenpeace International,[24] among others.

The organizations representing the industry, like ICMM or EUROMETAUX, strive to convey to the public and authorities the image of an industry that cares about the environmental and social impact of its activities, playing the role of interface between corporations, political authorities, and society. They make available to the companies updated information about the legislative and social trends of the countries in which they operate, gathering scientific evidence on the effects of mining and metals activities on the environment or human health. On the other hand, the ecological NGOs defend the public and the ecosystem in general from potential aggressions from the industry and put pressure on the legislators to implement more stringent environmental rules. Both sides are well organized and well financed. They have traditionally had a difficult dialog, although since 2003, the world forum organized by the Global Mining Initiative in Toronto has resulted in an improvement in their relationship and exchange of ideas.

Today, it would be unconceivable that a corporation could build its strategy while ignoring its social environment and without developing an adequate social interface. The success of mining and smelting activities is greatly dependent on the ability of managers to interact and understand the requirements of the society. Basic rules must be respected: for the industrialized countries, "be a good neighbor"; for developing countries, "be a good partner"; for indigenous people, "be respectful."

The way in which the mining rent is distributed between mining companies and host countries is still a highly controversial subject. If the total tax[25] (sum of royalties and other fiscal taxes) is too high, the companies would not be encouraged to explore and invest and, at the limit, would discontinue existing operations with the corresponding permanent loss for the host country. If the tax level is too low, more companies will be encouraged to invest, but their activity will not benefit the local economy sufficiently. An optimal level exists between these two extremes and should be sought. Experience demonstrates that a fluid dialog between the two parties is best. A last consideration is the effect of price fluctuations on the government's attitude: when the prices are high, the temptation to increase taxes is high, too. If the prices drop, it will be difficult to return to the previous tax levels. Again, a transparent attitude on the part of the companies, explaining the effects of price volatility over the long term, would help in finding the right balance.

CHAPTER FIVE

Integrating Sustainability into the Organization

J. A. Botin

INTRODUCTION

In an industrial context, management deals with optimizing the use of human, material, and financial resources in *operationalizing* strategy goals. Today, sustainability is a fundamental pillar of a mining company's strategy; therefore, sustainable mine management may be conceived of as the process of operationalizing the sustainability principles of a mining company. Most mining companies state their commitment to the values of sustainability in their vision declarations and policies. However, not many achieve an efficient integration of those values down into the operational levels of the organization.

Corporate commitment is an essential condition for integrating sustainability, but it is not sufficient. Another key condition is a business culture in which sustainability is a high professional and business value and objectives are implemented through commitment rather than compliance. Furthermore, the integration process requires of an organizational structure specific roles and integration mechanisms[1] and adequate information management systems.

Therefore, the sustainability challenge is (at least in a mining context) on the side of management. This is evidenced by the strong management focus of the sustainable development frameworks proposed by the International Council on Mining and Metals (ICMM),[2] the United Nations (UN) Global Compact,[3] and other multiparticipant initiatives offering policy guidance on sustainable development to the minerals industry, such as these examples:

- The ICMM's "10 Principles of Sustainable Development," a framework for the integration of sustainability into the company structure, focuses on concepts such as culture, structural integration, strategy implementation, continual improvement, and so forth, all of which are challenging management tasks.
- The UN Global Compact, a globally recognized framework for corporate responsibility and ethics, states: "To achieve sustainable development, environmental protection shall constitute an integral part of the business process and cannot be considered in isolation from it." Again, this implies complex management tasks and management systems.
- Equally, the "Towards Sustainable Development Initiative"[4] emphasizes business culture as a requirement for integration when it states: "Our actions must reflect a broad spectrum of values that we share with our employees and communities of interest, including honesty, transparency and integrity."

This chapter focuses on the integration of sustainability down to the operational levels of mining companies, the organizational structures, and the management roles and systems required for integration. The chapter is composed of six sections.

"Organizational Structure for Sustainable Management" deals with the organizational structure of mining companies, focusing on the positions, roles, and other integration mechanisms and systems that are required for the integration of sustainability values at operational levels.

"Integration of Sustainable Development into Mining Operations" provides the authors' perspectives on sustainable development and its incorporation into corporate strategy. It also attempts to make the critical link between sustainable development at a corporate level and how it is effectively translated and implemented on the ground in actual mining operations. Several useful views from mine managers on the challenges and nuances of making sustainable development work in a mining context in a developing country are presented.

"Managing for Stakeholders' Expectations: The Seven Themes of Sustainability" provides an approach to sustainable mine management that relies on combining the sustainability expectations expressed by local stakeholders and those identified in corporate plans and guidelines to sustainable development.

"Environmental Management System: A Sustainable Management Tool" focuses on environmental risks and describes the process of implementation of a certified environmental management system (EMS) in a mining operation and the advantages of its implementation during the preproduction stage. It also analyzes the advantages of operating under an EMS in terms of operational efficiency, public image, and involvement of stakeholders.

"Case Study: Partnership for Sustainable Development in Ghana" describes the various components of the strategy employed by Gold Fields Ghana to maximize the effectiveness of its sustainable development programs and to create a leading example of best practice in the international mining industry for community engagement and sustainable development.

"Case Study: Industrias Peñoles—A Large Organization Committed to Sustainability" describes the organizational structure of Peñoles and how the strategic objectives of sustainable development are integrated across the organization by means of the MASS System (Environment, Safety, and Health System).

ORGANIZATIONAL STRUCTURE FOR SUSTAINABLE MANAGEMENT

As a fundamental area of corporate strategy, sustainability must be integrated into the organization at all management levels. The integration process, often difficult and challenging, requires an organizational structure with integration mechanisms, management roles, and systems ensuring proper communication, coordination, and control.[5]

Conceptually, the design of the organizational structure of any company results from the following three business processes:

- A segmentation process, whereby decision authority and responsibility is divided into several operating units;
- An integration process, focusing on the implementation of certain mechanisms (integration mechanisms), ensuring that the operating units resulting from segmentation operate in alignment with the corporate strategy; and
- An empowerment process, through which the decision rights—executive and controlling—and responsibilities of each operational unit and each management level are defined.

The main characteristic of the organizational structure of a company is the criteria used for segmentation at the top management level (i.e., senior officers and vice presidents). These basic criteria identify the different types of organizations. Typically, mining companies may be segmented by functions (e.g., production, engineering, marketing), by divisions or business units (e.g., energy coal, base metals, gold), or through some combination of both descriptors. In some cases, segmentation is, to a certain degree, two dimensional (i.e., matrix organizations), where some positions have a double dependency (i.e., to the business unit managers and to the country managers) as the means to ensure that key strategic decisions are made after considering the local constraints.

Any organization needs *integration mechanisms* so that segmentation does not result in strategic misalignment among the segmented parts. Hierarchy is the main integration mechanism, but organizations require other means of integration, such as business culture, corporate plans and policies, staff roles, management information systems, and integration structures such as committees, task forces, and so forth.

The empowerment process aims to optimize the degree of autonomy or decentralization of decision making in the organization. The degree of decentralization and autonomy is mainly related to the size of the company, the geographical dispersion, and the nature and strategic diversity of its business but also on business culture and the information technology (IT) management systems available. Conceptually, maximum decentralization is always desirable, provided that decisions are coherent with company objectives and the decision-maker has the information, the professional capacity, and the motivation required for deciding. In each case, these constraints establish the limits to decentralization.

The structure of a company should focus on a correct balance of segregation versus integration, strategic coherence versus flexibility, and agile decision making versus information requirements.

Organizational Structure of Mining Companies

The criteria for the structural segmentation of a mining company follow. (Figure 5.1).

Small Mining Companies

Functional segmentation is a standard for small mining companies operating one or two mines in a single geographical area. In this structure, functional managers report to the top executive (i.e., chief executive officer [CEO], chief operating officer [COO], or executive vice president). For example, the company in the organization flowchart in Figure 5.1 is segmented into five functional areas (e.g., mine production, human resources, environmental health and safety, technical services, and finance and administration).

Also, the functional organization is an industry standard for unit mining operations within medium-sized and large mining corporations. For example (Figure 5.2), the Podolsky mine (FNX Mining Company) in Sudbury, Ontario, is organized in six first-level positions:

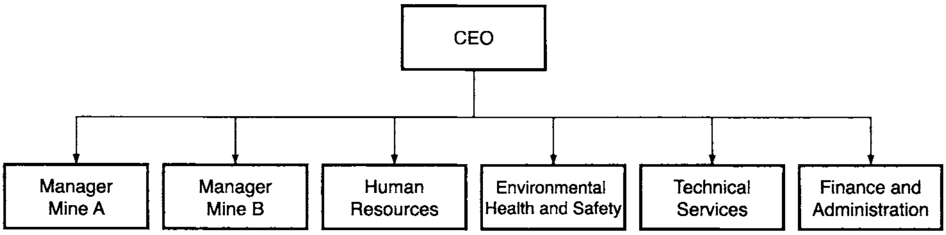


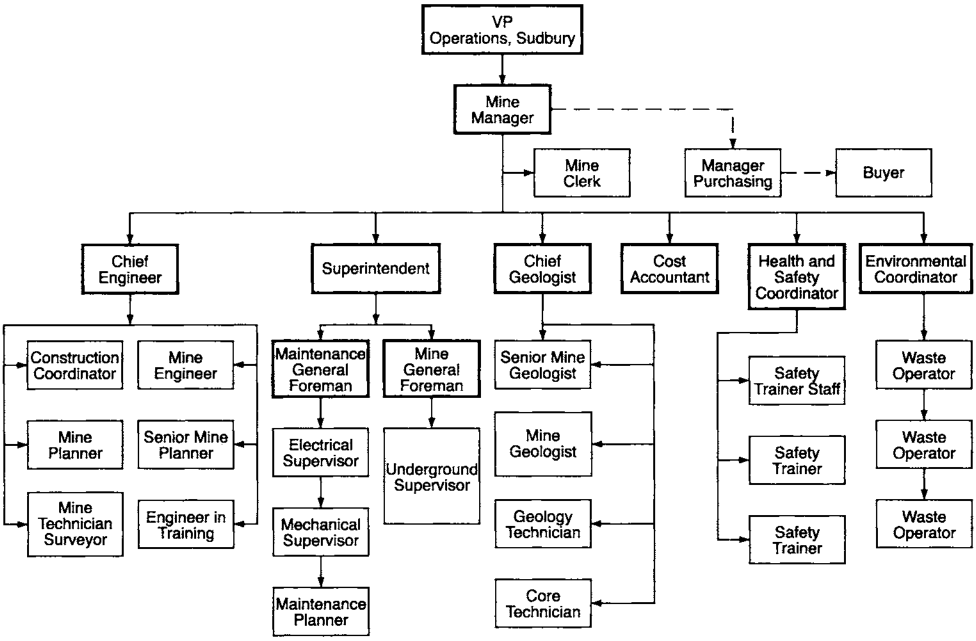
FIGURE 5.1 Typical flowchart of functional organizations

- The chief engineer, accountable for mine planning and engineering;
- The mine superintendent, accountable for production;
- The chief geologist, accountable for ore reserves management and grade control;
- The health and safety (H&S) coordinator, accountable for H&S coordination and control;
- The environmental coordinator, accountable for the coordination of environmental plans; and
- The cost accountant, accountable for the cost control system and cost reporting.

Also, as shown in Figure 5.2, unit mine operations use functional segmentation to organize the second and third organizational levels. In some cases, sustainability is considered a function and becomes the responsibility of a functional manager. In the organization outlined in Figure 5.1, this is the manager of environmental health and safety, who is accountable to the top executive.

Functional organizations are ideal for a single mine or a small mining company operating two or three mines within a small region. The functional managers reporting to the top executive (i.e., the general manager or the CEO) are specialists in their fields, thereby allowing for a simple and cost-efficient structure. However, being specialized professionals, functional managers often lack overall business vision, so the important decisions tend to get centralized at the top level. As the company grows larger, this dynamic can compound to make decision making slow and inefficient.

Because of this constraint, as mining companies grow larger and become the operators of several mines and projects and/or expand their activity into two or more geographical regions or countries, the organizational structure must change from functional to divisional, as described in the following paragraphs.



Courtesy of FNX Mining Company

FIGURE 5.2 Organizational flowchart of Podolsky mine

Medium-Sized Mining Companies

The organizational standard for most medium-sized and large mining companies is divisional segmentation, where the segmentation criteria may be the product (e.g., coal, copper), the region, the business unit, or a combination of these criteria.

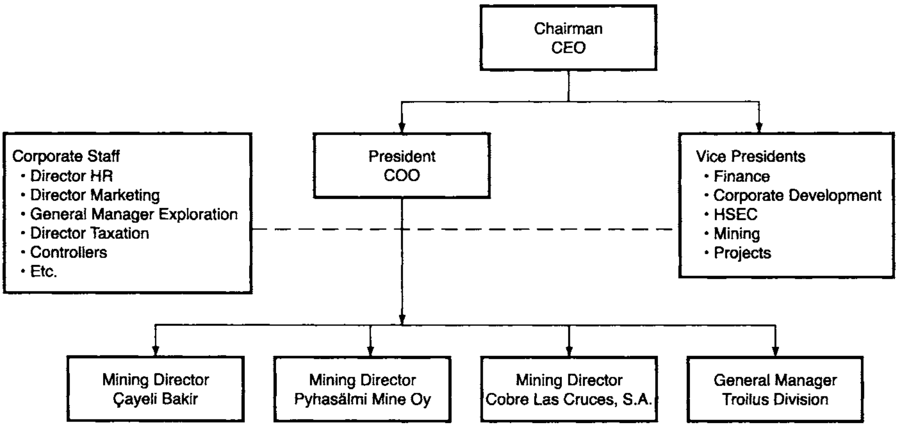
As an example, Inmet Mining, a Canadian copper mining company that produced some 80,000 t of copper in 2007, is expecting to grow to a copper production of approximately 260,000 t in 2011.[6] The company has become global with operations in Canada, Turkey, Finland, and Spain and minority interests in Papua New Guinea and Panama. The company is organized in four operating divisions, as shown in Figure 5.3.

A typical divisional organization decentralizes operational responsibly down to the division level but remains centralized at the corporate (top) level for some strategically important functions in order to ensure alignment with corporate strategies and to prevent excessive redundancy of services. Typically, centralized functions are financial strategy (vice president of finance), corporate development; health, safety, environment and community (HSEC)/sustainability strategy; human resources (HR) policies; and others.

Furthermore, this increased decentralization of decision making down to the divisional levels requires the implementation of significant IT systems and the acceptance of some level of functional redundancy in the organization. In any case, an adequate balance between division autonomy, corporate strategy, and cost-efficiency must be the leading consideration.

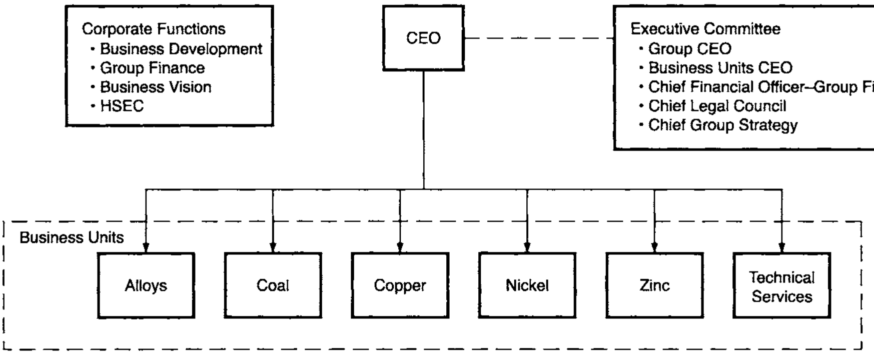
Global Mining Giants

The organizational standards for the global mining giants (e.g., BHP Billiton, Xstrata plc, Rio Tinto, Anglo American, CVRD, and others), although formally divisional, goes one step further by allowing for some degree of strategic diversity. Although in the conventional divisional organization (Figure 5.3) the strategy is unique and centralized at corporate level, global mining giants become *business conglomerates* operating in two or more business sectors within the minerals industry (e.g., metals, energy coal), each with a specific business strategy, legal structure, and financial services. Here, the corporate (top) level retains the functions that are necessary to maintain a common business mission.



Source: Data from Inmet's Web site

FIGURE 5.3 Divisional organization flowchart of Inmet Mining Company



Source: Data from Xstrata's Web site

FIGURE 5.4 Organization flowchart of Xstrata plc

For example, Figure 5.4 shows the organization of Xstrata plc, a mining group with a market capitalization of more than US$50 billion. In 2007, Xstrata was organized into six business units. The group's business vision is summarized as follows:[7]

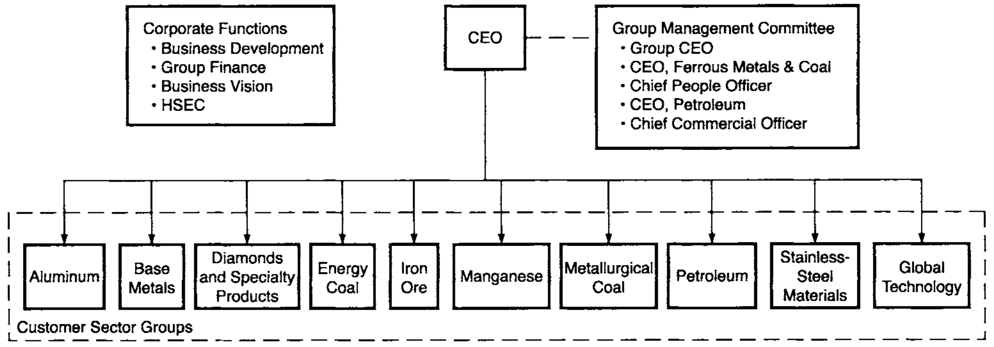
> We will grow and manage a diversified portfolio of metals and mining businesses with the single aim of delivering industry-leading returns for our shareholders. We can achieve this only through genuine partnerships with employees, customers, shareholders, local communities, and other stakeholders, which are based on integrity, co-operation, transparency, and mutual value-creation.

The six business units (alloys, coal, copper, nickel, zinc, and technical services) operate as independent businesses under their own direction, where the business unit strategy is designed to compete in a specific industry sector and to be aligned with the group's business mission. At the corporate level, Xstrata retains executive and controlling functions of group strategy and finance, business development, and sustainability (HSEC).

Another example (Figure 5.5) shows the organization of BHP Billiton, a mining company with a market capitalization of more than US$100 billion. The group is organized into 10 business units, which are named "customer sector groups" to emphasize customer focus. The group's business vision is summarized as follows:[8]

> To create long-term value through the discovery, development, and conversion of natural resources, and the provision of innovative customer and market-focused solutions. To prosper and achieve real growth, we must (i) actively manage and build our portfolio of high quality assets and services, (ii) continue the drive towards a high performance organization in which every individual accepts responsibility and is rewarded for results, and (iii) earn the trust of employees, customers, suppliers, communities and shareholders by being forthright in our communications and consistently delivering on commitments.

In this case, the segmentation criteria is the customer sector groups, where each sector group (e.g., aluminum, base metals, diamonds and specialty products, energy coal, iron ore, manganese, metallurgical coal, petroleum, stainless-steel materials, and global technology) operates as an independent company with its own direction, strategy, and financial and legal services.



Source: Data from BHP Billiton's Web site

FIGURE 5.5 Organization flowchart of BHP Billiton

At the corporate level (Figure 5.5), the Group Management Committee retains the executive and controlling functions on group strategy, group finance, commercial, human resources and ethics, and sustainability (HSEC).

Most other mining giants are also organized as business holdings with some differences in the scope of the group business mission statement and corporate functions.

Sustainable Management Versus Company Structure and Culture

As stated previously, the meaning of sustainability in the minerals industry relates to the responsible and efficient management of mineral assets, human resources, health and safety, environmental, and community issues. To achieve this goal, the values of sustainability must be integrated across the organization down to the operating levels. Efficient integration of sustainability relates to structural and cultural factors, mainly the following:

- Business strategy (vision and mission) on sustainability
- Business culture and leadership
- Structure with specific integration mechanisms (roles, plans, and systems)
- Public reporting standards
- Independent assurance

In the following paragraphs, these factors are analyzed in more detail.

Business Strategy on Sustainability

The vision statement (issued by the CEO) is the directional guideline on the values and purpose of the organization. Here, sustainability must be properly addressed. Today, most mining companies' vision declarations refer satisfactorily to sustainability, as can be seen by the following examples:

- Alcoa:[9] Sustainability is "to deliver net long-term benefits to our shareowners, employees, customers, suppliers, and the communities in which we operate."
- Anglo American:[10] Sustainability is a management focus "on adding value for shareholders, customers, employees, and the communities in which the group operates."

- Newmont[11] values: "(i) Act with integrity, trust and respect; (ii) Reward creativity, a determination to excel and a commitment to action; (iii) Demonstrate leadership in safety, stewardship of the environment, and social responsibility; (iv) Develop our people in pursuit of excellence; (v) Insist on and demonstrate teamwork, as well as honest and transparent communication, and (vi) Promote positive change by encouraging innovation and applying agreed upon practices."
- Newcrest:[12] "To maintain its position as a leading producer of gold and copper, creating shareholder wealth in a manner that also benefits our employees and the communities and environment in which we operate."
- FNX Mining Company:[13] "FNX is committed to providing a safe and healthy workplace; environmental protection for the natural environment; and safety and well-being to our host communities. We will use proven health and safety and natural resource management tools and practices to minimize risk in project exploration, evaluation, planning, design, operation and closure."

Mission statements formulate strategy by targeting the position of the company in the market and the level of excellence required to achieve it. Typically, the business mission addresses sustainability by establishing a "sustainability framework," where a set of corporate policies on sustainability is defined. For example, sustainability frameworks put out policies on the following issues:

- Business excellence for economic sustainability
- Health and safety, human resources, and employee development
- Conservation of the environment
- Social license to operate (local communities, governments, and other stakeholders)
- Code of ethics, public reporting, and independent assurance
- Main sustainability challenges

Business Culture and Leadership

The integration of sustainability in a mining company may imply major changes in the company strategy, and often the company's ability to change the direction of its strategy can be seriously restricted by an inadequate business culture.

Sustainable management is best achieved when business culture is characterized by the following values:

- Sustainability is a self-motivated professional value.
- Sustainability objectives may be implemented through personal commitment of employees rather than compliance with policies and regulations.
- As a result of the first two values, decision making regarding sustainability may be decentralized to the lowest possible management levels.

Regarding leadership, sustainable management finds important synergies with the concept of "transformational leadership." Bass[14] defines transformational leadership as a type of leadership that "... starts with the development of a vision, a view of the future that will excite and convert potential followers. This vision may be developed by the CEO or may emerge from a broad series of discussions .... The most critical aspect is complete buy-in from the leader and/or team which has articulated and developed said vision."

TABLE 5.1 Mechanisms for sustainable development integration

Sustainable Development Integration Roles	Sustainable Development Integration Plans and Systems
Chief executive officer	Corporate charter (vision and mission)
Sustainability committee	Sustainability framework and policies
Vice president, sustainability	Sustainability standards
Division managers, sustainability	Sustainability management system
Site managers, sustainability	Management procedures
	Public reporting on sustainability
	Independent assurance (auditing)

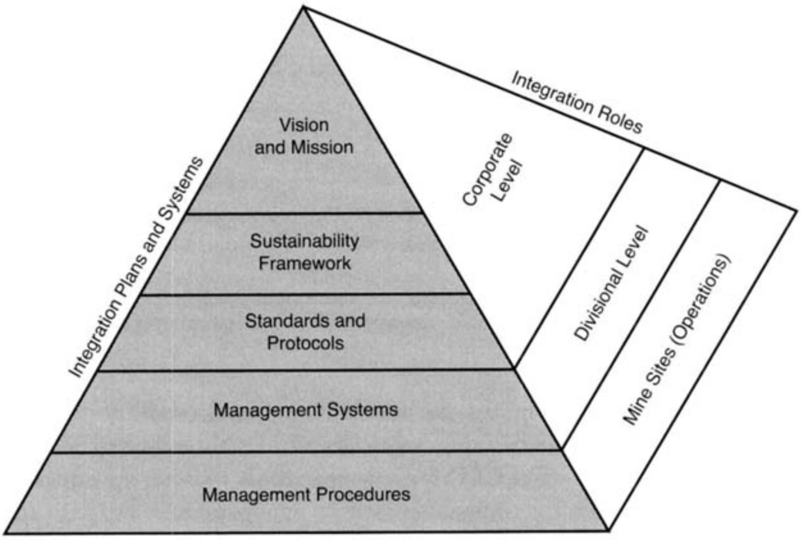


FIGURE 5.6 Hierarchy of sustainability management system

Integration Roles[15]

Methodological aspects of, and exemplar models for, the integration of sustainable development (SD) into the structure of mining companies will be addressed later in this chapter. The following paragraphs focus on the management positions and roles required to support the sustainable management process. These are listed in Table 5.1. The integration mechanisms in Table 5.1 refer to two types of mechanisms:

- Integration roles, i.e., the individual positions or ad hoc committees with accountability for the integration of sustainable development values and objectives, and
- Integration plans and systems, i.e., the policies, standards, and other management tools required to manage for sustainability at operating levels.

Both integration mechanisms—roles and plans/systems—are hierarchical (Figure 5.6), where integration roles act on the line of hierarchy and integration plans and systems integrate the planning, implementation, and control of the sustainability objectives.

As an example, Figure 5.7 shows a structural model for sustainable management of a large mining company (a "global mining giant"). The company in this example has a divisional structure; however, in the case of a small company operation with a functional organization (Figure 5.1),

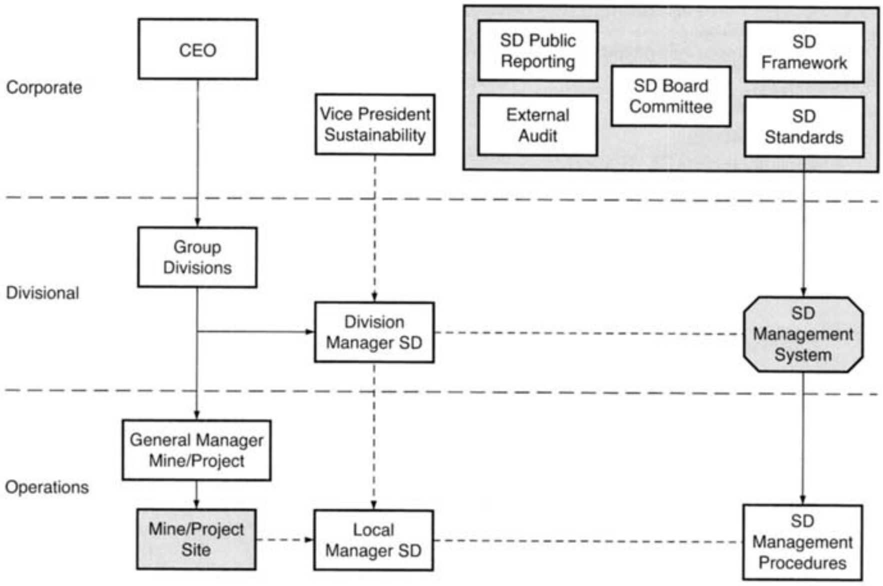


FIGURE 5.7 Structural mode for sustainable management of a large mining company

the model would be conceptually similar, but the divisional level would not exist. The model (Figure 5.7) includes integration mechanisms that are described in the following paragraphs.

The chief executive officer. The CEO formulates a vision, oversees the implementation of strategic plans, and ensures that the company presents a strong, positive image to stakeholders. Regarding sustainability, the CEO presents and reinforces a motivating vision on sustainability and ethics, and formulates challenging goals.

The board committee on sustainable development. Typically, the Sustainable Development Committee is composed of a group of three to five directors appointed by the board. Its main role is to assist the board in overseeing the sustainable development plans and performance, specifically the following:

- Sustainability risks (health, safety, environment, communities)
- Compliance with company's sustainability framework
- Evaluation of results in relation to sustainability standards
- Performance and leadership of the management and staff
- Public reporting and external audits on sustainability

The vice president, sustainability. In most divisionally organized mining companies, the vice president, sustainability, is a staff position reporting to the CEO or COO and is accountable for setting strategy, establishing goals, and integrating sustainability down and across the organization.

This role is critical for the integration of sustainability at operational levels. It has the following functions:

- Leadership, cooperation, and assistance to the divisional heads on sustainability matters
- Leadership and cooperation with HR for the integration of sustainability values in the process of hiring, training, and motivating managers and staff at all levels of the organization
- Leadership of a team of divisional and local sustainability managers and staff

- Accountability for the development and implementation of the Sustainable Development Information Management System, external reporting, and independent assurance on sustainability matters
- Development and maintenance of an external and internal network for information and professional contacts on sustainable development matters

Divisional managers, sustainability. Typically, the divisional manager is a staff member of the head of the division or business unit but maintains a functional dependence on the vice president, sustainability. He or she has overall accountability for sustainable development matters within a division and has a leadership and assistance role for the implementation and utilization of the SD Information Management System, sustainability audits, and SD reporting. In small, functionally organized companies, this position does not exist.

Site managers, sustainability. The site manager is a staff position reporting to the general mine manager or project manager and has overall accountability for the management of sustainable development at the operational level, completing the integration process. In this position, leadership, motivation, and the ability to negotiate with site managers and supervisors are important.

Integration Plans and Systems

The implementation of sustainability plans at operational level requires the use of adequate IT-supported information management systems. Other important integration mechanisms are public reporting and independent assurance (Figure 5.7). Standards, management systems, and procedures are described in the following paragraphs.

Sustainable development standards. The SD standards are a set of management standards issued to interpret and support the sustainable development framework and policy on sustainability at all management levels in the company. Also, the SD standards act to formalize the conceptual base for the design and implementation of specific SD management systems driving the continual improvement objectives of the company.

The SD standards refer to all stages of management (planning, leadership, and implementation and control). For example, Xstrata plc[16] has an SD system based on the following 17 standards.

- Policy and planning standards:
  - Leadership, strategy, and accountability
  - Planning and resources
  - Risk and change management
  - Legal compliance and document control
- Leadership and implementation standards:
  - Behavior, awareness, and competency
  - Communication and engagement
  - Catastrophic hazards
  - Operational integrity
  - Health and occupational hygiene
  - Environment, biodiversity, and landscape functions
  - Contractors, suppliers, and partners
  - Social and community engagement
  - Life-cycle management—projects and operations
  - Product stewardship

  - Incident management
  - Emergencies, crises, and business continuity
- Control and corrective action standards:
  - Monitoring and review

In most cases, mining companies' SD frameworks and standards are designed to be consistent with international environmental H&S standards (ISO 14001,[17] OHSAS 18001,[18] etc.) and international SD frameworks (ICMM, UN Global Compact, etc.).

An SD standard should include the "intent" or management area that addresses the objectives or expectations and also refer to the management procedures for the control of results. For example, Table 5.2 shows an SD standard on health and occupational hygiene from Xstrata plc.[19]

Management system. SD management systems are important tools supporting the integration of the SD management processes (planning, implementation, control, and reporting) at operational levels. An SD management system has several main objectives:

- To support the planning, control, and reporting processes required for the implementation of the objectives and expectations derived from the SD standards for each individual mining operation;
- To establish—for each SD objective—the measurement units and methodology, baseline values, performance targets, and management responsibility;
- Using the "balanced scorecard" system, or other evaluation framework, to integrate system input data values into overall sustainability performance; and
- To produce a hierarchical reporting system to report on performance to management at all levels and to allow for analysis and decision making.

Public Reporting Standards

Publicly listed mining companies are required by stock exchange commissions to issue an independently assured annual report on sustainability, but many nonlisted companies also consider independently assured public reporting essential for maintaining a positive public reputation.[20]

The annual sustainability reports of many mining companies are prepared in compliance with global reporting standards such as the Global Reporting Initiative (GRI),[21] the Mining Association of Canada (Towards Sustainable Mining), and others.

The use of a recognized reporting standard facilitates the inclusion of the company in sustainability indices (Dow Jones Sustainability World Index, FTSE4Good Index, etc.)—indices of companies meeting globally recognized corporate responsibility standards.

Among the public reporting frameworks on sustainability, the GRI is probably the world's most widely used. GRI is a public reporting framework providing guidance on how organizations can disclose their sustainability performance.

The GRI Framework (G3) is accessible online and is structured in five reporting sections:

How to Report

1. Principle and guidelines
2. Protocols (detailed reporting guidance)

What to Report

3. Standard disclosures
4. Sector supplements
5. National annexes (unique country-level information)

TABLE 5.2 Xstrata plc sustainability management standard for health and occupational hygiene

	Standard 9: Health and Occupational Hygiene
	Intent: Systems, plans, and programs are established and implemented to identify, analyze, and evaluate, so far as reasonably practicable, and enhance the health and well-being of workers, contractors, and visitors, and provide a workplace that is free from significant occupational health and hygiene hazards. Public health risks affecting the local communities associated with our operations (including HIV, AIDS, and malaria) and initiatives are implemented to mitigate these in partnership with appropriate stakeholders.
	Requirements and Expectations
1	Occupational health assessment and surveillance systems and plans are established and implemented that include **i.** Pre-employment health assessments that establish a baseline position and assess fitness for work; **ii.** Regular health surveillance appropriate to the level of exposure; **iii.** Communication of the results of health assessments and surveillance with due regard for confidentiality.
2	Occupational health and hygiene systems, plans, programs, and controls are established and implemented to **i.** Identify occupational health and hygiene hazards including those associated with all work environments; **ii.** Assess employee and contractor exposure to hazards with reference to internationally recognized monitoring; **iii.** Eliminate, as far as reasonably practicable, or otherwise minimize exposure to hazards; **iv.** Provide personal protective equipment where other controls do not effectively reduce the risks; **v.** Drive continuous improvements in occupational health and hygiene.
3	An effective illness and injury management system is implemented that **i.** Considers the location and nature of the operation, site, or project's ability to provide effective medical and first aid; **ii.** Considers the physiological, psychological, and sociological elements of injury or illness; **iii.** Ensures that health care is administered under the guidance of properly qualified professionals; **iv.** Ensures that rehabilitation systems and procedures promote early intervention to assist optimum recovery from work injuries or illnesses and aids return to work; **v.** Takes all reasonably practicable steps to assist or provide rehabilitation and suitable duties to employees who are injured at work; **vi.** Maintains the injured person's job position for as long as is reasonably practicable or as specified under relevant laws.
4	Systems exist to identify significant public health risks and to assess the potential or actual impact on Xstrata's contractors and local communities associated with the operation, such as HIV and AIDS, tuberculosis, and malaria. Where high or rapidly growing prevalence of HIV and AIDS is identified as a risk, confidential, voluntary HIV testing and treatment programs are implemented in the workplace, complemented by education and awareness initiatives to provide community access to testing and treatment for HIV and AIDS to be undertaken where relevant, and with appropriate stakeholders.
5	The health and well-being of the workforce shall be promoted through access to health information and programs.

Source: Data from Xstrata plc

GRI has published a Mining and Metals Sector Supplement that was developed in cooperation with ICMM. This supplement is structured into five sections:

1. Context for Sustainability Reporting in the Mining and Metals Sector
2. Aspects to Be Reported Through Narrative Descriptions
3. New Economic Indicators for the Mining and Metals Sector
4. New Environmental Indicators for the Mining and Metals Sector
5. New Social Indicators for the Mining and Metals Sector

Independent Assurance

To accomplish its purpose, a sustainability report must be credible and generally accepted by all stakeholders and potential investors. Without independent assurance (audit), credibility is unlikely to be achieved.

Audits are normally performed on an annual basis by the internal audit team under the direction of an independent auditor. The objective is to provide independent assurance that the management practice and performance is in compliance with the SD standards and public reporting of the company.

Assurance practices of mining companies vary widely, but the use of standards such as AA1000 is increasing.[22]

Conclusions

Management is the key challenge with respect to making sustainability work—this is evidenced by the sustainability frameworks proposed by ICMM and other public initiatives relating to business culture, structural integration, continual improvement, and other complex and challenging management processes.

Today, most mining companies' charters reflect a total commitment to the values of sustainable development and business ethics. This is an essential condition for efficient integration of sustainability across the company, but it is not sufficient. Equally important—and much more difficult to achieve—is creating a business culture in which sustainability is a high professional value, so objectives may be implemented through personal commitment rather than compliance. A third condition is an organizational structure provided with specific roles, integration mechanisms, and adequate management systems.

Acknowledgments

Some of the material and ideas presented in this section are derived from information provided by and discussions with Paul Jones, general manager of sustainability for Xstrata; Anthony Macuch, COO of FNX Mining Company; and Ian Wood, vice president of sustainable development for BHP Billiton. The chapter author gratefully acknowledges these individuals' contributions to this discussion.

INTEGRATION OF SUSTAINABLE DEVELOPMENT INTO MINING OPERATIONS*

Any consideration of the integration of sustainable development strategy into corporate structure and the proximal cascading of this down to operational levels must, out of necessity, start by considering the definition of sustainable development. Definitions and deliberations related to quantifying and qualifying sustainable development are provided in other chapters of this book and are not repeated in depth here. If it is assumed that the overwhelming majority of mining and mineral processing companies worldwide are at least broadly aware of sustainable development, or are familiar with the concept, attempts can be made to tie down a corporate definition of it.

Sustainable development models adopted and practiced by mining companies worldwide are typically based on triple bottom line accounting or the capitals models, or variations thereof. Again, these models and the foundations for them are discussed elsewhere in this book. In these authors' experience, *sustainable development* as a term, a concept, has often evoked negativity and mild derision among some senior corporate players when presented as a fundamental component of their organization's long-term operational vision. It is seen as merely a public relations exercise to appease specific stakeholders without any real benefit. In addition, its origin within the ecological movement has tainted it with overly green or *ecocentric* hues, with many executives believing it to be merely another manifestation of environmental pressure impacting profits and economic growth.

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* This section was written by B. Johnson and D. Limpitlaw..

TABLE 5.3 Stages on the pathway toward sustainable development

Stage	Action	Description
1	Prepare	Prepare minimal sustainable development efforts, while assessing the issue, what other companies are doing, and potential opportunities.
2	Commit	Commit to moving forward in addressing sustainable development and choose a strategic direction for their sustainable development actions.
3	Implement	Launch programs consistent with their sustainable development approach.
4	Integrate	Make sustainable development part of everyday business processes.
5	Champion	Act as a leader and champion for others within industry on sustainable development.

Source: Global Environmental Management Initiative 2004

But, in reality and in its proper form, sustainable development transcends this. It is business, just done differently (i.e., not business as usual). And it is this doing business differently that is the essence of the sustainable management philosophy. Mining operations today have little choice but to operate differently—their long-term survival depends on it. Those mining companies that have made the business case link between sustainable development and short-, medium-, and long-term corporate strategy are the ones that will continue to remain financially sustainable and viable and will ensure the renewal of their respective social licenses to operate.

The current response from mining operations ranges from opposition to the idea of sustainable development to transformation of operations that respond effectively to the need for, and opportunities presented by, sustainable development.[23] The latter response typically occurs in stages, as indicated in Table 5.3.[24]

Challenge of Integrating Sustainability Principles into Business Operations

This challenge is considered in two ways: (1) integration into the mining corporate and operational management cycle, and (2) integration across the product value chain.

Integration Into the Management Cycle

In the past 10 years, the primary response from business to the challenge of sustainable development has been on three levels:

- To develop visions, policies, and mission statements reflecting commitments to sustainable development;
- To implement certifiable environmental management systems (e.g., ISO 14001); and
- To report on their financial, environmental, and social performance in safety, health, and environment or sustainability reports (i.e., triple bottom line reporting).[25]

These responses are important. However, in many instances, they are undertaken in isolation from an overarching sustainability strategy and/or framework for translating commitments into practice. Their effectiveness is therefore limited by poor integration into the full business management cycle. Going further, operational implementation is even harder if not held together by an overarching strategy.

Integration Across the Product Value Chain

Mining operations need to ensure that sustainability principles and actions are integrated across the full spectrum of the business and the product (or service) value chain.[26] The management of environmental and social impacts cannot be fully addressed by the actions of the Safety, Health, and Environment department alone. In fact, one of the key constraints of sustainable development that managers have raised (see "Operational Examples of On-the-Ground Sustainable Development Implementation" later in this section) is that these departments often operate as silos, which hinders the effective implementation of sustainable development.

Challenge of Incorporating Biophysical, Social, and Economic Elements into Strategy and Operations

Responding to the sustainable development challenge increasingly requires that business look beyond the short-term financial profit motive and contribute instead to meeting the following "triple bottom line" objectives:[27]

- Economic prosperity and continuity for the business and its shareholders and stakeholders;
- Social well-being and equity for both employees and affected communities; and
- Environmental (biophysical) protection and resource conservation, both locally and globally.

Challenge of Addressing External Political, Environmental, and Socioeconomic Drivers, Risks, and Uncertainties

Looking beyond the elements of sustainable development that lie within the realm of direct control and management of a mining operation, a number of external factors may influence how an operation is able to contribute to sustainable development. Some of these facilitate the contribution by business to sustainable development, whereas others may be limiting. It is important for companies to identify and recognize both these positive and negative drivers when developing a framework and strategy for integrating sustainability principles into their operations.[28]

There are a variety of examples of external drivers:

- International and national conventions and policies supporting sustainable development
- Initiatives to build a free and inclusive international market that is not distorted by subsidies, tariffs, or nontariff barriers
- Global trends and risks, for example, the effects of climate change, declining oil supplies, or the increase in uranium demand due to the increasing profile of nuclear power

Challenge of Creating Innovative Solutions

The World Business Council for Sustainable Development (WBCSD)[29] has developed and promoted eco-efficiency as a management philosophy that encourages business to search for environmental improvements that yield parallel economic benefits. The WBCSD's guidebook, *Eco-Efficiency: Creating More Value with Less Impact,* presents the argument that it makes good business sense to be more eco-efficient, as companies can thereby provide more value from lower inputs of materials and energy and with reduced emissions. The challenge to mine operations is to improve their eco-efficiency by, for example, reducing material consumption, reducing energy intensity, reducing and managing impacts, enhancing recycling, and maximizing use of renewable resources.[30]

These challenges apply both to large multinational companies and to small and medium-sized enterprises, operating in emerging economies and industrialized nations alike. It must, however, be borne in mind that eco-efficiency is not sufficient by itself because it integrates only two of sustainable development's three dimensions (i.e., economics and ecology). The third element, social equity and enhancement of quality of life, must also be addressed simultaneously. The challenge lies in using innovation as a way to positively influence all three elements of sustainable development, rather than as a driver for promoting increased consumption.

Challenge of Deciding on the Appropriate Level of Commitment to Sustainable Development

Mining operations need to determine the organization's level of commitment and management response to sustainable development appropriate for its situation and reevaluate them frequently. This decision is influenced by several factors, such as the values held by the company's leadership (see the Sasol example later in this chapter), owners, and investors; the risk appetite of the company; the financial strength of the company; and the degree of internal and external pressure the company experiences regarding its sustainability implications. The challenge becomes apparent when trying to balance and respond to multiple, often conflicting, expectations of the company's role and purpose in society.

Making Sustainable Development Operational: The Main Integration Problems

One of the primary objectives of this section is to provide a "coal face" perspective on some of the challenges of trying to operationalize sustainable development in the South African environment and then to consider its relevance within the global mining theater. Research and assessment[31] called upon for the purposes of this book (focused on selected southern African mining operations and those responsible for sustainable development on the ground) revealed interesting perspectives on operational sustainable development. Key to understanding how to realize sustainable development operationally is first to understand the constraints mine managers face when implementing sustainable development on a day-to-day basis.

Research undertaken for this book focused on discussions undertaken with a number of high-level managers responsible for sustainable development, either on their mine specifically or across operations (corporate SD managers). Responses to the question: "What are the biggest challenges faced when linking corporate sustainable development strategy and on-the-ground implementation?" elicited an interesting picture:

- Different personnel vary in their (operational) SD approaches. A mine in Namibia is currently undertaking three key upgrade projects involving, among other things, the construction of a new ore sorter and acid production plant. Each of the project managers responsible for these projects approaches sustainable development very differently (e.g., the generation of dust from the new ore sorter plant and the management thereof). This is often problematic because a consistent approach to sustainable development within and across the company at a corporate and organizational level is a cornerstone of its strategy.
- Differential application of sustainable development by mine personnel is largely dependent on the age of the staff member and the associated experience of sustainable development. Interestingly, there is often an inverse relationship between age (experience) and the application of sustainable development principles operationally. Typically, a full spectrum of approaches and attitudes toward sustainable development will be encountered in most mining companies. Again, the example of the mine with three new capital projects is illustrative. Out of the three capital appropriation requests that were completed for the three projects, only one incorporated SD principles into the decision-making criteria underpinning the capital request rationale (decision-making matrix). In this example, this project was led by the youngest of the staff, who ensured best practice technology was secured to optimize sustainable development. Anecdotal discussions have indicated that the application of sustainable development principles on the ground by older mine staff often does not come naturally because there is less familiarity with the concept and how to translate it operationally.

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- Some companies may become overly comfortable with sustainable development. Linked to this is a trend in some mining companies for disbanding sustainable development awareness training programs and corporate sustainable development setting tools among mine staff. This generally occurs because sustainable development is deemed to have been fully incorporated operationally. The feeling among sustainable development operational staff is that this action may be premature and there is a continuing need for sustainable development awareness and training programs on the ground.
- Commitment to sustainable development both upstream and downstream is critical. Sustainable development buy-in is essential across the organizational supply chain in order for sustainable development to work operationally. For instance, if components of the (new project) supply chain upstream (e.g., contractors) are not well versed in the implementation of sustainable development in the planning and construction of, for instance, a new acid production plant, sustainable development will not be successfully translated on the ground. Similarly, downstream players (the mine's clients) can equally affect the realization of sustainable development. If, for example, International Organization for Standardization (ISO) criteria are applied by these buyers of a mine's products and upstream supply chain components are not aligned, the mine will not be operating within sustainable development principles.
- The right human capital is crucial to a sustainable development program. Corporate HR departments often display a lack of involvement, participation, and understanding of sustainable development in their support of mining operations. Having "the right people with the right attitudes" is absolutely pivotal to the implementation of sustainable development on the ground. This needs to be taken into account in HR training programs and in recruitment (see Chapter 6) There are further examples of HR's role in sustainable development. As a case study, an ongoing mine expansion program involves the expansion and securing of new accommodations for an increased workforce. Traditionally, HR would probably not get involved in operational aspects like this, but from a sustainable development perspective it is critical because the provision (building) of new facilities can have profound effects on the mine's surrounding social environment and its human capital. If the message received from other (nonoperational) organizational divisions is that sustainable development is not important, then it certainly will not work on the ground.
- Mining and corporate social investment. Corporate social investment and reporting are often the most challenging parts of sustainable development. They are too often seen as public relations exercises, especially if the business case for sustainable development has not been firmly established. For this particular aspect of sustainable development to work, senior management must be committed to it and it must have been developed from deep listening to communities on the ground.

Integrating SD into Strategy and Making It Happen Operationally: Getting Started

The development of a corporate-level vision to include a sustainable development ethos is generally the first step in ensuring that corporate-level sustainable development strategy is established and ultimately translated operationally. While articulating a vision may be regarded as often wooly and slightly nebulous (especially in the context of a book focused on operational sustainable development), it is nonetheless an important starting point. It reflects the values of the

CHAPTER SIX

Human Resources Management

L. W. Freeman and H. B. Miller

INTRODUCTION

The effective management of human resources, including employee recruitment and development, is as critical to the long-term success and economic viability of a mining company as is the development of new orebodies and exploration targets. Whether they are professional/administrative staff, highly skilled production employees, or general mine labor, these individuals comprise the backbone of any mining and resource company, where their skills, effort, and personalities greatly influence the ability of these organizations to succeed and create wealth. While the impact of labor productivity and cost on the economics of mining operations have long been a major focus of management, the traditional philosophies engrained in the mining industry toward human resources and workforce issues have recently undergone substantial change. What precipitated this change is debatable; however, many believe the cause is symptomatic of societal changes in employee attitudes and the daunting challenges facing mining companies as a consequence of a shrinking talent pool, government regulation, negative public image, and the rapidly increasing skill competencies required of today's miners. One thing is clearly evident: the expectations of employees toward employment and company management are very different than they were just two decades ago. This condition often transcends cultural and political boundaries, where the perceived responsibilities of mine management toward labor continue to expand and evolve as a function of globalization, government mandates, and societal expectations. The role of mine managers and supervisors is no longer oriented solely toward maximizing the potential utility of employees in terms of performance and work quality. In addition, they must foster a work environment that is conducive to attracting and retaining high-quality employees and to providing the necessary training to meet the needs of these highly mechanized and technology-dependent operations. As such, the ability to manage talent and understand the psychological and physical needs of a given workforce are now skills that must be fundamental to all levels of mine management.

Throughout most of the world, one of the most prominent risks now facing mining and resource companies involves their ability to develop and maintain a social right to operate. Although the legal authority to mine a specific property is embodied in the regulatory consent granted by governmental agencies, this "right to mine" is only as valid as the explicit or implicit social license granted by the potentially affected communities and stakeholders. In exchange for this social license, mining companies make a commitment to local communities to provide tangible benefits and improve the quality of life of residents during and after mining. Although often overlooked, employees play a critical role in facilitating this social license. Employees serve as a conduit for disseminating information about the company and its practices to the general public. The nature of this exchange extends beyond issues involving mine operations and environmental stewardship to how the company values its employees. Everything associated with employee talent, ranging from recruitment to skills development and safety, impacts a company's reputation and how it is perceived by local communities, either directly or indirectly. This perception and the relationship between a company and its employees are often the primary drivers on whether communities allow individual operations to continue to operate successfully. In addition, employees also convey important information back to the company about social and community issues. This feedback is critical for assessing the outcomes of specific social programs and identifying key factors that might indicate community needs or potential conflicts.

The primary theme of this chapter is to present topics that are fundamental to the creation of a corporate culture that promotes the productive utilization of human resources and the development of sustainable business practices that produce tangible benefits for the company, employees, and the communities in which they operate. This balance of this chapter is divided into four sections.

"Values-Based Principles" reviews corporate values of mining companies, focusing on achieving a business culture that fosters ethics, social license, and safety, and clearly represents a commitment to upholding standards and codes of conduct.

"Employees as Portals" analyzes the role of employees as "portals" through which each party to the social license can communicate and the importance of employees as interpreters and communicators of the needs of the community.

"The Quiet Revolution" discusses the challenges facing the minerals industry as a consequence of shortages of skilled labor and managers with the types of leadership skills and experience necessary to address the growing social responsibilities and demands they now must face.

"Talent Toolbox" discusses the management principles and tools in relation to developing a corporate culture that nurtures employees to succeed, maximize their potential, and play pivotal roles as "portals" to the community.

VALUES-BASED PRINCIPLES

Corporate values form the cornerstone of any business culture that promotes and fosters the productive utilization of human resources. These corporate values comprise the core beliefs, operating philosophy, and guiding principles that govern how a company interacts with other businesses, its employees, and society. Although these values are prominently featured in the mission statements and annual reports of most companies, they should also be readily apparent to outside observers. Within most mining companies, corporate values typically include considerations regarding ethics, social license, and safety, and clearly represent a commitment to upholding standards and codes of conduct relative to company employees, local communities, the environment, and stockholders/investors. It is essential that these values be understood by every employee within a company, regardless of position or classification, and be discussed regularly. Employees should be recruited and developed with respect to these values, and held accountable for ensuring that they are followed. The most valuable leaders are those employees, regardless of title, who manifest these values. Compromises should be unacceptable, where small breaches are as grievous as large ones, in as much as they reflect quality of character. In the vernacular of safety, all incidents and potential hazards are indicators of accidents, regardless of outcome. Such is the case for all values-based principles. Employees have the inherent responsibility to adhere to the corporate values and ensure that their peers do as well, where transgressions should be dealt with in a direct and transparent manner. All aspects of human resources management start and end with these corporate values.

Ethics

A company's ethics are inherently defined by the behavior of its employees. Accordingly, ethics play a critical role in how a company recruits, develops, and evaluates employees. Ethics is a surprisingly complex subject that goes well beyond the scope of this section. However, a few comments serve to introduce this extremely important topic. Although there are often well-defined boundaries that establish the limits of ethical conduct based on employee morals, regulatory policies, industry standards, and corporate values, a company's ethics are usually defined by the actions and behavior of its employees with respect to "gray areas." A gray area is where there is no absolute boundary separating ethical and unethical behavior or when, in the absence of prescriptive policy or standards, employees define ethics based on their own interpretation of the situation. For example, breaches of ethics such as theft and lying are easy to define. However, what about exaggeration for personal gain? Most people believe that exaggeration skirts the edge of lying to the degree that personal gain is directly involved. How directly? Imagine the case of a geologist who is considering an opportunity to acquire a mining property adjacent to an operating mine. Is it ethical to ask for a tour of the mine for the sole purpose of deciding whether the acquisition is warranted? Most industry professionals would likely believe this is an unethical act, particularly if the intent to acquire the adjacent property was not disclosed in advance of the mine tour. How about corporate intelligence? Is it ethical to spy on a competitor's drilling activities? Most people in industry would probably indicate that this type of behavior borders unethical conduct but might be situational. Conversely, what about requesting technical and economic information from a contractor regarding the activities of a competitor? In this case, most would believe it is ethical to ask, but unethical for the contractor to divulge information that would disadvantage his or her client or reveal anything deemed confidential. Is it ethical to withhold information from a competitor with regard to systems that might improve safety? Most would agree that all values-based aspects of business are to be shared and should not be held as a corporate advantage. Suffice it to say, ethics is a complex subject that often deals with issues that are not black and white. It is the gray areas that define a company's culture. As such, the ethics of any corporation or business are the product of its employees and are greatly influenced by the character of the employees the company recruits and develops. In addition, codes of conduct and company values need to be discussed regularly, particularly with regard to these ethical gray areas, to ensure every employee in a given company understands the expectations and responsibilities that accompany employment.

Social License

Social license is a covenant drawn up between the company and the affected communities and epitomizes a dynamic partnership crafted on the basis of trust and shared vision. Normally formulated to mitigate risk, the nature of this partnership is unique for each mine and community; it is dynamic in as much as both the circumstances of the mine and the community are constantly changing. As is often the case, this sophisticated covenant attempts to balance the concerns of individual stakeholders who are participating in this partnership. From the perspective of most companies, financial risk is normally a paramount issue. From the perspective of the community, any potential risk that may result in the degradation of quality of life will likely be a major concern.

How can such a covenant be maintained in the face of constant change and between two disparate parties? Employees are the key to maintaining a social license. They are the common element linking the mine/company to the community. Employees serve as the company's portal to the community, as well as the community's portal to the company. The actions and treatment of employees are realities with respect to the value systems of the parties engaged in the partnership, where employees attest to day-to-day realities of the company. Accordingly, recruitment, development, and retention of employees are critical components for the process that defines corporate culture and social license.

Although the specifics in each social license will vary, the principle of shared vision with rights and responsibilities upon which the license is developed is constant.

Each social license has two phases:

1. *The initial phase under which the mine is granted a right to begin operations.* The initial social license is granted on the basis of anticipated development needs of the mine and the changes in the community associated with this development. Lacking real-life experiences from which to draw, it is granted on the basis of promises and trust. The terms of the social license are established as part of the formal mine permitting process. The relationship between the mine and the community starts with first contact during exploration and continues through the evaluation process. The "realities" upon which trust is established are manifested through these early periods of activity and grow as individuals from local communities are hired as employees. The initial phase ends with a new reality associated with the surge of employment at the beginning of mine construction. Trust, a commitment to work together, and the ability to develop a shared vision are the key ingredients to success in the initial phase.
2. *The operating phase under which the mine functions as a business entity.* This relationship follows the initial phase and ends with successful mine closure and reclamation. It typically lasts from half a dozen years to decades, during which time there are an unlimited number of events that define the actual relationship between the mine and the community. Maintaining trust, working together, and sharing a constantly evolving vision are required for a successful operating phase.

The conceptual model for the social license is the triple bottom line (TBL). In this context, TBL refers to the process by which a company gauges success. Traditionally, success has been measured relative to financial (economic) performance and compliance with stockholder expectations. Although financial performance is still a central tenet of corporate success, TBL implies companies should also be held accountable with regard to their actions and contributions toward social and environmental factors. As such, measuring the success of a company should encapsulate all three of these criteria: economic, environmental, and social (Figure 6.1). From a community's perspective, environmental and social factors are quality-of-life issues that extend to employment, social stability, standard of living, and the health and welfare of people and their environment. For many companies, the concept of the TBL is the vision for sustainable mining and social license, and is the basis for their corporate culture.

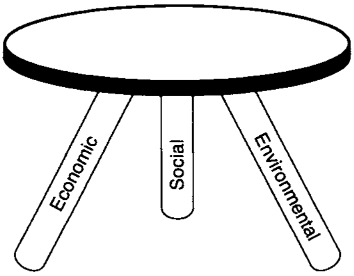


FIGURE 6.1 Triple bottom line

In this scenario, employees play a complex but integral role. They deliver the capacity for a company to succeed economically through the application of their skills and talent. Through their actions as representatives of the company, employees also directly impact the social and environmental components of the TBL. As discussed, one of the more interesting roles employees fill is that they confirm to the community that the mine is operating under the terms of the social license. Conversely, as members of the community, employees also serve as a conduit from the community back to the company.

Safety Management: Building a Culture of Prevention

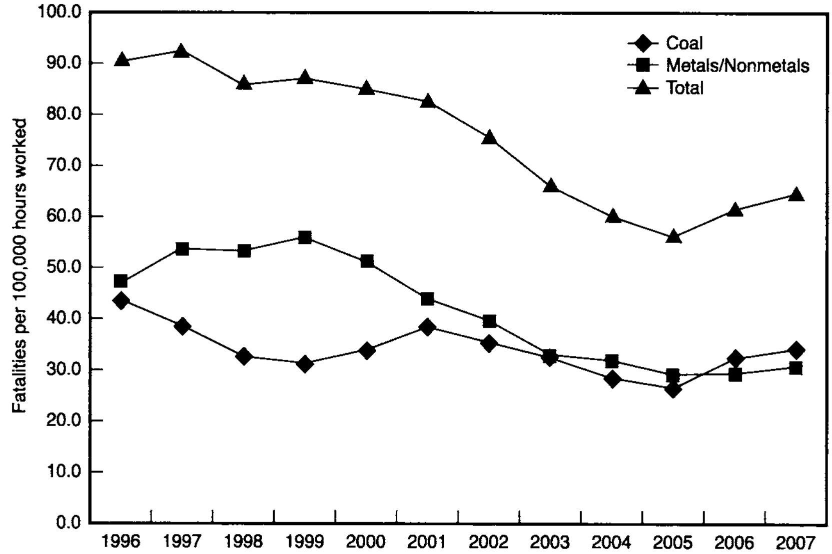
It is widely acknowledged that the most efficient mines are also the safest ones. In most major operations, very systematic and comprehensive planning, monitoring, and control processes are implemented to provide continuous improvements in the health and safety of miners, both on and off the job. These processes also have direct implications toward incremental improvements in labor productivity and cost. Today, a total loss control perspective pervades mine management philosophies, and the general definition of an accident as anything that occurs that was not planned is widely held.[1]

Most major multinational mining companies have committed to the principles of sustainability and have embraced the importance of health, safety, environment, and community as part of their social responsibility and license. This commitment is often emphasized in the mission statements of these companies and in their annual reports to stockholders. In many cases, these companies have also established performance targets as a way to gauge the success of their programs and serve as corporate objectives. For example, BHP Billiton has targeted zero fatalities, zero fines, and zero prosecutions.[2] The BHP Billiton management process is systematized corporation-wide, as summarized by the following excerpts from a 2004 report:

> All sites [are] to undertake annual self-assessments against the BHP Billiton HSEC [Health, Safety, Environment and Community] Management Standards and have plans to achieve conformance with the Standards (p. 8).
>
> To help us better understand and manage HSEC risks that are critical to our business, risk registers are in place and being maintained at all sites and at Customer Sector Group and Corporate levels of the Company, in line with our HSEC target. Work was also undertaken to better align HSEC risk assessment processes with our Enterprise-Wide Risk Management processes to improve the efficiency of assessments.

Although program details and specifics may vary, this type of corporate philosophy and commitment has been adopted by most of the major mining corporations and information is readily available on their Web sites (e.g., www.angloamerican.co.uk, www.newmont.com, www.fcx.com, and www.riotinto.com).

Following a decade of record accomplishments in mine safety, the U.S. underground coal industry was rocked by a series of multiple-fatality disasters in 2001, 2006, and 2007. The 10-year recent history of the 3-year rolling average number of fatalities and of the 3-year rolling average fatal incidence rate in the mining industry are shown in Figure 6.2 and Figure 6.3 respectively. Among several studies scrutinizing mine safety, the National Mining Association (NMA) established the Mine Safety Technology and Training Commission, which studied a 25-year history of U.S. mine disasters and focused on requirements for an approach to prevent lost-time injuries and fatalities systematically. With the consensus of a diverse membership, the commission's 2006 report[3] recommended that "a comprehensive approach, founded on the establishment of a culture of prevention, be used to focus employees on the prevention of all accidents and injuries."



Source: Mine Safety and Health Administration database

FIGURE 6.2 Three-year rolling average number of fatalities in mining, 1996–2007

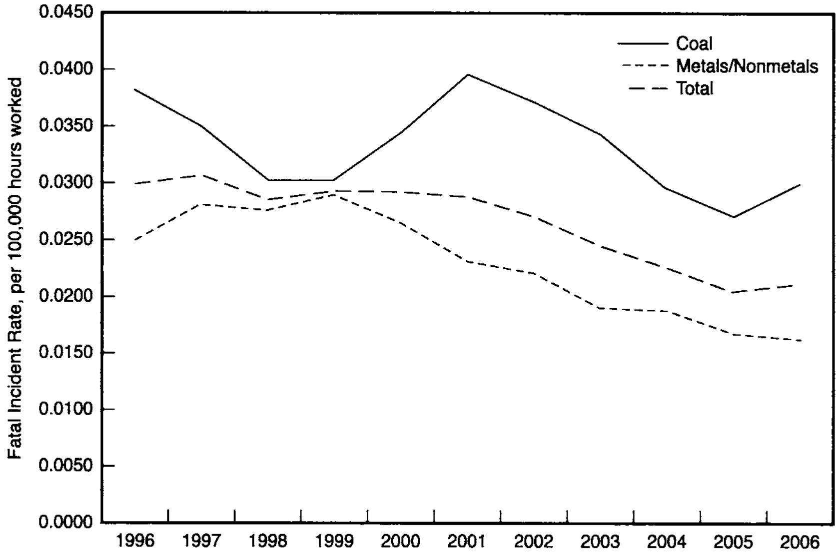


FIGURE 6.3 Three-year rolling average Fatal Incidence Rate in mining, 1996–2006

Noting the Australian adoption of risk management and the industry's significant improvement of mine safety performances, the report further recommended "every mine should employ a sound risk-analysis process, should conduct a risk analysis, and should develop a management plan to address the significant hazards identified by the analysis."

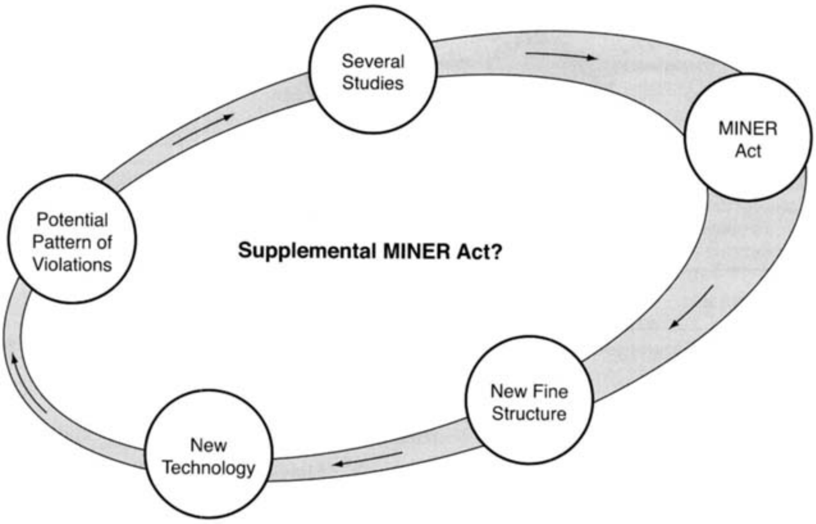


FIGURE 6.4 Impacts from 2006 U.S. mine disasters

One of the commission members, Consol Energy chief executive officer J. Brett Harvey, reinforced the study's position that the goal of the industry should be zero fatalities and zero lost-time accidents.[4] At the 2007 meeting of the Utah Mining Association, he embraced the new safety paradigm by saying:

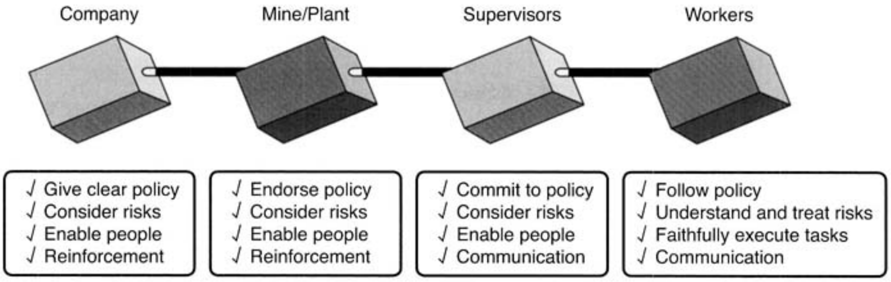
> We are in the process of instituting a new approach to safety awareness and training that we believe will accelerate our drive to zero accidents throughout the company. We will start with the premise that our normal state of operation is no accidents. An accident is an abnormality that is unacceptable. Accidents are an exception to our core values.

Building a Mine Safety Culture of Prevention

Beyond the studies mentioned previously, the aftermath of these highly publicized mine disasters brought major new mine safety and health legislation passed by the U.S. Congress (including the Mine Improvement and New Emergency Response [MINER] Act of 2006),[5] a significant increase in the fine structure of citations for violations of regulations, and strong initiatives to develop new technology for mine communications and life-saving devices. It also led to the development by the Mine Safety and Health Administration (MSHA) of a methodology and algorithm—pattern of violations—to target poor safety performances at mine operations (Figure 6.4). A second mine safety initiative is now being considered in Congress called the Supplemental MINER Act. These activities and initiatives raised the stakes for poor safety performances to a much higher level, as follows:

- Having a fatality is a prohibitive stigma,
- Having lost-time accidents targets operations,
- Having a pattern of violations is costly, and
- In either situation, MSHA and public scrutiny will also be very undesirable.

Paramount in the new perspective developed following 2006 and 2007 is a new emphasis on systematic safety improvement. Focusing on the bottom line, major companies' operating plans



Source: After L. Grayson 2001

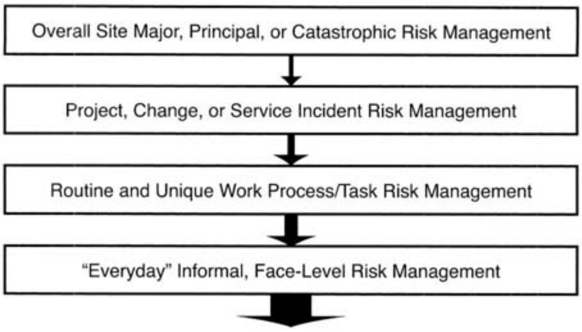
FIGURE 6.5 Roles of managers, supervisors, and workers in building a safety culture of prevention

do not sanction losses of any type, adopt a continuous improvement mindset, expect good execution of all work tasks (by management and labor), and expect that losses of people, time, money, equipment, injuries, energy, and so forth will be avoided. The role of each manager, supervisor, and worker becomes critical as losses are perceived as exceptions to business—or the plan. For success, it is imperative that a culture of prevention be introduced, reinforced, and cultivated.

The roles of managers, supervisors, and workers are briefly described in Figure 6.5. In essence, the key facets in building a mine safety culture of prevention relate to setting, committing to, and following policy; considering, understanding, analyzing, and treating identified risks; enabling and empowering workers toward faithful task execution; and maintaining good, interactive communication among supervisors and workers, which is reinforced by higher levels of management.

Concerning the building of a culture of prevention, the NMA commission report noted the following:

> A critical action to ensure success of the process for any company is the creation of a "culture of prevention" that focuses all employees on the prevention of all accidents and injuries. In order to achieve this culture, operators, employees, the inspectorate, etc., share a fundamental commitment to it as a value. In essence the process moves the organization from a culture of reaction to a culture of prevention. Rather than responding to an accident or injury that has occurred, the company proactively addresses perceived potential problem areas before they occur.
>
> The tenets of the core business and personal values are critical links to achieving success. Founded on these aspects, a systematic and comprehensive process depends on other keys for success as well, which include the following:
>
> - Focus on ZERO Accidents, Injuries and Occupational Illnesses
> - Use a Holistic Approach
> - Identify, Disseminate, and Adopt Best Practices
> - Implementation of a Risk Management Process
> - Going Beyond Compliance
> - Minimizing the Footprint
>
> In the end, the industry must strive toward instilling a paradigm of prevention. There is no single path or approach to fashioning the safety culture. Rather the industry must



Source: After Hudson 2006

FIGURE 6.6 Evolutional journey toward risk management and building a culture of prevention

call upon engineering solutions, education of the workforce, and enforcement as tools to help create this culture. It must also enlist the commitment of all employees to be an integral part of the process aimed at zero incidents. Training is undertaken as a preventative measure, especially for honing critical skill sets for hazard awareness and control for every employee at every level of an operation. This safety commitment is the foundation on which the industry must build to fortify the protection for all employees from incidents or injuries, and not just from fires and explosions.

Culture building is not, however, easy to do. Companies that have applied risk analysis and management for many years also recognize that the change to a "culture of prevention" via "systematic and comprehensive risk management" involves a journey.[6] Professor Hudson depicted the journey graphically for Shell Oil in Figure 6.6,[7] where the process is shown as a series of steps. Importantly, moving through each of these steps is believed to take several years—each contributing to the building of the culture.

Corporate or division leaders set the stage and play a critical role in challenging all employees to seek accident-free performances, insisting on building a culture of prevention. Serious transfer of accountability then must permeate downward to the next level of responsibility. At this stage, the mine/plant manager plays a critical role in challenging supervisors to seek accident-free performances, which further builds the culture of prevention. In the end, supervisors must transfer accountability for accident-free performances to the workers. Ultimately, each worker plays a critical role in changing the culture permanently by (1) executing tasks faithfully according to best practice, (2) not taking shortcuts, (3) examining the workplace, (4) performing proper pre-op checks, and (5) using good judgment.

Risk Management

Risk management is a well-known loss control methodology that has been applied by many industries, including chemical, oil and natural gas, nuclear, military, aviation, environment, and space.[8] These industries consider risk management as an integral part of their daily business. A number of generic risk assessment and management standards and guidelines are available. The NMA commission report noted the development by the University of Queensland, Minerals Industry Safety and Health Centre (MISHC), of a guideline document aimed to provide advice on risk assessment within the Australian mining industry.[9] Based on several standards, risk management is a process comprised of several steps:[10]

1. Establish the context.
2. Identify risks.
3. Analyze risks.
4. Evaluate risks.
5. Treat risks.

During this process, there is regular communication and consultation as efforts progress, as well as regular monitoring and review of activities.

There are many different ways to assess risk relative to mine safety performances. Common methods include trend plots of incidents (violations, near misses, downtime, etc.), tabling data for prioritization of action plans, using matrix plots to prioritize multiple risks (major hazards, injury causes, violations), and quantitative risk analysis using advanced methods such as fault tree analysis, failure modes effects analysis, preliminary hazard analysis, and so forth. An example of a trend plot for a specific violation of the MINER Act is shown in Figure 6.7.

Table 6.1 presents lost-time accident data listed in descending order in column 2, for frequency of occurrence, and in column 4, for lost workdays. It is interesting to note that based on frequency, 79.1% of total reportable accidents are accounted for by five categories of injury while 92.8% of the lost workdays are accounted for by the same five categories, in a different order.

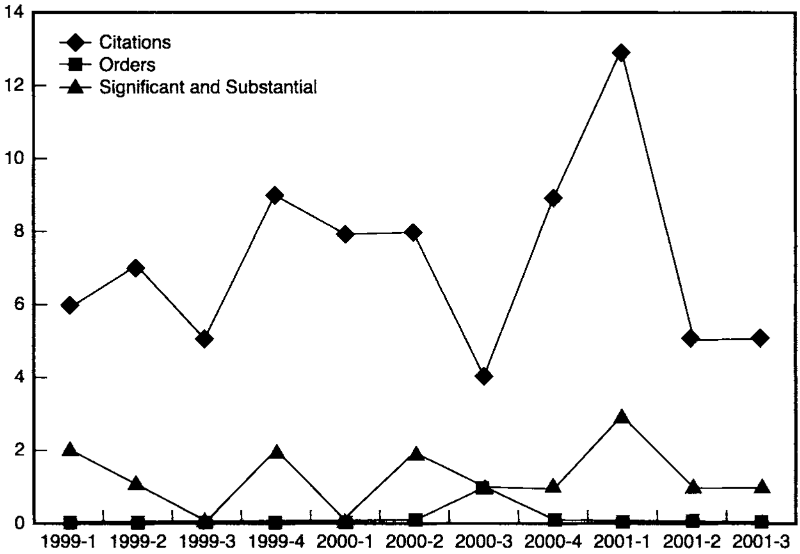


FIGURE 6.7 Trend plot of citations for violation of correction-of-hazardous-conditions regulation

TABLE 6.1 Prioritization of risk mitigation for lost-time accidents

Accident Class	Number	Accident Class	Workdays Lost
Material Handling	52	Material Handling	2,213
Handtool	23	Machinery	913
Slip/Fall	20	Slip/Fall	681
Machinery	17	Powered Haulage	910
Ignition/Explosion	9	Handtool	336

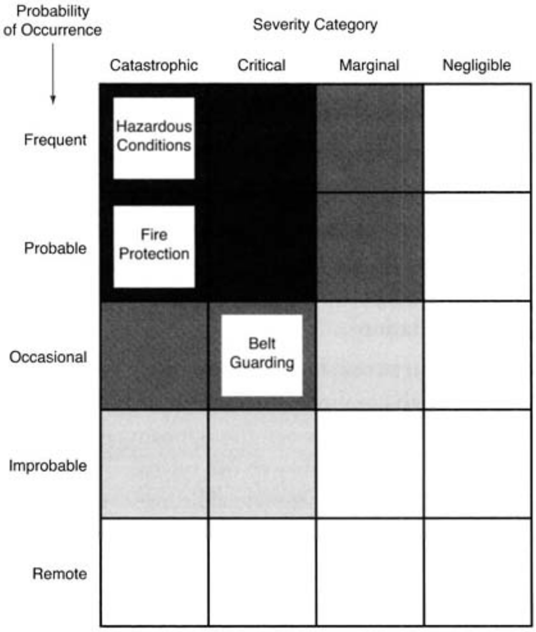
This approach shows the value of the 80-20 rule (Pareto principle) in prioritizing which lost-time accident categories should be addressed first.

Using probability and severity categories, a risk analysis matrix can be developed for any type of events and used to identify unacceptable risks for an operation (Figure 6.8).[11] It can also be used to prioritize which risks will be addressed (i.e., action or actions taken to eliminate or reduce risk, and in which order). An example risk analysis matrix is given in Figure 6.8 using some common mine hazards. The highest priority cells are located in the upper left part of the matrix, while the lowest priority cells are in the lower right corner. The approach could be used to compare the impact of many different events, and both quantitative and qualitative risks can be represented.

The Bottom Line

In a complex physical system, a weak link can cause a failure or loss. Similarly, in a human system, weak links in human performance, such as taking a shortcut, misjudgment, poor task performance, and so on, can cause a failure or loss. Ultimately, each person at an operation plays a role in safe, efficient, cost-effective production—whether that person is a corporate or division manager, the mine/plant manager, a supervisor in production or maintenance, a technical staff person, or a worker. As managers and workers alike realize their roles, a commitment to a safety culture of prevention and executing that commitment systematically reaps the following paybacks:

- The majority of excursions from plan are eliminated—lost-time accidents, citations for violations of the MINER Act, downtime, untimely progress on projects, problems with contractors, and so forth.
- The industry will strive for continuous improvement across the board as excellent performers—always looking for better ways of doing work and sustaining business.



Probability of Occurrence ↓	Catastrophic	Critical	Marginal	Negligible
Frequent	■ Hazardous Conditions	■	▨	□
Probable	■ Fire Protection	■	▨	□
Occasional	▨	▨ Belt Guarding	░	□
Improbable	░	░	□	□
Remote	□	□	□	□

FIGURE 6.8 Example qualitative risk analysis matrix for three mine hazards

Acknowledgments

The material and ideas presented in this section were contributed by Dr. R. L. Grayson of the Pennsylvania State University, Department of Energy and Mineral Engineering, University Park, Pennsylvania. The chapter editors extend their sincere thanks to Dr. Grayson for his contribution and participation in the development of this section.

EMPLOYEES AS PORTALS

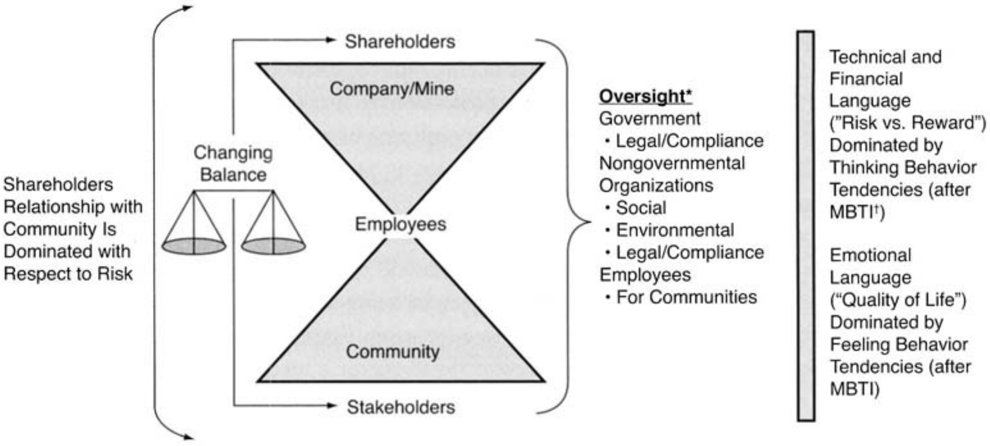
Depending on the specific circumstances, the triple bottom line (TBL) puts employees in a unique position of influence. In effect, these employees represent the interests of both parties participating in the social license (i.e., the company and the community). This represents a radical departure from traditional business philosophies, where large companies often viewed employees as simply the means through which they could achieve corporate objectives and create wealth. This is the traditional language of business. However, communities possess a very different perspective (language) that revolves around quality-of-life issues that are based on values systems. Values systems are attested to and measured by the actions of companies and their representatives (i.e., employees and contractors). Inside this intricate relationship, employees are both members of the company and the community and are, therefore, portals through which each party to the social license can communicate.

Carrying this analogy further, a portal (window) is only as good as the quality of the glass used in its construction. Any imperfections in the glass result in a distorted or obscured view of the events occurring on either side of the portal, regardless of what the actual reality is. Similarly, it follows that employees represent the company to the community and the community to the company. The values and the actions of the company are no more correct and proper than how they are perceived by the community. Furthermore, the needs of the community are only understood to the degree that employees understand and can communicate these needs to the company in such a way that management can take action. As such, the ability of a company to mitigate the risk of losing its social license largely rests on the actions, knowledge, and perceptions of their employees.

Therefore, employees serve three primary purposes:

1. Complete necessary tasks associated with mine production and operations;
2. Serve as a vehicle to accomplish wealth transfer from the mine operation and the community via salaries; and
3. Serve as portals of communication to maintain the social license as a dynamic, evolving covenant between the community and the company, thereby mitigating risk to the company (loss of operation) and to the community (loss of livelihood and preventable social and environmental degradation).

This complex relationship between local communities (stakeholders) and the company (shareholders) is facilitated through employee interaction, as is illustrated in Figure 6.9. The figure emphasizes the differences and risks between the opposing groups, where employees serve as the interface that provides balance and stability to the system. That said, who ultimately has the responsibility for initiating and maintaining the social license—the company or the community? Many believe that the balance is systematically shifting from the former to the latter. Although companies still have the responsibility to facilitate social license and fulfill commitments related to their core values, they rarely have the ability to dictate the terms of the social license, nor can they operate effectively without the continued support of the community. For companies, this places an even greater dependency on their employees to mitigate potential social risk and



* Critical in developing economies and marginal companies.
† Myers-Briggs Type Indicator.

Source: After Freeman 2006–2007

FIGURE 6.9 Employee interface

represent their interests by advocating the merits and corporate values of a given operation. This has direct ramifications on the type and character of employees a company will recruit, as well as human resource policies related to employee training, development, and performance assessment.

THE QUIET REVOLUTION

As the minerals industry begins to experience the ramifications of a decade-long shortage of skilled labor as a consequence of demographics and tremendous growth, mining companies face an equally daunting challenge of finding managers with the types of leadership skills necessary to address the growing social responsibilities and demands they now face. Although many of the traditional character traits and skill sets associated with managers are still vitally important, the changing social expectations that stem from social license and the TBL necessitate that company leaders possess talents and capabilities very different from just a generation ago.

Managing social risk now requires the ability to interact effectively and influence a wide array of different groups and organizations external to the company, including those representing local communities, government and regulatory entities, media, environmental and social activists, and nongovernmental organizations (NGOs). Although managers have always needed the personal skills to influence and motivate labor, the difference is that managers rarely have substantive control over external stakeholder groups. In some situations, social license means delegating, or at least sharing, some element of control with these groups (e.g., the local community). As such, managerial responsibility for some activities that can directly impact mine and mill operations may be dependent on the participation, input, and/or approval of these stakeholders. To many managers in the minerals industry, this situation may be very unsettling. It recognizes that mitigating and managing social risk is largely dependent on influencing skills rather than through their authority as a representative and agent of the company, and requires a higher level of leadership in order to be successful. For those managers schooled and developed over the course of the last three decades, where authority tracked with responsibility, this may be difficult to accept and perhaps even more difficult to practice. This calls for no less than a revolution in the way management and future company leaders are recruited, trained, and mentored. In many progressive mining and resource companies, this process is well under way.

In most corporate settings, major changes of this type typically are met with resistance and are slow to materialize. Many human resources professionals, however, believe this won't be the case in the mining sector, given the extraordinarily high rate of managerial turnover expected in the near term. As projected, half of the current practicing professionals in the mining industry will retire in the coming decade. Similar trends are also expected for the skilled labor pool from which frontline supervisors are often identified and recruited. As a consequence, almost by default, a new generation of managers and supervisors will quickly be taking the helm of these operations. Fortunately, these individuals are likely to be more accomplished in the use of influence as a leadership style due to current trends in education. Regardless, company management must pick and train their potential successors carefully to ensure a successful transition with leadership capable of operating under the social terms and expectations of today's employees and stakeholders.

Shortage of People

A number of studies commissioned in recent years have identified several ominous trends that have and will continue to impact nearly every sector of the mining industry. Nearly 50% of the current workforce will retire in the next 6 to 8 years, and finding replacements with the necessary skill sets will become an extremely difficult challenge.[12]

Traditionally, those retiring from managerial positions in the mining industry fell into a demographic group ranging from 60 to 65 years of age. In most instances, these retirees were replaced by young, mid-career professionals from 30 to 45 years of age. Owing to the demographics associated with the baby-boom generation and long-term trends in the graduation rates of U.S. mining schools, there currently exists a distinct shortage of 30-to-45-year-olds in the industry.[13] Consequently, there are few successors to replace the managers who are currently retiring. Based on available data, it appears that this shortage will persist for at least the coming decade.

To illustrate this point, Figure 6.10 shows the number of mining engineering graduates from U.S. universities as compared to the average spot market price for copper. As the figure indicates, the dynamic associated with the shortage of mining engineers is not specifically related to the recent surge in commodity prices. Rather, the primary driver appears to be the attrition rate caused by retirement and the demographics associated with the baby-boom generation. That said, the impact of market prices in stimulating new projects and mine expansions is undoubtedly having an effect in tightening an already grossly labor-deficient market. The continued economic growth and activity in China, India, and other developing countries should promise to exacerbate this labor demand into the foreseeable future.

The x-axis of Figure 6.10 is delineated by both the year of graduation and average copper price. Also shown is the approximate age of the graduate in 2006. The y-axis is a percent normalized to the year 2000. As can be seen from the figure, the mining engineering graduation rate peaked in the early 1980s at more than 700 graduates. Since the late 1980s, the graduation rate has varied from 150 to less than 90, with an average rate of approximately 125 graduates per year.

Research conducted by the Society for Mining, Metallurgy, and Exploration, Inc.,[14] suggests that the sustaining rate for new mining engineers entering the industry is somewhere between 300 to 350 per year. This implies that the U.S. mining industry has been running at a deficit of some 200 graduate mining engineers per year for more than 20 years. It is, therefore, theorized that the mining industry has been "living off" the relative surplus of graduates from the early

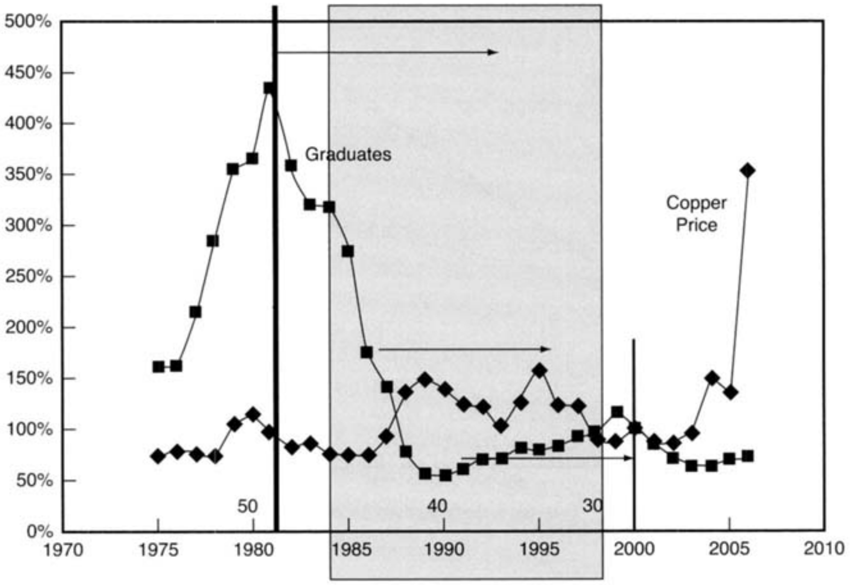


FIGURE 6.10 Total U.S. mining graduates versus average copper price

1980s in mining engineering, as well as other critical disciplines, including extractive metallurgy and economic geology. Virtually all other technical disciplines, in all other developed economies, exhibit similar statistics.[15]

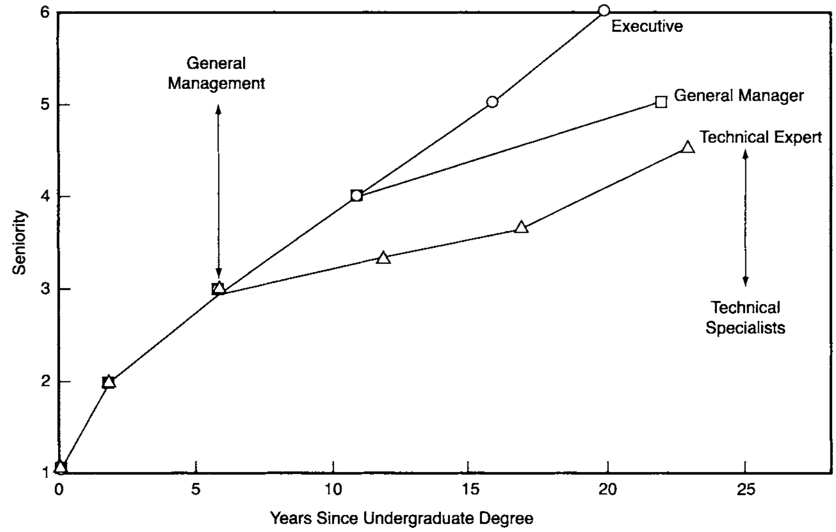
The talent shortage is acute and not easily remedied. Although there is currently tremendous competition for new graduates, these inexperienced engineers simply cannot replace the vast majority of those who are retiring from the industry because they do not possess the required skills and competencies. In most cases, it takes time (experience), training, and mentoring to acquire and develop these attributes. This point is clearly illustrated in Figure 6.11.[16] This figure was developed by analyzing the career paths of hundreds of the most successful people in the mining industry in order to determine the time necessary to develop the competencies required for increasing levels of responsibility.

The x-axis of this figure represents the years of experience since graduating from college with a professional degree. The y-axis establishes the individual's work-related title, as well as his or her relative level of responsibility, ranging from new graduate (1), specialist (2), senior specialist (3), manager (4), general manager (5), and executive (6). The most successful professionals are represented by the left-most line on the graph.

This research indicates that it took 10 years for the best of these graduates to develop the competencies necessary to become managers. Consequently, it seems logical to conclude that most new graduates are not likely to be capable of replacing manager-level retirees in a period less than this (e.g., 10 years). The loss of management as well as leadership will leave a large gap in the talent pool of the mining industry.

Shortage of Competent People

Well before companies run out of people to fill positions, they will run out of competent people to fill positions. As such, employees and new recruits will be asked to assume the responsibilities of positions for which they are ill-suited or ill-prepared. As described previously, despite shortages



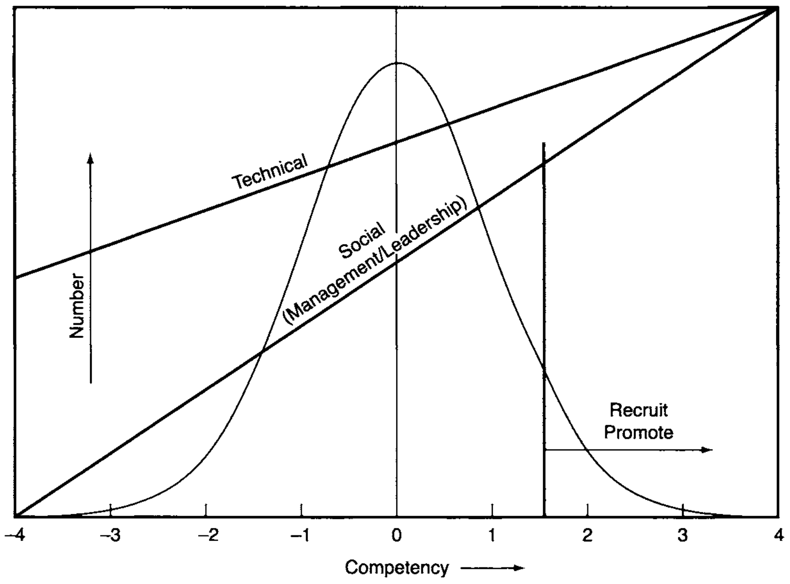
Source: After Freeman 2006–2007

FIGURE 6.11 Professional competency development in the mining industry

of skilled labor, there is particular concern over the pending shortfall of managers and supervisors with social skills sufficient to meet the demands of these positions successfully. High school graduates with particularly strong math and science skills are usually drawn to engineering when they reach college. In most university curriculums related to mining, economic geology, and mineral processing, education is strongly focused on math and science. Therefore, virtually all of the graduates from accredited universities are likely to be technically competent. This, unfortunately, cannot be said about their social skills. The typical student entering a university mining program in the United States is likely to be more interested in and display a higher degree of competency in technical skills than in those dealing with social issues. In fact, these students generally refrain from taking courses in communications, leadership, and management unless required to do so. In addition, the structure and emphasis of most engineering curriculums, along with accreditation requirements, further contribute to the relatively low priority placed on social and leadership skills development.

Figure 6.12[17] illustrates this point, where a normal curve represents the overall competency of people within the workforce. In this figure, the x-axis corresponds to different levels of competency and the y-axis denotes the percentage of the population of professionals. Relative technical competency is illustrated as a straight line connecting the upper right corner of the figure (representing the highest possible level of technical competency) to a mid-point on the y-axis (representing professionals at the lowest acceptable level of overall competency). Relative social competency is illustrated by a second straight line varying from the highest level on the right to virtually zero on the left. The statistical model of Figure 6.12 recognizes that these professionals were neither drawn to mining disciplines on the basis of social skills nor were their social skills specifically advanced during the education process.

Ideally, managers and leaders are drawn from the upper portions of the competency normal curve. As shortages of people emerge, leaders and managers with less competency will be called on to fill critical positions. Although their technical skills are likely adequate to fulfill the requirements of the job, they may fall substantially short with respect to social skills.



Source: After Freeman 2006–2007

FIGURE 6.12 Technical and social competencies

Thus, the industry is likely to run out of competent people before it runs out of people to hire. Demographics dictate that these unfortunate phenomena promise to become more acute over the next decade, even while the need for a substantially higher degree of social competency is necessary for mines to maintain a social license and operate successfully.

TALENT TOOLBOX

The concept of the talent toolbox is based on the practical application of fundamental management principles with respect to developing a corporate culture that nurtures employees to succeed, maximize their potential, and play a pivotal role as a portal to the community.

Leadership

In the context used here, social skills refer to competencies that are crucial for an individual to be successful as a manager as well as a leader. Management is simply defined as responsibility that corresponds with authority. Leadership, however, can be characterized as the ability to meet responsibilities without using authority. As such, leadership is fundamentally different than management in that it is often viewed as the ability to achieve specific corporate goals and objectives by influencing others over whom they have no authority.

Management implies a relatively high position on an organizational chart while leadership can exist anywhere within the organization. Leaders can influence those above and below them in the organizational ladder, as well as their peers. Most important, however, is the ability to influence parties not part of the formal organization. This might include local communities, regulators, investors, potential employees, and special interest groups. For example, it is usually ill-advised for mine managers to attempt to "manage" a community that is party to the mine's social license. They can, however, offer leadership and thereby provide some measure of influence on the community.

A fundamental concept of the philosophy of "employees as portals" discussed in this section is that it provides each employee the opportunity to be a leader.

Just as all employees have the potential to serve as leaders, all employees also have an opportunity and an inherent responsibility to serve as portals to the community. For example, a truck driver from a mine who coaches his or her son in Little League baseball has countless opportunities to represent the values of the company to the parents of other children on the team, as well as the parents of opposing teams and league officials. Similarly, this coach has a unique opportunity to understand the needs of the community on which the dynamic social license is crafted and influence how the resulting business practices (sustainable) are developed and implemented.

Fairly or unfairly, the truck driver coach can often be much more effective in communicating the values and culture of the company than even the general manager. The participation of mine management in civic and charitable organizations and community issues is often perceived by the community as stemming from the economic and vested interests of the mine rather than from a sincere concern over a community's well-being or quality of life.

Developed Versus Developing Economies

Employees of mines in both developed and developing economies can and do play an important role in serving as portals to the community. Although there are fundamental differences in the capacities of typical employees and communities that are dependent on the unique economic characteristics of the mine's location (developed versus developing countries), the overall dynamic remains fairly similar.

The capacity of the typical employee to understand and represent the circumstances of the mine and the community can vary significantly. Employees from developed countries are likely to be at least high-school-educated and have had an opportunity to encounter a number of professional and personal experiences outside their home community. Those from developing economies are less likely to be as well educated and to possess the same type of experiences in the outside world.

Although the role of employees to serve as portals of communication between the company and the community are important in both economies, this function is arguably more critical in developing countries where:

- The level of community understanding with respect to evaluating short-, medium-, and long-term benefits and risks associated with specific decisions related to project development are likely to be low;
- Governments are less likely to be capable of serving in a position of oversight; and
- The need for economic benefits is greater. This lack of capacity invites an overemphasis on short-term economic benefits by communities in developing communities, which in turn may be detrimental to sustainable and prudent decision making.

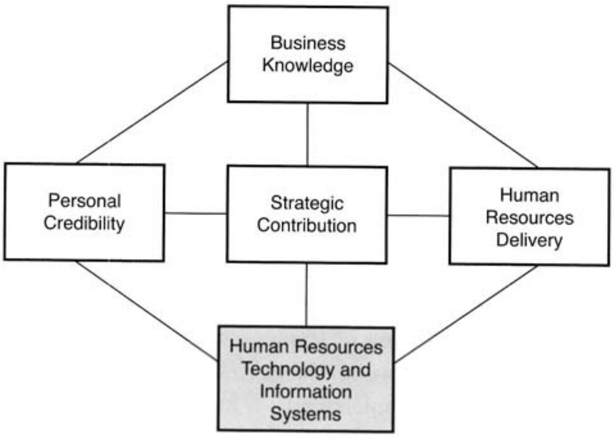
The deficiency in the capacity of communities in developing economies to represent themselves effectively in the process of developing a social license, as well as in the evolution of this relationship over time, is commonly filled by NGOs and special interest groups. Many NGOs aptly serve in this capacity, where mining and resource companies will often encourage their involvement. Unfortunately, many cases exist where some of these external groups and organizations possess ulterior motives and/or political and ideological agendas that destabilize this process and irreparably damage the relationship between the mine and the community stakeholders. In other cases, the NGO simply does not possess the expertise, knowledge, or resources to participate in this capacity properly and performs a disservice to the communities they are trying to help. As such, it behooves companies with mines in developing economies to build capacity and relationships with the potentially affected communities and stakeholders early in the process (e.g., exploration). This includes the NGOs and other groups that may participate on behalf of the community. In addition, the company must reach out and actively engage current and potential employees living in the community in order to convey trust and promote a corporate culture that will eventually enable these individuals to serve as effective portals to the community.

Information Management

Business strategy drives all activities in a company. Therefore, the human resources (HR) function requires defining the processes and tools around a specific business strategy. In HR, there are unique tools and levers a company can pull to get the outcomes necessary to drive strategy, but decisions need to be backed with data. This section is more about the data and pulling knowledge from that data than the systems themselves. Information management is one area where the HR function has something to learn from other functions of the business, such as the finance and commercial functions. Especially in engineering-led businesses such as mining and construction services, data is paramount in driving decisions. HR programs and initiatives that are in alignment with the strategy and backed up with a payback, NPV, IRR, or simply convincing data are easily sold as adding value. However, making those arguments with HR data is obviously easier said than done. Human resource information systems or human resources management systems (HRMS) are the databases and tools of HR-related data for driving decisions. HRMS capabilities have been enhanced into an integrated toolbox that can expand to the desired complexity of most organizations. Some of the most important HR decisions come down to what an organization will not use in a large and complex HRMS.

The Model

Information management is an integral part of the HR value proposition. The model in Figure 6.13 displays areas of HR capabilities that are demanded from the business. HR data and technology are an important part of the offering. There is a strong link from the HR technology and information systems to the ability to deliver. HR delivery has to do with responsiveness, staffing, development, and performance management, but without the processes and tools of an integrated HR information system, it cannot be delivered effectively.



Courtesy of Wayne Brockbank, University of Michigan

FIGURE 6.13 Model of human resources capabilities

Data-Driven Departments

HR departments that are data driven will be the most successful in helping the organization achieve business results. HR metrics are a way to drive these results. Whatever is measured and consistently reviewed is taken seriously in organizations. Understanding that the management team is dominated by managers who are data driven and quite competitive helps design effective communication to drive behavior in the business. For example, a large part of the HR strategy is built around retention of the right employees. Reviewing simple turnover rates and tracking of high-potential employees drive certain behaviors in the business. The regional managers understand the simple strategy and push the group to aspire to hold on to these valuable individuals and also add to the company's talent ranks by recruiting high potentials.

HR data is perhaps among the most difficult data to compile and retain. The complexity, volume, and continuous inputs stand out as reasons that records are not kept up to date. Employee self-service is perhaps the best methodology in certain areas, such as training records, development plans, and personal data. Every HRMS needs to be built for a purpose, as there are large amounts of data that have no value if kept. Only the data that is essential for driving business strategy should be a focus. Constant reviews of data are tedious but important. Any data tied to costs per department will usually be picked up immediately. Likewise, data linked to cost centers are usually kept up to date because of most organizations' focus on efficiency and costs. The greater the amount of HR data maintenance that can be tied to the business' bottom line (costs) or performed through employee self-service, the more efficient data maintenance will be.

High-Performance Organizations

A critical part of the HRMS is performance data on individual employees. Resource companies have generally kept and used performance ratings. Few have compiled and analyzed the data for use in driving performance in the future. A simple lag indicator analysis to run is the correlation between performance of employees, financial performance of the business, and management total rewards for the same time frame. It will give a good indication of how pay for performance is working in one's business. Taking that information and influencing behavior for the future can add value.

Another example of using HR data to optimize organizational performance is through what some companies label as "contestability" sessions. This is not the method of forcing performance data to fit a curve as a normal distribution; however, it is having a conversation with line managers and asking questions and understanding why managers have rated a certain way within a peer review. In the contestability session, before any employee is given a rating, managers at the appropriate level discuss the ratings they are giving their employees and discuss their reasons. The session is driven by data, and managers are encouraged to discuss specifics on progress of objectives. This process driven by data helps managers understand how the organization keeps people accountable within the culture of the business and places rigor in the process.

Focus List of High-Potential Employees—Key Retention Information

In addition to performance data, another critical area for information is in business succession plans and the resulting development plans of employees. There is no doubt that data on succession and key positions in the company is essential to strategic planning. This information is usually straightforward and simple to understand. Where it gets more complex is tailoring development plans with key individuals for particular roles in the future. With recruiting top talent becoming more difficult and an overall shortage in certain engineering areas, more in-depth time and energy should go toward sitting down with certain individuals and planning a career path. After the plan is discussed and agreed upon, placing the information in a system to track

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progress and help plan for the future is essential for this process to be successful. One competency that high-performing employees often lack is the ability to develop themselves continually and actively. This is a good way to drive behavior through information systems by tracking the progress of development plans.

Global Environment

Resource companies have always had a global aspect to them because of the orebodies they mine around the world. Given that fact, they are also becoming increasingly global in leadership and global organizational structures. Some companies have global matrix leadership teams and others make strong attempts to share best practices, synergies, and a common culture around the world. Never underestimate the "power of time zones" in regard to managing cross-border and cross-cultural work teams. HR information must take into consideration the complexities of language, foreign exchange (FX), country regulation on information, and culture. One example of complexity in global information is the FX issues with regard to short-term incentive targets. The question becomes a discussion on holding employees accountable for the risk of FX, a component over which they have no control. The only control they can take is possibly to mitigate against the downside. What happens when the company hits the target on a local level in local currency but they do not make the overall targets in the country where the shareholders sit because of FX rates? It has been determined that senior executives in the company must take on the additional challenge of FX rates because the shareholders are looking at the local market share price, wherever that might be. The stock market does not give the business a break because of FX rates. Deeper in the organization, short-term incentives are structured based on local currency. These decisions are strategic in nature and will reflect the culture of the business.

When it comes to information in a global organization, the simpler the process, the more successful it will be in organizing, updating, and holding people accountable. Translation issues in data and communication can widen the gaps of country borders. Having data in the HRMS in the local language is obviously very important; it's also mandated in certain parts of the world, such as Quebec in Canada.

Compensation—Total Rewards

Traditional HRMS have been able to collect and analyze employee compensation information. This is even more important given the higher demand for talent. The traditional 12-month review of compensation is being tested, with companies sometimes doing 6-month reviews, which are even more frequent for certain professions. HR information must be real time and proactive in keeping the basics, such as market data and local trends, correct. The reasons employees leave a company are often because of their managers and the corporate culture. But if a company does not get the basics correct, such as keeping salaries in line with the market, retention can be quite difficult.

Systems now attempt to compile total rewards or all parts of employee compensation in some form to help understand the costs of employment and also to educate the employees about all the other benefits. This is a bigger issue in the United States and other countries that do not have a government mandate on minimum health benefits, with employee benefits packages becoming a large part of total rewards. Employees often do not realize how much a company contributes to benefits packages and retirement plans. Employees often discount defined contribution and defined benefit plans unless companies take the time to educate their employees with data on how much the company contributes to the plans. However, the company needs to be competitive in the market before distributing a total rewards statement. Informing the workforce that they are underpaid in the marketplace does not inspire employee loyalty.

CHAPTER SEVEN

Management of Exploration

J. A. Espí

INTRODUCTION

As defined in this chapter, mineral exploration is comprised of the technical and management activities and processes leading to the discovery, definition, and technical evaluation of mineral deposits.

Mining is necessary to sustain economic prosperity and quality of life, and this requires continued exploration for new mineral deposits. As easily discoverable near-surface orebodies are exploited, exploration needs to target deposits located at greater depths and more remote locations.

Mining and mineral exploration companies are faced with increased government regulations and voluntary adherence to sustainable development frameworks. This chapter discusses a mining regulatory framework and some voluntary "best practices" dealing with issues of corporate social responsibility and social license in the context of mineral exploration activities.

Regarding strategic trends, Heffernan[1] pointed out that in 2000, the exploration strategy was following three major trends: (1) a decrease in greenfields or "grassroots" exploration and increasing activity around existing operations (brownfield), (2) an increase in mergers and acquisitions, and (3) an upsurge in strategic alliances, particularly between majors and juniors. Today, these trends are basically valid.

Probably the most significant strategic change in this decade is the dramatic increase in the role of listed junior exploration companies. In the next section, Hudon refers to a study by Canadian-based Metals Economics Group[2] and reports it is estimated that in 2007, total world expenditures in exploration for nonferrous metals reached US$10.5 billion, whereas the junior mining sector has accounted for more than half of global exploration spending.

Regarding sustainable management issues, the exploration process does not require any alteration of the land uses where it takes place or any major development; therefore, its social and environmental impacts are rather limited. However, exploration represents the initial interaction between a mining company and the local communities, so building a trusting relationship with stakeholders at the exploration stages is essential to the achievement of social license. In this regard, the business perspective of social license as a strategic advantage in gaining access to mineral resources is gaining the attention of mining companies. In this context, an excellent sustainable development draft framework for exploration activities has been developed by the Prospectors and Developers Association of Canada.[3]

Also highlighted in this chapter, the application of international standards to the evaluation and reporting of exploration results is essential for transparency and ethics considerations when reporting to shareholders and when dealing with the hosting communities and other stakeholders. The balance of this chapter is composed of four sections.

"Regulatory Framework for Mineral Exploration" discusses the mining regulatory framework and voluntary "best practices" dealing with issues of sustainability development and corporate social responsibility in the context of mining exploration activities.

"Exploration Strategy of Mining Companies" reviews the different exploration strategies of the minerals industry, focusing on the links between exploration strategy and sustainability.

"Exploration Management and Sustainability" describes the exploration management activities and processes, focusing on corporate social responsibility issues. It also discusses several sustainable development frameworks as applied to mineral exploration.

"Ore Resources Inventory Management" focuses on key criteria for sustainable management of ore reserves inventory, the use of resource management systems, the classification of resources and reserves, and the concepts of grade control as it applies to ore resource management.

REGULATORY FRAMEWORK FOR MINERAL EXPLORATION*

Mining is a nonrenewable resource industry and may therefore at first appear to be on a collision course with sustainable development. In order to reconcile mining activities with sustainable development objectives, the mining regulatory framework, including the securities regulatory framework, must provide for guarantees that mining companies must be required to follow.

The World Business Council for Sustainable Development states: "Corporate social responsibility is the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as the local community and society at large."[4]

This section discusses the mining regulatory framework and some voluntary "best practices" dealing with issues of corporate social responsibility (CSR) in the context of mining exploration activities.

The Concept of Mineral Exploration

It is generally accepted that mining is a process that begins with the exploration for and the discovery of mineral deposits that continues through ore extraction and processing to the closure and remediation of worked-out sites. Exploration is thus at the very heart of mining. Mineral exploration basically consists of a number of interlinked and sequential stages, which involve material expenditures, financing, and risks. Each successive stage involves more time and more money.

With increasing environmental restrictions and administrative hurdles, the search for minerals has extended to more hostile geographical environments. Exploration investment is further affected by the metals demand and supply, the prices of metals, the ability to raise capital, and shareholders' satisfaction.

The mining industry is capital intensive. From exploration to mine closure, mining operations may have a serious impact on the environment and communities where the mine is located. The sum of all the risk factors determines why mining is unique and different from other economic activities. According to some, it takes one thousand grassroots prospects to make a discovery and it takes one hundred discoveries to make a mine. According to a study by Canadian-based Metals Economics Group (MEG), it is estimated that, at the end of 2007, total world exploration expenditures for nonferrous metals companies listed on the stock exchange had reached US$10.5 billion.[5]

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* This section was written by M. G. Hudon.

Regulatory Framework

Policy and regulatory regimes affect the attractiveness of a country for exploration investment; the timelines, predictability, and certainty are important factors. The exploration companies are faced with an increased general regulatory framework including land use, project environmental assessment reviews, aboriginal issues, abandoned mines, and regulatory issues from the regulatory securities authorities. There is a feeling that the mining industry is increasingly the subject of complicated regulations. Some say that it is more difficult now to be a mineral exploration company than it was 15–20 years ago.

In some regions, regulations regarding security, health and safety, land tenure, and the environment have tripled. According to a PricewaterhouseCoopers report, mining companies are now spending upwards of 20% of their annual expenditures meeting regulatory requirements.[6] A whole new set of regulations now deal with social license to operate and the duty to consult and accommodate stakeholders.

The Mining Code

In almost all cases, ownership of rights in or over mineral substances forms part of the domain of the state. No person may therefore prospect or carry out exploration or mining activities without a permit or license issued by the governmental authority having jurisdiction.

Exploration licenses or permits. In some instances, exploration permits or licenses are issued upon paying the prescribed fees and completing and delivering the form prescribed by regulations. In these cases, the required work program is prescribed by regulation. In other instances, the exploration permit or license will be issued subject to the applicant satisfying the responsible governmental authorities that it has the financial and technical capabilities to carry out a work program negotiated with the responsible governmental authorities.

It is recommended that in all cases, a qualified independent technical report be filed upon the application for an exploration permit or license. Such a report, prepared by an independent qualified person, should include social and community factors, as well as technical aspects.

The holder of a mining exploration permit or license is generally subject to general applicable laws dealing with, among other things, the general regulatory environmental framework, including the forest, water, wildlife conservation, and agriculture regulatory frameworks.

Disclosure—notices. The holder of an exploration permit or license must generally be required to transmit to the mining authorities a report on exploration work performed and the results of the work, the whole subject to prescribed confidentiality rules.

Before commencing grassroots or surface exploration work, no notice, under the Mining Code, is generally required to be given to the mining authorities. However, in the case of underground exploration, a provision should provide for required written notices before commencing operations.

Protective measures. The mining regulatory framework should generally require of the holder that protective measures be taken to prevent any damage that may result from the exploration work or the discontinuance of the exploration work. The mining regulatory framework should provide that if the holder fails to take such measures, the mining authorities have the right to suspend the holder's right until such time as the default is remedied or have the right to cause such measures to be taken at the expense of the holder.

Land rehabilitation and restoration work. The principle provided by the Mining Code should be that every holder of an exploration permit or license must submit a rehabilitation and restoration plan approved by the mining authorities before commencing exploration work, the whole as determined by regulation. Usually, such plan is approved after consultation with the governmental authority responsible for sustainable development.

The contents of the plan should be spelled out in the mining regulatory framework; the plan should provide for rehabilitation and restoration work to be performed during the duration of the permit or license. The plan must include a description of the guarantee serving to ensure performance of the work required by the plan.

The mining regulatory framework will generally provide for provisions in cases of default and more particularly will award the mining authorities the right to cause the work required by the rehabilitation and restoration plan to be performed at the holder's expense and to recover the cost thereof out of the guarantee.

The mining regulatory framework should also give to the mining authorities the right to suspend or revoke exploration permits or licenses when the prescribed work has not been executed or when the work report submitted has not been accepted. Before suspending or revoking an exploration permit or license, the principles respecting administrative justice must apply.

Guarantees. The rehabilitation and restoration plan should include a description of the guarantee serving to ensure the performance of the work required by the plan.

The amount of the guarantee should correspond to a prescribed percentage of the anticipated cost of carrying out that part of the work required under the plan that relates to the rehabilitation and restoration of the site. The forms of the guarantee may include

- Bonds issued or guaranteed by a recognized government and having a market value at least equal to the amount of the guarantee,
- Guaranteed investment certificates or term deposit certificates issued by a recognized bank or a trust company,
- An irrevocable and unconditional letter of credit issued by a recognized bank or a trust company,
- A security or a guarantee policy issued by a legal person legally empowered to act in that quality, or
- A guarantee provided by a third party secured by an acceptable collateral.

The mining regulatory framework may, in either circumstance, also allow for the right of the mining authorities to subject the approval of a rehabilitation and restoration plan to the advance payment of all or part of the guarantee. Powers should be given to the mining authorities: (1) to increase the amount of the guarantee or reduce it depending on the circumstances, and (2) to request the payment in full of the guarantee if the financial situation of the holder could prevent the payment of all or part of the guarantee.

Environment Quality Legislation

In general, the environmental legislation requires the mining company to perform an Environmental Impact Statement (EIS), aiming to evaluate the environmental impacts and risks associated with mining operations and determine the monitoring, control, and remediation actions that should be implemented in the project to minimize the environmental risks.

Conflicts. The mining regulatory framework should provide that none of its provisions should affect or restrict the application of the general legislation dealing with the quality of the environment.

Authorization. The environmental quality legislation framework will generally provide that no person may undertake any construction, work, activity, or operation, or carry out work as provided for by regulation, without following the rules for Environmental Impact Assessments (EIAs) and, as the case may be, without obtaining an authorization certificate from the responsible environmental authority.

Generally, the regulatory framework will

- Determine the classes of construction, works, plans, programs, operations, works, or activities to which such rule applies;
- Determine the parameters of an EIA with regard, namely, to the impact of a project on nature, the biophysical milieu, the underwater milieu, human communities, the balance of ecosystems, archaeological and historical sites, and cultural property;
- Prescribe the terms and conditions of the information and of the public consultation pertaining to any application for an authorization certificate or for an EIA for all or some of the classes of projects contemplated; and
- Define types of EIAs and the terms and conditions of presentation.

The rules should clearly state which projects are automatically subject to the EIA or notice procedure and those that may be or are automatically exempt from said measures. For example, all mining site developments, including the additions to, alterations, or modifications of existing mining site developments should automatically be subject to assessment, while exploration projects, except for below-ground projects, should not automatically be subject to the assessment and notice procedure contemplated in the environmental legislation framework.

No project not automatically subject to the EIA and public notice procedure should be undertaken unless a certificate of authorization or an exemption from the EIA and review procedure has been issued by the responsible environmental authority.

Every person intending to undertake a project that is not automatically subject to the EIA and public notice procedure must give prior written notice of his intention to the responsible governmental authority and briefly indicate the nature of the project, the place where the project is to be undertaken, and the date foreseen for the start of the work, the whole as prescribed by regulation. The said notice must deal with technical, economic, and social implications of the project.

The proponent of a project that is automatically subject to EIAs shall prepare an EIS, either preliminary or detailed, or both, according to the prescribed directions and recommendations of the responsible governmental authority and in conformity with the regulations made under the law. Such statement should deal namely with a qualitative and quantitative inventory of the aspects of the physical and social environment that could be affected by the project, such as fauna; flora; human communities; the cultural, archaeological, and historical heritage of the area; agricultural resources; and the use made of resources of the area.

The content of the notices and statements should be prepared by a qualified independent person.

The Capital Markets and Securities Regulatory Framework

A mining exploration company will finance its operations and growth through the capital markets. The main source of financing for mining exploration companies comes from the issuance of new shares in their capital stock, be it by way of public or private financing. Access to venture capital is essential given the nature of mining exploration and that stock exchange listed companies account for the bulk of worldwide exploration budgets.

Financing

According to MEG, which tracks only junior financings for more than 2,000 companies, nearly 90% of the companies covered by its studies are based in Canada (1,002), Australia (439), the United States (89) and the United Kingdom (82); 60% of the world's exploration and mining companies are listed on the Toronto Stock Exchange or the Toronto Stock Exchange Venture in Canada; and 50% of all equity financing is done in Canada.[7]

Disclosure

Once a company becomes public and/or gets listed on a stock exchange, it is subject to certain disclosure requirements and other good governance requirements. Transparency and good governance are the underlying basic principles of stock exchange rules, securities laws, and regulations.

The policies governing such a framework do not generally require from listed companies the obligation to disclose, in annual reports, environmental or sustainable corporate policies. Such policies sometimes require listed companies to adopt and disclose their good governance policy, which mainly deals with internal management issues.

There appears to be a tendency to regulate financial disclosures and to forget disclosure of CSR. Some securities commissions that regulate companies that have issued shares to the public (and which are listed on stock exchanges) are urging such companies to improve reporting of risks and liabilities regarding the physical environment.

Investments

Institutional investors appear to be requesting improved disclosure of environmental risks; some investment firms' portfolio managers and pension funds analyze, before an investment decision is made, the past record on how mining companies treat the environment and the communities in which they operate. As a result, some mining companies are now considering the interests of their shareholders, those of their other stakeholders including the communities they operate in, and the protection of the environment as part of their duty.

A number of banks have adopted a set of environmental and social guidelines, the Equator Principles. Under these principles, companies or countries that apply to the member banks for certain infrastructure projects must show that these projects would not have negative effects on people and the environment.

Technical Report

For publicly listed mining exploration companies that intend to obtain financing, a technical report often must be filed describing the geology of the project, prior programs, if any, the details of the exploration program to be executed, and the social and economic implications. This report is generally prepared by an independent competent person, a geologist, or an engineer duly registered with a recognized professional corporation.

Voluntary Frameworks

Mining companies interested in improving their social and environmental performance as part of their business have a wide range of voluntary tools available to them. Such tools can vary widely in terms of objectives, scope, costs, level of formality, partnerships, extent of stakeholder involvement, and many other characteristics. These tools can be applied to one or more of the planning and implementation stages of corporate operations.

There are a variety of principles, guidelines, and codes of conduct that mining companies can use to develop their commitments:

- The OECD (Organisation for Economic Co-Operation and Development) Guidelines for Multinational Enterprises and for Corporate Governance
- United Nations Global Compact
- Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Guidelines
- The Prospectors and Developers Association of Canada (PDAC) Guidelines
- Global Sullivan Principles
- Association of British Insurers (Corporate Governance and Investment Guidelines)
- Canadian Coalition for Good Governance
- Global Reporting Initiative (GRI) Guidelines[8]

In its voluntary "Exploration Best Practices Guidelines," CIM has adopted the following principle regarding environment, safety, and community relations: "All field work should be conducted in a safe, professional manner with due regard for the environment, the concerns of local communities and with regulatory requirements. An environmental program, including baseline studies, appropriate to the stage of the project should be carried out (...)." The guidelines add: "This set of broad guidelines or 'best practices' has been drawn up to ensure a consistently high quality of work that will maintain public confidence and assist securities regulators. The guidelines are not intended to inhibit the original thinking or application of new approaches that are fundamental to successful mineral exploration."[9]

GRI is the leading international standard for sustainability reporting. More than 1,000 organizations from 60 countries use the GRI Guidelines to produce their sustainability reports. All sorts of organizations report using the GRI Guidelines, such as corporate businesses, public agencies, smaller enterprises, nongovernmental organizations, industry groups, and others.

PDAC has developed online tools to assist companies in developing their own sustainability policies in exploration. This organization's "e3—Environmental Excellence in Exploration" online manual launched in 2003, is a comprehensive Internet-based toolkit that offers leading examples of environmental and social responsibility in the minerals industry.[10] Such a framework should namely provide good practice guidelines, performance indicators, and reporting criteria. The draft principles and management essentials proposed by the PDAC are summarized in the "Exploration Management and Sustainability" section.

Challenges and Conclusions

Access to lands for mineral exploration is critical for a healthy mining industry, and the interests of affected communities must be considered. Permitting and consultation issues should be dealt with by the regulatory framework. Issues in exploration that involve people must be addressed at the outset, including community relations.

A large portion of the world is open to mining companies, which are offered numerous exploration investment options. Key factors—some controlled by the government, others beyond its control—have an impact on the ability of a country to attract investments. Given that mining exploration is a high-cost, high-risk business, investors will be attracted by those countries with prospective geology, a reliable mining code, a reasonable tax regime, political stability, and reasonable sustainable development best practices.

Today, there appears to be growing pressure on mining companies around the globe to adopt CSR guidelines as part of their business plan. Social sustainable development guarantees do not generally appear to be a requirement prescribed by law or regulation. It is left to the mining companies to subscribe voluntarily to various codes and standards, which are being promoted by various companies and seldom without material consequences.

In order to promote sustainable development, governments should adopt a regulatory framework that would provide for consequences in cases of default. The mining companies should be required to adopt a sustainability development policy in which their business and social responsibility is spelled out; it should be clearly stated that business goals will be achieved in a safe, transparent, environmentally and socially responsible way. An effort should be made by governments to promote a better balance between the competing interests of mining companies and communities.

Companies requesting an exploration permit or license should be required to file their corporate governance policy with the mining authorities at the very start, including sustainability development and corporate responsibility issues; the application for listing on a stock exchange should also include a similar policy. Such corporate governance policy could (in the absence of an applicable regulatory framework) make reference to international guidelines, disclosure, and transparency.

The regulatory framework should also provide for the filing of a prescribed technical and social report regarding all mineral exploration projects, or at least for below-ground projects. Such disclosure requirements would be a condition precedent to the delivery of exploration permits or for the authorization required for the commencement of work. The content of such a technical report would be prescribed by regulation. The report would be based on information prepared by or under the supervision of a qualified independent person.

The regulatory framework could refer to the permitted use of foreign or international codes, standards, or policies regarding such reports. Given that mining guidelines, industry practices, and standards are evolving, the regulatory framework should adopt such forms (regulations, guidelines, policies, etc.) that are flexible and that may be adapted quickly to developments regarding best practices.

Every person engaged in exploration should be requested to forward annually or quarterly to the mining and, as the case may be, to the securities authorities, a report and a forecast for the following year, showing namely the nature and cost of the exploration work, the rehabilitation and restoration work performed or to be performed, and community expenses and involvement.

Wherever impact assessment reports or notices are required for an exploration project, the mining regulatory framework should prescribe the contents thereof and provide for specific CSR requirements as to its content. Table 7.1 shows sample content for CSR.

Once the exploration permit is awarded or renewed, title holders should be required each year to describe completely their practices with specific reference to the prescribed guidelines or rules. Such disclosure should be filed with the responsible mining and securities regulatory authorities. In their disclosure, the mining companies should describe their practices against each guideline or rule and, if their practices differ, reasons should be provided for the discrepancies. This mandatory disclosure against guidelines or rules should provide investors with useful information and enhance the quality of the capital markets and the environment. Mining companies listed on stock exchanges should be required to issue yearly comparative sustainability reports outlining the social, environmental, and economic performance of all operations.

In the event such guidelines or rules are not fully addressed by the mining companies, the mining and securities regulatory framework should provide for measures dealing with sanctions ranging from daily penalties to the suspension of the title holder's rights up and until such defaults are remedied. The capital markets' regulatory bodies should provide for the suspension or delisting of a company's securities where it continuously fails to meet such disclosure requirements.

TABLE 7.1 Sample regulatory framework for corporate social responsibility

Business Practices
• The policies for corporate governance, ethics, and sustainable development
• The budget for environmental and social aspects and human resources
• The required compliance of contractors and subcontractors in contracts to the company's policies regarding social, environmental, health and safety issues, and human rights
• All and any information that is relevant to their activities, subject to confidentiality constraints
• The company's transparency policy
• Project-related social and environmental matters and risks
• The policy dealing with employment matters and its public disclosure
• The policies and procedures for the management of environmental issues, including remediation and reclamation of lands, health and safety, and public disclosure
Due Diligence
• The nature and intent of the due diligence activities regarding social, cultural, environmental, and human rights issues
• The policy and procedures for prior and informed consultation with groups affected by the project
• The policy and procedures for update of informed consultations
Communities
• The policy concerned with communities and public disclosure including indigenous peoples, lands, and resources
• The policy and procedure for community relations; land access, compensation, and dispute resolution
• The procedure for the mutual exchange of information
• The execution of land access agreement
• The information about the company and exploration program
• The implementation of monitoring and reporting information procedure as to the social and environmental aspects of the project
• The consultation process, the adoption and public disclosure of policies and procedures for employment, use of local suppliers and services, and community development

Regarding the role of the regulatory framework in the promotion of sustainable development, the tax aspects related thereto should be examined. The costs of community consultations, baseline environmental studies, and feasibility studies should qualify as exploration expenses, giving the investors the right to deduct such expenses; the taxation framework should encourage the cleanup of abandoned sites. Under Canada's Income Tax Act,[11] contributions to a qualified environmental trust (QET) are deductible in the year of contribution. Such a QET is defined as "a trust resident in a province and maintained at that time for the sole purpose of funding the reclamation of a site in the province that had been used primarily for or for any combination of, the operation of a mine or a waste dump, where the maintenance of the trust is or may become required under the terms of a contract entered into with Her Majesty in Right of Canada or the province, or is or may become required under a law of Canada or the province (...)."

EXPLORATION STRATEGY OF MINING COMPANIES

Exploration is the most strategic activity of any mining company. Therefore, the efficient management of the exploration portfolio is essential to sustainability. By and large, the success of a mining company is determined by its capacity to transform today's exploration targets into tomorrow's cash-flow streams.

Sustainable exploration strategies should be focused on controlling decision risks, considering risk as chance of failure or loss. Singer and Kouda[12] consider three ways to control failure risk:

1. Increasing the number of prospects,
2. Increasing the economic potential of prospects, or
3. Improving prospect management.

Management aspects are discussed in the "Exploration Management and Sustainability" section, where successful exploration management is mainly linked to three management aspects: (1) in-depth knowledge of the legal framework and organizational structure of local, regional and national administrations where the company operates, (2) high ethics, and (3) environmental and social responsibility.

MEG economist Michael Chender[13] considers the traditional drivers of exploration strategy to be the need for corporate growth, high metal prices, availability of risk capital, and new discoveries that open up new areas to exploration. Some "internal" drivers are also important, such as: what is in our pipeline now, the potential of discovery near our mines, and how much should we spend just to keep up with our present exploration rights.

From the strategic management perspective, resource growth can be achieved by direct investment in exploration or by relying on others (e.g., junior companies) and subsequently acquiring the resources. As previously highlighted by Hudon, listed junior mining companies accounted for almost 50% of the world exploration spending of US$10.5 billion in 2007.

David Timms[14] highlights that the tremendous success of the junior exploration model is related to seven competitive advantages:

1. Operate with cost efficiency,
2. Select the best people (mine finders),
3. Develop a multidisciplinary team,
4. Devise meaningful incentive schemes,
5. Explore in ore-permissive areas,
6. Design long-term programs, and
7. Drill more holes into selected targets.

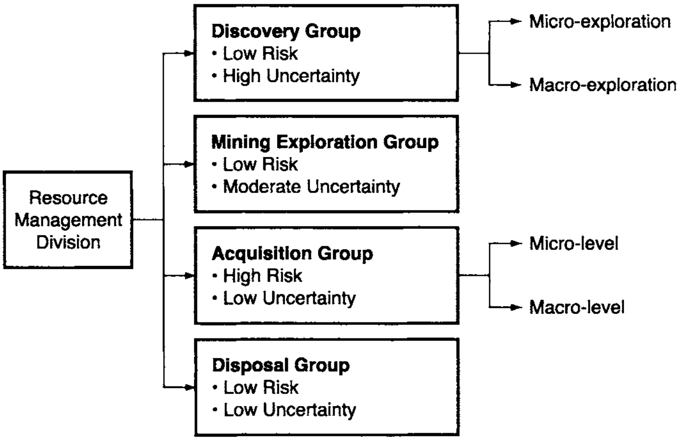
Other important strategic decisions are the distribution of capital budget among exploration targets and the use of contractors (drilling, geophysics, and logistics).

Strategic Alternatives for Exploration

What shareholders and other investors expect from a mining company[15] is that it can deliver a growth in reserves and production by whatever means, either by organic growth through the success of company's own exploration division or, alternatively, through acquisitions or joint-venturing. Another factor is the investor's perception of the quality of company's management and the technical expertise of the exploration group.

An important strategic question is deciding between achieving mineral resource growth through in-house exploration or by focusing on acquisitions of exploration assets with high upside potential. It's also important to find out how these two options are perceived by investors. From a strategic perspective, this question will determine the size and the expertise required for the company exploration group, as well as its role in the organization.

Gunthorpe[16] proposes a structural model (Figure 7.1) describing the functions of the mineral resource management group of a mining company. The model defines four management sections, the functions and responsibilities of which are related to the risk, and the uncertainty of the decisions to be made.



Source: After Gunthorpe 2001

FIGURE 7.1 Four functions of resource management and growth

The model considers two discovery strategies: greenfield and brownfield. The greenfield exploration strategy focuses on the discovery of new orebodies in areas where other orebodies have already been discovered or in areas with no previous discoveries but showing favorable geologic conditions. Brownfield exploration focuses on the environs of existing mining operations, aiming for the discovery of extensions and repetitions of known orebodies, and a lower probability of a major new discovery.

The strategy of growth via "discovery" is considered as low risk/high uncertainty because capital intensity may be controlled, but the probability of success may be low. Similarly, brownfield exploration risk is low because it can be controlled and uncertainty is somewhat lower (higher probability of success). Therefore, growth through exploration should be considered a conservative, low-risk strategy.

As an example, AngloGold's exploration strategy[17] is to discover gold reserves via brownfield exploration at a cost of less than US$9/oz Au reserves, and greenfield discoveries at an exploration cost of less than US$30/oz Au reserves.

In contrast, strategies of growth via acquisition are uncertainty-controlled (the acquisition decision may be taken under low uncertainty), but the financial exposure is associated with the decision and therefore is maximum.

Asset disposal is an important part of exploration strategy that carries a substantial risk. Here, risk is associated with disposing of an asset without having fully assessed its economic potential.

As previously stated, the exploration strategy should be focused on managing for risk. However, risk management strategies vary depending on the size and the financial capacity of the company. Only a few global players have the financial capacity to run high-risk exploration strategies involving both acquisitions and discovery-focused exploration.

As an example, two leading gold companies, Newmont Corporation and Barrick Gold Corporation, with similar sizes and business purposes, have different growth strategies. While Newmont focuses on growth through exploration as its main strategy, considering acquisitions on an opportunistic basis only, Barrick Gold focuses on growth through acquisition of assets. Both

Exploration Strategy of Rio Tinto

- ✓ Our prime focus is on mining large, long-life, low-cost orebodies. We recognize that medium term growth will come largely from further development of assets we already own.
- ✓ Today's mining industry is highly competitive and Rio Tinto needs to improve continually in order to keep ahead.
- ✓ Our fundamental principles will not change, but we do contemplate some changes in emphasis.
- ✓ Capital spending on new projects has been rising steadily in the last few years as we have developed a number of high-quality greenfield projects and some major brownfield extensions. In addition, we have development studies progressing on 15 more projects. Over the past year we have transferred five projects from exploration to the product groups.
- ✓ Our level of success reflects efforts we have made over a number of years and is a tangible result of our commitment to exploration.

Source: Data from Rio Tinto Ltd.'s Web site

FIGURE 7.2 Exploration strategy: Rio Tinto

strategies are valid, though probably Newmont's seeks economic efficiency while Barrick Gold seeks faster growth.

Other examples of exploration strategies for three global mining companies, Rio Tinto, AngloGold Ashanti, and Barrick Gold, are described below.

Rio Tinto's corporate strategy[18] (Figure 7.2) focuses on developing large orebodies that can be mined at a low operating cost. This strategy allows for basing medium-term growth on resources already discovered and evaluated.

AngloGold's exploration strategy[19] (Figure 7.3) gives maximum priority to growth from expansion of ore reserves nearby existing orebodies (brownfield exploration), considering high-risk greenfield exploration as a second priority.

Barrick Gold's exploration strategy[20] (Figure 7.4) is based on expanding its resource portfolio through acquisition and focusing its own exploration effort on the expansion of ore reserves from existing operations.

In general, the exploration strategies of most gold and base metal companies seek a balance between both exploration and acquisition strategies by operating their own exploration program while following the market for acquisition opportunities.

Also, most medium/large mining companies carry out exploration through joint ventures with junior companies, seeking competitive advantages in case of a discovery. Exploration joint-venture programs are also carried out between large mining companies, in this case, aiming to reduce financial risk.

The present business cycle of high prices is significantly influencing the strategy of mining companies. The process of globalization of the mining sector is taking place at a much higher rate, with mergers and acquisitions becoming the main strategy for survival. The structure of the mining sector has changed dramatically through a rapid process of business concentration, with a handful of global giants dominating the sector.

Exploration Strategy of AngloGold Ashanti

- ✓ The replacement of production ounces through near-mine (brownfields) exploration continued to remain a high priority for AngloGold Ashanti in 2006. During the year, brownfields exploration activities continued around most of the group's current operations.
- ✓ In 2006, exploration activities in new areas (greenfields exploration) were primarily focused on the Tropicana joint venture project in Western Australia, in Colombia, and in the Democratic Republic of Congo (DRC). Joint ventures and partnerships with other companies facilitated additional greenfields exploration activities in Russia, China, Laos, Colombia, and the Philippines, while the company divested its exploration assets in both Alaska and Mongolia during the year. The discovery of new long-life, low-cost mines remains the principle objective of the greenfields exploration program, although AngloGold Ashanti is also committed to maximizing shareholder value by exiting or selling those exploration assets that do not meet its internal growth criteria and also by opportunistically investing in prospective junior exploration companies.
- ✓ During 2006, total exploration expenditure amounted to $103 million, of which $52 million was spent on brownfields exploration. The remaining $51 million was primarily invested in three key greenfields areas (the Tropicana joint venture in Western Australia, in Colombia, and in the DRC), with the remainder being spent in Russia, China, the Philippines, and Laos. Exploration expenditure is expected to increase to $163 million in 2007, with $77 million to be spent on brownfields exploration and $86 million to be spent on greenfields exploration.

Source: Data from AngloGold Ashanti's Web site

FIGURE 7.3 Exploration strategy: AngloGold Ashanti

Exploration Strategy of Barrick Gold

- ✓ Barrick has a motivated, discovery-driven team looking for gold in many countries around the world and plans to spend about $170 million on exploration in 2007. Reserve development and replacement of production is a major priority at all sites. The Company consistently funds its exploration programs throughout all gold cycles, and has a proven track record of finding ounces at both greenfield and brownfield projects.
- ✓ Exploration is focused on highly gold-endowed districts where Barrick controls large land positions, the primary ones being the Goldstrike and Cortez districts in Nevada, the Frontera District in Chile/Argentina, the Lake Victoria District in Tanzania, and at Porgera in Papua New Guinea. In addition, the Company is exploring earlier-stage projects and evaluating exploration opportunites in emerging districts around the world.
- ✓ Three key factors drive the Company's exploration success: the motivation and technical excellence of its exploration team, the policy of consistently investing in exploration, and the robust and balanced pipeline of exploration projects. The Company's disciplined exploration strategy maximizes the chance of near-term discovery by putting the best people on the best projects and advancing the best projects more quickly up the exploration pipeline.

Source: Data from Barrick Gold's Web site

FIGURE 7.4 Exploration strategy: Barrick Gold

Focused Strategies

Strategic management of exploration relies on three main factors: the people, the processes, and the quality of the projects. All mining companies aim to excel with respect to these management principles (people, processes, and projects) but may differ in focus and the standards of quality of the projects.

As an example, Gold Fields[21] focuses on high geology standards and exploration databases. In Gold Fields, any geological knowledge should be included in a geographic information system (GIS) and exploration data should pass a quality assurance process. To this aim, the company runs high-quality technical support systems and employs highly qualified exploration geologists and quality assurance experts who control all stages in the exploration process.

Exploration strategies may also aim for specialization by focus, substance, geography, geological environment, and even technology. This is illustrated in Table 7.2.

Another important strategy aspect is the fact that exploration investments tend to go to countries and regions where they are well received (i.e., those with a stable and favorable legal framework) and to areas with higher potential for discovery.

However, some of the recent "world class" orebodies had a metalogenesis unknown at the time of discovery. This is where no experience on similar orebodies was available, as was the case of Neves Corvo, Candelaria, and Century. New discoveries have confirmed the mineral "fertility" of the circum-Pacific belt and the potential of the belt in areas like Pakistan, Iran, Turkey, and the Balkans. Furthermore, the giant orebodies of Escondida and Grasberg were found by using geological criteria only.

EXPLORATION MANAGEMENT AND SUSTAINABILITY

Mineral exploration is the first phase of the mine life cycle and is comprised of the technical and management activities and processes leading to the discovery, definition, and technical evaluation of mineral deposits. Usually, mineral exploration starts with the definition of large areas where mineral prospecting may be carried out to identify one or more exploration targets of smaller size within it. In a second stage, each of these targets is subject to more detailed and cost-intensive exploration activities, aiming to define mineral deposits with economic potential, where detail drilling may lead to the definition of orebodies of economic interest.

Mineral exploration generally has a low environmental and social impact, and, in most cases, it does not succeed in its objective of developing a new mine. However, being the initial environmental and social footprint of mining, managing exploration in a responsible and transparent manner is critical to achieve social license to operate should exploration lead to project development and mining.

Stages of the Exploration Process

Exploration is normally carried out in three stages:

1. Area selection,
2. Target generation, and
3. Resource evaluation.

Area Selection

Area selection is the process whereby the area having the greatest potential for obtaining economic ore is selected. Area selection is based on the application and testing of orebody genesis models from previously discovered orebodies on the basis of the knowledge on ore occurrences

TABLE 7.2 Typical differences in exploration strategy of mining companies

Strategy Focus	Company	Priorities
Substance	Orezone	Au
	Northern Shield	Platinum group elements
	Anvil	High-grade Cu, Au
Orebody—Genesis	Anvil	In mineral belts
	Compass	Regional experts
Orebody—Placement	Anvil	Shallow orebodies
	Newcrest	Deep orebodies
Region, exploration type...	Minvita	United States
	Anvil	GIS data storage
	Albidon	Districts well known
	Newcrest	Grass roots—good databases
	Teal	Known orebody models
	Northern Shield	Good data, politically stable areas
Environmental impact	Anvil	Low impact and good local contacts
Exploration teams	Albidon	Technical expertise and experience of team
Know-how	Compass	Rare metals
	Albidon	State-of-the-art exploration technology
Portfolio	Anvil	"Balanced pipeline of products"
Financial objective	Aur Resources	ROI > 15% Life > 10 years
	Nippon Mining	High value—downside cost potential
Stage and business structure	Silver Gray	Minority share
	Teal	Existing projects
	Alba Mineral Resources	Advance project stages
	Minvita	Joint venture in "grass roots"
Country risk	Teal	High country risk
	Kinbauri	Political stability

in the area and the mechanisms of their formation. The required knowledge is acquired via the study of geological maps and visual inspection of the area by experienced geologists, using available databases and publications.

The exploration activities performed in this stage, often referred to as reconnaissance exploration, include the compilation of previously existing information, aerial photography, and remote sensing investigation. Also, limited geophysical work (magnetic, electromagnetic, and radiometric methods) and some geochemical methods may be performed in this stage. The reconnaissance may sometimes affect areas from hundreds to several thousand square kilometers wide.

Target Generation

The target generation phase involves investigations of the geology via mapping, geophysics, and geochemical or intensive geophysical testing of the surface and subsurface geology. In some cases, for instance in areas covered by soil, alluvium, and platform cover, drilling may be performed directly as a mechanism for generating targets.

This process applies the disciplines of mineral deposit modeling, geology and structural geology, geochronology, petrology, and a host of geophysical and geochemical disciplines. The process is used to make predictions and draw parallels between the known ore deposits and their physical form and the unknown potential of finding a "look-alike" within the selected area.

Geological mapping is performed over the selected area in the previous stage and geological information is digitized into databases, and geological maps of the selected area are produced. Mapping in this stage includes outcrop lithology, stratigraphy, and structural geology, mineralogical alterations, and structural data, such as intrusions, faults, folds, and so on. This information is essential to deduce the location of hidden mineral deposits. It is usual to take samples for the mineralogical, grain size, and textural study under the microscope.

Geochemical exploration is performed by means of a systematic sampling and a chemical analysis of rocks, stream sediments, soil, water, and vegetation to determine the location of dispersion halos of chemical elements. Geochemical exploration would start with the reconnaissance of wide areas in order to reduce the survey areas gradually, and it would end up with the selection of "targets" to be considered for the resource evaluation stage. Thus, the geochemical studies must be completed with the chemical and mineralogical knowledge of the deposit.

The type of study carried out will depend on the degree of geochemical and geological knowledge of the surveyed area, on the nature of the explored land, and on the company operative strategies.

Geophysical exploration is performed to measure the variation of physical properties of the ground, which may result from the existence of a hidden orebody. The most common geophysical methods are gravimetric, magnetic, electrical, forced current, seismic, and radiometric. The environmental impact associated with modern techniques of geophysical exploration is considered minimal and not permanent.

Resource Evaluation

Resource evaluation is undertaken to quantify the grade and tonnage of a mineral occurrence. This is achieved primarily by drilling to sample the prospective horizon, lode, or strata where the minerals of interest occur. The ultimate aim is to generate a sufficient density of drilling to satisfy the economic and statutory standards of an ore resource.

Drilling is performed to obtain a direct knowledge of subsurface mineral deposits. The first drilling stage is performed on a very wide drilling pattern and aims to locate possible mineral deposits at an acceptable drilling cost. If results are satisfactory, a closer pattern of drilling may be required to determine the geometry and grade distribution of potentially economic orebodies within the mineral deposit. The drilling method may be auger, rotary drilling, diamond drilling, and others, depending on the type of ground, the depth, and the drilling objectives. Additionally, this stage may require metallurgical testing in order to define the possible mineral behavior in a technical and commercial view.

Following the exploration process, a stage of "reserve definition" is undertaken to convert a mineral resource into an ore reserve, which is an economic asset. The process is similar to resource evaluation, except that it is more intensive and technical, and is aimed at statistically quantifying the grade continuity and mass of ore. The end of this process opens the project feasibility stage to carry out detailed studies to determine if the deposit may be mined at a profit.

Mineral Exploration Players

The following paragraphs discuss the main actors and stakeholders involved in the exploration process.

Governments and Government Agencies

Governments are in charge of the public administration of the mining laws and regulations. They also issue exploration and mining permits, and enforce compliance with safety and environmental regulations.

In many countries, the geological service and other government agencies make available the basic data on geography, geology, and airborne geophysics to the exploration companies at a moderate price. Moreover, some countries provide exploration right holders with the exploration information developed by companies that have previously held the exploration rights for a given area.

Within the European Union countries, the role of the government in supporting mining and exploration is defined in a report by the Enterprise Directorate General,[22] as follows:

- Coordinating or undertaking geological or geophysical surveys to provide general data on the location and nature of mineral reserves,
- Contributing to the funding of a national geological institute or survey,
- Providing financial assistance to private companies involved in exploration, and
- Providing information for land use planning and issuing licenses/permits to allow exploration.

Individual Prospectors

These are freelance geologists, landowners, or exploration consultants who hold the mineral exploration rights in areas with exploration interest. In most cases, their limited financial capacity only allows prospectors to carry out the area definition stage and offer the rights to junior or senior exploration and mining companies.

Junior Exploration Companies

"Juniors" are stock exchange listed companies that only operate in the exploration segment of the mineral industry. Typically, they become highly specialized in exploration as a business and have a small but highly specialized professional structure. The business objective of a junior is to add value to their exploration targets, through raising funds in the stock markets and making efficient use of these funds by bringing exploration to a more advanced stage with a lower risk of failure. Eventually, they hope to bring exploration targets to the feasibility stage and then sell them for a profit.

As previously highlighted by Hudon, juniors play a key role in today's exploration. According to a study by MEG,[23] in 2007 junior companies accounted for more than half of global exploration spending.

Senior Mining Companies

"Seniors" are companies that operate in both the mining exploration and mining operations segments of the minerals industry. These companies may choose to gain access to new ore resources by carrying out exploration by themselves or in joint ventures with other companies or alternatively by acquiring resources through purchase.

Contractors and Services Suppliers

Exploration companies contract out some services, such as drilling, geophysical surveys, geochemical exploration, geological services, engineering services, geostatistical evaluation, land acquisition, information technology (IT) systems and data management, labor recruitment services, legal services, sampling campaigns, auxiliary labor, and vehicle and air transportation.

Social and Economic Stakeholders

In addition, the exploration activity involves several social stakeholders and interested parties:

- The landowners, occupiers, and users of the land, with whom the exploration company must negotiate for the rights of access and/or temporary occupation;

TABLE 7.3 Land access requirements

Activity	Access Requirements
Basic exploration	Exploration license
Airborne surveys	Generally, only Civil Aviation flight approval required
Exploration rights	Record of the rights depending on the legal requirements
Drilling campaigns	Landowner permission (direct negotiation with landowner)
Tree cutting	Permit from local environmental authority
Construction/excavation	Regional/local government permit and agreement with landowners

- The communities hosting the exploration activity with which the exploration company must maintain a relation based on trust and transparency, aiming to earn the social license; and
- Potential investors and financial institutions in the controlling and auditing role.

Land Access to Mineral Exploration

The access to lands with mineral potential for mineral exploration and development purposes and certainty of tenure for viable deposits is a major component of maintaining a viable mining industry. Single or conflicting land use designations create a climate of uncertainty and are a serious impediment to attracting and retaining mineral exploration.

Land use planning is done at the government level (national or regional). It is done through an integrative process in which different claims of utilization are subjected to an evaluation process on the basis of which the land use planning authority identifies areas where, in principle, no minerals extraction will be allowed, areas where extraction may be allowed but is subject to certain conditions, and areas where, in principle, extraction will be permitted.

The mining industry faces restrictions when accessing the area to be explored and exploited, going into direct competition with other users of the territory, who can see in mining activities an impediment to the development of other activities.

The required licenses in the different exploration stages vary, depending on the territories to explore. Table 7.3 summarizes the access requirements for different exploration activities.

For land use planning to be an effective tool, it is essential that it be based on a solid and well-substantiated database that includes all necessary information. From a minerals development point of view, it is crucial that the information concerning mineral deposits be entered into the land use databases to ensure that minerals are considered in all land use planning decisions. Incorporation of minerals in land use planning decisions is considered good practice and essential for a sustainable minerals supply in Europe.[24]

Environmental, Safety, and Health Issues

In general, environmental and social impacts of mineral exploration activities are associated with short- and long-term changes in land use. Exploration requires longer-term infrastructures, such as campsites, roads, and fuel storage; it also generates short-term changes in land use in relation to exploration excavations (pits, trenches, etc.) and access and support infrastructure for exploration drilling. Other environmental impacts are related to the effects of exploration activity on water quality and wildlife. Environmental impacts of exploration activities are summarized as follows:

- Temporary infrastructure campsites:
  - Access roads

TABLE 7.4 Information requirements for a Declaration of Environmental Factors

General information	The general details of the proposal, as licensee or operator name and address
Physical environment	Landform and topography, soil and surface units, surface cover, drainage, hydrogeology
Biological environment	Vegetation cover, fauna, and habitat
Environmentally sensitive locations	Areas having particular ecological, cultural, or conservation value
Human environment	Uses of land, roads, and tracks
Exploration program	Access tracks, drilliing, water supply arrangements, camp, excavation, and drill site clean-up procedures
Potential environmental impacts	Disturbance of native vegetation, soil disturbance, disturbance to scientific and cultural sites, fauna disturbance, visual disturbance, fire, groundwater contamination, surface drainage interference, introduced weeds, and rubbish and waste

Source: After Minerals and Energy Resources South Australia, 2002

  - Landing runways
  - Fuel storage
  - Ditches, pits, trenches
  - Drilling site excavation and spills
- Impacts on water quality by uncontrolled effluent discharge to environment
- Impacts on wildlife:
  - Approach of animals attracted by food waste
  - Effects on migrations derived from human presence
  - Damage to wildlife

Regarding land reclamation and impact mitigation, the exploration company must comply with the conditions imposed in their required licenses or permits, as well as with the conditions agreed upon with landowners and the local authority. Furthermore, the exploration activity is subject to inspection and audits by the different government agencies. As an example, the Minerals and Energy Authority of South Australia[25] requires exploration companies to submit a Declaration of Environmental Factors (DEF) in situations where field exploration involves the use of heavy earthmoving equipment (e.g., bulldozers, backhoes, excavators) or when drill rigs are proposed in areas deemed environmentally sensitive.

By applying the DEF procedure, the company is required to identify elements of the environment that may be at risk from the proposed exploration activities and the ways in which potential impacts can be prevented or managed, as summarized in Table 7.4.

Few occupations expose individuals to such a variety of hazards as mineral exploration. Several characteristics are somewhat unique to the industry and affect safety considerations and monitoring. The workplace encompasses wilderness areas ranging from alpine to near-desert conditions and from arctic to temperate environments. The unwary could succumb to any one of many potentially fatal hazards, including falls in crevasses or on precipitous ground, avalanches or falling rock, hypothermia, hyperthermia, asphyxiation, exposure, drowning, lightning strikes, tree falls, animal attacks, insect stings, and injuries resulting from aircraft, vehicle, and boat travel.

Additional health and safety hazards, which some may consider more conventional, may also be encountered in the workplace and must be addressed. These hazards can include noise, ergonomics, working in confined spaces, working around heavy industrial machinery, working in and around excavations, and working at heights, which requires fall protection.

The exploration managers, field supervisors, and technical staff should be thoroughly familiar with safety procedures. Particular attention must be directed to contractors' personnel and new labor. Appropriate safety and first aid equipment, and suitably trained personnel should be available at working locations. In this regard, many companies have developed safety manuals and guidelines with the continuing objective of reducing accidents.

The Association for Mineral Exploration British Columbia[26] has recently updated their health and safety document, *Safety Guidelines for Mineral Exploration in Western Canada* with the objectives of ensuring that

- Exploration sites are equipped with appropriate first aid kits, attendants, and access to emergency communication;
- All persons employed at an exploration site are trained in safe working practices specific to site conditions;
- Any pits, trenches, and excavations are made safe;
- Exposure to uranium and thorium is limited;
- People are protected from electrical hazards, such as those potentially posed by the use of induced polarization geophysical survey systems; and
- Explosives are used and stored safely.

The manual includes detailed procedures for first aid, training, pits, trenches and excavations, induced polarization geophysical survey systems, use and storage of explosives, working in and around fixed wing and rotary aircraft, and legal responsibilities.

Social Impact

Although the largest social impacts of mining activities are linked to the development and production stages, the exploration activities may have a social impact associated with increased expectations for wealth growth as a result of a discovery, which would lead to the creation of new jobs and the opening up of new businesses. This early social impact is more significant when exploration takes place in poor and underdeveloped regions or in areas where First Nations have been recognized as having special rights on mineral wealth. In these regions, mineral exploration is perceived as an opportunity for human development and better living standards; therefore, any exploration activity generates great expectation. Some business opportunities associated with mineral exploration may generate new jobs in hosting communities; the construction of a camp site and other infrastructure, food and lodging, vehicle rental, drilling and earthmoving operators, and so forth.

Exploration Management Essentials

Probably the best and the most complete sustainable development framework for exploration activities has been developed by the PDAC.[27] The PDAC framework provides information at two levels:

1. Exploration Principles and guidelines (vision and mission statements)
2. The e-3 Environmental Excellence in Exploration online manual[28]

The Exploration Principles and guidelines aim to "implement and maintain ethical business practices and sound management systems that include sustainable development as a factor in business decision making." The guidelines are specific recommendations for responsible exploration and development activities, which are classified into seven groups:[29]

1. Ethical business
2. Human rights
3. Project due diligence and pre-engagement
4. Community engagement
5. Community development
6. Environmental protection
7. Health and safety performance

The e-3 Environmental Excellence in Exploration manual is an exploration management manual focusing on community engagement and environmental practices. PDAC offers it in the form of an online toolkit for mineral exploration.

The management approach of the e-3 Manual is expressed by the "Management Essentials" section, which outlines key management issues to be addressed proactively by site project management. Management essentials are summarized into 13 areas:[30]

1. Exploration code of conduct
2. Environmental and socioeconomic challenges
3. Community relations
4. Legislation and permitting
5. Planning
6. Contractor selection and management
7. Health and safety
8. Wildlife
9. Fire prevention, policy, and response
10. Training
11. Reviews and audits
12. Record-keeping
13. Reporting

For example, the area of management essentials on planning is outlined as follows:[31]

- Take into account costs required to remediate or reclaim any environmental impact, and to address the concerns of local communities.
- Carry out exploration work in a thoroughly professional manner.
- If necessary, perform baseline study prior to environmental impacts.
- Assign individual responsibilities to each employee in relation to environmental performance and empower them with required decision capacity.
- Make sure that exploration imperatives do not take precedence over environmental issues.
- Involve environmental professionals at an early stage, so that their input can be considered and implemented where appropriate.
- Perform due diligence if potential liability may have been acquired with the purchase of mineral rights.

The technical content of the e3 Manual is laid out in six activities, which are (1) land acquisition, (2) surveys, (3) access, (4) camp and associated facilities, (5) stripping and trenching, and (6) drilling. The information for each of the six activities is assembled by management issues, such as planning needs, land disturbance, site management, air management, fish and wildlife management, water use and conservation, spill management, hazardous materials, waste management, and reclamation and closure.

Reporting of Exploration Results

Reporting exploration results in accordance with international standards is essential for listed mining companies and in general when reporting to government institutions and agencies. Furthermore, standard reporting of exploration results is essential for transparency and ethics consideration when reporting to shareholders and when dealing with the hosting communities and other stakeholders.

International standard definitions are required to improve the transparency and consistency of reporting mineral reserves and resources worldwide. They will also help to improve communication, aid in the reassessment of mineral inventories, reduce risks for investment by helping to avoid the nightmare of share price inflation, and, most importantly, "*keep the bears out of the beehive.*"[32] The international standards for classification and reporting of ore resources are described later in the "Ore Resources Inventory Management" section.

For a general sustainability reporting framework, readers should refer to the Global Reporting Initiative.[33] GRI is a multistakeholder initiative, formed in 1997 to develop and disseminate globally applicable sustainability reporting guidelines in collaboration with various United Nations agencies, notably the United Nations Environment Programme. GRI became independent in 2002 and published the second version of its *Sustainability Reporting Guidelines*. A third iteration, known as G3, was launched in October 2006.

GRI incorporated a Mining and Metals Sector Supplement, which was developed in cooperation with the International Council on Mining and Metals (ICMM). This was described in Chapter 5.

Sustainability Frameworks for Minerals Exploration

Nearly all governments of countries with important mining potential have already included guidelines for environmental management in mining exploration processes. Moreover, there are many easily accessible handbooks for the development of both mandatory and sustainability reports (GRI and others). An excellent example is *Guidelines for Environmental Management in Exploration and Mining—Exploration and Rehabilitation of Exploration Sites,* published by the State of Victoria (Australia) in 2002.[34]

Every mining exploration campaign must identify and foresee the possible environmental and social impact that the process can have. It is true that during the course of exploration campaigns, the environmental impact is not excessive, especially in the "grassroots" stage.

Other sustainability frameworks make reference to corporate social responsibility (some are described in other chapters of this book):

- Australian Minerals Industry Code for Environmental Management (1996), now Code 2000
- ICMM Sustainable Development Framework (2003)
- International Organization for Standardization (ISO) 14001 Environmental Management Systems (2002)
- Mining Certification Evaluation Project—Australian Regional Initiative (2002)
- United Nations Global Compact (2002)
- U.S.–U.K. Voluntary Principles on Human Rights and Security(2003)
- World Bank Operational Directive on Involuntary Resettlement (2003)

- The Equator Principles (2003)
- United Nations Universal Declaration of Human Rights (2001)
- The Voluntary Principles on Security and Human Rights (2000)
- The OECD Guidelines for Multinational Enterprises
- The International Finance Corporation (IFC) Performance Standards on Social and Environmental Sustainability
- The IFC Environmental Health and Safety Guidelines

Acknowledgments

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ORE RESOURCES INVENTORY MANAGEMENT*

Mineral deposits are finite, either physically or economically, so efficient management of ore reserves is critical for sustainability. This section focuses on key criteria for sustainable management of ore reserves.

The classification of geological resources as ore reserves is a dynamic process; therefore, the management of ore resources requires resource management systems (RMSs) capable of calculation and updating whenever internal or external parameters change. Internal parameters, such as mining costs and metallurgical recovery, or external parameters, such as market prices, may cause geological resources to become ore reserves or vice versa.

An RMS capable of fast and reliable data management will enable a company to react quickly to any operational and market change affecting business economics. Furthermore, an efficient RMS will help in the identification and management of environmental risks associated with the varying characteristics of the ore.

The software market offers integrated software packages for resource management and mine planning; often, mining companies use several commercial and internally developed software applications to fit their needs.

Regardless of the number of software applications used, the key requirement is that data storage, manipulation, and backup are centralized in a single-server system, where users may be assigned specific levels of reading and editing authority as a function of their responsibilities in the project. Unfortunately, this is not always the case; too often, data management is split among several departmental databases, causing duplication, loss of information, and data processing problems.

Terrain Models and Digital Models

Most commercial software packages can import and export topography of terrain and excavation data in several formats, but DXF is the most commonly used format. DXF can use many types of drawing units, including triangulation. After the topography has been imported, the software is ready to work on mine planning and design, creating digital renderings, and so forth.

Modern mine design software uses triangulation to generate surface and three-dimensional (3-D) volume models. Considering the geometric complexity of geological and orebody models, very few users have the technical capacity and the spatial vision to work in three dimensions (Figures 7.5 and 7.6).

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* This section was written by C. Castañon.

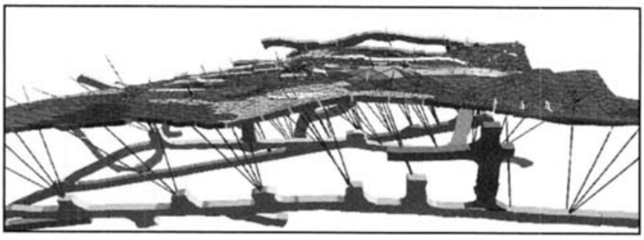

FIGURE 7.5 3-D model of a flat tabular orebody

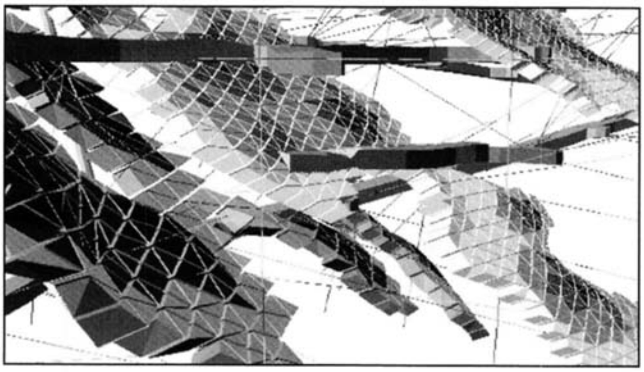

FIGURE 7.6 3-D model of a steeply dipping tabular orebody

Definitions and Classifications of Resources and Reserves

The distinction between resources and reserves is not limited to geologic and mining aspects, but it extends into some ethical and economical implications. Also, public mining companies are subject to regulations by the Securities and Exchange Commission (SEC) for filing and public reporting of exploration information, resources, and reserves.

In any case, the estimation, classification, and reporting of ore resources requires certain flexibility because different criteria may be applicable, depending on each particular case. Also, mining companies may apply their own resource management methodology and use international reporting standards to comply with SEC requirements. The following paragraphs outline the CIM reserves and resources definitions.

A *mineral resource* is a concentration or occurrence of natural, solid, inorganic, or fossilized organic material in or on the earth's crust in such form and quantity and of such a grade or quality that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics, and continuity of a mineral resource are known, estimated, or interpreted from specific geological evidence and knowledge.

An *inferred mineral resource* is that part of a mineral resource for which quantity and grade or quality can be estimated on the basis of geological evidence and limited sampling and reasonably assumed, but not verified, geological and grade continuity. The estimate is based on limited information and sampling gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings, and drill holes.

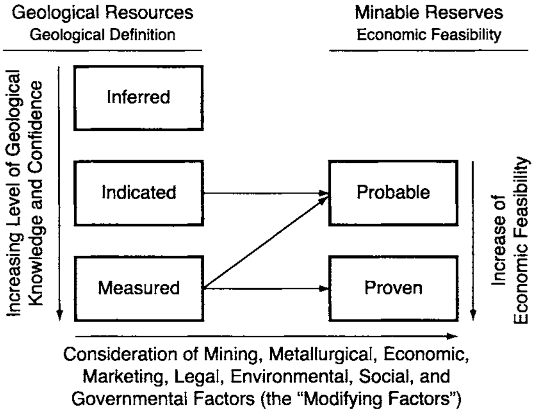

FIGURE 7.7 Relationship between resources and reserves

An *indicated mineral resource* is that part of a mineral resource for which quantity, grade or quality, densities, shape, and physical characteristics can be estimated with a level of confidence sufficient to allow the appropriate application of technical and economic parameters to support mine planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings, and drill holes that are spaced closely enough for geological and grade continuity to be reasonably assumed.

A *measured mineral resource* is that part of a mineral resource for which quantity, grade or quality, densities, shape, and physical characteristics are so well established that they can be estimated with confidence sufficient to allow the appropriate application of technical and economic parameters to support production planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration, sampling, and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings, and drill holes that are spaced closely enough to confirm both geological and grade continuity.

A *mineral reserve* is the economically minable part of a measured or indicated mineral resource demonstrated by at least a preliminary feasibility study. This study must include adequate information on mining, processing, metallurgical, economic, and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified. A mineral reserve includes diluting materials and allowances for losses that may occur when the material is mined.

A *probable mineral reserve* is the economically minable part of an indicated and, in some circumstances, a measured mineral resource demonstrated by at least a preliminary feasibility study. This study must include adequate information on mining, processing, metallurgical, economic, and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified.

A *proven mineral reserve* is the economically minable part of a measured mineral resource demonstrated by at least a preliminary feasibility study. This study must include adequate information on mining, processing, metallurgical, economic, and other relevant factors that demonstrate, at the time of reporting, that economic extraction is justified. A graphical model of ore resources is shown in Figure 7.7.

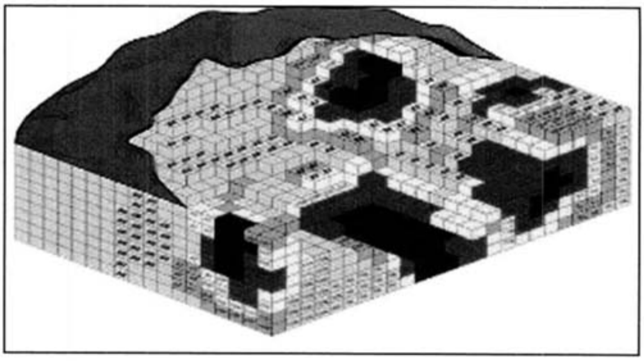

FIGURE 7.8 Block model of a massive orebody

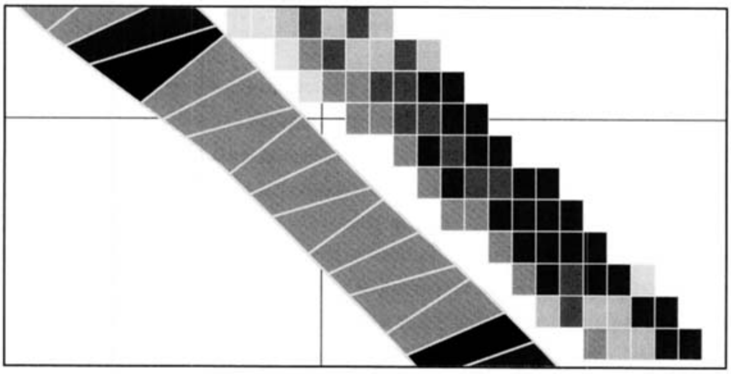

FIGURE 7.9 Block modeling of thin, tabular orebodies

Estimating Resources from Block Models

Several methods for estimating ore reserves have been extensively used in the past (sections, polygons, triangles, etc.). Today, the generalized use of commercial 3-D software, IT-assisted massive data management systems, and geostatistics has resulted in the generalization of the use of block model methods, reducing the use of all other methods to preliminary estimates or to double-checking calculations performed using block models.

In this section, we focus on the use of the "digital blocks" method, in which the orebody is modeled as a set of parallelepipeds (blocks), all with the same dimensions and where the grade (or property) estimated for each block is assigned to its center (Figure 7.8).

Almost any orebody may be modeled by using block model methods. In the case of thin tabular orebodies (Figure 7.9), block models have limitations. In this case, standard block modeling generates a notched outline requiring smoothing. To solve this problem, some commercial software has implemented methods for smoothing model boundaries. A second problem associated with the application of block models to tabular bodies is defining how the core sample assay data should be used, and in what direction. Block models, in general, interpolate drill samples rather than using the entire hole intersection. Regarding the direction of the mineralization, interpolation using drill samples—not hole intersection—generates the loss of directional information (bedding plane direction), which is important when intense folding is present.

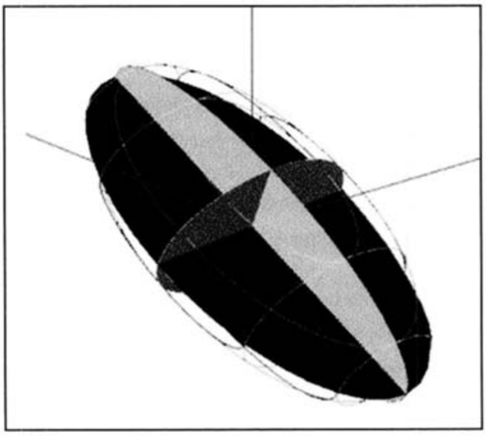

FIGURE 7.10 Search ellipsoid

Search Ellipsoid

The first step is the definition of the "ellipsoid of search." This is the ellipsoid that, when centered at a point of the orebody, will contain all data points that are close enough to be assigned a "weight" in the estimation by interpolation of a regionalized variable associated to the center point. As an example, the grade at a certain point is estimated by weighted interpolation of the grades measured at all data points located within the ellipsoid of search. Other data points outside the ellipsoid will not be used.

Normally, orebodies present "directional anisotropy," that is, different regularity in different directions. Anisotropy is modeled by orienting the search ellipsoid with its longest and shortest axes respectively oriented with the directions of maximum and minimum regularity, the intermediate axis being perpendicular to the other two axes. The length of the ellipsoid axes is a scale factor where the scale distance in the three axis directions is transformed by dividing actual distance by the scale factor.

For a given orebody, each element (e.g., Cu, Au, Zn), property (e.g., ore type, rock quality designation [RQD], color) or parameter (thickness, density, etc.) shows a different anisotropy field and, therefore, a different ellipsoid.

As an example, Figure 7.10 shows an ellipsoid with scale factors of 1, 2, and 3. When estimating the grade at its center, the same weight should be assigned to a sample located at 30 m along the principal axis (scale factor = 1 or 30/1) as to a sample located at 15 m along the secondary axis (scale factor = 2 or 30/2) or a sample at 10 m along the tertiary axis (scale factor = 3 or 30/3).

For tabular orebodies, it is common practice to choose the principal and secondary axis (axis of maximum and minimum regularity), respectively, in the bedding plane and perpendicular to it.

Block Model Structure

Following are the main criteria for the design of a block model database:

- All unit blocks are equal in size and geometry. Some commercial programs allow for subdivision of unit blocks to adapt better to the geometry of the orebody. Each block is identified in the database by its position indices (id_x, id_y, id_z).

- Position indices are integer numbers representing the relative Cartesian coordinates of the center of the block with respect to three orthogonal axes (x, y, z) or (East, North, Elevation). Normally, the origin is at the center of the block that has these coordinates: (1, 1, 1).
- The table of blocks (database) is defined by the said position fields (id_x, id_y, id_z), plus fields for all data and fields for the interpolation of the properties to be associated with the block (e.g., block grades, density, lithology, hydrology). In addition, the block registry includes other fields to record codes for important block properties (e.g., geology, rock mechanics, hydrology, resource type, planning codes, block monetary value).

International Standards for Ore Resource Reporting

The first mineral resource reporting standard was the *Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves.*[35] It was developed by the Joint Ore Reserves Committee (JORC) in 1971 to establish minimum standards, recommendations, and guidelines for Public Reporting in Australasia of Exploration Results, Mineral Resources and Ore Reserves. In 1989, it developed into the "JORC Code" and was incorporated in the Australian Stock Exchange listing rules in the same year, with guidelines added in 1990.

In 1991, the Society for Mining, Metallurgy and Exploration, Inc., in the United States published its guide for reporting and, that same year, the Institution of Mining and Metallurgy in the United Kingdom also revised its standards, largely based on the JORC Code.[36]

The leading principles governing the operation and application of international reporting standards are transparency, materiality, and competence with focus on public reporting of exploration results, mineral resources, or ore reserves, prepared for the purpose of informing investors or potential investors and their advisors.

Commonly, the standards provide guidelines for the classification of mineral resource and mineral reserve estimates into various categories. The category of an estimate implies confidence in the geological information available on the mineral deposit, the quality and quantity of data available on the deposit, the level of detail of the technical and economic information that has been generated about the deposit, and the interpretation of the data and information.

Mineral resource and mineral reserve estimates and resulting technical reports must be prepared by or under the direction of, and dated and signed by, a qualified person. A "qualified person" means an individual who is an engineer or geoscientist with at least 5 years of experience in mineral exploration, mine development, production activities, and project assessment, or any combination thereof, including experience relevant to the subject matter of the project or report, and who is a member in good standing of a self-regulating organization.

Sustainable Management Considerations

Terrain and orebody block databases may be used as a tool for sustainable management of regionalized variables related to sustainability. When used in combination with commercial mine planning and design software, they provide exploration management the capacity to analyze different exploration scenarios.

The following data obtained from field geology, geochemistry, and exploration drilling should be stored in databases from the early exploration stages:

- Geological data: Stratigraphy, petrology, and structural data;
- Topography data: Position of holes, dip, direction, deviation measurements, ground surface survey points, and so forth;
- Geotechnical data: Core sample RQD and joint sets;

- Groundwater parameters: Water table, permeability rates, and water quality;
- Multielement assays: Performed on core samples, including elements that may be of economic importance or may have a negative impact on the environment or on metallurgical processes (e.g., As, Sb, Hg, Bi, Se);
- Land management data: Land ownership and uses, soil type, surface water quality; and
- Environmental baseline data: Data required for an environmental baseline study.

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CHAPTER EIGHT

Managing Project Feasibility and Construction

J. A. Botin

INTRODUCTION

Project management begins with the selection of areas for grassroots exploration or when entering into project acquisitions. As the project develops, building a trusting relationship with stakeholders is essential. A mining project will be more successful when guided by targeting the highest possible standards in technical, safety, and environmental issues, and in corporate social responsibility, and by openly sharing these core values with the wide variety of stakeholders.

Integrating sustainability into a mining project begins with the identification of stakeholders, their values, and objectives. Shields and Solar[1] visualize this process as follows:

> Alternative management approaches are developed that reflect those objectives. Social and environmental impacts are predicted for each alternative, technical aspects are considered, and costs estimated. Technically or economically infeasible, or unsustainable, alternatives are revised or rejected. Feasible alternatives that support sustainable outcomes are then presented to the public for debate and negotiation with the goal of choosing an alternative that is acceptable to the public. Once an acceptable management alternative has been identified, it is implemented, monitored, evaluated, and revised as needed. The process of revision once again requires public participation and the cycle is repeated.

This chapter presents an approach to the management of mining projects where the focus is placed on sustainability as the key to successful project management and to ensure long-term benefits throughout the mine life cycle.

In its content and objectives, the chapter compiles the personal experience and viewpoints of the authors as project managers, each with a different perspective. In its objectives, it aims to provide the reader with the authors' thinking without attempting a systematic approach to project management systems and techniques.

This chapter is composed of five sections. "Mining Project Feasibility and Construction: An Overview" presents the owner's vision of how a mining project should be managed from the advanced exploration stages and early scoping studies to construction and startup. The author focuses on the organization and structure of mining projects, project evaluation procedures, the key project management decision, and how financial risk relates to project assumptions and parameters. The author, Norm Anderson, a former chief executive officer (CEO) of a leading mining company, gives very valuable views, opinions, and guidelines for the best practices on the key tasks and problems to be dealt with when managing a mining project.

"Mining Project Management: The Sustainability Challenge" provides an overview on the importance of integrating sustainability in the project. It also addresses the management challenges related to environmental and social issues and other project aspects affecting the hosting communities, the permitting agencies, employees, contractors, and other stakeholders.

"Project Management and Stakeholders" offers an in-depth management view of the problems of identifying the stakeholders who might be present in a mining project, learning about their position and expectations, and deciding how the company should interact with stakeholders to achieve project objectives. It also focuses on the importance of proper management of external and internal communications and reporting.

"Project Feasibility Evaluation: New Trends" introduces readers to the economic side of sustainability, the importance of the project evaluation process in the optimization of the project returns, and the long-term benefits to stakeholders. It also describes how criteria for financial analysis are established and presents methods of evaluating investments.

"Case Study: Las Cruces Aquifer Protection System" presents a case study on the environmental risk caused by an important aquifer intersecting the pit in the Las Cruces mining project, and the remediation measures implemented to control this risk.

The chapter editor gratefully acknowledges the assistance of the mining companies that have contributed information and suggestions on the preparation of this material. Special appreciation is due to Cobre Las Cruces, S.A., for the information and assistance the company provided to the authors of the sections titled "Project Management and Stakeholders" and "Case Study: Las Cruces Aquifer Protection System."

MINING PROJECT FEASIBILITY AND CONSTRUCTION: AN OVERVIEW*

The management of the preproduction evaluation stages of a mining project can be seen as a "stepwise risk reduction process" (Figure 8.1), where increasingly larger amounts of capital are invested through time to reduce uncertainty and financial risk. This process can last anywhere between a few years and decades and is divided into stages of increasing capital intensity.

Scoping Studies Through Feasibilities

At the end of each stage, a drop/continue decision is made on the basis of existing information and, should the decision to continue be made, the project enters into a new evaluation stage of higher capital intensity. At the last stage, referred to as the final feasibility stage or simply feasibility stage, the project reaches a level of financial risk at which it is acceptable to stakeholders to proceed to construction and reach the production stage.

Although the number of evaluation stages and its scope are variable, three levels of evaluation studies are often required to lead a project to the production stage: (1) scoping studies, (2) prefeasibility study, and (3) final feasibility study.

Scoping Studies

After a project is identified, whether by discovery or acquisition, it is necessary to assess its worth. This might be a preliminary quick look, with rough numbers as to tonnage, grade, recovery, costs, and prices; if encouraging, this quick look should lead to a scoping study. This is the first formal level of feasibility work, and probably would have a 25%–40% accuracy . . . sometimes greater, sometimes less. As an example, a scoping study was done on the Red Dog Zinc

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* This section was written by M. N. Anderson.

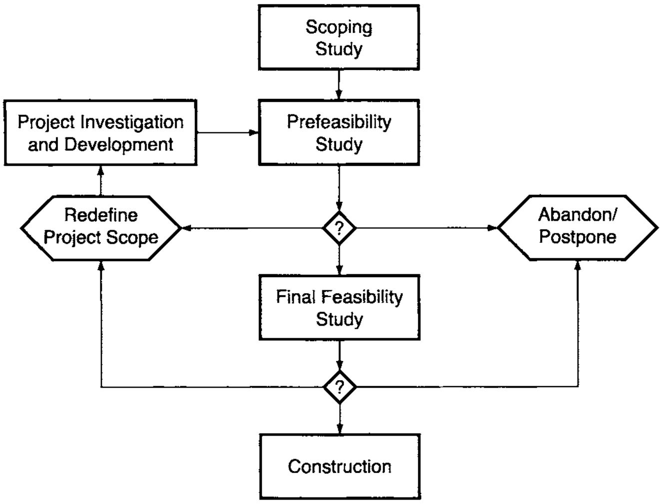


FIGURE 8.1 Typical legal and regulatory framework for mining projects

deposit in Alaska after only seven diamond drill holes that turned out within 10% accuracy. Good people and a little luck can do a lot in a short time at the start, and it helps set the strategy going forward!

Scoping studies would not likely be considered bankable but would cover all the subjects one would expect in a full-blown, final study (e.g., tonnage, grade, geology, mine plan, metallurgy, flow sheets, capital costs, operating cost, environmental considerations, economics). Most importantly, early studies also identify "what's missing," such as complete in-fill drilling, complete metallurgical testing, geotechnical work, environmental testing, a better understanding of the product markets, competition . . . and other risks.

Assuming the scoping study does not kill the project, the company is now ready to raise or appropriate the moneys to do the further drilling, tests, and studies.

Prefeasibility Study

If the scoping study indicates a very robust project, it is possible to bypass this study and proceed directly to the final feasibility study. The "what's missing" work is launched in any event.

Less certain projects are probably best covered with a prefeasibility study first, which will cost less than the final study (but is also less accurate); it can also provide time to seek solutions to the most vexing problems, whatever they might be.

Again, these studies will cover all the topics covered in a final feasibility study, only in less detail.

Final Feasibility Study

This one will be expensive, it will be thorough, and if it is well done, it will be conclusive and bankable if the results are positive. The company's banks will determine whether it's bankable. How competently the study is written, how well the risks and their management have been identified, how well the technical aspects have been solved, and so forth, all determine the project's bankability, but the banks will make the final determination.

It's crucial to keep in mind—it might not be a positive report; the project could fail... and it must be allowed to fail if that's where a good study leads. The author of the report is the proponent. Others will act as opponents looking for the weaknesses. The report should be written with this in mind. This subject will be discussed further later in this section.

Organizing and Managing a Feasibility Report

Hiring a competent engineering contractor to prepare the feasibility report is, of course, important. However, it's equally important or perhaps even more important to appoint senior, experienced people to be the owner's representatives, to manage the exercise, to help make the contractor selections, to work closely with them and make the day-to-day decisions in a timely and wise way. The owner's representative should know the history of the project, the company's management philosophy and goals, and the resources available (financial and technical) within the company; this representative should also have sufficient authority to move the project forward. Likewise, he or she also needs to know when and how to inform senior management of progress and to get them involved in decision making and approvals.

In today's buoyant business scene, finding competent, experienced engineers is challenging. Younger, less experienced people are being thrust into key roles. They can do good work, but this does underline the need to manage the process well, understand the limits, and to call for help when required.

The owner's representative therefore must interview the staff being nominated by the contractor, understand these limits, and know where to get help.

Environmental and Social Considerations

Permitting, social, and environmental considerations are probably the most significant changes that have taken place in feasibility work in the last 50 years. Good management has always called for reasonable care and attention to these matters, but since becoming law some 40 years ago, these concerns have added considerable time and cost to projects. Indeed, these considerations have created a whole new and growing industry.

These subjects are covered in more detail in other chapters of this book. Their importance in this section warrants these highlights:

- Background flora, fauna, and weather records and surveys begin immediately as soon as a new project is identified.
- Safe disposal sites for tailings and waste rock are identified and planned.
- Air emissions and water effluents are identified and, if necessary, plans for mitigation begin.
- Staffing, hiring, and accommodations can sometimes be a huge consideration, particularly in remote locations.
- Safety and security, on and off the job, is a growing concern and cost.

Safety, environmental, and social considerations are part of the concept of sustainability, one of the more recent issues that have affected the way companies plan projects. All of these concerns lead to permitting, which involves two or three levels of government, which has grown to be another impressive subset industry. It takes time, it takes money, and it takes talent and good laws to be successful.

Codes of Account

It's worth mentioning here how important it is that, once project cost estimating begins, a code of accounts be established from the beginning that can be used through to the end of construction.

In the past, when accounting programs were less sophisticated, changes in the code of accounts often made it difficult or impossible to compare how costs changed from scoping to feasibility to construction. It was frustrating to management and boards of directors and, equally importantly, it made a valuable cost-control mechanism useless.

Know When to Stop/Complete the Study

As with construction, as studies draw to a close, they often start to drag. There's the potential to start asking questions that should have been settled weeks or months earlier or perhaps to begin chasing minutia, trying to anticipate too much, trying to be too perfect. Delays at the end of the prefeasibility or final feasibility study cost money and may add little of value. Two examples can best illustrate this:

- A great (robust) project at the prefeasibility stages does not need all the i's dotted or t's crossed. It's time to finish it up and move forward to the bankable stage.
- At the final feasibility study stages, a weak project will need all the best people working together at the end to find the best technical input and reach the right conclusion.

Technical Considerations

A few of the more technical considerations necessary for a good report merit some mention: geology, metallurgy, and mining.

Geology. When a potentially good discovery or acquisition comes into play, it is often the geologists who bring it forward. The discovery has been drilled, mineralogy has been studied, reserves and resources have been cataloged, and areas requiring more exploration identified. It's ready for an initial scoping study, which, if successful, eventually leads to a final feasibility study.

Two or three problem can arise. The prospectors/geologists, who have been celebrated for their successes, now have competition for the spotlight as the mining engineers and metallurgists arrive. If not handled well, this sense of no longer being the center of attention can be heartbreaking for the discoverers, but it is inevitably part of the process.

In addition to this stress, the focus of drilling evolves, changing from drilling to find new ore to fill-in drilling to upgrade resources to reserves and prepare for initial mine planning, drilling metallurgical test holes and condemnation holes to ensure the shaft or the mill or the tailings pond will be safely located, and so forth. Further exploration can sometimes be stopped too soon and important upside opportunities can be missed. On the other hand, continually adding new ore while feasibility work and permitting are underway can create troublesome delays. An example of this occurred at the Red Dog mine in Alaska in the early 1980s. What appeared to be a thrust faulted offset of the main zone was discovered and tested briefly. It was 5 miles away from the main zone and appeared not to be of better grade, larger, or lower cost, so the exploration was stopped, thus locking in reserves and facilitating permitting. Twenty years later, it was treated with confidence as a new discovery, so it's important to know when to stop exploration.

Mining engineers and metallurgists sometimes do not know as much geology as they should nor do they always pay sufficient attention to the geologists with whom they work. This can lead to mistakes. Geologists, on the other hand, must inform themselves of potential downstream problems stemming from their reports.

In conclusion, it is important to include a well-written geology/mineralogy report in all feasibility studies. Likewise, it is important that the mining engineers and the metallurgists read and understand this section. Readers of these reports should ask for help if they encounter something they don't understand. Here are some simple rules of thumb to keep in mind when reading this section:

- Some secondary minerals like chalcocite, smithsonite, or franklinite, although high grade, can lead to metallurgical problems. Energite can carry too much arsenic to be easily marketed. Marcasite, which is not usually a marketable by-product, can also create metallurgical problems.
- Certain massive iron sulfides can create environmental problems. They can be easily oxidized to the point where secondary sulfide explosions can be encountered during underground mining. When brought to the surface, they can oxidize quickly, heating up and resulting in serious pollution and transportation problems.
- Certain host rock (waste rock) contaminants can also create problems. Small amounts of iron sulfide in country rock can lead to acid rock drainage problems. Gold contained interstitially in pyrite might not be dissolvable without first oxidizing the pyrite. Organics in host rocks may act as a price grabber. Clay in a mill or in a heap leach can be a very serious problem.

Representatives of each discipline working on these studies must develop "antennae" to search for potentially fatal flaws that, left uncaptured, can kill the project. If captured early enough, these flaws can often be solved or their effects mitigated. Such a mishap appears to have occurred at a Tonopah, Nevada, sulfide copper heap leach project 10 years ago. The basic geology described a mudstone host rock, with argillic alteration and fault gouge. Subsequent metallurgic column testing showed more degradation to fines (clay) during acid irrigation, but it appears to have been missed earlier. The project moved forward, operations began, only to fail soon, with clay preventing efficient irrigation and recoveries that were dismally low. This fatal flaw should have been identified—it was a geological problem that could have been solved.

Metallurgy. Refractory ores have been cursed over the centuries, yet many great solutions to the problems they pose have been found and will continue to be found.

So, when one sees a new project with good tonnage but modest grades and bad metallurgy, it always warrants a second look-maybe there is some higher-grade, less refractory ore to be found to get the project launched . . . and to provide the time to find the right solutions for treating the tougher ores. A small oxide gold cap over a large refractory sulfide body is one example. Another might be a small, sweet chalcocite or bornite blanket overlying or underlying an arsenic-ladened energite body.

In these cases, the capital cost, the marketing, and the environmental/permitting problems to do the sulfides can be overwhelming and the project can stall . . . particularly in a down market.

If the tonnage and grade and location are inviting, and the bank account allows pursuing them, these projects can be worth the effort required to move them forward. Evolving technology also offers hope for their development in the future. One hundred years ago, flotation was only a dream before it unshackled an enormous number of previously refractory ores. Similarly, 50 years ago, heap leach technology was also only a dream until it changed the metallurgy textbooks on how to tackle low-grade ores. Autoclaves are tackling many of the high-grade refractory sulfides, but this process may not be affordable for the lower-grade ones. Arsenic continues to plague arsenopyrite-hosted gold and energite coppers, but for how long?

Some of the many innovators have dreams worthy of investment. However, some critics do not invest time and capital in prototype processes. Fortunately, dreamers have always been a persistent lot, and a new generation of solutions certainly will inevitably emerge.

Mining. Rarely does one see bad design decisions in open-pit mines that cannot be revised at a sensible cost. But developing a new underground mine incorrectly, then changing the mine plan, can lead to an expensive redevelopment problem.

Queue River (copper) in Australia was a small, high-grade project, conceived as a trackless, Avoca cut-and-fill project. The Avoca system was all the rage at the time and the building of a ramp access was begun, but it quickly ran into very bad ground.

The situation was reassessed. The ore and surrounding host rock were in good ground. The mining method was reviewed and the team chose instead to sink a small woodframe shaft, a long-hole open stoping scheme, and backfilling with cemented rock/gravel fill. Although this approach was old fashioned, it worked well.

So, new underground mine systems must be selected carefully. Any neighboring mines should be visited if possible or at least any mines using the system being considered. And it's not always wise to follow the herd when a new system evolves, whether it's designed for the mine, the mill, or the smelter.

The previous paragraphs assume a mine project, which is the start of the cycle, but similar disciplines apply to smelters and refineries, of course. Nothing really changes except the technology and people, but the rules are generally the same.

For example, in Trail, British Columbia, when the Kivcet Lead Continuous Smelting Process was being studied to replace the old sinter/blast furnace system to overcome age, rising costs, and new environmental, hygiene, and safety rules, there was close communication with the organization's Australian competitors, who were pursuing the same goals, to find the best way. It is quite legal to collaborate technically, and the joint effort was worthwhile.

Feasibility Reports

The authors of any feasibility report must understand and keep in mind who will read it. The readers will include the board of directors and the CEO . . . who might or might not be interested in or able to understand much of the technical "stuff." The bankers, brokers, and accountants might concentrate on the financials, evaluation, and risks. The regulators will focus on their end of the business in detail. Finally, those who follow, the construction team who will do the final design and build the new plant, will use the feasibility report as their starting point but might not reach exactly the same design conclusions. The need to answer the questions of a wide range of readers often leads to the creation of a multivolume report.

The board of directors might only read the executive summary, and some might not get past page 3 or 4, plus some other details. Some on the design and build team, however, should read every page. The bankers' consultants should, too . . . but might not. The bankers and brokers likewise might only read the executive summary, the financials, and the risks.

Therefore, it's important to write a thoughtful executive summary, as well as a complete report that covers all the bases, including thoughtful conclusions and recommendations sections that flag all the items that need follow-up, and a full appendix. All the sampling, testing, and security precautions that were done and by whom, what source material was used for capital and operating costs, and so forth should be shown.

These reports cost a lot of money and cover a lot of ground, so it's critical to make them complete and readable.

How Is a Project Evaluated?

Evaluating the worth of big-dollar investments, which require large amounts of upfront capital and the long payout times commonly encountered in mining projects, is a serious task. Although the topic is worthy of several full chapters in a book such as this, here it will be dealt with in a few pages.

Sometimes the CEO and board of directors will accept a less rigorous feasibility report—if it describes a robust project—and run with it. They must keep in mind, however, the report might have underestimated things by 15% or 20% or more . . . but if it's robust, it might be judged worthy of approval. Sometimes, on less robust projects, extra evaluation is warranted.

When acting as a bank consultant, one should look for a number of items, described in the following paragraphs.

Size Improves the Rate of Return

Sometimes, the company might see a large, low-grade copper porphyry mine, for example, that initially was conceived as producing 30,000 t/d, but which produced an unsatisfactory return. It is enlarged, perhaps several times, and ends up as a 90,000 t/d project with an internal rate of return (IRR) of 15%, which reduces the mine life from 30 years to 10 years. It might become a "bet the company" investment for a small company in a down market. Also, due to the now-shortened mine life, there's little time to recover from bad markets or mistakes. This scenario warrants a hard second look!

Blue Sky Resources

Some investors and bankers often won't consider any resource other than measured and indicated reserves. It's a conservative rule that they use and one that must be lived with. However, when evaluating new projects or acquisitions, there is a time to consider the "blue sky potential" of a property, as well as a time for sound geological thinking. This is a time, too, when the board of directors will benefit from this advice.

Perhaps the most obvious example of when resources other than reserves must be considered are deep, narrow-veined gold mines. These typically have only 2 or 3 years of reserves on their balance sheets, which is hardly sufficient to pay out a new investment. This is why these projects often start small and grow. It's too expensive and unnecessary to develop more than 2 or 3 years of reserves in such mines—if the geology is well understood.

So there is a time and a place for such resources to be used in evaluation, and it should be clearly described. Maybe the banker should even give it a peek.

Use of a Mine Contractor

When mine contractors are available, they can often come in, do the stripping and initial mining and crushing, and relieve the capital budget. Some mine contractors can be nothing but headaches. It's a valid strategy, but eventually the owners should consider self-mining, which can save anywhere from 10% to 30% on mine operating costs.

This is useful to keep this in mind when first engaging the mine contractor. He or she will properly amortize his or her equipment on the job, with the mining company's money. Mining companies should check out a rent-to-own arrangement whereby they might, in 5 years, earn a significant equity in this equipment at a modest extra cost. This is often more applicable to open pits than underground mines.

It is also notable that conversion to self-mining can be accomplished with many of the contractor's crew changing over.

The same kind of thinking is applicable during construction. Usually, some of the construction equipment (cranes and loaders) could be purchased through this sort of arrangement, so that at the end of the job, it belongs to the mine owner, who can choose to dispose of it.

Capital and Operating Costs

Contractors doing feasibility studies have data on capital and operating costs from around the world and are able to factor this data intelligently into new projects as they arise. Having said that, the owner and the banker's consultants must judge the validity of this factoring. If serious (i.e., damaging) discrepancies arise, with the owner saying costs were too high or the banker's consultant feeling they are too low, then a problem develops, which is usually solvable. There is also the matter of future liability that the contractors must consider. If the differences in opinion are not large or damaging, they can usually be bundled and analyzed in the sensitivity part of the report.

Tonnage and Grade

When the owner continues to drill after the official reserves have been set, new (hopefully more positive) results can best be addressed in the sensitivity or conclusions sections of the final report.

Economic Models

Owners, contractors, bankers, and investment houses will all have their own models and will also enjoy putting the mining company's numbers in their models.

At or near the start of the study, the owner and the contractor should decide on how they want the economics (spreadsheet) presented. They should each check their model against the others and resolve any significant differences. This can often be resolved in the footnotes, which would address how to indicate tax treatment, how payout is calculated (from the start of construction or from the start of commercial production), and so forth.

Price of the Product

Large companies might have in-house annual pricing committees to study and recommend long-term pricing to be used in budgeting and feasibility studies. Bankers, contractors, and smaller companies will depend on the myriad of "crystal ball gazers" in investment houses and commodity consulting houses, all with good people studying the same data used by the big mining houses. The crystal ball gazers will publish those results for all to see (for a price). This usually results in a good, healthy spread in the estimates.

These estimates can then be assembled to show this spread and calculate the means and the averages. Table 8.1 shows three such assemblies of estimates, gathered over a few months in early 2007.

TABLE 8.1 Assemblies of metal price estimates

	Assembly I			Assembly II			Assembly III		
Product	**High**	**Low**	**Average**	**High**	**Low**	**Average**	**High**	**Low**	**Average**
Copper 2007—US$/lb	3.25	2.20	2.61	3.06	2.27	2.85	3.50	2.27	2.88
Zinc 2007—US$/lb	1.95	1.00	1.65	2.06	1.46	1.72	2.15	1.15	1.65
Copper (long term)—After 2010	NA	NA	NA	1.50	1.00	1.19	1.30	1.10	1.20
Zinc (long term)—After 2010	NA	NA	NA	0.75	0.52	0.62	0.85	0.50	0.67
Gold (long term)—After 2010	NA	NA	NA	710	490	556	700	450	575

NA = not applicable

The assemblies are a mix of from 9 to 27 "guesses" on metal prices by various investment houses. The average is the arithmetic average of all the guesses for each assembly.

By using different assemblies, of course, it would be possible to come up with different numbers—and to know they are all likely to be wrong. The average numbers of the assemblies in Table 8.1 are "close enough," except for gold. And this is (likely) the most difficult and most volatile, and the guesses will have some wide swings at the top and bottom. Naturally, investors will have their ideas, too—all of which should be captured in a good sensitivity analysis in the reports.

Inflation and Leverage

In a down market, one might see financial engineers play with leverage and inflation and *not* make the game rules clear. It is certainly possible to change the return on investment significantly doing this.

The best recommendation is not to do this. In the evaluation, this game in sensitivity should be played only if necessary and the rules should always be made clear.

Compare the Project with That of the Competition

Several good firms are producing cost curves based on data they acquire by visiting mines worldwide for each of the principal commodities. These are *not* inexpensive. Although, of course, they cannot be 100% accurate, they can provide a well-thought-out guess, each calculated the same way, for a lot of mines. It's a good measure of competitiveness.

Cost curves allow a company to evaluate, albeit roughly, the cost position of its project compared to that of competitors. When interpreting cost curves, one should be cautious about the following:

- During a serious downturn, state-owned mines might not follow the same rules as in the private sector. They might not (ever) shut down, even though they have high costs.
- Some mines produce high grades in a downturn (they might have to do so to survive) and mine lower grades in good times. Or they might produce high grades in good times to maximize profit. This makes it difficult to judge supply and demand (forecast prices) and make good cost comparisons.

It's crucial to understand the pricing risk in a downturn *or* through a price cycle. This is complicated by the "super cycle" in which the industry now appears to be stuck. But even long cycle prices do come down eventually.

Risks

As the conclusion of work on the feasibility report approaches, it's wise to take a moment to consider the risks listed in Table 8.2.

TABLE 8.2 Site-specific risks

Country Risk	Geotechnical Risk
Permitting Risk	Geological Risk
Social Risk	Transportation Risk
Environmental Risk	Market Risk
Manpower Availability	Infrastructure Availability
Weather	Capital Costs
Competition	Operating Costs

These and many other site-specific risks will raise questions that the CEO, the board of directors, the bankers, and all the other stakeholders have a right to and will/should ask. *All of them should be covered in the feasibility report.*

What does a competent due diligence consultant look for when studying a new feasibility study? This is the frame of mind into which report authors must put themselves before issuing feasibility studies. So what exactly *do* due diligence consultants look for?

- **Economics.** The last page of the executive summary and the spreadsheet in the economics section of a good report will usually tell the banks the story. If the return on investments (IRR) is robust, the life of the mine is around 15 years or longer, the long-term price projections look reasonable, and the author of the report is reputable, chances are it will be a worthy project. However, they will read the rest of the report, looking for obvious flaws. But if no serious unanswered concerns arise, the company should be ready to negotiate financing.

  At the other end of the spectrum, if the IRR is showing around 12% to 15% (depending on location), the life of the mine is 10 years or less, the long-term pricing seems to be a stretch, and the report is obviously not well-written or understandable, then the hunt for the "fatal flaw" begins.

  Most studies will fall somewhere in between these two extremes. One might have an IRR of 15% to 16%, a mine life of 12 to 14 years, and a long-term price in the high-normal range. In this case, one might find that the geology has evolved during the study to be larger than originally thought, resulting in lower unit capital and operating costs, which has the delightful effect of improving the IRR to meet or exceed the "hurdle rate," which one likes to think of as being between 15% and 18%.

  One such (as yet undeveloped) project, looked at several years ago, was conceived as a 30,000 t/d copper open-pit/mill operation and was rather isolated. During the study, it grew to 60,000 t/d, then to 75,000 t/d, then to 90,000 t/d—and the mine life dropped, the grade dropped, and the strip ratio dropped as expected. The resulting project hit the magic IRR of 14.9%, but it was not financeable.

  Sometimes, projects like this need a completely new start. Is there a high-grade core with which a 5,000-t/d used mill can be justified? Bethlehem Copper in British Columbia started this way in 1955, on a large, low-grade orebody. Initially, they focused on the higher-grade areas, paid off their debt, then expanded the mill and lowered the cut-off grade. After several of these additions in 20 years, they were up to 30,000 t/d, the correct size for the reserves and with no debt, so the project was profitable. Perhaps other companies should occasionally do some retroactive thinking like this. Economics is obviously an important risk and a driving incentive. What else?

- **Geological risk.** The geology of a new project is centered on tonnage and grade, as it must be. Today's computer-oriented geologists have mastered what used to be tedious, time-consuming hand calculations. Today, with the press of a button, it's possible to change the cut-off grade and have a new higher-grade or lower-grade mine design in minutes. With a second click, one can see how the economics and mine life change with these new parameters. It's wonderful.

  But there is more to geology than that and sometimes fatal flaws appear, which might be ignored if a metallurgist, mining engineer, or bank consultant doesn't read, recognize, and reject them. Mining history is littered with such casualties, particularly where the grade has been overestimated, sometimes on purpose.

- **Mining and metallurgical risks.** Although these risks have already been addressed several times, it's worth mentioning again because it's critical to ensure that competent people do this planning well.
- **Cost risks.** Clients might push for and some report writers will yield to the pressure to include unachievably low capital and operating costs in their reports. Even in today's Sarbanes-Oxley- and 43-10-regulated environment, these lowball numbers can slip though the net. These incidents will continue to be part of the business, but they must be identified and dealt with appropriately.
- **Environmental risks.** Environmental risks are similar in many ways to cost risks. Permitting/regulatory oversight mechanisms are in place, but projects with likely environmental shortcomings can slip through. They too must be identified and dealt with appropriately.
- **Market risks.** This is an integral part of the economic risk exercise. Markets for products change, usage levels change, price cycle lengths change. Enormous changes in technology over many years have resulted in a reduction in the cost of a unit of production and, in so doing, have lowered the noninflated price of copper, zinc, aluminum, and many other metals. A big, high-grade discovery like the Escondida copper mine in Chile or the Red Dog zinc mine in Alaska can also contribute to this price deflation effect.

  But the industry is now undergoing what some might call it a paradigm shift. China, India, and many third-world countries are having an impact on the business. Rising energy prices are making a serious impact. Government intervention, wars, and terrorism continue to affect the industry.

  How will these situations affect the price of products going forward? It is necessary to ask oneself a question: is there a real paradigm shift that will keep this super cycle motoring on for several more years, resulting in a super-long up cycle in metal prices and a reversal of the long-term price erosion that the industry has witnessed for nearly a century? Or will the industry once again see copper prices of less than $1.00/lb, zinc at $0.40/lb and nickel at $2.50/lb? The answer is vague, but the risks are quite clear.

Construction Stage of a Project

For a new project that has been approved and has been financed, permitted, and so forth, it is often tempting to consider turning it over to an engineering, construction, and project management company, giving them a budget and telling them to build it. However, this approach is generally unworkable.

The feasibility work has accomplished less than 5% of the final design, and not all of that work might be acceptable. This is the last opportunity to reconsider *all* the major design decisions. A new revised budget will be developed; every few months after that, a new estimate (that is, a forecast) will arrive. Later, when the design reaches about 90% completion, construction might have reached 40% completion, and the project is now on a version 3 forecast. After 2 or 3 years, the project is at 100% completion and the plant starts. Only then will it be possible to see the final cost number and know how good the initial code of accounts was and how well the construction was managed.

The principles and criteria for good feasibility management apply to construction as well. A good owner's representative or project management team should be appointed and that person or team given sufficient authority and support to do the job. The project leader should participate in the hiring and contract negotiations with the engineering/construction contractor, hire his or her own staff, know what downstream construction permitting approvals are required, and be aware of what reports are expected and what startup responsibilities the owner has. The owner's representative should also understand project insurance and the insurance coverage that should be provided (by owners or contractors) during the construction phase of the project.

The owner's representative during the construction phase might or might not be the same person who was in place during the feasibility work, and the construction contractor might or might not be the same contractor as the one who performed the feasibility work. It is tempting to use the same personnel during both processes. The problems, challenges, and rewards in this engineering/construction phase are remarkably like those during the feasibility work.

Someone once proclaimed that any new project has three phases:

- **Phase 1—Discovery and Feasibility:** This is a period of thoughtful, well-considered plans and judgments, based on not too many details or final plans other than tonnage and grade. These are thoughtful times with one eye always on costs; time might not be a primary issue.
- **Phase 2—Construction and Startup:** This is a headier period during which details are worked out. Time is an issue (sooner is better) and cost prudence is generally set aside to speed the process—right through to 1 or even 2 years of production and on to full production rate.
- **Phase 3—Fine Tuning:** This is when the size of the capital expenditure (capex) is finally known. It's now possible to gain a good idea of what the achievable mine grade will be and there is probably still some way to go to achieve optimal operating performances. This is not an easy time. It takes a different management style and it is an important period!

After a successful feasibility study, it's time to start *all* over again as well as to take one last look at all the design decisions made earlier, particularly from new eyes on the owner's side, from people who will later bear the responsibility of starting up, maintaining, and operating the new infrastructure. Likewise, during the actual construction and development of a mine, a future general foreman will spot and improve on details that might have been missed in the final design. Techniques on how to manage water inflow (depth of the ditches), for example, or how to monitor effluent outflows from the mill can be incorporated. A lot of small but important details can be added to the as-built drawings and need not/should not go back to design.

The nitty-gritty of construction—union or open shop, housing for construction people, temporary offices for contractor and owner, buying versus leasing construction equipment, security, weather-related logistics, timing of orders for equipment with long lead times, selection of subcontractors—will go on for as long on the contractors stay. A sound owner's representative/project management team will assist in finding the best solutions to problems as they arise.

Relations with regulators, neighbors, and local political officers (and tax assessor) will need attention.

All the details—from design, to where the spare parts will come from, to the new code of accounts for operations, to hiring good staff (from superintendents to janitors)—will need to be completed before startup.

As construction nears the end, it is necessary to decide *how* and *when* to take over from the contractors and who from that group (if anyone) should be kept onboard for startup. There's no more hand-holding, no others to blame for shortcomings. This is when previous attention to detail pays off dramatically. It can also be a time of adrenaline rushes and sleepless nights, particularly if some details have been missed.

Despite all of everyone's efforts, some mistakes will undoubtedly emerge during the startup. Small mistakes can be corrected in minutes or during planned shutdowns. Big mistakes might call for a more careful understanding of the problem and the solution. If it's an expensive correction, it might mean another trip to headquarters for more money—not easy, particularly if the project is already over budget or behind schedule. But it must be corrected and the sooner the better.

The construction contracts and financing arrangements will both contain completion and performance guarantees and targets. It will be to everyone's advantage to achieve these targets quickly and well. This again leads back to all the details that are so important during final design and throughout construction.

Rather than dwelling further along these lines, it might be helpful to look at a few examples (case studies so to speak):

- There have been cases where the capital cost breakdown from prefeasibility to feasibility to the final project budget was different and therefore, not comparable. This unfortunate situation shouldn't be allowed to happen.
- There are cases in which good feasibility work was followed by faulty final design, without proper owner input, so the finished product was not what the owner wanted. It's important not to let this happen.
- Sometimes, new projects in new areas fail to gain local acceptance. At times, this is the result of neglect because someone didn't recognize the need to build local understanding or support or someone wasn't assigned to do the job. At any rate, it doesn't get done and major problems ensue. There are many examples of this happening, particularly when dealing with cross-cultural issues. It's often not easy to do and it can be *fatal* if it's not done right.
- One newly hired mill general foreman, who arrived early to help supervise equipment installation, spotted a +12-inch-diameter horizontal pipe connection leading from a slurry sump to a pump. He had it shortened to 8 inches to reduce the risks of sanding up (plugging) in the connection. It was a simple fix to do and likely prevented an untold number of shutdowns.
- The cost of shipping heavy or bulky equipment by rail (if available) is probably less than the cost of shipping by truck, but once the equipment arrives, it might have to be unloaded from the railcar onto a truck and moved another mile or 10 miles to a lay-down yard at the site. What does that cost and would it not be better to pay the extra trucking cost all the way? Good procurement advice is important.
- When one organization started a new underground mine in Missouri, it was thought that the ventilation had been well planned. However, after a year, during the summer, the ambient heat, high humidity, and diesel smoke in the underground air stream produced serious (dangerous) fogging problems. What to do? A bright young engineer suggested reversing the ventilation airflow. Although not ideal, this technique worked. In doing this, ventilation air was cooled slowly and the fog cleared significantly.
- Just-in-time procurement of parts works fine in an automobile assembly plant, saving on inventory and double-handling costs, but it often does not work well on a construction job, particularly when business is booming, the construction site is remote, and prices are rising quickly because of inflation. Sometimes, it pays to buy early and inventory it until it is needed. Sometimes, construction owners' representatives need direction in making these decisions.

To conclude this section, the construction period is when reducing time (to completion) is money. Analyses of details should not be allowed to paralyze the schedule.

Conclusion

Mines are expensive to build and payouts (generally) are slow compared to many businesses. If the company enjoys a successful startup, when product prices are rising, the team's work will make them heroes, despite the mistakes that might have been made. If, on the other hand, the mine's startup has been only average and its products hit a falling market, these same mistakes will be magnified 100 times, expensive corrections might be more difficult to fund, and the payout will be prolonged.

It's vital to remember that it will only be possible to know what the final capital costs, operating cost, recoveries, and achievable ore grades will actually be after the mine has operated successfully for a year or two. There are many unknowns at the start of any mining project, so it's important to give maximum attention to the details from the beginning and to hope that any mistakes/errors will be compensating errors, both good and bad.

MINING PROJECT MANAGEMENT: THE SUSTAINABILITY CHALLENGE

The management of a mining project actually starts even before exploration begins, when the company decides where to do its exploration. The initial choice of a particular area to explore should be based not only on its geological potentiality but also on its political, social, and economic background. The area selected might be a historic mining district or in a greenfield site with no previous mining record, but in any case, the project manager should be concerned with learning the peculiarities of the site regarding political, environmental, and community issues. When the exploration stages lead to a discovery that eventually turns into a mining project, a myriad of latent situations, new or unidentified impacts, and stakeholders can appear.

The sustainability challenge to managers of a mining project is present in almost all project areas and tasks. This challenge relates to management problems associated with sustainability, such as

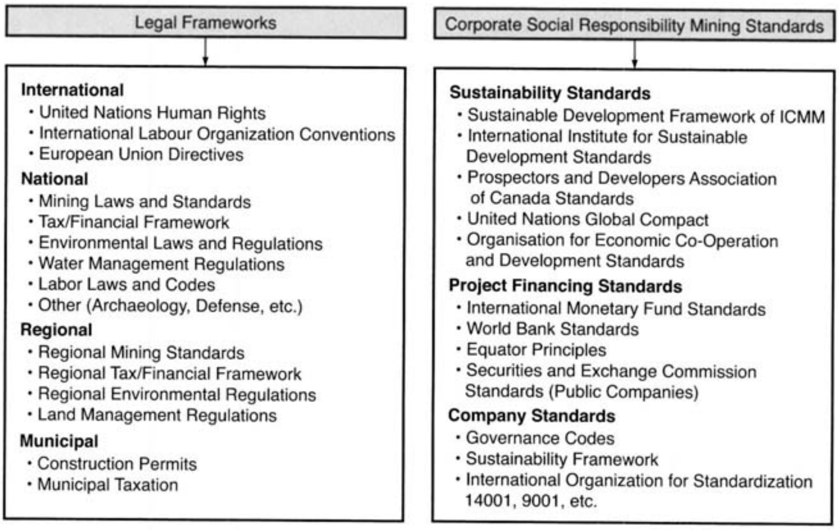
- Permitting, mining regulations, and standards;
- Environmental risks;
- Social risks and benefits from mining;
- The issues of social license and corporate social responsibility; and
- Management of human resources, contractors, and other stakeholders.

Some of these management problems are discussed in this section.

Permitting, Legal Frameworks, and International Standards

Because the mining industry is global and many mining companies operate across the continents, it is crucial for the project manager to become familiar with the provincial and local regulations applicable to the permitting process of the project in question and the government agencies in charge of those regulations. These steps are necessary not only for carrying out project financing, but also for public communication and for reporting the progress of the project.

Permitting, of course, is a complex and time-consuming management process. Depending on how many different permits are required from how many agencies, permitting sometimes takes several years to complete. Generally, the permitting process is easier and shorter when the company gets a social license to operate from the hosting communities and other stakeholders. In this regard, an important factor for companies is to voluntarily adhere to the international legal framework and international mining standards. Some of these regulations and standards are shown in Figure 8.2.



Legal Frameworks

International
- United Nations Human Rights
- International Labour Organization Conventions
- European Union Directives

National
- Mining Laws and Standards
- Tax/Financial Framework
- Environmental Laws and Regulations
- Water Management Regulations
- Labor Laws and Codes
- Other (Archaeology, Defense, etc.)

Regional
- Regional Mining Standards
- Regional Tax/Financial Framework
- Regional Environmental Regulations
- Land Management Regulations

Municipal
- Construction Permits
- Municipal Taxation

Corporate Social Responsibility Mining Standards

Sustainability Standards
- Sustainable Development Framework of ICMM
- International Institute for Sustainable Development Standards
- Prospectors and Developers Association of Canada Standards
- United Nations Global Compact
- Organisation for Economic Co-Operation and Development Standards

Project Financing Standards
- International Monetary Fund Standards
- World Bank Standards
- Equator Principles
- Securities and Exchange Commission Standards (Public Companies)

Company Standards
- Governance Codes
- Sustainability Framework
- International Organization for Standardization 14001, 9001, etc.

FIGURE 8.2 Typical legal and regulatory framework for mining projects

Management of Environmental Risks

Because environmental risks must be identified and quantified early, a preliminary Environmental Impact Statement should be part of the project scoping study performed during or on completion of the exploration stage.

Environmental Baseline Study

When the owner's team is on site and operational, an environmental baseline study (EBS) should be undertaken or, if already performed at the exploration stage, revised and detailed. The EBS is an investigation aiming to establish the baseline level of potential contaminants in soils, surface water, and groundwater, and to evaluate the initial status of other environmental risk factors, such as air quality, dust levels, gases, noise levels, ecosystems, and archaeological sites. The EBS should also plan for continual monitoring, through which changes in conditions can be documented.

Environmental Impact Study

Once the EBS has been completed, the environmental impact study (EIS) should be launched. The objective of an EIS is to evaluate the environmental impacts and risks associated with mining operations and determine the monitoring, control, and remediation actions that should be implemented in the project to minimize the environmental risks.

In addition to evaluating impacts associated with potential contaminants and environmental risks addressed in the baseline study, the EIS should evaluate other impacts derived from mining, such as water and energy use, cyanide, tailings, and waste dump management. Also required as part of the EIS or in separate documents are the decommissioning and reclamation plans and the postclosure monitoring and control requirements.

The EIS should include conservative estimates of all environmental costs, including those associated with regulatory oversight, reclamation, closure, and postclosure monitoring and maintenance. For important environmental risks, it is advisable to analyze best-case and worst-case scenarios and to develop appropriate response strategies in consultation with potentially affected communities.

Environmental Impact Assessment

Governmental regulations generally require mining companies to submit the EIS as part of the permitting process. The EIS is the basic document used by the U.S. Environmental Protection Agency or equivalent government agencies to issue the official Environmental Impact Assessment (EIA) for the project. However, regulations can vary from one country to another.

The EIS is the base used by the government to determine the financial-surety instruments to be required at permitting. Most governmental regulations consider the EIS a public document that regulates the publicity procedures and timeframe and ensures that all stakeholders can gain access to the information, so that participation in the EIA process is effective. Also, some companies provide technical and financial support to encourage stakeholders to participate in this process.

The EIS/EIA process is an important part of sustainable management and, as such, is subject to public debate regarding its efficiency as a sustainable development tool. As an example of this debate, the "Framework for Responsible Mining"[2] public debate platform of mining stakeholders on environmental and social issues associated with mining has developed "leading edge" recommendations to improve EIS/EIA standards:

- Minimizing water and energy usage and reducing greenhouse gas emissions should be a stated mine management goal.
- Companies should monitor and publicly report airborne hazardous emissions.
- Maximum noise level requirements should be implemented at the project boundary.
- Net acid-generating material should be segregated and/or isolated in waste facilities.
- Mine operators should adopt the International Cyanide Management Code and third-party certification should be utilized to ensure safe cyanide management.
- Reclamation plans should include plans for postclosure monitoring and maintenance of all mine facilities, including surface and underground mine workings, tailings, and waste disposal facilities. The plan should include a funding mechanism for these elements.

Management of Social Risks and Benefits of Mining

The management of social and environmental risks of a mining project is closely related to the company's achievement of a social license.

The concept of social license was first described by Pierre Lassonde as "... the acceptance and belief by society, and specifically our local communities, in the value creation of our activities, such as we are allowed to access and extract mineral resources ..."[3] In practical terms, social license refers to the process of gaining the acceptance of the hosting community to conduct mining operations and to apply best practices standards, aiming to leave a benefit across social, economic, and environmental areas.

Social license is often won or lost through the initial interactions between local communities and the project management team. In this regard, the management objective should be to demonstrate that the project will achieve sustainable long-term benefits for the hosting communities. Furthermore, this objective should be pursued in consultation with stakeholders.

Good and fluid relations between the company and the community and other stakeholders should be based on trust as the only means to foster participation and commitment and gain social license to operate. To this end, most project managers seek consultation with local communities. However, in most cases, the consultation process is limited to informing the community about the expected benefits to the community and explaining how the community will be protected from any negative impacts, but no real negotiation takes place.

Clearly, building trust among stakeholders requires their effective participation in decision making regarding environmental and social risks and expected benefits, specifically

- Identification and evaluation of environmental and social risks associated with the project and agreement on the means of remediation and control, and
- Agreement on the benefits to be expected and the short- and long-term positive effects to be achieved from the project.

Therefore, a sustainable management approach to project permitting is to engage in a participatory process with the community and other stakeholders, fostering participation in decision making and agreement. This approach implies that the company should disclose all pertinent information regarding the mining project and should engage in consultation regarding the understanding of technical reports and facilitate independent audits as required by stakeholders.

One approach to a social license standard is the Seven Questions framework[4] for assessing sustainability. This framework was developed by the International Institute for Sustainable Development in 2002 as part of the Mining, Minerals and Sustainable Development (MMSD) project. Seven Questions is a standard procedure to determine if the net contributions to sustainability are positive over the longer term.

Another framework to guide interactions between mining companies and communities is the Community Development Toolkit[5] developed by the Energy Sector Management Assistance Program, the World Bank, and the International Council on Mining and Metals (ICMM) in 2005. It consists of seventeen tools to facilitate community development over the mining project life cycle, including exploration, feasibility, construction, operations, decommissioning and closure, and postclosure.

Both the Seven Questions and the Community Development Toolkit are described in detail in Chapter 3 of this book. In Chapter 6, the concept of social license is analyzed from the perspective of human resources management.

Social Risks

Many social risks are associated with mining operations located in remote, often underdeveloped, regions of the world. Others, like changes in land use, are inherent in mining, regardless of social environment. Some of the risks are

- Risks associated with long-term changes in land management and land uses;
- Risks to health and safety (e.g., dust and noise) inside and outside project boundaries;
- Risks related to short- and long-term impacts on surface and groundwater resources;
- Massive immigration associated with mining projects located in poor regions, with immigrants attracted by the job opportunities generated by mining;
- Risks related to resettlement and relocation of communities;
- Excessive economic dependency on mining; and
- Risks to livelihood of local population dedicated to artisanal mining.

Social Benefits

The benefits of mining are mainly associated with increased employment opportunities, increased financial capacity of community institutions, company sponsorship of sustainable community projects, and entrepreneurship aimed at sustainable economic growth and diversification.

Many companies are moving toward partnering with hosting communities and involving them directly in decision making. Partnering with communities and third parties for development is becoming instrumental in helping a company obtain a social license to operate.

Social License: A Business Perspective

Intangible assets, such as reputation, are widely viewed as comprising a substantial and growing portion of a company's value. This is especially true in the minerals industry, where reputation is a critical strategic asset.

Strategic Perspective: Access to Human and Mineral Resources

As it applies to corporate strategy, the concept of social license can be extended to a mining company's achievement of a positive public reputation on ethics and social responsibility issues. This business perspective of social license is rapidly gaining the attention of mining companies as a management approach to reduce the financial risk and uncertainty of new mining projects and also as a strategic advantage.

Mining companies perceive a positive reputation as an advantage when gaining access to mineral resources and also to human resources, two key strategic advantages in mining. For example, Rio Tinto states that it has been able to develop its Diavik mine in Canada and other projects that never would have come to fruition without its public commitment to corporate social responsibility. Rio Tinto also states, "... in the long run, the trust that we are creating by building sustainable relationships will enhance our ability to gain preferential access to the essential 'people resource.'"[6]

Many companies have begun to integrate social and environmental risk into their risk management system. As an example, ICMM's Sustainable Development Framework includes the following: "Consult with interested and affected parties in the identification, assessment and management of all significant social, health, safety, environmental and economic impacts associated with our activities" (Principle 4).[7] Failing to identify and manage social, health, safety, and environmental risks can cause significant economic losses.

Project Finance Perspective: Access to Financial Resources

Investors of all types are focusing more attention on environmental and social issues when investing in and insuring mining projects. The adoption of the Equator Principles,[8] a globally recognized benchmark for the financial industry for managing social and environmental issues, by several mining companies and many of the world's leading banks might be considered as a trend toward higher social and environmental commitments and social license by the minerals industry. Financial institutions adopting these principles are taking into account the positive financial consequences of social license in financing new mining projects. Similarly, mining companies aligned with the Equator Principles consider the benefits of an easier and more favorable access to credit when financing new mining projects.

The Equator Principles are a set of categorization, assessment, and management standards designed to identify and address any potential environmental and social risks that a proposed project might present. Equator banks have undertaken not to finance any project with a total capital cost of US$10 million or more unless the project can comply with those standards or there is satisfactory reason to deviate.

The International Finance Corporation (IFC) applies its Performance Standards to manage social and environmental risks and impacts and to enhance development opportunities in its private sector financing in its member countries eligible for financing. The eight Performance

Standards establish benchmarks that the client is to meet throughout the life of an investment by IFC or other relevant financial institution:[9]

1. Social and environmental assessment and management system
2. Labor and working conditions
3. Pollution prevention and abatement
4. Community health, safety, and security
5. Land acquisition and involuntary resettlement
6. Biodiversity conservation and sustainable natural resource management
7. Indigenous people
8. Cultural heritage

Standard 1 establishes the importance of (1) integrated assessment to identify the social and environmental impacts, risks, and opportunities of projects; (2) effective community engagement through disclosure of project-related information and consultation with local communities on matters that directly affect them; and (3) the continuous management of social and environmental performance throughout the life of the project. Standards 2 through 8 establish requirements to avoid, reduce, mitigate, or compensate for impacts on people and the environment, and to improve conditions where appropriate.

Though not a commonplace case, junior mining companies are becoming increasingly aware that social license can reduce social and environmental risks and so has a positive impact on their capacity to get funds in the stock markets and represents a sizeable added value when selling its projects. Insurers are increasingly addressing environmental and social risk issues. This has significant importance for project financing and capital cost. American International Group became the first major private insurer to adopt a policy to manage social risks. Other companies are expected to follow. Notably, political risk insurance will become more important as the need to access resources in environments with greater political complexity grows.

Other Key Project Stakeholders: Employees and Contractors

For a complete analysis of the management and interactions between a mining project and stakeholders, see the "Project Management and Stakeholders" section. The following paragraphs outline some important management aspects to be dealt with during the early stages of a mining project.

Human Resources

An important project risk is related to human resources and the human resources management organization and structure required after production startup. Therefore, investigating the labor market in the hosting and nearby communities is an important project task. Precise information and data on the availability and cost of skilled labor, occupational statistics, and unemployment rates will be required for the feasibility study. Early consultation with labor unions, human resources consultants, and employment agencies will help to obtain the information required and will foster the interest and the cooperation of these stakeholders during the feasibility, construction, and start-up stages of the project.

The important role of human resources in achieving and maintaining the social license is analyzed in more detail in Chapter 6 (Human Resources Management).

Contractors and Suppliers

Project contractors and suppliers are very important stakeholders during the project stages. They are a major source of information during the prefeasibility and feasibility stages and the leading force during construction. It is therefore important to investigate the local, national, and international markets for project contractors and suppliers and to manage creating a list of qualified contractors and suppliers for project use. Whenever possible, local contractors should be considered.

Local Industry Managers and Entrepreneurs

It is important to establish contact with local industry leaders and entrepreneurs, especially those in the minerals industry and related sectors in order to establish personal contact and search for shared professional and business interests. They can help the project and provide important management and cost information.

Landowners

Many projects require acquiring numerous small land lots from a large number of owners, which makes land acquisition a difficult, time-consuming, and challenging task—and a significant project risk. Landowners are important stakeholders, and early contact with them is the key to establishing positive personal relations between landowners and project management.

The management of land acquisition and the importance of a fluid relationship with landowners is analyzed in the "Project Management and Stakeholders" section of this chapter.

Other Interested Parties: The Project Summary Report

As soon as the project has been defined at the conceptual engineering level, a project summary report should be prepared for use as public information to all stakeholders and interested institutions. The project summary report should be widely distributed to internal and external stakeholders, landowners, local authorities, regional and national government agencies, and the media. It should be a top-quality 20- to 30-page booklet and should be presented as the initial step in a process of permanent dialogue with stakeholders.

Conclusion

An emerging standard of best practices in the mining industry aims to leave net positive benefits across social, economic, and environmental areas that are sustainable after closure. In the foreseeable future, there will be growing pressure to ensure that mining projects and operations are managed for sustainability and a legacy of economic, social, and environmental benefits long after the mine closes.

The achievement of social license for mining projects and creating a positive corporate reputation and image are perceived by mining companies as an important strategic advantage when gaining access to mineral resources, human resources, and financial resources.

Acknowledgments

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PROJECT MANAGEMENT AND STAKEHOLDERS*

Mining's interaction with the surrounding world has been a complex issue for centuries. Its major impacts, broadly negative in environmental terms, broadly positive in economic terms, and contradictory regarding labor, social, and local wealth effects, have led to agreements and clashes, clichés, and ignorance between mining and hosting communities. Mining is a unique world, frequently located in remote or uninhabited areas, mostly in rural settings, and in countries with varying degrees of political and socioeconomic development; mining has at times imposed its own rules, condoned to a greater or lesser extent in exchange for job creation, industrialization, and taxation benefits.

But times are changing for mining. A growing conscience has appeared about environmental impacts, public input, nongovernmental organizations (NGOs), union involvement, and indigenous rights, as well as internationalization of information and so on. In past years, this new scenario has opened up serious problems and increasing difficulties for mining companies already in operation and even more serious ones for new projects.

Even international best-sellers have focused on the environmentally negative legacy of mining, the scale of lasting residual impacts[10]—contaminated water from abandoned mines, sterilization of the land—and as a consequence of this legacy, one of the most recurrent requisites for a new mining project from its very outset is to address end-of-life issues, designing a sustainable (environmental and socioeconomic) and safe closure with an eye to the distant future. As recognized by an important workshop organized by the World Bank in 2002,[11] mine closure is one of the most important issues confronting the mining industry. The way responsible companies approach it will be seen as a very important step in promoting a change in the mining industry.

In the last decades, an attitude toward a two-way communication with the "outside" world has gradually been translated into corporate policies and transposed onto the day-to-day business of many other mining enterprises. Standalone sustainability corporate reports have now become a common business practice.

Project Background

How mining companies operate in their interaction with stakeholders depends on a number of factors. *Size* and *internationalization* of a company are among them. Some companies tend to be more sensible, experienced, and proactive in understanding and promoting such corporate policies. This approach is not philanthropic but based on mutual respect and equilibrium. The policy has to pervade the whole corporate organization in order to be really effective, credible, and perceived as such for most (if not all) of the stakeholders. Corporate structures (e.g., decision making, human resources, and compensation/rewards) must reflect this policy. It should aspire to be an example of how the company works and adapts to the realities of the host country. Some companies, usually local or the old ones, develop a strong cultural relationship with stakeholders over the years, rooted in a shared (although not necessarily easy) history with the host country, common development, and deep understanding of their values and needs. These companies can be valuable partners for other corporate enterprises seeking to enter into new mining scenarios.

Time is also a factor. Understanding and incorporating stakeholders' positions cannot be a matter of improvisation. Corporate policies have to be devised and agreed upon, then converted into actions, which in turn must lead to positive results. All this takes time, usually counted in years.

The so-called global village is essentially an urban (and intellectual) concept. Today's developed and underdeveloped worlds continue to present extreme differences, more significant in rural areas, where mining tends to be located. Agriculture and local industries as well as other

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* This section was written by G. Ovejero Zappino.

local business initiatives develop naturally with local understanding of the country's peculiarities, whereas mining usually seems a strange culture, not only because of its technicalities and impacts, but also because of the international nature of the mining entrepreneurs. In addition to the purely technical aspects of mining, culture, language, work habits, and so forth also present challenges.

However, with the exception of political or legal issues, many feasibility studies or due diligence reviews still do not involve an in-depth study or simply fail to address or understand the cultural background and the stakeholders' positions where a project is located.

Whether located in a historic mining district or a greenfield site with no previous mining history, a new mining project requires a comprehensive, in-depth approach to the site's peculiarities and stakeholders' perspective. The same should also apply to existing operational mines, because they function in a continuously changing world.

In the case of projects discovered purely through exploration, this approach should be more manageable, because the initial decision to choose a particular corner of the planet is theoretically based not only in its geological potential but also on its political, social, and economic background. This means, in theory, that the main stakeholders influencing the development of the project will have already been taken into consideration. However, once the discovery becomes a feasible, exploitable project and, subsequently, a mine, a myriad of latent situations or previously unidentified or new impacts, and therefore stakeholders, can appear.

Information technology (Internet, e-mails, and cell phones) provides a tool for exploring and reporting between mining and stakeholders, but it also creates a parallel, virtual world that does not always coincide with reality. Anti-mining groups, for example, are much more active than mining companies, not only through the Web but on the street and in the media, and their views can lead to a distorted perception about how a mining project or operation is perceived by stakeholders.

Stakeholders

The stakeholder concept, developed and promoted in the 1980s by R. Edward Freeman,[12] refers essentially to a party that affects, or can be affected negatively or positively by, the company's actions.

The stakeholder concept is applicable to any business activity, but it has found an extensive application in the mining industry, due to the great diversity and magnitude of its potential (positive and negative) impacts and the controversial legacy of mining around the world throughout history.

Identifying and interacting with the relevant stakeholders is essential to producing good results. But much still needs to be learned about how to identify and involve stakeholders, as the World Bank[13] was to note, which suggests that a good way to identify appropriate stakeholders is to start by asking questions:

- Who are the "voiceless" for whom special efforts might have to be made?
- Who are the representatives of those likely to be affected?
- Who is responsible for what is intended?
- Who is likely to mobilize for or against what is intended?
- Who can make what is intended more effective through their participation or less effective by their nonparticipation or outright opposition?
- Who can contribute financial and technical resources?
- Whose behavior has to change for the effort to succeed?

TABLE 8.3 Mining project stakeholders

The Company's Directly Related People, Business, and Investor Institutions
Shareholders
Financial and lending institutions and financial analysts/the World Bank
Employees (and employees' families)
Contractors, suppliers, and customers
Government, from Municipal to National or International Levels
Legislators, regulatory bodies, members of the judiciary, security forces, and the executive/ministries
Ombudsmen
Intergovernmental Organizations
United Nations bodies (i.e., focused on corporate responsibility, human rights, environment, labor)
Regional bodies with authority for policy-making and enforcement (e.g., the European Union, Organisation for Economic Co-Operation and Development, Association of Southeast Asian Nations, Organization of American States)
Society
Directly affected parties: host and surrounding communities; landowners
Indirectly affected parties: Agriculture, private business, tourism, competitors, etc.
General public and broader society: local to global
NGOs: environment; development; humanitarianism, human rights; citizen platforms; etc.
Religious institutions
Religious protagonists with an effect independent of institutions (i.e., a local priest)
Media (press and opinion leaders)
Political groups
Labor unions
Professional associations and scientific/technological bodies and universities
Indigenous people and individuals
Minorities and other historically marginalized groups
The environment

A list of prominent stakeholders (not necessarily in order of importance) with direct or indirect interest in the mining project is shown in Table 8.3.

Normally, the groups with common interests are the shareholders, the employees, and the contractors, suppliers, and customers. But they operate in a very complex social, economic, regulatory, political, and even religious framework where other stakeholders must be considered.

High corporate standards, transparency ("far easier said than accomplished," Jackson),[14] clear targets and positions, and recognition of the perspectives of external stakeholders must, among others, be common factors when interacting with stakeholders.

The Company's Directly Related People, Business, and Investor Institutions

Interaction with these stakeholders is well regulated through official meetings and annual reports to shareholders. Lending institutions and their advisors, as well as financial analysts, have to be provided with clear information, beyond the project economics, related to sensitive factors potentially affecting financial exposure and stock value, such as environmental liabilities, permitting delays or no permitting, legal appeals from third parties, social opposition, and so forth. For financial analysts as well as for due diligence processes, social aspects are an important part of the list of items to deal with, such as the project's negative impact on third parties, anti-mining movements, or public resources depletion.

Employees, contractors, suppliers, and customers can be the project's strongest supporters. All of them, especially employees, will diffuse within the local communities the most accurate image of the company's behavior. Regular information should be provided on the project development through in-house newsletters, meetings with management, full site visits (including employees' families) and annual conventions.

Government

Government regulatory agencies are the administrative key to project permitting. Governments are the primary decision makers and implementers of policies and projects. One of the initial difficulties when permitting a project is insufficient or poor relationships with the numerous government agencies involved or even incompatible approaches and policies. Recommended proposals to the authorities to solve this issue (partially) can be (1) the allocation by each government agency of a responsible coordinating officer, and (2) to hold coordination meetings and workshops with presentations on the project, making the authorities aware of schedules and deadlines and, above all, agreeing on common permitting conditions and criteria.

It is essential to develop an impeccable, open, and frank relationship with the authorities in order to create credibility and common trust and to maintain their confidence by strictly complying with the legislation and permitting conditions. Demonstrating good business practices will secure project development and access to new projects.

One of the administration's main concerns and challenges at present is the aftermath of mining, confronting some companies' managers who might think this is an issue to be resolved by others in a distant future, when present players will not be personally involved. The better this issue is addressed, the greater the acceptance of the project.

Society

The general public constitutes the most complex group of stakeholders, not only because of its varied nature and the difficulty in assessing its requirements and concerns, but also because of potential conflicts of interest with project development. However, that said, beyond cultural differences, basic human needs and behavior are the same everywhere. Public hearings, direct consultation, and social baseline studies are the most straightforward ways of approaching the matter.

Public hearings, listening, and answering are necessary exercises to be carried out through formal and informal ways. Formal procedures are provided by regulated public access to the project documentation during the permitting process. This public enquiry usually leads to questions, recommendations, or allegations by public third parties, to which the mining developer has to reply satisfactorily in writing. Some can end in judicial appeals with different outcomes. In some countries, the legislation provides the interesting opportunity, before starting a full permitting process (which can take years with unknown results), to prepare a small project summary to be distributed by the government to a variety of government branches, NGOs, institutions, citizens, and so forth. The aim is to identify ideas, recommendations, potential conflicts of interest, and so forth to be gathered by the government and to be sent with comments to the mining entrepreneur. Although perhaps imperfect, it at least provides valuable insight into many government and interested/affected parties' views, plans, and positions and enables the permitting actions and documents to address the fundamental issues.

People sometimes complain that the usual 30 days formally allowed for public review (followed by more opportunities for closely affected parties) can pass unnoticed or are insufficient for a thorough review. The company should consider the advisability of reinforcing the information through parallel informal ways, such as public presentations, newsletters, or other means to encourage better understanding of a project and try to promote favorable opinion.

When interacting with directly affected parties, prearranged and ad hoc communication meetings to discuss particular issues are mandatory. The parties' requests have to be carefully evaluated and answered as promptly as is feasible. An adequate response must be given to prevent issues from growing with misunderstandings or wrong expectations. Project impacts have to be quantitatively (and qualitatively) assessed and addressed through constructive dialogue and actions. These assessments should be based, whenever possible, on previous baseline studies—indeed, it is most advisable to conduct preoperational baseline studies and community perception surveys.

Direct consultation and social baseline studies provide a better insight into stakeholders' issues, and are complementary to the formal procedures of public hearings. Founded in 1998, the Global Mining Initiative promoted the Mining, Minerals and Sustainable Development (MMSD) project[15] in 1999, based on an independent, multistakeholder-based review of how the minerals and metals industry can best contribute to sustainable mining development. The MMSD project ended at the Johannesburg World Summit (September 2002) on Sustainable Development. The final report, *Breaking New Ground*, included a number of basic recommendations with regard to stakeholder involvement:

- Greater cooperation among those stakeholders with similar interests and the importance of enhancing capacity for effective actions at all levels
- Constructive dialogue with key constituencies
- Effective community development management and tools

More recently, in November 2007, Anglo American used its Web site to make public the comprehensive, detailed Socio-Economic Assessment Toolbox,[16] which provides a way to develop a rigorous profile of the communities surrounding mining operations and a precursor to participating, practically and effectively, in community development priorities.

A commitment should be given to contribute to community welfare through existing development programs and by engaging local people, suppliers, and contractors with such programs measured to gauge their effectiveness. Third-party assessment helps to understand, plan, implement, and account for social and economic performance at a local operations level.

Above all, it is important, regarding social engagement and consultation, for mining companies to be aware of the potential for backlash if those consulted perceive their input is being disregarded by the project. Two key problem areas come to mind:

- Perception of insufficient benefits or inadequate development programs
- Perception that the project itself is being constructed/operated in ways that stakeholders consider irresponsible or disrespectful

This second point causes more animosity and is often overlooked by companies.

Interacting with NGOs requires specific approaches. Technically, an NGO is an officially recognized entity that is not affiliated with governments or companies, but common usage relates the term *NGO* to organizations geared toward a cause rather than toward profit. NGOs fit into a range of cross-cutting, nonexclusive categories: geographic (local, national, regional, and international) and subject area (development, humanitarianism, environment, human rights). Their positions on mining can range from pro-engagement to anti-mining: a number of NGOs participate in sustainable mining initiatives and projects, while others hold back purely because of mining companies' involvement. Some of these groups maintain a constant, close scrutiny (sometimes constructive and beneficial, sometimes neither fairly nor objectively based) of a company, its operation, and the government regulators, at times with a certain impunity in their declarations and activities.

Dealing with the media requires the company to provide information readily about project development (milestones, goals reached, environmental performance, technological innovations, ending with background corporate information) and respond to issues that arise (silence is not an option). Ideally, a personal relationship with media management and journalists should be maintained. When writing press releases or answering questions, short answers should be given ("less is more"), and one must stick to the facts, and use plain, understandable language. It is

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recommended to establish different levels for media interaction: (1) media specializing in business and economy, which is the natural medium for a mining project; (2) local or provincial information sections in the general media, used by the general public; (3) editors, managers, and owners of the chief media (press, television, radio, etc.); and (4) regional and local media present in the municipalities where the project or mine is sited.

It might also be wise to consider "the environment" as a distinct stakeholder. This is controversial because the term *stakeholder* typically refers to human individuals and entities. However, there is increasing support for the notion that the environment itself, and elements of it, have standing, regardless of how environmental change might impact human beings.

For practical reasons, some companies have edited specific and detailed guides for conduct on community relations, environmental and health, and safety items, covering from the very beginning when the first exploration team sets foot on the site up to the complex relationship developing over the various stages of a project.

As a final general note, there is no agreement on what constitutes a mining stakeholder, and not all mining projects affect or are affected by all these stakeholders.

Administrative Licenses

Any responsible mining activity has to be fully supported by administrative licenses based on the legal and regulatory framework of the host country, obtained throughout a permitting process. The permitting process has become an increasingly colossal, complex, tangled, and lengthy exercise requiring specific staff and highly professional legal advisors assigned to this task. The numbers of key and collateral permits, and the number of different regulatory authorities involved (municipal, regional/state, national/federal, even international), can reach surprisingly high figures. Permitting can easily take from 3 to 5 years, depending on a variety of factors, and it continues throughout the entire life of the project. Successful permitting requires the following factors at a minimum:

- Full knowledge of the existing legal framework and awareness of oncoming legislation. When needed, international or state-of-the-art regulations or recommendations, such as the ones from World Bank, provide useful references. Regarding future legislation, active participation in the open, public consultation process is highly recommended.
- Continuous and expert legal advice and support
- Conceptual permitting design and schedule, showing the critical permitting paths. Legal shortcuts should be avoided.
- Allocated staff and budget
- Preparation of high-quality mandatory projects (technical, environmental, social, feasibility studies). Identify/select the right consultants, using local ones whenever possible, especially in the environmental and sociocultural and socioeconomic areas.
- Active interaction with the administration/government bodies. If possible, a coordination committee involving the different administration players should be organized, extended if necessary to representative stakeholders.
- Continuous follow-up of permitting items and project development with the administration bodies, with a relationship based on common trust and ethical behavior.
- Persistence, tenacity
- Clear understanding of commitments assumed regarding the general and specific conditions of the awarded permits

CHAPTER NINE

Mine Planning and Production Management

N. Mojtabai

INTRODUCTION

This chapter gives an overview of units of operations in mining that play an important role in the success of the project and, therefore, in meeting the production requirements at an optimum point, while minimizing the undesirable side effects of mining operations on the environment and the communities. The sustainability of the operations depends on the economic success and protection of the benefits of the company, the communities, and stakeholders. Although the topics that are covered in this chapter are technical, there is no focus on the design or technical aspects of these units of operations. The intended goal is to draw managers' attention to how these operational components could result in serious problems such as environmental impacts, damage to property, harm to the health and safety of both employees and residents of nearby communities, and economic outcomes that can result in early or premature closure of the mining operation.

Mining is an interdisciplinary operation that consists of many different units of operation. These units of operation are all integrated into a single system that runs the mine. Some of these units or sections of the mine might be working together, either in parallel or in series. Although each unit operates as a single entity, it is interconnected with the rest of the operation. All units of operations rely on each other's performance and any lack of efficiency or productivity will carry across the entire operation. It is the management's responsibility to make certain all components at the mine operate in harmony at their peak productivity.

This chapter has 12 sections.

"Mine Planning and Grade Control" starts with the discussion of long-term and short-term planning, and ore grade control. A brief introduction to tools and techniques that are used in planning and grade control follows.

"Rock Fragmentation by Blasting" concentrates on rock fragmentation and drilling and blasting operations. The emphasis is on safety and control of adverse effects of blasting on the surrounding area and neighboring residences. Important parameters that control the outcome of a successful blasting operation are discussed. Specific issues and parameters related to safety and adverse effects are summarized as well.

"Loading and Hauling" provides an overview of important aspects and parameters that must be taken into consideration when designing and planning the material-handling systems. The focus is on how the loading and hauling equipment should be integrated into the mining operation. There are no discussions or details on specific types of equipment. It is assumed that the management and those in charge are familiar with all material-handling systems.

"Ground Control" focuses on the importance of ground control as part of a successful and safe mining operation. Issues related to ground control are summarized. Again, no theoretical background on this subject is given. The goal is to bring the importance of ground control to management's attention.

"Mineral Processing" gives an overview of mineral processing and all the steps involved in the complete processing cycle. Various techniques are introduced with a limited amount of technical and theoretical discussion. The environmental issues related to mineral processing are discussed.

"Leaching" covers issues that have been of major concern with leaching operations. Leaching is becoming a very popular and economically attractive alternative to milling and processing. However, it does present some environmental challenges, which are discussed in this section.

"Mined Rock and Tailings Management" concentrates on the problems associated with the large amounts of rock and tailings produced by mining operations. These products of the mining operation have no value and must be handled and placed on surface. The volume of tailings and mined rock has been consistently increasing as mining operations become larger. Managing these materials is very challenging and mistakes can have catastrophic outcomes.

"Reclamation and Closure" discusses the reclamation and closure processes, important aspects of mining operations that require special attention, planning, and managerial control. The importance of reclamation and closure related to public health and safety is discussed.

"Maintenance Management" focuses on the importance of maintenance to the success and continuity of the operations. Safety and environmental issues related to responsible maintenance are discussed.

"Case Study: Grade Control Systems at El Valle-Boinás Mine" illustrates the importance of ore grade control as part of planning and managing a mining operation.

"Case Study: Reliability Assessment of a Conveying System at Atlantic Copper " is related to processing and maintenance. This section describes a methodology for improving maintenance practices based on the application of reliability-centered maintenance and mathematical modeling for the conveyor belt system at Atlantic Copper.

"Case Study: Overview of the Aznalcóllar Tailings Dam Failure" is related to a classic problem with mine tailings dam failures. It reviews the lessons that can be learned from such events.

MINE PLANNING AND GRADE CONTROL*

Short- and long-term production planning is a primary influencing factor for sustainability in mining operations. A sustainable mining plan should minimize the effects to the mining business process caused by variability in commodity pricing, inflation of mine costs, declining ore grade, and declining mining conditions such as increased depth of cover. Design factors with the capacity to increase sustainability include layout, application of new technology, mine infrastructure, proactive communications, and interfacing with land, water, socioeconomic forces, and postmine reclamation. These planning considerations will be examined in the following paragraphs for surface and underground mines.

The main function of the mine design and planning team is to provide the necessary technical support to ensure the optimum operational efficiency and sustainability of mining operations. Although the long-term mine planning process determines the production and economic objectives, the short-term planning and control processes are key to the efficient use of resources, performance evaluation and control, and the timely implementation of corrective actions.

This section aims to describe the main mine planning functions and processes and highlights the management aspects that are key to sustainability.

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* This section was written by C. Castañon and J. A. Botin.

Long-Term Planning

Long-term production planning and scheduling is concerned with the development of an optimum mining sequence for ore and waste required to sustain production. The production schedule takes into account operating constraints, blending requirements, economic considerations, reclamation, and other operational and sustainability constraints.

Long-term mine planning includes a variety of specific functions:

- Detailed definition of minable ore reserves in sufficient quantity to sustain production
- Detailed engineering and layout of mining blocks/stopes, optimum mining sequences, and production schedules to serve as the basis for 1-year and 5-year operating plans
- Evaluation of performance, productivity, and costs required for the preparation of the 1-year plan
- Evaluation and revision of dilution and cut-off grades used in long-term planning
- Advice and data management role for the preparation and control of the annual operations plan and budget
- Preparation and annual revision of 2-year and 5-year plans
- Update of planning, design, and scheduling of waste dumps and tailings dam
- Preparation, updating, and control of environmental management and mine closure plans
- Ongoing equipment replacement analysis and economic evaluation work
- Reporting functions on all the preceding functions
- Maintenance of the database management systems, the general mining packages, and other mine planning tools used in the planning process

Short-Term Planning

Short-term planning is concerned with schedules on a daily, weekly, or monthly basis, as well as grade control and mine geology functions. The goal is to furnish the requirements of the operating plant with ore of uniform quality to ensure its operating efficiency. The short-term plan has to comply with the long-term plan, take into account equipment availability, and accommodate blending requirements.

Daily, weekly, and monthly short-term plans are required at a mining operation for sustainability. These plans are derived from the yearly plan. A robust short-term planning process with commensurate follow-up provides the feedback that planners need to correct long-range plans. Short-term planning includes a number of main functions:

- Shift/day plans: First-line supervisors plan and mine at specific locations that maintain continuity, and identify and mitigate on-shift risk.
- Weekly plans: General supervisors plan down shifts, construction, and spoil placement, as well as design updates and forecast weekly production.
- Monthly plans and weekly updates: Superintendent- or manager-level personnel update monthly forecasts to production and costs.
- Quarterly plans and monthly updates: A rolling plan adds a new monthly plan to replace the month just completed.
- One-year plan and quarterly updates: The 1-year plan is the basis for the annual operations plan and budget. The plan is normally updated quarterly.

- Ore grade control and mine geology functions: This is a shift-by-shift definition of ore–waste boundaries, ore grade forecast, loading faces, waste dumping points, mill throughput forecast, and so forth.
- Mine surveying (mine, stockpiles, dam, etc.): This is the daily staking of ore–waste boundaries and blastholes, ongoing toe-crest surveying, and so forth.
- Blast engineering and design: This includes blast engineering and design, fragmentation studies, blasting performance studies, vibration control, and so forth.
- Ground control
- Ore stockpile control
- Mine–mill grade/tonnage reconciliation
- Performance and time studies
- Reporting functions on all of the preceding functions

Ore Grade Control Function

Grade control refers to a decision-making process in which the classification of a block as ore or waste is revised on a day-to-day basis. This is done by ore graders and mine geologists through blasthole data processing, visual observation of faces, and operational considerations.

Concept of Grade Control

The grade control process comprises a number of data processing, studies, and management activities (supervision, meetings, and coordination) aiming to take the final decision on the destination of production units (e.g., a haulage truck, scooptram), to the plant or to a specific mine dump. It also involves a number of control functions related to the analysis of deviations between the planned and actual values of grades, dilution, tonnages, and metallurgical recovery, all of which are critical for sustainable management.

Scope of Ore Grade Control Function

The scope of the grade control function is different for each mine and depends on the mining method (open-pit/underground), the type of resource (precious metals, coal, etc.), the size and shape of the orebody, and other factors. Furthermore, for a specific mine operation, the grade control function is a continuing improvement process that evolves with time.

Depending on operational requirements, the grade control function can range between a simple visual delimitation of the ore–waste boundaries to a highly sophisticated process usually required at economically marginal precious metal operations.

Ore grade control focuses on the following issues:

- Recalculation of minable reserves. Often, the tonnage, grades, and spatial distribution of the ore reserves reported at the feasibility stage lack the precision and detail required for medium- and short-term planning.
- Definition of ore–waste boundaries at mining faces. This is important and not always easy.
- Day-to-day definition of the minimum size of unit mining blocks. This depends on bench height and the type of ore loading equipment used.
- Day-to-day control of moisture. This is especially difficult in soft or oxidized ore.
- Control of dilution
- Monthly and year-to-date reconciliation of mine, mill, and concentrate sales statistics

- Design of the size and geometry of production blasts, aiming to optimize dilution by selective blasting of materials with different blasting behavior
- Management of mining ore–waste faces and broken ore inventories, aiming to ensure that enough loading places are available and blasthole assays and other relevant information is available on time
- Follow-up and control of bench toe and crest elevation
- Bench height optimization studies. The higher the bench height, the higher the mining productivity but also the higher the dilution.
- Mine planning and design changes in relation to changes in annual production plans. When production objectives increase, it might be necessary to review the design and operating parameters.

In conclusion, it might not be easy to quantify the economic and sustainability returns from grade control, but it can be said that money invested in improving grade control systems will improve the bottom-line results of the company.

Definition of Cut-off Grade

Break-even cut-off grade is defined as the lowest grade of a mining block that can be mined and processed, considering all applicable costs, without incurring a loss or gaining a profit. In calculating the cut-off grade, sustainable management requires that all costs incurred during the entire mining life cycle, including costs associated with environmental and social responsibility actions, be taken into account.

In a specific mining situation, the term *cut-off grade* applies to the grade value used by the mine as the decision criteria for the classification of a mining block as ore or as waste. This value could be equal to or greater than the break-even cut-off grade.

The choice of the cut-off grade influences the profitability and the life of the mine, two key aspects of sustainability. Depending on the planning objectives, various cut-off grade concepts are applicable:

- A long-term planning design cut-off is required for the design of the ultimate pit outline. In this case, the cut-off grade is defined as the lowest grade of a mining block that can pay for its mining and processing, the mining of the incremental waste blocks associated with it, and all other applicable costs.
- An operational—short-term—cut-off grade is used to decide whether a mining block at the face should be sent to the mill or to the mine dumps. In this case, the cut-off grade is defined as the lowest block grade that can pay for the difference in cost between each alternative.

When the cut-off grade is used for preliminary evaluations during the exploration and feasibility stages, where reserves have not been proven in significant quantity, approximate cut-off grades are determined from cost information obtained from similar projects.

Equivalent Grade for Multielement Ores

When the orebody contains more than one element of economic value, the value of the block can be referred to an equivalent grade of the principal element (the element bearing the maximum value).

The concept of *equivalent grade* is frequently applied to resource calculations in polymetallic orebodies, where several elements are present, some payable (Cu, Zn, Pb, etc.) and others penalizable (As, Sb, etc.), where one of the elements bears most of the block value (principal element) and the rest are by-products.

Equivalent grade is then defined as the grade of the principal element that alone would account for the total net value of the block. By using this concept, the economic value of the block is represented by a single grade value.

The equivalent grade is calculated as the sum product of the grades of the elements and the relative unit value factors. Relative unit value factors for each element are estimated as the ratio of the unit value of the element (positive or negative) and the unit value of the principal element. Obviously, the unit value factor of the principal element is the unity.

$$E_1^{eq} = E_1 + E_2\frac{u_2}{u_1} + E_3\frac{u_3}{u_1} + \ldots \qquad \text{(EQ 9.1)}$$

The calculation shown in Equation 9.1 should take into account the effects of the metallurgical recovery and other factors that might affect the net unit value of the elements. In fact, any aspects that can have a differential effect on each element must be considered, such as

- The mill feed mix that might be required to optimize the metallurgical process—metal recovery and concentrate grade—of each element;
- The effects on plant performance related to the variation of plant feed grades and different elements;
- The variations in element recovery as a function of its grade in the mill feed ore;
- The proportions in which each element reports to the different concentrate products obtained; and
- The concentrate sales contract of each concentrate product and the penalties applied.

Another approach is to reduce grades of by-products in proportion to the actual payable metal content (payable recovery) after all metal losses, smelter charges, and penalties, thus calculating the metal content equivalent to the income received.

Use of Information Systems and Mine Planning Software

Integrated mine planning software can be used to process and evaluate iterations of geologic interpretation and geostatistical routines efficiently, optimize mine layouts to identify major expansions and mid-life development (such as moving to a new mining district, a major pit pushback, new refuse dumps, and new shafts or access), and essentially evaluate all alternatives and identify the most cost-effective mine plan.

Specific optimization tasks include interrogating the geologic data set with all modules of geostatistics, searching for the best estimating method for ore grade block values. Iterations of the mine layout are done to minimize development time to reach the production phase of mining. Such planning can sustain mining when the mineral price increases, thus lowering cut-off grade. This phenomenon occurs frequently in tabular and lenticular reserves such as coal, trona, potash, and limestone. The planning process can identify the cost of leaving conveyors and infrastructure in place, and when economics would dictate that the equipment be removed. The goal is for the mine planners to become intimately familiar with the deposit—to mine the reserve on paper. Such hands-on familiarity will always lower the mining cost per unit during execution.

Most commercial mine planning packages include mine design modules for open-pit and underground mining. Open-pit design modules use dynamic programming algorithms such as those of Lerchs and Grossman for the optimum design of ultimate pit limits and pit pushback stages, pit smoothing, and road design. Underground mine planning modules use solid modeling as a planning tool, where drifts, raises, ramps, shafts, pillars, and stopes are represented as "solids" that constitute the unit planning blocks.

Integrated software packages are powerful tools for efficient, interactive evaluation of different production plans and schedules and mining scenarios. Though the plans being compared might not necessarily be optimal, the capacity for easy and fast generation and evaluation of many different mining scenarios by experienced planning engineers yields optimum results.

Sustainable Management Issues

Control is an essential management function. Sustainable management should focus on the control of those operational aspects that are most critical for sustainability. Some of these key aspects are discussed in the following paragraphs.

Grade Control Quality Indicators

An overall quality indicator is obtained by comparing tonnage and grade estimates and actual mill feed values. If the difference on a monthly basis is less than 10%, grade control quality might be considered acceptable. Here are some other quality assurance indicators:

- Control of the grade control sample preparation system
- Control of possible systematic errors of the sample assay laboratory by repeating 5% to 10% of the sample assays using an external laboratory and performing statistical analysis of variance and trends on a monthly basis
- Monthly reports on reconciliation of grade control, ore stockpiles, and mill feed

Reconciliation of Mine and Plant Production Statistics

Reconciling mine and plant production records is an important quality assurance process, but in some cases, attempting it causes confrontations between the mine and plant superintendents and produces no practical results. This always happens when management lacks a formal reconciliation standard defining the procedure and the steps to be followed.

The mine–plant reconciliation process aims to reconcile the following three production statistics:

- The year-to-date tonnage and grade of the run-of-mine (ROM) ore estimated by the annual mining plan;
- The actual tonnage and grade fed to the plant as calculated by the grade control process; and
- The year-to-date metallurgical balance, which gives the actual tons and grades treated by the plant, as measured at the mill feed weight meter and online sampling.

The analysis of deviations among the three data sets is an important part of the continuing improvement process. The following is suggested as a general approach to this process:

1. Estimate the volumes of ore mined precisely.
2. Estimate dilution for each bench or mining zone separately.
3. Develop a ROM ore sampling method allowing for a good estimate of ROM tonnage and grade.
4. Install and maintain a reliable online sampling system for the mill, with automatic samplers for mill feed and tailings and, possibly, at the head and tail of each plant process line.
5. Issue a monthly mine–plant reconciliation report, showing deviations and trends.

The most important aspects of the reconciliation process are ore grades and metal content in the mine, the mill, and the concentrates and products sold. In this regard, it is important to consult with experts in the areas of sample preparation and quality control.

Management of Ore Stockpiles

Mining operations use ore stockpiles for flexibility and better control of the process. Here are some examples of ore stock:

- Stocks of ore by grade: Used to optimize mill feed grade by mixing ore from different stockpiles.
- Stocks of ore by grindability: Seldom used but would optimize grinding capacity and increase recovery when grindability of ore is very variable.
- Stocks of ore causing process problems or smelter penalties: Used to blend this ore with normal ore in a controlled proportion, so that the process is not affected negatively, or to keep the undesirable element below the penalty grade.
- Marginal ore dumps: For temporary stock of ore below the operational cut-off, but having the potential to become economic in the foreseeable future.

Here are some important considerations on stock management:

- Ore stockpiles use large land surfaces and might contain reactive elements, which could cause environmental risks. Therefore, the stockpile should be properly designed and engineered to protect the environment from any potential risk. Measures such as impermeable liners and drainage systems are often necessary.
- When reconciling tonnages in large stockpiles, it is recommended to implement the means (topographic surveys and dump statistics) to measure the in-situ density (swell factor) so that precise volume and tonnage calculations can be performed at any time in the future.
- Also consider the progressive oxidation of ore, which will affect metallurgical recovery when the ore is processed.

A more detailed description of the grade control functions and processes is presented in the "Case Study: Grade Control Systems at El Valle-Boinás Mine" section.

Information Management Systems

Sustainable mine planning requires using the capabilities of modern integrated information management systems and mine planning software to optimize the mine plan. This software gives planning engineers the capacity to manage and process information, analyze different mining scenarios, and react to operational changes and take advantage of all possible opportunities. Most commercial mine planning software includes a drill-hole database, block modeling, pit optimization algorithms, long-term planning applications, production scheduling, and grade control.

Orebody block modeling and associated databases are powerful tools for sustainable management because they organize a variety of important types of data:

- Geological data: Stratigraphy and petrology data is necessary for the characterization of different types of waste low-grade material and its allocation to mine waste dumps. It is also important for metallurgical studies, mill management, and so forth.
- Geotechnical data: This includes characterization of the strength of the block rock, rock quality designation, joint type and direction, and other data required for mine design, grade control, ground control, blast design, and vibration control.

- Groundwater parameters: This information includes the water table, permeability rates, and water quality and its evolution during the mine life cycle.
- Land management: Terrain models covering the mine site and hosting communities can be used as a tool for sustainable management throughout the entire mine life cycle. They include land uses, surface water quality control, soil quality control, land reclamation, and so forth.
- Sales contract management: Block databases including the multielement assays of the ore for contaminants, penalty/bonus elements (e.g., As, Sb, Hg, Bi, Se), are useful in the sales planning and control processes for contract management.
- Environmental risk assessment: Block model data is also useful in the advance assessment of potential environmental risks associated with certain contaminants.
- Operational performance data: ROM ore grades and dilution, metallurgical recovery, operating cost and performance, and other operational variables can be correlated to ore type, rock types, geology, structure, and so forth. The storage of these variables in the block model is important for continuous improvement of operations.

Regarding ore grade control, the use of information systems is essential. Production must comply with plant feed requirements, and the grade control function must be performed as quickly and efficiently as required. Therefore, the grade control function must be equipped with the data processing equipment and software systems required for timely definition of ore–waste boundaries.

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ROCK FRAGMENTATION BY BLASTING*

Rock fragmentation is the first stage of production of mining operations. All construction and development stages such as removal of overburden, shaft sinking, excavations of accesses to the orebody (adits, inclines, raises, etc.) require breakage of the rock material into sizes that the next unit of operation can handle. The efficiency and success of other units of operations (e.g., loading and hauling, crushing, and grinding) following fragmentation depend on the effectiveness of rock fragmentation. Fragmentation can be achieved by means of mechanical breakage or the use of explosives.

Rock blasting is the most efficient technique for fragmentation, specifically when large volumes of rock must be fragmented over a short period of time. However, the process of rock fragmentation has several undesirable side effects that require major attention. These issues are discussed in the following sections.

Economics of Rock Fragmentation

Economical and effective rock blasting requires knowledge and experience in terms of design of a blast round. However, strict compliance with safety and security, environmental standards, effects on nearby structures and residences, and induced damage to the remaining land boundaries of the excavation (tunnel perimeters, pit slopes, benches, etc.) add additional complexities to the blasting operations. The blasting engineer and the mine manager must be fully aware of

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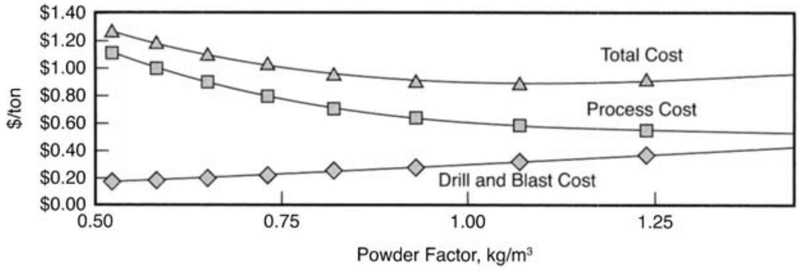
* This section was written by B. Cebrian.



Source: Eloranta & Associates 1999

FIGURE 9.1 Mine-to-mill approach for optimum mining–milling comminution cost

the consequences of these side effects in order to prevent authorities, associations, or groups of individuals from inquiring and attempting to shut down these operations. In other words, blasting operations could become a social problem and will affect and reduce the sustainability of mining operations.

Mechanical excavation has been used extensively in tunneling (tunnel boring machines, soft ground tunneling machines, etc.), shaft sinking, raise boring, and production of soft ores such as coal, potash, salt, and so forth. These excavation tools are very effective and generate a minimum of undesirable side effects. However, rock fragmentation using explosives is still the most effective and economic choice in large operations where mechanical excavation is no longer feasible.

Rock Breakage with Explosives

Drilling and blasting is a mechanical, repetitive operation. Regardless of this, it requires taking a series of key aspects into account, because there can be dramatic short- and long-term effects on safety, economy, production rates, mine stability, and ore recovery as a result of improper blasting techniques and management.

First, blasting must not be considered as an isolated operation in the chain of production in a mine. Because blasting is the first step of excavation, right before the loading-hauling and comminution processes, proper blasting can benefit these units of operation by fragmenting rock efficiently and uniformly within an appropriate size distribution suited to the material-handling equipment. Therefore, an optimum fragment size range must be obtained in order to minimize the handling and crushing costs. The consideration of the incidence of proper blasting in the overall process is known as the mine-to-mill approach and is currently at the leading edge of hard-rock mining management concepts. Figure 9.1 illustrates the unit operating cost of drilling and blasting as well as material handling as a function of powder factor (i.e., explosive weight or energy per unit weight of blasted rock). It must be noted that as the powder factor increases, the resultant fragmentation will increase. This in turn will reduce the cost of loading, hauling, and crushing of the ore, mainly at the primary crusher. However, at the same time, the cost of drilling and blasting at a higher powder factor or degree of fragmentation will increase. As Figure 9.1 shows, there is an optimum powder factor or fragment size where the total cost is at minimum.[1]

Achieving this optimum fragment size requires significant knowledge of many factors and parameters that control the outcome of a blast design. These factors can be divided into three categories:

- Geology: Geological conditions of the rock mass to be blasted play an important role in the behavior of the rock when blasted. Important parameters are hardness of the intact rock and natural fractures and weakness planes.
- Explosives: Explosive properties must be taken into consideration very carefully. The type of explosive(s) must be suited to and compatible with the site conditions.
- Blast design parameters: These parameters are blasthole diameter and length, spacing and the pattern of blastholes, amount of charge per blasthole, and timing and sequence of initiation of each hole.

All of these parameters are interrelated and must be taken into consideration when designing a blasting operation. The operators must also be aware that the results of a blast are site specific, so close observation and some testing might be required. Details of the blast design are not within the goals and the objectives of this book and will not be discussed here. However, management must be sure that the blasting crew and the design team understand the connection between the blasting operation and the downstream operation. The manager is responsible for interaction and coordination between drilling and blasting and mine planning, production, and processing departments. Planning and scheduling of blasting must be set in such a way that there is always sufficient blasted rock available to maintain the peak design production without any delays.

Blasting quality depends on many factors (e.g., drilling, explosive type and quality, firing sequence), but proper drilling and explosive quality are probably the two most critical for good blasting results. If drilling is not accurate, well designed, and properly implemented, blast efficiency and costs will be greatly affected. This is why drilling and blasting are usually organized under the same supervisor.

A drilling and blasting engineer needs to coordinate with the planning department and the load–haul staff on a short- and medium-term basis. This allows for a well-scheduled drilling (drill rig movement along the mine, maintenance, meters drilled rate predictions) and blasting (explosives provisions, blasting crew, and explosives-loading trucks) process.

Mechanical Excavation

Because of the lower cost and higher efficiency of using explosives to break the rock material, drilling and blasting seems to be a method that will be widely used well into the future. It will continue be so as long as no new digging machinery technologies are developed that are capable of high-rate, low-cost production in excavating intact hard-rock masses. Mechanical excavation is more effective and economical than blasting when conditions are suitable. This method of rock breakage can be applied in most civil projects and some development sections in underground mining. Furthermore, mechanical excavation techniques do not cause the social and environmental problems associated with blasting, which can create major issues when blasting operations are conducted near populated areas. These issues are discussed in later sections. However, when large volumes of rock need to be broken, such as in mining operations, blasting is the most feasible and effective fragmentation method.

Sustainable Management Issues

The importance of achieving an optimum fragmentation was discussed in the preceding paragraphs, but the side effects of blasting must not be overlooked. Blasting can have a severe impact on the surroundings if the designers concentrate only on the fragmentation and primary cost of blasting. With the increase in population, residential communities are expanding into rural areas and encroaching on mining sites. As the vicinity of mining areas becomes populated, the problems associated with blasting will become more and more severe. The mine operators must pay close attention to the impacts of blasting on these residential communities. These impacts could range anywhere from structural damage to health problems and annoyance among residents. Litigation and paying for the damages can become very costly, and it can result in the complete shutdown of the operations. Controlling these problems will add challenges and complexity to the design of a blast round. Various impacts of blasting operation and problems that must be taken into serious consideration are summarized in the following paragraphs.

Ground Vibrations

Blast-induced ground vibration is the main problem when there are residential and other structures in the vicinity of the blasting area. These problems can range anywhere from major structural damage for extreme cases down to annoyance and disturbance of humans and animals where the vibration levels are within their perceptions. If these issues are not properly handled, the operators might have to deal with major complaints and costly litigation, and the outcome might be a complete shutdown of operations.

The level of ground vibration at any point depends on the amount of charge per delay, distance, sequential timing of each blasthole, the frequency of ground vibration, confinement of the charge, type of explosive, and geology of the site. All these parameters, as well as the safe limits set by the regulations (if any) or the level that is acceptable to the neighbors, must be taken into consideration when designing a blast round. A survey of nearby homes and structures that might be susceptible to damage must be performed prior to the start of blasting operations. The purpose of this survey is to establish the condition of the structures and pre-existing cracks and damages. A third-party consultant should be used to perform the preblast survey. Monitoring of ground vibration at the most sensitive structures must be performed as well. It is also recommended that additional measurements at various distances to be made in order to establish the site-specific ground vibration and wave transmission. This will allow the designers and operators to make predictions of what vibration levels can be expected for future designs. Again, it is a good practice to use a third-party consultant to perform the monitoring.

Timing of the blast is another important factor that affects the response of people to ground vibration. Blasting should be done during the time of day when people are most active and the ambient noise is high. This will reduce the level of perception and annoyance.

Keeping records of all blasting, such as design parameters (charge diameter, length of blasthole, weight of charge in each hole, initiation system used, spacing of blastholes, delay timing, and pattern) with a drawing, time of blast, and all the measured vibration levels is very critical and important.

Airblast

An airblast is the result of overpressure, low-frequency compressional waves traveling through the air. Airblasts are generated in addition to ground vibrations when blasting. The main causes of airblast, as with ground vibration, are improper blast design and blasting practices. Airblasts are generated when explosive gases are suddenly released into the atmosphere. Another main cause is the high-velocity movement of the rock face at the instant of detonation of the charges. Factors that affect the airblast include maximum charge per delay, delay timing and direction, depth of charge, exposed charges, temperature gradients, wind speed and direction, topography, and atmospheric conditions.

Damage from airblasts from blasting is very unusual and rare. The most notable damage is broken windows. However, airblast could become the main cause for complaints if the levels of air overpressure are high. Studies have shown that there are no health or psychological hazards to humans due to airblast from blasting.

Airblast could become a problem in underground mining as well. Excessive overpressure could be hazardous and could cause damage to underground structures and ventilation control devices, such as doors and regulators.

Flyrock

Flyrock is the main cause of injury in blasting. Flyrock is classified as uncontrolled fragments of rock reaching great distances and outside the perimeter of the blasted area or the mine. It can consist of different sizes, from a few centimeters to sizes larger than boulders. Flyrock can also damage homes, structures, and equipment.

The main causes of flyrock are excessive amounts of explosive, too much or too little burden, an insufficient amount of or ineffective stemming, the presence of voids and weak structures or formations in the close vicinity of blastholes, and poor delay patterns and timing.

Fumes

Detonation of explosives generates large quantities of gases. These gases play an important role in fragmentation and placement of the blasted rock. Under ideal conditions, gases primarily consist of carbon dioxide, nitrogen, and water. However, other products can be generated, including poisonous gases such as carbon monoxide and nitrogen oxides (NOx), which could cause health concerns. These fumes are not usually a major concern in surface blasting if they can be dispersed by wind or movement of air. If those in charge of detonations anticipate that excessive fumes will be generated, the direction of the wind must be taken into consideration if it is likely to blow toward residential areas and communities. In underground mining or blasting in general, fumes can be a serious problem, and proper ventilation and suppression of these gases is required. Explosives that generate excessive fumes must be avoided.

There are a variety of causes for the formation of excessive poisonous gases: poor explosive mixture or formulation (non-oxygen-balanced), contact with water when non-water-resistant blasting agents are used, poor initiation, and anything that can cause poor and incomplete reaction of the explosive. It must be noted that formation of these gases as the result of poor or incomplete detonation of explosive is accompanied by low energy and therefore ineffective breakage.

Dust

Dust is classified as fine particles that can remain suspended in the air for a long period of time. Blasting can generate large quantities of dust. Dust can become a health issue, particularly if it consists of material that can be toxic. The generation of dust depends on the material being blasted and the blast design parameters (too much explosive, poor timing, not enough stemming or confinement, etc.). Just as is the case with fumes, wind direction at the time of blasting must be taken into consideration if excessive dust is expected and there are nearby residential or other populated areas.

Safety in Blasting Operations

As the result of extensive research and development in explosive material and devices, the safety records in blasting have improved significantly over the years. However, a small accident or incident in blasting can and will result in a catastrophe or loss of life or limb. Such accidents could very easily result in loss of production and possible shutdown of the operation. It is the responsibility of the management to make sure that safe and approved blasting practices are followed. The main health-related risks associated with blasting operations are described briefly in the following paragraphs.

Flyrock. Flyrock is the main cause of injuries in blasting. The causes of flyrock were discussed in previous paragraphs. A minimum safe distance of 800 m should be maintained when large-diameter blastholes are used. This minimum distance refers to a flat, even surface and it should be considered as an initial cautionary measure. In this sense, any incident of flyrock falling near control points or outside of the estimated safety area is a warning sign and an indication of the need to review procedures and safety distances.

Misfires. A charge or portion of a charge that has not detonated is classified as a *misfire.* A misfire is the most dangerous situation in blasting and must be treated with the maximum level of care and caution. Misfires can be the result of *cut-offs* in the initiation lines (electric wires, detonating cords, nonelectric lines, etc.), poor connections or discontinuous lines between charges, defective initiators or explosives, or insufficient current when electric blasting is used. Causes of cut-offs include the explosion from the previous hole breaking into the next hole, shifting of ground and cutting the lines, and the impact of flyrock on surface initiation lines. An unexploded and unidentified charge can be impacted by the loading equipment or any other type of equipment, which can very easily detonate the charge. The explosive charge with the primer can be carried to the processing plant and cause a serious incident at the plant.

Misfires must be avoided at all costs. The continuity of connecting lines must be checked prior to blasting. Usage of proper timing and initiation systems can reduce the risk of misfires. Old and deteriorated explosive material should not be used. After each blast, the blasted area must be inspected for misfires. Only authorized and trained personnel must enter the area, and, in the event of a misfire, they are the only individuals who should handle the problem.

Several techniques and procedures can be used to remove and eliminate the dangers of misfires. If there are regulations regarding the handling of misfires, they must be followed. A sufficient time interval must be allowed before taking any action to remove the misfire. The unexploded charge or charges must be identified first. Any exposed remnants of unexploded charge can be removed very carefully. In the case of ammonium nitrate/fuel oil, it can be simply washed out with a water hose. Drilling and firing a hole charged with small amount of explosive near the unexploded hole can cause either sympathetic detonation or expose the unexploded charge.

It is the responsibility of the management to make sure that well-trained and qualified individuals are in charge of the blasting operation and handling misfires. The managers must also make sure that all the regulations and required procedures are followed.

Improper handling, storage, and transportation of explosives. Improper handling, storage, and transportation of explosives and initiation devices can lead to catastrophic accidents. All laws and regulations regarding handling, storage, and transporting explosives and initiation devices must be understood and followed.

Storms, static electricity, or mechanical stress on explosives/detonators. Electric storms, static electricity, and mechanical stress such as impact can result in premature and uncontrolled detonation of explosives. These problems can be eliminated if all the procedures and regulations for handling and usage of explosives are followed. Therefore, only qualified and trained personnel must be in charge of handling and transporting the explosives and other explosive devices.

In general, the occurrence of accidents is usually low, but consequences are often fatal (risk = probability × consequence). Only trained and supervised personnel should be involved with the handling of explosives. Procedures should include external auditing of safe practices, because routine sometimes hides real danger or threats. Incorrect, unsafe practices can commonly become routine in blasting without crews being aware of the specific dangers into which they are falling. Communication between operators and mine access control points/crew should be clear.

All procedures must be commonly and explicitly understood, with no dead points at which no communications are possible.

Blasting in Populated Areas: A Case Study of La Araña Cement Quarry

The Financiera y Minera quarry provides limestone to the Italcementi Group cement plant in Malaga (Spain). This operation is located in an urban environment that has experienced great expansion due to its coastal location. Decades ago, when the cement plant and quarry were established, that was not the situation, but a highway and several communities and beach resorts currently surround the site.

Years ago, the blasting operations used electrical detonators along with detonating cord on the surface. As the mining operations became larger and got closer to the surrounding communities, concerns grew regarding the impact of blasting operations. The existing blasting practice was causing airblast and ground vibrations at levels that became a major concern. The vibrations due to operations in the vicinity of the residential structures were reaching a level that needed attention. Although the majority of vibration levels were within the legal limits, they were high enough to be perceptible and very noticeable by people. As better and safer initiation system technology (nonelectric) appeared on the market, management at the plant decided to study new ways to approach rock blasting. The first measure taken was to contract with a responsible and experienced blasting team that would take major steps to protect the communities surrounding the cement plant. The new blasting contractors started a completely new blasting procedure, consisting of accurate drilling, a nonelectric detonating system (eliminating the detonating cord), proper stemming, and continuous recording of vibration levels.

More detailed site-related studies were done to understand vibrations at the Financiera y Minera quarry. In June 2007, an on-site vibration analysis was performed to establish the specific characteristics of the rock mass in different directions toward the sensitive areas. Also, a complex shooting sequence plan was studied to analyze possible destructive interference of that rock mass, which could help reduce overlapping of ground waves. It has to be noted that, although PPV (peak particle velocity) values are well below the legal limits, human sensitivity to vibration and preventing complaints were reasons enough for the mining company's management to implement a continuous monitoring and vibration reduction program, along with explaining and communicating with community representatives and the most affected individuals.

In a further step, to combine vibration level reduction with acceptable fragmentation on the rock pile, a different set of drilling grids and use of gas bags (to reduce the amount of explosives used) were tested in a series of blasts. Although these tests proved useful in fragmentation analysis terms, those blast designs showed no clear benefit from the vibration perspective.

Finally, results from double-decking (dividing the explosive charge in the holes) blasting showed potential for keeping vibrations low and around the 1-mm/s level (Figure 9.2), which is below the level of human sensitivity (down to 2 mm/s). Also, electronic detonators provided useful information on tailored sequencing of the blast at different areas of the quarry. Figure 9.2 shows the progressive changes in vibration levels as different designs were used. It is clear that the vibration levels are reduced when double-decking loading is used. This procedure can increase the cost of blasting, but the benefits will recover these costs. The benefits include better fragmentation and therefore a lower cost of material handling and crushing. Other major benefits include reduction of complaints and legal battles, as well as harmony between the operation and the community, which is a very important factor in sustainability.

As shown in Figure 9.2, the average values of PPV in millimeters per second at the quarry increase over time. Values greater than 2 mm/s are darkly shaded (1% chance of complaints

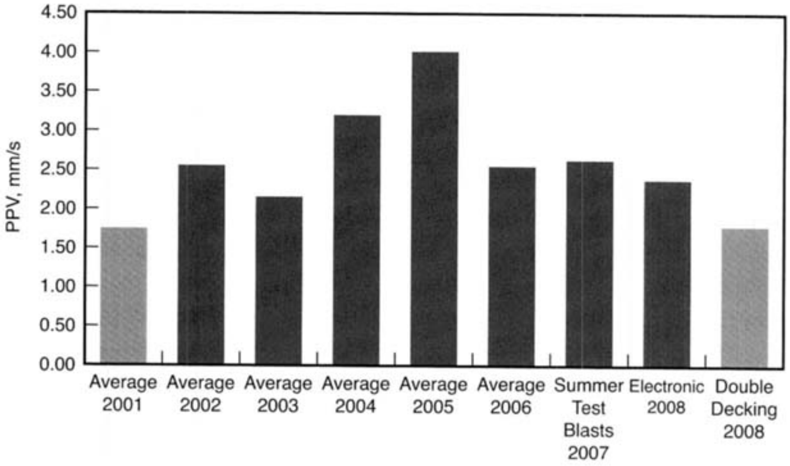


FIGURE 9.2 Evolution of average annual PPV values at Financiera y Minera quarry

according to John Floyd[2]) and values less than that level lightly shaded. In the summer of 2007, specific designs reflect four test blasts for both an increase in fragmentation and a decrease of vibration. Two electronically sequenced blasts have been recorded and processed as this book was written, with an average of 2.37 mm/s. Two double-deck blasts have been fired, but only one offered a valid value of 1.77 mm/s at the same control point; there was no reading on the seismograph in the other blast. More test blasts are being performed as this book is being written in order to obtain a valid average value for both systems.

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LOADING AND HAULING

Loading and hauling represents a major part of material handling in the mining industry. After processing, loading and hauling is the most energy-intensive process and therefore is accountable for the second highest operating cost. The success and sustainability of a mining operation is heavily dependent on the overall efficiency and productivity of the loading and hauling system. It is the responsibility of the designers and planners to make sure the loading and hauling operation meets the production requirements and goals safely, economically, and effectively. It is then the responsibility of the managers and operators to perform the tasks according to the designs and implement all the required steps in order to meet the production goals. The hauling and loading system or equipment is integrated into all other units of operation, as well as the design of various components of the mine. Therefore, the system must be compatible with all other units of operation in the mine.

Equipment Selection Procedure

The equipment selection process is a difficult and complex task. There are a large number of suppliers and equipment types, and the technology changes rapidly. The equipment to be used will be dictated primarily by the mining plan and production goals.

An evaluation must be made of all of the heavy equipment related to price, availability, product support, local vendor capabilities, and so forth. Product support is very important in the selection of any equipment. This will dictate the maintenance staffing requirements, as well as capital expenditures on such things as shops and tools. Some local vendors supply very little support; others provide very significant support in both parts and supply availability, as well as supplying contract maintenance personnel and off-site component rebuild. Availability of parts and supplies in remote areas is a major concern. An evaluation must be made regarding delivery of parts and supplies to the mining operation, which might include use of the product transportation systems such as railroads, trucking, and so forth.

One of the main supply items of any mining operation is the source of fuel and lubricants. Care must be taken to evaluate all possible suppliers, looking at price and supply capabilities. There are a variety of sources of information for equipment selection:

- Personal experience
- Trade magazines
- Technical literature
- Trade expositions and conferences
- Talking to other users
- Visiting similar operations
- Visiting and contacting other operations in the area

Several alternatives are possible when selecting a piece of equipment:

- Make it: It is possible to manufacture some pieces of equipment in-house. The advantage of this is that the costs could be lower and it might be the only alternative when certain equipment is not otherwise available. The problem with this alternative is that it requires manufacturing facilities and skilled machinists and workers. Some replacement parts can be built in-house, which could reduce costs without major requirements in terms of facilities.
- Buy it new: New individual pieces of equipment or a fleet of equipment can cost much more than used equipment. However, new equipment can be expected to have much higher reliability, efficiency, productivity, and lower operating costs than used equipment. A simple economic analysis over the life of the operation or the equipment can determine the economic advantage of new versus used equipment.
- Buy it used: Buying used equipment can be a viable alternative to new equipment. Used equipment might cost less to purchase, but it will not have the same productivity as new equipment and it will have higher operating and maintenance costs. Again, a simple economic analysis can determine the advantage of used versus new.
- Lease it: Leasing equipment can be considered as an alternative to purchasing. Generally, large machinery with a long expected life and use will not be economical to lease. Leasing can be advantageous for fleets of small vehicles for general-purpose uses.

Important Factors That Affect the Productivity of Hauling and Loading Equipment

The selection and operation of mining equipment or a fleet of equipment depends on production scheduling and mining plans. It is useful to understand the definitions of some terms and factors that play an important role in performance and therefore in the selection and design of a hauling and loading system. Kennedy[3] has defined these factors, which are summarized in the following paragraphs.

Time Frame

During the feasibility study and mine evaluation, all data and estimates are based on a 1-year time frame. Economic analyses are always on an annual basis. Whether the analyses are for short-term or long-term planning, the costs and production rates are projected over a number of years or for the entire life of the project. The life of a mine depends on the reserves and the level of daily production designed, which must be determined very carefully.

Operations Scheduling

Operations scheduling relates to the number of annual hours of scheduled operation. The importance of establishing this at the early stages is that it controls the output of the material-handling equipment over 1 year. Most very large mines are scheduled to operate 365 days a year, three shifts per day. Not all sections or operations are scheduled to work 7 days per week and three shifts per day. For example, sections such as the administrative, engineering, and technical group might work only 40 hours per week on day shifts only. Drilling and blasting operations might be scheduled differently as well. It is not common to drill and blast at times other than the day shift, and blasting during the weekends is limited as well. Most heavy maintenance functions are performed on day shifts. Some mines can plan a total shutdown for legal holidays and so forth.

Overall Job Efficiency Factor

Overall job efficiency refers to the percentage of time that a machine or a system will operate at its peak output while in service in the mine. This can be evaluated as an hourly factor and it is an average number of minutes per hour. The loss of efficiency is due to the delays that occur during the scheduled operating hour. Causes of delays or downtime during the hour include the following: fueling and servicing of equipment; recess and lunch time, if lunch must come out of an 8-hour shift; poor coordination of different components of a system (e.g., shovels and trucks); and crowding at the loading, dumping, transferring, or exchange points. This factor is mainly controlled by the planning and management of the operation and the coordination of various groups or sets of unit of operations that work in series or parallel.

Mechanical Availability Factor

Much like the job efficiency factor, mechanical availability is the percentage of time that a piece of equipment is ready and available to perform work. Loss of mechanical availability refers to time when the machine is completely out of operation as a result of breakdown during the period when it is scheduled to work. This downtime should not be confused with the loss of time due to lack of job efficiency. A machine could be 100% available but not scheduled to work. This available time should not be included as part of the mechanical availability. The equipment manufacturers tend to overestimate the mechanical availability of their products. It is a good practice to determine the actual availability factor for each machine during the operations. Equipment downtime could be due to a variety of factors: mechanical conditions, operating conditions, the skill of the operator, the quality of the equipment, the complexity of the machine or the system, and most importantly, the maintenance program at the operation. The mechanical availability factor is used to determine the number of back-up machines needed to maintain the designed production rates. For example, if 10 trucks are needed to perform a task (with the efficiency factor taken into consideration), a mechanical availability of 80% requires a total of 13 trucks in the fleet (10/0.80).

This is where the maintenance program plays an important role in the productivity of the operation (see the "Maintenance Management" section). A good maintenance program will increase the availability of the equipment. It must be noted that the cost of increased maintenance must be taken into consideration when evaluating the economics. The additional cost of maintenance could exceed the savings from a higher availability factor. In the example outlined in the preceding paragraph, if the availability factor is increased to 90%, the total number of trucks needed in the fleet will be 11. This could be a major savings in the capital costs for the fleet. Although equipment manufacturers tend to overestimate this number, the overall number for all machinery in surface mining is about 85%.

When calculating the total operating cost, the time that the machine is down as a result of mechanical failure should not be included. This is not part of the costing hour where the machine is on the job. The lost time due to lack of 100% efficiency should be included as part of the costing hour because the machine is at the site operating but not producing.

Annual Outage Factor

The annual outage factor refers to the total time, on average, that is lost as a result of complete loss of production at the mine in a year. This total stoppage could be the result of (1) bad weather conditions, such as a heavy snowfall or flash floods that cause water to build up in the pit and block roads; (2) loss of electric power due electrical storms and snowstorms knocking out transmission lines and substations; (3) moving large units of equipment; (4) slides in the mine; and (5) external causes, such as breakdowns in the transportation systems, strikes in some other segments of the industry, and local labor disturbances. This factor will have an effect on the entire operation, not just the loading and hauling equipment. With no available data, a factor of 95% can be used, meaning that the operations will be delayed 5% of the scheduled time. A higher value can be used in areas with mild climates where natural effects are small and limited.

Production Utilization

Production utilization can be considered as the product of all the other factors discussed previously (equal to job efficiency × mechanical availability × annual outage factor).

It must be noted that in all operations, achieving 100% efficiency from a machine or a system is not possible. A machine might be operating at 100% efficiency for a short time but, on average, over an hour, shift, day, or month, the amount or percentage of useful work from the machine could be much lower. All the factors described previously must be applied to the peak output of the machine in order to determine the actual production rate of the equipment. During a feasibility study, these factors are not known because the study is concerned with an operation that does not yet exist. Therefore, no productivity data is available. The engineer must make assumptions and use judgment and experience with similar operations and equipment to determine these factors. However, these factors must be reevaluated during the operation so that a more accurate estimate is available for future equipment purchases and the updating of mine planning.

During both planning and operation, there are a number of goals related to equipment:

- To keep as many units working efficiently as possible;
- To have minimum equipment doing the job in an assigned period of time; and

- To achieve the first two goals with high probability, at a constant production flow within the scheduled time.

Equipment Selection Criteria

Before the start of the equipment selection process, a set of criteria must be developed. These criteria might be unique to the operation and can vary from operation to operation. The following general questions should be considered during equipment selection:

- Does it fit into the entire operation and other handling systems?
- Does it help to optimize material flow with maximum output and minimum cost?
- Can it operate continuously with minimum interruptions?
- Is it as simple as is practical? It's advisable to avoid complex systems.
- Is it capable of utilizing its maximum capacity?
- Does it use a minimum of operator time or labor?
- Does it utilize gravity wherever possible, depending on the mining system?
- Does it require a minimum of space?
- Does it handle as large a load as is practical?
- Does it operate safely?
- Does it use the maximum level of mechanization and automation?
- Is it flexible and adaptable?
- Does it have a low deadweight-to-payload ratio?
- Does it require a minimum of loading and unloading time?
- Does it need little or no rehandling?
- Does it require as little maintenance, repair, power, and fuel as possible?
- Is it reliable and does it offer maximum availability?
- Will it have a long and useful life?
- Does it perform the handling operations efficiently and economically?

Degree of mechanization is very important in equipment selection. As the degree of mechanization increases, the unit operating cost decreases. However, an increase in mechanization results in an increase in capital cost and maintenance due to the complexity of the system. Therefore, the optimum level of mechanization must be used. An "ideal" piece of equipment is always available and working.

Equipment Selection Procedure

As mentioned previously, the loading and hauling equipment must be compatible with the mining system and meet the production goals. All the important factors and criteria, such as those in the preceding list, must be established and defined prior to the process of equipment selection. In general, the following procedures should be followed:

1. Relate all factors pertinent to the problem.
2. Determine the appropriate degree of mechanization.
3. Make a tentative selection of equipment type.
4. Narrow the choices.

5. Rank and evaluate the alternatives.
6. Check the selection for compatibility with the rest of the system.
7. Select the specific type of equipment.
8. Prepare specifications.
9. Procure the equipment.

Multicriteria/multifactor analysis can be used when several alternatives with a large set of factors and criteria are considered. This technique allows for a quantitative comparison by assigning a weighting to each criterion. A scoring scheme can be established so that each factor or criterion will receive a score. Then each score is multiplied by the weighting factor and the final total score is compared. Generally, the main controlling factors for alternatives are cost, standardization, and reliability. The use of computer programs (artificial intelligence) is very beneficial.

Basic Steps in Selection Process

The process of selecting a loading and hauling system involves the following steps:

1. Determine required production.
2. Determine reach or haul path.
3. Calculate cycle time.
4. Calculate capacity.
5. Repeat to improve productivity.
6. Calculate fleet size.
7. Repeat to reduce ownership and operating costs.

Sustainable Management Considerations

The sustainable management of the loading and hauling requires a management focus on efficiency and safety, with some environmental issues (e.g., dust control and air pollution) also requiring special attention.

Safe Working Conditions

A large loading and hauling unit can create a very dangerous working environment. However, through proper training and enforcing all the safety rules, it's easy to create safe working conditions. Attention must be paid to the design and placement of haulage roads. The minimum width and sight distance must be carefully designed and implemented. Keeping all material-handling units isolated as much as possible will significantly reduce workers' exposure to unsafe conditions. There are federal, state, and local laws and regulations, as well as those set by the companies, related to safe equipment operation. These laws and regulations are based on many years of experience, observations, studies, and experiments. Operators and managers must follow and enforce these laws and regulations. Accidents will result in loss of time, production, equipment, and, worst of all, loss of life and limb.

Environmental Issues

The main environmental concerns are those associated with equipment that uses internal combustion engines. This problem is mainly a concern in underground mines. Through proper ventilation and maintenance of the equipment, the problem can be eliminated or reduced. Use of electric power instead of internal combustion engines can completely eliminate this problem.

Dust generation from the haul roads can become a major health problem, as well as a safety problem, because excessive dust will reduce visibility. Well-maintained roads and continuous application of dust-suppressant reagents will minimize this problem.

Maintaining High Productivity

It is the responsibility of the chief operators and managers to ensure that the material-handling system can operate at its peak efficiency and utilization. State-of-the-art technology must be used in selecting and operating a fleet of equipment. However, the best available equipment might not work at its peak efficiency if the units are not compatible and scheduling of assignments is not done properly.

The overall efficiency of the material-handling system can be improved by implementing a good training program for the operators and proper scheduling and synchronization of all the units. The effect of skilled operators on the safety and performance of any equipment is obvious. Delays and bunching times at the loading or dumping sites, as well as crossing points, will increase the cycle time of the haul units and cause major reduction in overall job efficiency. Computer-controlled dispatch systems will solve this problem in a complex system. In many cases, mining operations have managed to increase their efficiency and productivity by more than 50% by introducing these dispatch systems. Automation can significantly improve the productivity because the human factors are either eliminated or reduced. However, such systems can become too complex and expensive.

Equipment that operates continuously, like conveyor belts, has higher productivity. This type of equipment must be considered and used where the conditions make it suitable. However, the complexity and the presence of large numbers of moving parts will reduce the reliability.

If several different material-handling systems are working continuously, the overall utilization of the whole system is the product of the utilization of each individual unit. In this case, if there are delays or a failure in one unit, the entire system will be delayed or stopped. Placement of storage, either in the form of stockpiles or bins, at the transfer or contact points will reduce or eliminate this problem.

GROUND CONTROL

Ground control is a major component of the design and operations of both surface and underground mines. The integrity and stability of all openings and excavations such as shafts, drifts, stopes, haulage tunnels, inclines and declines, benches, and slopes are extremely important in all mining operations. The costs associated with support requirements in underground mining could be extensive. It is always a major challenge for the designers to protect the openings while keeping the costs low. In surface mines, steepening the slopes can save a large amount of money by reducing the amount of waste to be mined. On the other hand, steeper slopes will increase the chance of a failure and could result in loss of life and serious damage to the property and the operation.

Ground control should be performed in parallel with the mining operation. It is an integral part of the planning and production. It is the responsibility of the management to understand the requirements, processes, and interaction of the ground control systems, as well as the basic theory. The management must ensure that all the ground control systems are implemented and installed according to the plans and designs with the highest level of quality control. Ground control can become very costly. With unlimited resources and funds, it is easy to provide a support system that never fails. However, in mining operations, the profit margins are very narrow and funds are limited. This makes the job of the engineer in charge very challenging. The engineer is forced to push all ground control systems and devices to their limits. The engineer in charge as well as the management should not allow safety to be compromised for profits.

Role of Ground Control in Mining

The role of ground control in mining is to establish a safe and stable working condition. The responsible geotechnical engineer must understand all aspects of the mining operation, such as production requirements, type of material-handling system used, mining method, ore control, drilling and blasting or any other means of excavation, associated costs, economics, and so forth. The engineer must also have a clear knowledge and understanding of the geology of the mine, as well as the shape and extent of the orebody. He/she must be well aware of the ground conditions as well as plans for future mine expansion. Ground control must work in parallel with operations and be able to interact without hindering or slowing down other mining activities. The engineer must also understand how the ground reacts as mining operations progress, and how the mining activities affect the implemented support systems. The main challenge is that each rock mass has unique properties. There is no single or standard solution to ground control problems guaranteed to produce certain and correct answers consistently. The engineer has to come up with a practical solution from the basic and limited geologic data available as he/she progresses through the design and planning process. The engineer has to know how to use and combine all the available tools to solve the problems associated with ground conditions that change constantly.

The role of ground control in mining is very different from the role it plays in civil engineering projects. Generally speaking, the safety factor used in the design of structures in a mine is much lower than what is used in civil-engineering-type structures. However, this is not because safety is less important in mining. This is where the ground control becomes challenging in mining. As mentioned previously, the profit margins are narrow in mining and the total mining costs must be kept to a minimum. The major difference between mining and civil structures is the useful and expected life of the structures and facilities. Basically, the life of a civil engineering project is very long—more than 10 years. In mining, only certain parts such as shafts, main haulage drifts, underground shops, and storage areas are considered to have long lives. These components are designed with a higher safety factor. However, structures like stopes and temporary accesses have short lives and they are not designed with a high safety factor. Again, the role of the ground control program is to keep the opening stable and safe for the duration of its use and life. One important aspect of a ground control system that designers must understand is that the role of the support system is to make the surrounding rock or material self-supporting, and it should utilize the rock as the principal supporting structure. Again, this must be achieved with as little disturbance as possible during the excavation and the usage of the structure.

The designers face the challenge of achieving an optimum design without compromising what is considered economically acceptable and safe.

Economic Consequences of Instability

Any type of collapse or failure in mining is costly in one form or another. Collapse of a section of a mine or the entire mine has severe consequences that are not acceptable. The monetary losses come from closure of access, loss of equipment, covering the exposed orebody with waste in case of slope failures, loss of haul roads, and so forth. For example, it will cost the company a lot of money to replace the lost equipment, to remove extra waste in order to expose the ore, to rebuild and reroute the haul road and accesses, and, in general, to employ all the remedial measures to recover the losses and fix the damage. In case of loss of life or limb, it is very challenging if not impossible to determine the cost of recovery in terms of dollars. Putting a dollar value on the loss of life or limb is a very difficult ethical issue with which to deal.

Implementation of ground control devices and systems can be costly and requires special attention. All the outcomes of the collapse must be assessed and the costs of both recovery and prevention must be evaluated. In many types of mining systems, the roof or the surrounding rock is allowed to collapse, or controlled and induced cave-ins are part of the mining method, such as in longwall mining, block caving, and sublevel caving. The effect of these closures and cave-ins must be assessed very carefully on the nearby structures and surface. Subsidence is a major issue when these techniques are used.

Failures and accidents could also have other negative effects that cannot be assigned a dollar value directly. Whenever there is an accident in which fatalities are involved, the negative publicity about mining operations will have an unconstructive and downbeat effect on the public. This can severely hurt the sustainability of the mining project.

The benefits of a good and successful ground control program are unlimited. Investing more money in the ground control program early can produce major cost savings in the future. Safe and stable openings also increase the recovery and therefore the income. For example, steepening the pit slopes on a large mine by a few degrees can save millions of dollars in terms of the cost of overburden removal or the same amount of income as a result of access to more ore. The cost of supporting and stabilizing underground openings and slopes depends on the level of safety that is required. What is considered to be safe depends on the application and usage of the structure. For example, Barton et al.[4] suggest the following categories of underground excavations based on the support requirements:

a. Temporary mine openings;

b. Vertical shafts;

c. Permanent mine openings, water tunnels for hydroelectric projects (excluding high-pressure penstocks), pilot tunnels, drifts, and headings for large excavations;

d. Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, and access tunnels in hydroelectric projects;

e. Underground power stations caverns, major road and railway tunnels, civil defense chambers, tunnel portals, and intersections;

f. Underground nuclear power stations, railway stations, sport and public facilities, underground factories.

As the categories move from *a* to *f*, the requirements for a high level of safety are increased. Note that the application, duration of usage, and importance of the categories increases from *a* to *f*. Consequently, the cost of support requirements and construction increases as well. For example, in case of category *a* (temporary mine openings), the outcome of a failure is not severe and the risks are acceptable. The probability of failure might be high, but the severity of a failure is low. Furthermore, in this particular situation, only trained and experienced individuals like miners are exposed and they are exposed for a limited time. On the other hand, this is not the case if you look at excavations that fall in category *e* or *f*. Again, in many mining situations, a safety factor of one or less has been used. A common case is in large open-pit mines where the slopes are designed and allowed to move. This is done by monitoring the slopes very carefully.

Modes of Failure

As in all engineering works, understanding and predicting the mode of failure is very crucial. Mode of failure dictates what type of support and remediation tool should be used.

Underground Mining

Underground openings are confined structures that are excavated through a rock mass. The behavior and response of a rock mass to any excavation or disturbance must be well understood and must be predictable. Hoek and Brown[5] categorize the modes of failure of underground structures as follows:

- Instability due to adverse structural geology: This is a potential mode of failure when the rock mass is faulted and contains a major set or sets of joints. Discrete blocks of rock form when these joints intersect. These blocks are potentially unstable when the excavation exposes them. They can either slide or fall freely into the opening. Sliding along a single dominant joint set is possible as well. The orientation of the dominant discontinuities with respect to the excavation plays an important role in instability of these blocks. The most effective support system for this condition is installation of rock bolts, resin dowels, and cables. If reorienting the excavation is possible, the stability can significantly be improved.
- Instability due to excessively high rock stress: Stress-induced instability occurs in the case when the rock is very weak or the ground pressure with respect to the strength of the rock mass is very high. This is the situation at great depths or at a shallow depth if large excavations are made. The result is formation of an overstressed zone around the opening. In this overstressed zone, the rock has failed and severe stability problems exist. Formation of the overstressed zone depends on the in-situ state of stress, the shape of the excavation, and the material properties of the rock mass. The size of the excavation controls the extent of the overstressed zone. Changing the shape of the opening can reduce or redistribute the stresses around the opening to a more favorable condition. Reorienting the opening might help if that is possible. Installation of supports can control the instability if stresses are not too high and severe.
- Instability due to weathering and/or swelling: Some rocks contain minerals with properties and behaviors that change as soon as they are exposed to air or water. They will undergo a severe weathering process and they will become very weak and flaky. In cases where the rock contains clay minerals such as montmorillonite, swelling will take place. Swelling is associated with expansion as a result of increase in volume, and will apply excessive pressure on the support and liners in the tunnel. The best method for remediation and control of this behavior is to apply shotcrete immediately after excavation.
- Instability due to excessive groundwater pressure or flow: This problem can be encountered under any conditions. It can be severe if the excavation is below the groundwater table and the water head is very high. High flow or high hydrostatic pressure will be a major concern if any of the conditions mentioned here are present. Dewatering and grouting are the main remedial measures that can be applied to control excessive water.

Open-Pit and Other Surface Mining

Slope failures are very common in surface mines. Unlike underground mines, rock masses are not confined and are completely exposed to open faces. Instability is mainly the result of exposure of dominant weakness planes. These weakness planes consist of faults, joints, bedding planes, contacts, or any form of a plane that can act as a sliding surface. In very weak rocks and formations, failure through intact rock is possible but very rare. These are the main types of slope failures:

- Circular failure: This type of failure is typical in overburden soil material. It is very rare in hard rocks. However, very weak and heavily fractured rock could potentially exhibit circular failure. In mining, this type of failure should be evaluated when overburden rock piles and tailings are being evaluated for stability.
- Plane failure: This type of failure is common in slopes where two sides are open and exposed and a single dominant joint or joint set is intersecting the slope. A single block or multiple large blocks can potentially slide along this sliding plane.
- Wedge failure: This is the most common mode of failure in rock slopes. When two discontinuities or joint sets intersect, they form a wedge. This wedge is potentially unstable if exposed in the slope face.
- Toppling: Toppling is not a common type of slope failure. However, when steeply dipping and closely spaced discontinuities are exposed at the face and dipping into the face, toppling can occur. The discontinuities form columns of rock and, under favorable conditions, these columns can turn and topple over.

Information on discontinuities is the most important data of this type, as will be discussed later. Water by itself does not pose any hazards in terms of instability. However, when discontinuities are present, then joint water pressure will be the main factor in instability.

Important Factors in the Design of Ground Control Systems

Several factors and parameters must be well understood and considered in the design and planning of the ground control program for various mine sections. These parameters must be determined as accurately and as early as possible in order for the design engineers to plan the ground control program. These factors are summarized in the following paragraphs.

Geology and Ground Conditions

The geology and the rock mass conditions are the most important factors in ground control planning. The stability of the openings strongly depends on the geologic parameters and conditions. These parameters must be determined at early stages of planning and design of mine structures and sections. The data collection, testing, monitoring, and observation must continue throughout the operations and construction in order to update the information and implement new designs. There are a number of important geologic parameters:

- Rock type: Whether the rock is sedimentary, volcanic, or metamorphic determines some of the general behavior of the rock mass.
- Rock engineering properties: Important engineering properties of the rock are those that determine the response of the rock mass when it is disturbed or stressed. These properties are strength parameters (cohesion and internal friction angle, for example), Young's bulk moduli, and Poisson's ratio. These parameters are very important in underground structures and are used to determine the reaction of the ground and whether the rock mass is

overstressed. The behavior of the rock mass is also used to select the best support system if needed. These are important input parameters when failure is due to severe stresses, as discussed previously. These properties are determined through lab and in-situ testing.

- Structure of the rock mass: As mentioned in the discussion of modes of failure, discontinuities play the main role in formation of potentially unstable blocks in both underground and surface operations. Important properties of weakness planes are the orientation (strike and dip) and shear strength parameters (cohesion and friction angle). Other useful information is length of the discontinuities, spacing or frequency of joints, and condition of joints (roughness, alteration, fillings, and separation). Strike and dip are measured in the field at the exposed faces. The friction and angle can be determined through direct shear testing. The cohesion is very difficult to measure, but back analysis can be done to estimate it.

State of Stress

The state of applied stress is an important parameter in the design of underground structures and ground control programs. Stress levels can be estimated using the overburden pressure. In-situ stress measurements are very reliable and useful. However, they are expensive and require access and special tools and skills. During the preliminary design stage, stresses must be estimated using some assumptions. Computer models and numerical analyses (such as finite element, boundary element, and discrete element analyses) are very useful and popular tools. Scenarios can be investigated using various stress conditions.

Hydrologic Conditions

Both surface and groundwater hydrology conditions should be studied. Surface hydrology is important in designing flood control and diversion channels, as well as erosion control structures. Surface water can cause some stability concerns in slope stability, particularly in overburden soil piles and tailings. If the surface run-off water filters in the slopes, tension cracks and discontinuities will cause a severe problem in rock slope stability. Excessive water pressure from the groundwater can become the main controlling factor in underground excavations, as discussed previously.

The location of the water table, quantities and direction of water flow, as well the quality of the groundwater must be evaluated. The quality of the groundwater, such as whether it is clean, brackish, acidic, alkali, or any other condition, is important to the operations. It is important to know whether the water can be used as needed for the operations, or if it is harmful or corrosive to the equipment and support systems. Knowledge about the quality of the water also determines whether it needs to be treated before releasing it back into the environment.

Shape and Size of the Excavation

The shape and size of the excavation do control the stability condition of the openings. The shape and size are determined by the application or use of the opening (i.e., shaft, adit, incline, decline, raise, main haulage access, etc.), the size of the equipment, the mining method, and the overall dimensions of the orebody and therefore the stope. The larger the excavation, the more instability problems that might be encountered. For example, when a block caving operation switched from the conventional gravity method or grizzly system to an LHD (load, haul, and dump) system, the ground control became a much more challenging issue. The difference between the two methods is that the openings are significantly larger when an LHD system is used. However, with the grizzly system, the size of the openings is smaller while the number of openings is significantly larger.

Production Rate

Production rate affects the ground control program indirectly. The designed production rate controls the expansion rate of the mine openings, which is a factor in design and implementation of the ground control program. It also determines the size and number of pieces of equipment, size of the facilities (both surface and underground), and so forth.

Economics

Like any other unit of operation in mining, the cost and benefit ratios play an important role in the design and selection of ground control methods. The economics of ground control systems were briefly discussed in the previous section. The engineer in charge must look at a set of support alternatives and select the most economic option.

Planning the Ground Control Program

The ground control program starts with the review of the mine plans, mine system, production requirements, type of material-handling equipment or system, and all other pertinent parameters associated with the mining operation. The planning then goes through the following stages of data collection and analysis:

- Stage 1: This stage involves the preliminary collection and interpretation of geological and regional data from existing historical documentation and the review of literature, geological maps, surface mapping, and core logs. This data, together with relevant mine operation information, should be used to assess the ground conditions that can be expected and to identify possible ground condition scenarios to be evaluated (e.g., favorable, most likely, and unfavorable).
- Stage 2: This includes preliminary analysis of all the data to establish any patterns. Those areas and conditions that require additional data and information are identified. Additional data will be collected if possible and the analysis repeated.
- Stage 3: The next step is to divide the proposed mine area into design sectors based on the geologic conditions and the mining activity. Each design sector has a unique property and might have different construction and support requirements. For each design sector, the expected mode of failure is predicted and ground control method(s) is recommended.
- Stage 4: Next, the support requirements are implemented as the mining operation commences and continues. Data collection, sampling, testing, and analyzing continue as operations go on. The process is involved with a continuous learning process through close observation and monitoring as mining is carried out. The ground control systems should be redesigned and updated as needed.

Monitoring

Monitoring should be proposed as a major part of the ground control program. Monitoring provides constant data to update and improve the tools and techniques that are used as part of the stability program. Monitoring also provides an early warning system to predict a potential failure and identify the location and source of instability. This increases the safety level and provides safe working conditions so the workers and operators can work with high confidence and comfort. The mine operators and managers are strongly encouraged to implement an extensive monitoring program as part of their operation. There are a number of common monitoring systems:

- Surveying points with a robotic totaling station: This tool provides a continuous record of movements. This has been used in open-pit mines extensively.
- Radar: This also provides a continuous readout of the slope movements.
- Optical surveying: This has applications in both surface and underground mines where access is available.
- Convergence measuring tools: This is normally carried out by means of a rod extensometer between the walls and roof of an excavation.
- Borehole extensometer: This measures the displacements in the rock mass surrounding an excavation. The data is very useful for understanding the behavior of the rock.

More and more advanced techniques are coming out, and operators should always consider using the most advanced techniques available.

A classical and most spectacular example of a successful monitoring program is the case of the slope failure at Chuquicamata mine in Chile in 1969. The details of this event can be found in an article by Kennedy et al.[6]

In June 1968, after signs of instability were noticed, a major monitoring program was implemented. An attempt was made to mine the unstable slope as much as possible to reduce the load. However, by late 1968, it was evident that a major slope failure was inevitable. It was not possible to stabilize the slope. Steps were taken to reroute the main haul road and stockpile material for the mill.

The monitoring program continued and on January 13, 1969, the plotted displacement data was projected to predict the date of failure. Based on the data from the fastest moving target, engineers predicted that the slope would fail on February 18, 1969. The sloped failed at 6:58 PM on February 18, involving approximately 12 Mt of material.

Full production resumed on February 19 after a shutdown of the pit for 65 hours. The mill continued working throughout this time from the stockpiled material.

What is spectacular about this case is not the accuracy of the prediction. It could have been off by several days or even a week. What is worthy of attention is that all the negative consequences of such a major failure were avoided and there was no loss of life, equipment, or time at the mill.

Ground Control and Sustainability

The longevity and safety of all mine structures and components rely on a successful ground control program. Any uncontrolled and unpredictable failure can cause major losses and even total shutdown of the mine. In this section, the importance of the ground control was reviewed. No data or information regarding the technical and theoretical steps in design of mine openings was given because it is not the responsibility of the mine managers to design the structures and the support systems. However, it is their responsibility to make sure that the mine components are designed to be safe and their integrity is preserved. However, management must have sufficient knowledge and background in geomechanics and support systems.

The mine can remain sustainable if it is safe and economical, and the ground control team is responsible for achieving that goal.

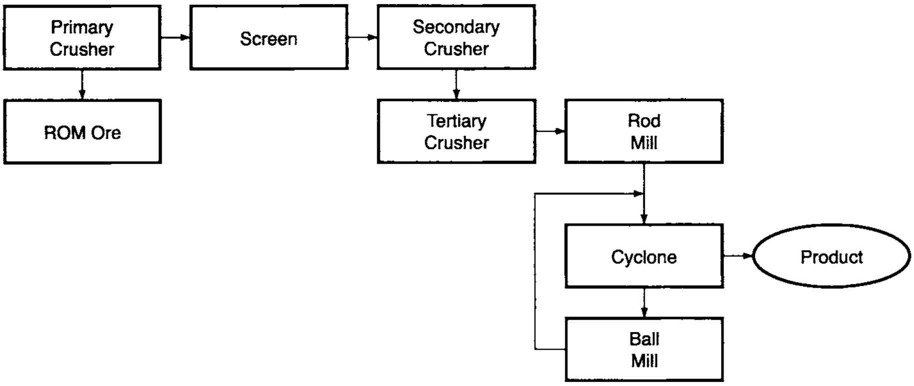

FIGURE 9.3 Conventional comminution process with three stages of crushing

MINERAL PROCESSING*

Mineral Processing Principles

Mineral processing is the process of extraction and concentration of economic minerals contained in ore.[7,8] It can be described by a multistage process:

1. Comminution (blasting, crushing, and grinding);
2. Separation by size and classification;
3. Separation by physical/chemical properties (flotation, cyanidation, etc.); and
4. Grade concentration.

Despite the fact that blasting is not considered part of mineral processing, the economics and efficiency parameters of blasting and plant processing must be studied as a whole. In this regard, blasting with explosives should be considered as the first stage of comminution.

In a mineral processing plant or "mill," size reduction takes place as a sequence of crushing and grinding processes (Figure 9.3). Crushing reduces the size of ROM ore to such a level that grinding can be carried out (usually from 12 to 19 mm top size). Grinding continues until mineral and gangue are substantially in the form of discrete particles.

Because most minerals are finely disseminated and intimately associated with gangue, they must be initially "unlocked" or "liberated" before separation can be undertaken. This is achieved by size reduction or comminution, in which the size of the ore is progressively reduced until a sufficient fraction of free mineral particles are available for separation.

Crushing takes place by compressing the ore against rigid surfaces or by impacting the material against surfaces in a constrained path. This is contrasted with grinding, which is accomplished by abrasion and impact of the ore by the free motion of a grinding media such as steel rods or balls, or ore pebbles.

Crushing is usually a dry process, although more modern techniques are beginning to apply waterflush technology in cone crushers. Typical crushing plants operate in stages, with reduction ratios from 3 to 6 at each stage. Conventional crushing processes are carried out in two or three size stages (primary, secondary, and tertiary crushing)

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* This section was written by A. S. Rodriguez-Avello.

Grinding reduces the ore size from 19 or 12 mm down to 1.5 mm for iron ores and to –65 mesh for most base metal ores. In some industrial plants, the product is ground to the fineness of talcum powder (on the order of 5 μm or less). Wet grinding is generally the preferred method, but dry grinding is used in some special cases.

Crushing

The devices most frequently used for primary crushing are gyratory or jaw crushers. Secondary and tertiary crushing uses cone crushers or hammer mills.[9]

Jaw crushers are devices in which two opposing nonparallel plates trap rock in an alternately expanding and shrinking aperture. Rock pieces are broken into progressively finer sizes until they drop through the gap at the bottom of these plates. Jaw crushers accept feed sizes up to 1,200 mm and produce nominal product sizes as small as 19 mm. Product size is determined by the distance between the lower ends of the jaws. This gap dimension can be adjusted by shims behind the stationary jaw assembly. The jaw crushers can be choke fed from hoppers or conveyors.

Gyratory crushers consist of two cones, one being a large truncated cone with the apex down; the other smaller one, with the apex up, is mounted inside the large one and driven eccentrically. This structure provides a progressive breaking action similar to that in a jaw crusher. However, unlike jaw crushers where production is cyclic, gyratories are capable of continuous output.

Cone crushers have a fixed compression surface with the shape of an apex-up truncated cone; the moving surface is another apex-up cone inside the larger one. The eccentric motion of the inner cone (or mantle) produces a reciprocating motion in the same pattern as in jaw crushers, and with similar effects. However, as with the gyratory crusher, there is no cyclic production. The large discharge opening of cone crushers makes their use practical for fine crushing. The Symons crusher is the most widely used cone crusher. It is manufactured in two forms: *standard* for normal secondary crushing and *shorthead* for fine or tertiary duty. Standard crushers can handle feed material from 250 to 100 mm top size and generate a product from 50 to 30 mm in size. Shortheads are designed to produce a top size from 19 to 6 mm.

Secondary crushing plants treat ore of 250 to 100 mm top sizes and produce a product with a top size of 19 to 12 mm. Shorthead crushers often work in closed circuit with screens and, in some cases, the feed to standard crushers is prescreened to remove the fines, thus increasing crusher capacity.

Hammer mills (also impact crushers) are made up of a set of cast iron hammers to crush the ore with repeated impacts. These units are designed to crush fragile or fibrous materials such as asbestos, fluorite, limestone, or coal. The hammers are made of Mn-steel or nodular cast iron with chromium carbide for abrasion resistance. To increase hammer life, each hammer pivots as it contacts material, although fixed hammers are used for coarse product discharge.

Grinding

Grinding[10] can be performed in two stages using rod mills and ball mills or in a single stage using autogenous grinding (AG) mills or semiautogenous grinding (SAG) mills.

Rod mills are tubular mills in which milling action is achieved with steel rods. They are capable of processing feed as large as 50 mm and discharging a product as fine as 300 μm; reduction ratios are normally in the range of 15–20:1. Normal top size of rod mill feed, however, is 19 mm.

Rod mills are considered for coarse grinding applications or, operating in two stages, discharging into a ball mill. In a rod mill, smaller particles slip through the spaces between the rods and are discharged without appreciable reduction. As a result of this action, the particle size distribution of a rod mill is much tighter than that of an equivalent ball mill.

Ball mills are tubular mills that use steel balls as the grinding medium. They are better suited for fine grinding. Circuits employing a ball mill are always operated in closed circuit with a mechanical or hydraulic classifier such as a cyclone or a classifier (i.e., rake, bowl, or spiral).

Pebble mills are tubular mills with a single compartment and charged with hard, screened ore particles as the grinding medium. Because the weight of pebbles per unit volume is 35%–55% that of steel balls, the power input and the capacity of pebble mills are correspondingly lower. This is compensated for somewhat by operating such mills at high critical speed relative to conventional rod or ball milling. Thus, for a given ore at a particular feed rate, a pebble mill would be larger than a ball mill, with correspondingly higher capital cost.

AG mills, especially with ROM or primary-crushed ore, have become increasingly important in recent years. With suitable ores, these mills reduce grinding media costs and can produce lower percentages of slimes or fines than do conventional rod and ball mills. Instead of steel media, the AG mill uses the action of large pieces of ore on smaller ones to produce size reduction. SAG refers to grinding methods using a combination of ore lumps and a reduced load of steel rods or balls as the media.

AG mills can be operated wet or dry. Dry mills cause environmental and occupational-health problems, do not handle clay content well, and are more difficult to control than wet mills. In certain applications involving grinding of minerals such as asbestos, talc, and mica, dry semiautogenous milling is used exclusively.

Separation by Size and Classification

There are two types of particle sizing separators: screens and classifiers. Screens are used normally for coarse size separations down to 6 mm; classifiers are used for fine separations as low as 200 mesh. Wet screening applications are beginning to compete with classifiers in some cases where close size separations are needed.

Classification[11] is a method of separating mixtures of minerals into two or more products on the basis of the velocity with which the grains fall through a fluid medium. In mineral processing, the fluid is usually water, and wet classification is generally applied to mineral particles that are considered too fine to be sorted efficiently by screening.

Many types of classifiers are on the market. They are designed to separate one or more ore fractions using gravity, water flow, heavy media, and magnetic or electric fields. Some of them are hydrocyclones, spiral classifiers, hydraulic classifiers, heavy-media separators, and magnetic separators.

Flotation

Froth flotation[12] is a versatile process that is used for many ores whenever the liberation size is too fine for gravity separation, and magnetic or electrostatic methods are not applicable. It separates ore particles by exploiting the differences in their surface behavior in the presence of air bubbles and water. To produce separation, particle surfaces are made water-repellent so that they readily attach to an air bubble or are kept water-wetted (hydrophilic) so they sink. In practice, this involves adding chemical reagents to an ore pulp to create conditions that favor the attachment of gas bubbles to one class of mineral particles. A conventional flotation circuit in a mineral processing plant is shown in Figure 9.4.

Several types of flotation cells are available on the market, each having its own unique characteristics. The principal difference between self-aspirated and forced-air designs is the position of the rotor inside the cell. Self-aspirated flotation cells (with elevated rotor) are expected to recover more ore particles with weak particle–bubble bonds or easily dislodged coarse grains.

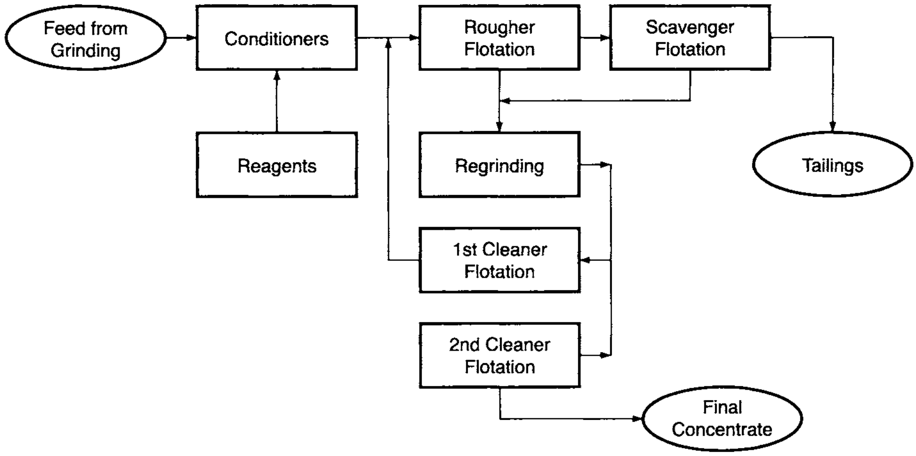

FIGURE 9.4 Flotation circuit

The bottom-based rotor cells have better selectivity when recovering fine particles, as a deeper draining froth can be used to allow entrained material to fall back into the cell.

In recent years, an increasing number of mills are installing column flotation cells to supplement or replace conventional flotation machines. Column cells consist of a cylindrical or square vessel, from 150 mm to 3.6 m across and up to 10 m high. Pulp is introduced about halfway down the vessel, and tailings pulp is extracted out the bottom through a valve controlling pulp level. The pulp is kept above the point of feed entry, and a very high froth column (up to 1.2 m) exists above the pulp. To stabilize this froth and provide a washing action within the froth, water is gently rained down from above the froth.

Cyanidation

Cyanidation is a simple process that exploits the solubility of gold in dilute cyanide solutions and its ease of recovery by cementation with zinc dust or by adsorption to active carbon. The major features of the process are the formation of a gold–cyanide complex ion, the requirement for air, and the sensitivity to pH.

Cyanide can also form complex ions with numerous other heavy metals such as copper, iron, mercury, and zinc. Thus, the presence of other ions derived from sulfide or oxide minerals in the ore can present difficulties in processing gold ores because the presence of these ions (referred to as cyanicides) can greatly increase the cyanide consumption, thus making the process economically unfeasible.

Dewatering

With few exceptions, most mineral separation processes involve the use of substantial quantities of water and the final concentrate has to be separated from a pulp in which the liquid/solid ratio can be high. Dewatering, or liquid/solid separation, produces a relatively dry concentrate for shipment.

Dewatering methods can be broadly classified into three groups: (1) sedimentation (thickeners), (2) filtration (filters), and (3) thermal drying (dryers). Dewatering in mineral processing is normally a combination of these methods. The bulk of the water is first removed by sedimentation or thickening, which produces a thickened pulp of perhaps 55%–65% solids by weight. Up to 80% of the water can be separated at this stage.

Filtration of the thick pulp then produces a moist filter cake of 80%–90% solids, which might require thermal drying to produce a final product with about 95% solids by weight.

Sustainable Management Issues

The sustainability of a mineral processing operation requires a management focus on operational efficiency (e.g., metallurgical recovery, water and energy consumption), the environmental issues (e.g., tailings disposal, cyanide use, and air pollution), and safety and health issues. In the following paragraphs, the main sustainable management issues are discussed.

Energy Consumption

Power consumption is the largest cost item in most mineral processing operations; therefore, optimizing energy consumption should be a major management objective. The crushing and grinding processes are normally the largest energy consumers in the mineral processing plant, but large energy savings are achievable through design optimization and efficient operation of other areas of the facility.

Mine–mill energy balance. Optimizing the mine–mill interface to increase efficiency and reduce energy consumption is a major challenge in mineral processing. This can be achieved reliably and inexpensively by measuring the performance of blasting operations as it relates to the subsequent improvement of crushing and grinding. Systematic estimation of the size distributions of blasted ore is critical to establishing a baseline for a predictive model to be used for the evaluation of process performance. Although conventional sampling techniques are not adequate for the large fragment sizes in muck piles, trucks, or crusher feed, video sampling systems and analysis of the raw images by specific software are one example of useful tools that could be used.

Mill motor efficiency. About 50% of the total energy used in mining operations is consumed in the mineral processing, mainly grinding. Therefore, improving mill motor efficiency is one way of achieving a significant amount of energy savings in the plant. A recent U.S. Department of Energy study determined that 44% of industry motors operate consistently at less than 40% of full load. Energy efficiency technologies for electric motors are a practical solution for variable load equipment such as crushing and grinding mills. A motor operates most efficiently when the load is 70%–95% of the rated load. There are a number of ways to accomplish this: shutting off an idling motor, right-sizing the motor, using frequency drives when it is essential to the process to change the speed, or installing reduced-voltage motor controllers.

Ball mill discharge: Overflow versus diaphragm. Overflow discharge ball mills are used when a product with high specific surface is more important than the particle size distribution curve. Diaphragm discharge-type mills are used to maximize power application to the coarse particles without production of excessive slimes. Twenty percent more energy is used than in an overflow mill of similar dimensions.

Dry grinding versus wet grinding. As a guideline, wet grinding consumes significantly less power than equivalent dry grinding, requires less physical space and less support structures, and reduces or eliminates required emissions (dust) control equipment. Dry grinding increases capital and energy consumption when processing moist or wet materials (requires predrying to less than 1% moisture), consumes less media and liner material, and eliminates the need for filtering and final drying later in the process in an open-circuit configuration. In areas where water is not available in sufficient quantities or the use of water is not allowable (e.g., cement, talc, potash), dry grinding is a viable option.

Energy-efficient screens. For larger feed between 40 and 150 mm, circular or linear motion inclined screens are often used. The latest advances in screen design are wider screens and more efficient, higher tonnage capacities. A recent development in high-frequency, low-

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deck-angle screens offers interesting new features in linear screen technology. It incorporates electromagnetic motors and specially designed resonators to amplify motion and cause only the screen panel assembly to vibrate at resonance, with low energy consumption.

Use of high-pressure grinding rolls. High-pressure grinding rolls (HPGRs) are now installed in crushing circuits as a replacement for conventional tertiary and quaternary crushers, increasing capacity and reducing power consumption. An additional advance in this technology is the use of HPGRs in parallel with cones in so-called reverse closed circuit with prescreening.

Operational Efficiency

Operational efficiency may be optimized at the design and the operational stages. An efficient plant design should achieve a proper balance between capital and operating cost. During operations, maximum efficiency is achieved through a management focus on maintenance, plant availability, and optimum metallurgical recovery.

Balancing capital and operating costs. Size reduction costs are important factors, not just in capital and operating items, but also in expected production, availability, and total service life. Investment paybacks are now in a time frame of 3 to 5 years. Effectively balancing capital and operating costs requires an experienced and practical understanding of how to use the energy efficiently and configure the crushing and grinding circuit for the best possible wear material service life.

Mill liners. The performance and life of mill wear parts must be carefully considered. There is great variation in the design, life, and cost of mill liners. In fact, liner life and change time are critical factors for mill availability and, therefore, plant performance. Mill relining machines can now place one 5,000-kg liner with the same speed as one 1,000-kg liner before, thus relining can be reduced from 160 hours to just 60 hours. The future could include robotic solutions, but the question is the capital cost, which is three times higher than with manually operated machines.

Screening panels. Screening media (panels) are made of polyurethane or rubber, although the sand and gravel industry still uses wire cloth. Although the polyurethane and rubber panels are much more expensive, they are also much harder wearing, and modular types using these materials have become increasingly popular.

Most of the major improvements that have been made are in wear protection systems using polyurethane and special high-durability coatings. Recent innovations include wear parts that last longer, extended periods for maintenance, and reliable monitoring systems, together with preventive (predictive) maintenance strategies that ensure better availability of the equipment, with less downtime and improved profits.

Plant maintenance. Good preventive maintenance programs can result in lower repair costs and greater equipment availability and, therefore, greater productivity. Newmont reports that after a comprehensive and effective training program, scheduled major maintenance outages that once consumed 30 days of production per year have been reduced to just 23 days; unscheduled maintenance stops have also been reduced.

Preclassification of ROM ore. The ROM ore delivered to the crushing plant contains particles of sizes less than the crusher setting. If this undersize material is fed to the crushing process, it will reduce crushing efficiency and produce higher wear, dust, and hold-up problems (if the ore is of a sticky nature). Because of it, this undersize material should be removed first or bypassed so that the available force will be applied to the coarser material.

Cylindrical flotation cells. Round tanks have proven to be more efficient and easier to operate than the rectangular cells because there are no corners, and mixing is more uniform, with minimal sanding effect. Also the froth bed is steadier across its entire surface area. The use of

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