COST REDUCTIONS BY U.S. MINERAL PRODUCERS:
REAL OR ILLUSORY?

by

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ABSTRACT

Over the past decade there have been many attempts to reduce costs as most commodity prices have plunged to record depths and have stayed at these levels for prolonged periods (only recently have they rebounded to their present heights). This thesis will dissect the reductions made, especially in terms of their permanency.

There are three types or categories of cost reductions: (1) permanent cost reductions; (2) permanent cost reductions, which in addition to reducing per unit costs, possess deleterious side effects (frequently a reduction in the mine life); and (3) temporary cost reductions. Categorizing cost reductions is important because it indicates how sustainable the renewed prosperity and international competitiveness of many domestic producers will be.

The completion of this task is accomplished by a two-part strategy. Firstly, the body of existing literature on the subject of cost reduction is reviewed. Secondly, a number of case studies, namely the reductions accomplished at the Bingham Canyon, Bagdad, and Henderson operations, are analyzed and viewed from within the
framework of the three cost categories.

Large variations exist among the three case studies in regard to their dependence upon each category of reduction. Nevertheless, the finding that only a limited portion of the cost reductions are temporary or, though permanent, have serious side effects, has important implications. In particular, it raises reservations concerning the argument that the U.S. competitive ranking inevitably must be slipping. On the basis of the three case studies, this argument, which presumes that domestic reductions are temporary or in some manner undermine the long run viability of the industry, seems largely misplaced. On the contrary, these concerns (represented by the second and the third categories of reduction) appear, based upon the facts, generally small or nonexistant.
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Chapter 1

INTRODUCTION

U.S. mineral producers have greatly reduced costs over the past several years, both in absolute terms and relative to the reductions made in many other mineral producing countries. The record profits being earned by many domestic producers are testimony to this (as well as also being a result of the general upswing in commodity prices). While it is widely assumed that these reductions have increased the competitiveness or comparative advantage of the United States as a producer of minerals, this need not be the case, at least not over the longer term.

All economies must continually adjust to new conditions. Sometimes those conditions are shifts in consumer demand, sometimes new technology, and sometimes changes in international competitiveness. To policymakers, the macro problems of the day always seem more immediate and dramatic; however, a longer time perspective would give priority to the problems of an economy in promoting the industries in which it is internationally competitive and in phasing out those in which it has lost its competitiveness.

Specifically, whether these cost reductions prove to be
permanent or merely short-term palliatives will determine to a great extent the long-run viability of the industry. Cost reductions can be placed into one of three distinct categories: (1) permanent reductions, such as those resulting from new technologies, that reduce costs without adverse effects on long-run competitiveness; (2) permanent reductions, such as those resulting from a raising of the cutoff grade within a mine that, in addition to reducing per unit costs, reduce the level of reserves and thus, in all likelihood, will shorten the length of mining; and (3) temporary reductions, such as those resulting from the postponement of maintenance work, that are not sustainable and at best defer the eventual day of reckoning when costs can no longer be delayed.

This analysis focuses on the division of cost reduction methods among the three areas outlined above. The longer term profitability of the industry is directly affected by this division. These categories will allow us to draw some conclusions regarding the sustainability of each cost reduction. By highlighting in which manner these types of reduction can occur, this thesis strives to make the understanding of their effects clearer.

This categorization will be achieved through a two-stage analysis, covering the work of others and relating this to current examples. As such, the analysis
will begin with a general discussion of the issues and a review of the existing literature, and it will then proceed to three case studies of operating mines in the United States. This two-stage approach indicates the similarities, and just as importantly the differences, between the efforts made at individual operations and those believed to be instrumental in general.

It is useful at the onset of any study to understand the parameters governing the subject under review. The mineral industries are different in many important respects from most other industries. Mineral products are sold primarily in terminal markets (for example the London Metals Exchange), so producers have little (or no) control over the price received. Conventional economic theory states that profit is a function of prices, quantities, and costs. Mining is an extremely high-risk industry. Highly complex mining techniques are necessary to extract minerals from extremely variable ore deposits. At the same time, the prices for metals fluctuate widely over short periods of time in the world markets. Both of these factors yield vagaries and uncertainties, giving rise to unpredictable financial results. Hence, cost control is paramount.

Mining in the United States is a capital-intensive industry, much more so than many manufacturing industries. Owing to the employment of extremely capital-intensive
processes, there is a significant difference between operating and total costs. Operating costs are those that can be avoided by not operating the facility. They are sometimes referred to as redfield costs or variable costs. Peck (1988) provides a clear definition of these and related terms: the terms redfield, greenfield, and brownfield come from the steel industry. They are easy to remember if the reader understands their origin. Redfield costs refer to existing plants, which in steel production light up the horizon. Brownfield costs refer to the expansion of existing plants, presumably because adjoining land is discolored by the steel furnace. The origin of the term greenfield for entirely new construction is obvious. Total unit costs include capital costs, in addition to items like property taxes and insurance, that must be paid whether or not the facility operates.

The scope of this work will focus on the competitiveness of existing producers, and hence on operating costs. Primary producers consider operating costs when deciding whether or not to operate a facility. A simple statement regarding a producer’s decision criterion is that a facility is operated only if its unit operating costs are equal to or less than the current price for the metal produced. Thus it is often sensible for a firm to continue operations at a facility even though the
price of the metal no longer covers the total unit cost (the facility at that point is operating at a loss according to conventional accounting standards).

This "basic" economic principle is, in reality, sometimes violated. History has provided many examples. For instance, high-cost producers may continue to produce even if price falls below average operating costs if they have expectations of a higher price in the near future, if the host government has production requirements, or if government assistance is forthcoming (RTZ Corporation 1987).

The operating or variable costs of the world's suppliers of a commodity can be arranged from the lowest to the highest (on a cost per unit basis). An approximation of a conventional short-run supply curve results (such a curve for aluminum is depicted in Figure 1.1 (Peck 1988). It should be noted that Figure 1.1 is an approximation for the supply curve for the entire aluminum industry and not the more familiar cost curve for an individual producer). A curve of this type indicates where production is likely to come from and which firms are likely to be the swing producers.

A different set of considerations applies when the construction of a new facility is contemplated. A firm will build such a facility if the discounted revenues
Unit operating costs of existing smelters worldwide based on capacity operations.

Total unit costs for a new smelter (high estimate).

Total unit costs for a new smelter (low estimate).

Price (cents per lb.)

Capacity (000,000 metric tons)

**Primary aluminum cost curves.** Source: Operating costs are from U.S. Department of Commerce, "Energy and the Primary Aluminum Industry" (mimeo, Washington, D.C., 1984) p. 53, based on data from Anthony Bird Associates. Total unit costs for a new smelter are based on table 7-3, footnote (a), of this volume. A tonne (metric ton) equals 1.1 English tons.

**Figure 1.1**

Primary Supply Curve

over its life are expected to exceed the discounted total costs, including a competitive rate of return on the invested capital. As depicted in Figure 1.1, this decision criterion can be translated into an expected price sufficient to cover the estimated total unit costs.

Although the most significant distinction in costs is between those of existing facilities (redfield costs) and the construction of new facilities (greenfield costs), there is an intermediate case: the expansion of existing facilities (brownfield costs). Brownfield costs are similar to greenfield costs in that total unit costs (including the cost of capital) are relevant. Brownfield costs apply to all modifications of existing facilities and, in the examples that follow, this type of cost will often be extremely important.
Chapter 2
THE AVAILABLE LITERATURE

The body of literature on cost reduction methods is quite extensive, having many examples in this most recent decade. The harsh economic realities of the 1974-1987 period stimulated innovations and technical changes enabling mineral producers to lower costs by more than was generally thought possible. The efforts of a few companies will be chronicled as prime examples, although many others exist. This chapter will examine the more general applications of the theories involved. It reviews work done by the U.S. Bureau of Mines and other research on methods of cost reductions.

2.1 U.S. Bureau of Mines

The Bureau of Mines, through its Mineral Availability Program (MAP), investigates the mineral supply potential of the United States and the rest of the world for a number of mineral commodities. Specifically, it identifies the important mines and mineral deposits and estimates the available mineral resources and production costs (U.S. Bureau of Mines 1987).

Bureau attempts to inventory the national mineral resource base began in earnest in the 1930s with studies of
manganese, copper, and other commodities. Subsequently, with the War Minerals reports (World War II) and the Materials Surveys beginning in the late 1950s, the Bureau began an evolutionary trend towards the systematic inventory of selected commodities. A comprehensive attempt at defining the national resource positions for copper, lead, zinc, gold, and silver was conducted in 1954 with the classification of U.S. resources according to measured, indicated, and inferred categories (such a classification system was a precursor of today's McKeivey Box system).

Although these unpublished studies were of limited scope, they did contribute to the conceptual development of the current availability studies. Unlike the current studies, a significant limitation of these early works was their failure to aggregate or to classify economic resources over a range of prices. The current studies, which do just this, were begun in 1967 with a program entitled, "The Availability of Minerals Under Various Economic Conditions." This program yielded reports documenting the availability of silver, molybdenum, chromium, nickel, uranium, tungsten, and other metals. Eventually, this system was automated in an attempt to garner the capability for timely and comparable evaluations of mineral supply potential.

The initial projection of the final content of this
data file was 100,000-200,000 deposits worldwide, of which 2,000-3,000 would possess short-term production significance, another 5,000-10,000 would possess paramarginal supply potential, and the remainder would have only long term potential for supply development. To date (1987), approximately 2,900 world properties (including processing plants) have been fully evaluated, while 200,000 location entries, primarily in the United States, comprise this mineral industry location system (U.S. Bureau of Mines 1987).

The Bureau's objectives are to depict the relative economic viabilities of significant mineral resources via availability curves. This type of analysis has been undertaken for a number of commodities and allows one to determine the change over time in relative competitive position. In order to do this, the Bureau identifies "cash" and "production" costs for each individual operation. Cash costs are defined as the sum of the operating costs at the mining, milling, smelting, and refining stages of production, including intracountry transportation costs, on a U.S. dollar-per-pound-recovered metal basis. Cash costs are thus quite similar to operating costs as described earlier. Production costs are defined as cash costs less byproduct credits (Porter and Thomas 1988). These definitions offer a consistent measure
of costs for each country and avoid problems resulting from other factors such as interest, corporate overhead, depreciation, and taxation expenses; all of which are volatile and inconsistent across countries. Figure 2.1 illustrates production costs for copper and is quite useful in estimating the competitiveness of producers.

2.2 Underlying Cost Reductions

It is apparent that success in reducing the adjusted cost of producing copper is often masked by the impact of factors beyond the control of the operating companies (adjusted as it is defined in Table 2.1 - cash costs adjusted for inflation and exchange rate fluctuations). The effects of fluctuating foreign exchange rates and differing rates of inflation on relative competitiveness have been significant in recent years. What follows attempts to quantify and to measure these effects for the major copper producing countries.

As Figure 2.1 indicates, the relative position of countries such as Chile, Mexico, Peru, Zaire, and Zambia improved over the specific time period, in large part because of significant currency devaluations when compared with the U.S. dollar. Although U.S. producers reduced their real cost of producing copper, they remained at a relative disadvantage in the international market because
Figure 2.1
Copper Production Costs

Table 2.1
Comparison of Changes in Nominal and Adjusted Cash Operating Costs

<table>
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<th>U.S.</th>
<th>Canada</th>
<th>Chile</th>
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<tr>
<td>Copper production (10^3 mt)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>950</td>
<td>441</td>
<td>813</td>
</tr>
<tr>
<td>1986</td>
<td>1096</td>
<td>452</td>
<td>1115</td>
</tr>
<tr>
<td>Nominal cash costs (U.S. dollars/lb)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>.97</td>
<td>.96</td>
<td>.56</td>
</tr>
<tr>
<td>1986</td>
<td>.62</td>
<td>.87</td>
<td>.35</td>
</tr>
<tr>
<td>Change, 1981 to 1986</td>
<td>(.35)</td>
<td>(.09)</td>
<td>(.21)</td>
</tr>
<tr>
<td>Adjusted cash cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981 (nominal)</td>
<td>.97</td>
<td>.96</td>
<td>.56</td>
</tr>
<tr>
<td>1986 (1/81 dollars)</td>
<td>.46</td>
<td>.71</td>
<td>.55</td>
</tr>
<tr>
<td>Change, 1981 to 1986</td>
<td>(.50)</td>
<td>(.26)</td>
<td>(.01)</td>
</tr>
</tbody>
</table>

Notes: Adjusted cash costs expressed in 1/81 U.S. dollars = nominal cash costs for operations as of 1/86 and adjusted for inflation and exchange rate changes since 1981; byproduct credits have not been deducted.

Cash operating costs are the sum of mining, milling, smelting, refining, and transportation costs in U.S. $/lb Cu. Does not include depreciation, interest, profit, or taxes; byproduct credits have not been deducted.

1Totals may not add because of independant rounding.

of the strength of the dollar over the 1981-1987 period.

As an example, the United States, Canada, and Chile have experienced very different rates of inflation during the 1980s. Using data for the period 1981-1986, cumulative inflation in the United States and Canada was 31 percent and 43 percent, respectively, while in Chile cumulative inflation exceeded 162 percent. Over the same period, the Canadian dollar and the Chilean peso devalued relative to the U.S. dollar by 17 percent and 287 percent (Porter and Thomas 1988). All three countries show reductions in production costs over this period (see Figure 2.1).

Adjusted cash costs have been calculated to remove the bias caused by these occurrences. The results are presented in Table 2.1. The reductions in adjusted cash operating costs demonstrate the effectiveness of the varying measures that were implemented to improve competitiveness. The large adjusted reduction in Canada and the small adjusted reduction in Chile indicate the degree to which cost-reducing measures may be masked by exchange rate and inflationary movements. The analysis which follows focuses on the methods believed to be relevant in the United States which resulted in the dramatic reductions (both nominal and real) witnessed.
2.3 Additional Work

The cost reduction literature (consult the Selected Bibliography for a listing) cites a host of reasons for these dramatic changes. During this period of economic hardship, survival for almost every mining company became the foremost objective and precipitated many, if not all, of the reductions.

A great deal of rationalization has taken place throughout the industry—mines have been closed, curtailed, or sold. Integration has been enhanced by selling certain mines to other producers who have smelting and/or refining capacity available. Many operations undertook new investments, often putting in place the latest technologies.

Some of the most advanced methods of mining technology were adopted. For example, leaching and solvent extraction means that "new" leachable ore is increasingly perceived as valuable rather than simply as waste. As leaching technology has become more viable, the primary developments have been the relative decline in the share of underground mines and the concomitant rise in the proportion of leaching operations. This development is highlighted in Figure 2.2. Although the data contained in this figure was collected only through 1985, the trend has continued and appears to have become more pronounced in recent years.
Figure 2.2
Types of Mining (copper)

New technologies were also applied to the other stages of mining; for example, in-pit crushing and materials handling. Related to this, improved efficiencies were sought; as a result, many mines began computerized onstream analysis and flow control, they adopted improved ball mill linings and larger flotation cells.

Many companies also addressed their labor situations, which in recent years had come unglued from the realities of mineral production. This meant both reductions in the numbers of workers employed and in hourly wage rates. Such reductions could not have been accomplished without the recognition by the unions of the seriousness of the problem. Contract negotiations went beyond wages: cost-of-living agreements were eliminated and many benefits were reduced. In sum, total labor costs were cut upwards of 20 percent (Secretary of the Interior 1987) from previous levels.

As indicated, survival at many operations became more important than extracting all of the remaining ore, so that many mining plans were recast to raise cutoff grades (at the expense of mine life). These new plans dramatically improved stripping ratios, which along with the shift to higher-grade ores, lowered the average mining cost per ton milled.

All of the above were combined with a delaying of
expenditures not deemed mandatory. This resulted in deferred maintenance, deferred overburden stripping, and the like. In general, such cost "improvements" can only be sustained over the short run; their continued practice will eventually diminish the economic viability of an operation.

2.4 The Example of Phelps Dodge

It is worthwhile to chronicle some of the more publicized examples of cost reduction made by domestic mineral producers to illustrate a few of the more salient methods employed. Phelps Dodge, the nation's largest copper producer, underwent a dramatic transformation by employing many of the methods described earlier. Perhaps one of the better examples concerned the situation which evolved at the company's Morenci (Arizona) copper mine. This is a large, low-grade porphyry copper deposit. The open-pit operation has the capability of producing roughly 215,000 tons annually (Judd 1988a).

Similar to the general problem faced by most of the other domestic copper producers, there was a pressing need to reduce costs at Morenci. Management received a number of proposals to attain this goal. The plan that was implemented called for two immediate changes in operations: first, the cutoff grade for material sent to the mills was increased (thereby decreasing the unit cost
and second, the closure of the Morenci smelter, which in 1984 was not only a high-cost smelter but one that management felt would require a significant capital outlay to retrofit. A consideration of total costs, and not merely operating costs, is evident in this second decision.

The results of these two changes had further effects. In particular, the decision to close the Morenci smelter left Phelps Dodge with more concentrate than its remaining smelters could handle. This, in turn, led to the decision to sell a portion (15 percent) of the Morenci mine/mill complex to a company with a smelter and a need for concentrate (eventually such a company, Sumitomo, was identified) (Judd 1988a). Together, these were instrumental factors in the reduction of unit costs at Morenci by 30 percent (Judd 1988b).

Phelps Dodge also believed that labor costs at Morenci had to be addressed. The battle between labor and management over this issue came to a head with the firing of striking workers. Replacement workers were hired at a much reduced pace, and, as a result, total employment at Morenci fell from 3,100 workers in 1981 to only 1,600 in 1987 (this reduction included almost 500 workers laid off when the smelter was closed). Partly as a result of these labor reductions, mine productivity, measured in tons per
manshift, has doubled from 295 tons in 1981 to almost 600 tons in 1987 (Judd 1988b). Although most of the media focus was on this reduction in laborers, the company also trimmed its white-collar staff by over 50 percent. The reduction in staff was accomplished by moving the company headquarters from New York to Phoenix (Durham 1988).

Phelps Dodge made a substantial effort at modernization and the utilization of new technology throughout its operational structure. It improved the efficiency of its ore transportation by the use of computer monitoring and by the installation of an in-pit crusher at its Morenci mine. Morenci was originally designed for rail haulage and operated that way for many years. However, truck technology has steadily improved, and by the 1980s it was evident that, on efficiency grounds, a new system of haulage was warranted. Thus, all train haulage in the pit has been ended and mining is now conducted with a fleet of 30-, 170-, and 190-ton trucks. This system, along with the new in-pit crusher and its use of conveyor transport, allows maximum efficiencies to be attained at the mine. This gain, together with the efficiency improvement in the copper concentration process (primarily achieved by employing analytic instrumentation), has been the largest factor in the 18 percent reduction in mine costs (Judd 1988b).
Another effective move resulted from the extensive employment of new production technology. The company has increasingly focused on the production of pure copper from leachates of wastes and tailings. This "solvent extraction-electrowinning" (SX/EW) technology results in operating costs of less than 30 cents/lb (for comparison, today's spot price for copper cathodes is well over 100 cents/lb and has been above that level for over a year) (Wall Street Journal 1989c). Capital costs (assuming an amenable deposit) are also considerably reduced when this new technology is employed.

Additional benefits from this technique are many. The leaching process disrupts the environment much less than does conventional mining; in situ leach mining removes little from the ground except the target metals. It also leaves a mine site that is more easily reclaimed to its original condition (the same is not always the case for a large open-pit mine) (U.S. Bureau of Mines 1989). Thus, this new technology offers both economic and environmental advantages over conventional mining. Phelps Dodge produced 17 percent of its copper by this innovative method in 1988, and the company plans to increase this figure to 25 percent in 1989 and eventually to 40 percent by the early 1990s (Durham 1988).

The company's best example of this heightened emphasis
is at its Tyrone (New Mexico) copper mine. The SX/EW facility was expanded at this operation, thereby doubling its annual production capability via this low-cost process (Judd 1988a). The capital outlay for this initial expansion had a payback period of less than two years (Judd 1988b). Additionally, Phelps Dodge intends to spend over $100 million in expanding production capacity at Morenci by adding a significant electrowinning facility (Wall Street Journal 1989e).

These are but a few examples of recent restructuring undertaken by a leading domestic mining company. As indicated, such restructuring has included major labor concessions, ownership changes, and capital investment in mine equipment and new technologies. These changes have enabled domestic metal producers to dramatically reduce costs, increase productivity, boost production, and (as the supply curve in the earlier section indicates) improve their competitive position relative to other mineral producing countries.

The experiences of Phelps Dodge are in certain ways similar to those of the case studies that follow, and it is worthwhile to note these similarities here. Phelps Dodge was dealing with superior orebodies. The company, in striving for a return to profitability, had four basic building blocks upon which to work. The first and most
important was the deposit that nature provided. To this was added applications of the remaining three: capital, technology, and manpower. In addition, the operations assumed a new outlook which is fundamental to profitability: each mine was viewed as if it were a producer of cash, rather than only minerals. G. Robert Durham, chairman of Phelps Dodge, clarified, "when mining engineers expand their thinking from putting 'rock in the box' to putting money in the bank, their perceptions on how to manage an orebody also expand" (Tunney 1988). This new outlook taken by Phelps Dodge is in large part responsible for the documented changes. These common threads will be found throughout much of this analysis and many of the same reduction methods will often be witnessed in the case studies which follow.
The dissection of cost reduction methods will be accomplished by using a case study approach: each case will employ methods similar to those written about earlier. However, not only will these methods be described, an attempt will be made to categorize each one into one of three areas (outlined at the onset of this paper). This will permit a distinction to be made between permanent and temporary reductions. To keep page-flipping to a minimum (and to refresh the minds of all), these three areas can be summarized as: (1) permanent cost reductions; (2) permanent cost reductions with important "side effects"; and (3) temporary cost reductions. The categorization of cost reduction methods should shed important light on the robustness and on the international competitiveness of the U.S. mineral industries.

3.1 The Bingham Canyon Operation

The methods employed at the Bingham Canyon operation have received extensive coverage in the attempt to restore this copper producer to world prominence. To give the reader an indication of the size and dominance of the
Bingham Canyon operation, this mine will produce 200,000 short tons or an estimated 9.5 percent of the U.S. primary demand in 1990 (U.S. Bureau of Mines 1985). In addition, the mine will annually produce an estimated 300,000 ounces of gold, 2.3 million ounces of silver, and 12 million pounds of molybdenite (BP Minerals 1988).

The turnaround of the Bingham Canyon operation is a good illustration of the revitalization that has taken place in U.S. mining. It was at this historic mine in 1905 that Daniel Jackling first applied the technique of large-scale production to a low-grade porphyry orebody. His vision (and its subsequent application) entailed efficient movement of massive quantities of earth. But the economics of Bingham Canyon hinged on the successful application of the newly developed flotation technology. This was the key to concentrating the low-grade ore. By the late 1920s, output had grown to make Bingham Canyon the largest copper mine in the United States. By 1980, Bingham had produced 12 million short tons of copper and 14 million ounces of gold from 1.6 billion short tons of ore. Through this date the mine had generated after-tax profits of $2.4 billion (BP Minerals 1988). Except for short periods of depressed metal prices, the margin between prices and costs had been generally adequate prior to the 1980s. By 1975,
in the face of a deteriorating market, the work schedule and the rate of copper production were reduced at Bingham Canyon. The oil crisis of 1973-1974 triggered a steep rise in inflation that forced up costs of energy, supplies, and labor. In addition, new environmental regulations resulted in added capital and operating costs. In 1979 and 1980, rising metal prices offered a temporary reprieve. However, the stage had been set for the difficulties that were to follow.

Kennecott (at that time the owners of Bingham Canyon; the operation has subsequently been sold to the RTZ Corporation) decided to do three things: cut costs without making any major capital investments; study how best to modernize Bingham's outdated facilities; and diversify through greater byproduct recovery the long term earning's base at the mine (BP Minerals 1988). Table 3.1 documents the critical aspects of this plan and their contributions to the overall reductions achieved at this operation (an explanation of the numerical content of this table follows in the text). In the spring of 1985, following five consecutive years of losing money, Kennecott shut down the Bingham Canyon operation. This was obviously the low point in the 80-year history of the mine.

3.1.1 **First Prong**

Plans were enacted in which Kennecott's three primary
Table 3.1

Primary Cost Reductions at Bingham Canyon

I. Total Operating Cost Decline¹ 40%
   (1985-1989)

II. Cost Reductions

   A. First prong 20%
      i. Mine plan 10%
         a. ore grade
         b. stripping ratio
      ii. Labor 5%
         a. wages and benefits 1.75
         b. productivity 3.25
      iii. Restarted operations 5%

   B. Second prong (modernization) 20%
      i. Ore handling
      ii. Processing

   C. Third prong (byproduct recovery)
      (such diversification has a long-term potential to impact costs, but it is not included in the 40% reduction)³

III. Total (A+B+C) 40% 40%

Note These are strictly this author’s estimates, based upon figures in the literature. They are meant to be used for comparative analysis and not as absolute figures. These are not official company numbers.

¹ Nominal dollars.
² These "percentages" and those which follow are percentage point contributions to the overall reduction detailed above.
³ According to USBM figures byproduct credits had very little (less than 5 percent) effect on U.S. copper production costs in the 1981-1986 period.
objectives were met. The long term copper cutoff grade was increased from 0.30 to 0.45 percent, thus raising the life-of-the-mine average grade from 0.6 to 0.7 percent. In the process, Bingham Canyon's stripping ratio was lowered. The revised mine plan and steeper pit slopes cut the stripping ratio by 40 percent, from 1.3:1 to 0.8:1. Studies indicated that the pit could be engineered to safely hold slopes about 10° steeper than what was originally assumed in earlier mine plans (about one-half of this steepening is made possible as a result of a better understanding of the structural characteristics of the pit wall; the second half is achieved by draining water from within 200 ft of the pit perimeter) (BP Minerals 1988). Frank Joklik, Kennecott’s chairman, commented that the good ore grade at Bingham Canyon was the instrumental factor in the success of these changes (Joklik 1987).

These alterations to the mining of the ore at Bingham Canyon have led to documented cost reductions; however, an analysis of their permanency reveals different results. The raising of the copper cutoff grade has produced a reduction in cost which is best categorized by the second type. Such a raising means that the mine’s level of reserves and hence its economic life will be shorter than would have been the case if comparable cost reductions had been effected by other more permanent means, such as the
new technology referred to earlier. Without a precise knowledge of the distribution of ore among grades, it is impossible to estimate the degree of this shortening; however, since the average grade of the processed ore was increased by almost 20 percent, the life of Bingham Canyon is likely to be considerably impacted. Thus these cost reductions, albeit permanent, have been achieved at a cost.

At the other end of the spectrum, the reductions in cost attributable to the lower stripping ratio at the mine were not achieved by mortgaging the mine's future. Instead they were made possible by new and increased knowledge concerning slope stability and, as such, come unattached to harmful side effects. These reductions will also be permanent and can be categorized by the first type.

In addition to this renewed focus on the orebody at Bingham Canyon, the situation surrounding labor costs was considered by Kennecott as part of its three-pronged strategy. The labor contract in place at the time was due to expire in mid-1986, and the company hoped to obtain substantial reductions in labor costs when the new contract was finalized. The company received just that. The new contract (which remains in effect through 1990) reduces total labor costs by 25 to 35 percent. Those workers who still have jobs (the workforce consisted of 7,000 employees in 1980 and only 4,000 in 1984; with the completion of the
modernization program in 1989, fewer than 2,000 are necessary), lost, on the average, upwards of 25 percent (Washington Post 1988) of their compensation, giving up benefits including sick leave and cost of living increases and settling for lower wages and large worker contributions to health insurance. As a specific example, the average wage was reduced by more than $3 an hour. On top of these reductions, copper output per employee was 30 percent higher than the same figure was at shutdown time (BP Minerals 1988).

These labor concessions are to some extent permanent. Certainly, costs are dependent upon labor productivity, which, as the evidence indicates, has increased. These productivity gains are not likely to be lost to any appreciable extent and hence, cost reductions resulting from them are generally permanent. However, now that a measure of prosperity has returned to the industry, the union members desire to win back some of what they gave up. This implies that labor costs are set to rise. This, in fact, has been exactly the case witnessed in recent labor accords in other companies. ASARCO reached an agreement with its workers which raised the base wage rate to a level above that earned by its workers prior to the company’s troubles (Wall Street Journal 1989d). Noranda’s (a significant Canadian copper producer) proposal to its
union for a 19 percent pay raise over the next three years and a 50 percent increase in pension benefits was rejected by 70 percent of the union membership (Wall Street Journal 1989b). Eventually, a slightly modified proposal was accepted. These are clear examples of likely labor cost increases which face Bingham Canyon when a new labor contract is negotiated.

An initial operating cost reduction of 20 percent was achieved as a result of this first prong in Kennecott's attack. The initial cost cutting program, which was completed in 1984, accounted for 10 percent of the reduction. The labor contract negotiated in 1986 accounted for an additional 5 percent. Finally, a further 5 percent reduction off the previous operating level resulted when the company restarted operations in 1987 (most of this is part of a residual factor which is very difficult to explain and hence to classify) (BP Minerals 1988). From the analysis above, it is clear that only a portion of this 20 percent reduction will prove to be permanent.

3.1.2 Second Prong

The second prong called for the study and the eventual implementation of a modernization program at Bingham Canyon. The outdated mining and processing facilities required major capital expenditures to reposition the mine as a viable world competitor. This modernization program
was slated to cost upwards of $400 million, a bold move anytime but especially so at a time when profits from copper mining were rare.

The program focused on the transportation and on the handling of the ore (rather than on the mining itself). As part of this focus came new in-pit crushing facilities, a conveyor system (to replace the outmoded and inefficient rail and track haulage system), new ore storage areas, a revamped concentrator, and new ore and tailings pipelines. This modernization effort has increased the scale of the facilities that transport and process copper ore. The result has been less maintenance, fewer employees (as documented earlier), and improved metal recoveries (BP Minerals 1988).

The cost reductions brought about in this manner are quite clearly permanent, and, just as significantly, they fall into the first category of reductions having no side effects. Their impact has been great, contributing approximately half of the overall operating cost reduction to the efforts which "saved" Bingham Canyon (BP Minerals 1988). This point harkens back to the distinction made between total and operating costs (or brownfield versus redfield costs). Once that capital has been spent, that cost is treated as sunk and it is thus irrelevant to an operating decision.
3.1.3 Third Prong

The third aspect of the strategy to reduce costs is less central to this study. Kennecott embarked on a major exploration program to locate other minerals (primarily gold) at Bingham Canyon. The mining of such minerals allows byproduct credits to be considered in the costs of copper mining. The amount of these credits fluctuates with changing commodity prices and such credits are really not an underlying factor in the determination of production costs. Nonetheless, these credits are vital to the strategy employed by Kennecott at the byproduct-rich Bingham Canyon operation.

The results achieved by this aspect are generally included with the reductions in cost which resulted from the modernization program. As indicated earlier, the magnitude of these reductions will fluctuate with the amounts of credits earned. Nonetheless, they are permanent (albeit uncontrollable) reductions, and they too are properly classified by the first type of cost reduction.

The overall cost reductions achieved at Bingham Canyon have enabled the operation once again to be recognized as the leading domestic copper producer. The unit costs of copper production have been reduced by a total of 40 percent from their level in 1980. This reduction, in nominal dollar terms, has been achieved despite
considerable inflation during the same time period (BP Minerals 1988).

The modernization program clearly resulted in permanent operating cost reductions (brought about, though, under the burden of a heavy capital expense). Some, and all indications point to a large percentage, of the remaining reduction clearly was achieved by methods such as highgrading, labor concessions, and so on that cannot be placed unequivocally into the first area of permanent cost reductions with no deleterious side effects. This suggests that up to one-half but more likely somewhere between one-fifth and one-tenth of the operating cost reduction achieved at Bingham Canyon may not be permanent. Table 3.2 presents a spectrum into which these methods fall; thereby highlighting the relative magnitude of each. In addition, Table 3.3 classifies these methods (and those attempted at the other case studies) into the three categories of cost reduction.

3.2 The Bagdad Operation

Another significant domestic copper producer is the Bagdad mine, located in Arizona and owned and operated by Cyprus Minerals. This company has greatly expanded its copper output in recent years, primarily through acquisitions. Its output is expected to exceed 600 million
Table 3.2

Spectrum of Witnessed Cost Reductions

<table>
<thead>
<tr>
<th>Percentage*</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational Factors:</td>
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<tr>
<td>Ore grade</td>
<td>BC</td>
<td></td>
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<td></td>
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<tr>
<td>Stripping ratio</td>
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<tr>
<td>Ore blending</td>
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<td>Blasting</td>
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<tr>
<td>Ore transportation</td>
<td>BC</td>
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<td>Other</td>
<td>B</td>
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<tr>
<td>Labor:</td>
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<td></td>
</tr>
<tr>
<td>Wages</td>
<td>BC</td>
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<tr>
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<tr>
<td>Equipment</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>B</td>
<td></td>
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</tr>
</tbody>
</table>

BC = Bingham Canyon  
B = Bagdad

**Note** The Henderson mine has been omitted for the reasons discussed in the text as well as for the fact that this operation mines a different commodity from the other two and hence may not be directly comparable.

* Keep in mind that these percentages are off of different bases; i.e. a 40 percent "base" at Bingham Canyon and a 35 percent "base" at Bagdad.
### Table 3.3

**Classification of the Primary Cost Reduction Methods**

<table>
<thead>
<tr>
<th>Category</th>
<th>Bingham Canyon:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i. Mine plan -</td>
</tr>
<tr>
<td></td>
<td>ore grade I</td>
</tr>
<tr>
<td></td>
<td>stripping ratio I</td>
</tr>
<tr>
<td></td>
<td>ii. Labor -</td>
</tr>
<tr>
<td></td>
<td>wages and benefits II</td>
</tr>
<tr>
<td></td>
<td>productivity I</td>
</tr>
<tr>
<td></td>
<td>iii. Restarted operations I, II, III</td>
</tr>
<tr>
<td></td>
<td>iv. Ore handling I</td>
</tr>
<tr>
<td></td>
<td>v. Processing I</td>
</tr>
<tr>
<td></td>
<td>vi. Byproduct recovery I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Bagdad:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i. Contract renegotiation I, III</td>
</tr>
<tr>
<td></td>
<td>ii. Ore blending, blasting, EGC, DPO I</td>
</tr>
<tr>
<td></td>
<td>iii. Equipment I</td>
</tr>
<tr>
<td></td>
<td>iv. Maintenance I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Henderson:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i. Power management system I</td>
</tr>
<tr>
<td></td>
<td>ii. Supplies and Equipment I, II</td>
</tr>
<tr>
<td></td>
<td>iii. Maintenance I</td>
</tr>
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<td></td>
<td>iv. Mining method I, II</td>
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<tr>
<td></td>
<td>v. Labor -</td>
</tr>
<tr>
<td></td>
<td>scheduling I, II, III</td>
</tr>
<tr>
<td></td>
<td>reductions I, II, III</td>
</tr>
</tbody>
</table>

1 This refers to the three categories of cost reduction:
   I. Permanent
   II. Permanent, with side effects
   III. Temporary
pounds in 1989 versus only 174 million in 1985, thus making
Cyprus the second largest domestic copper producer (second
only to Phelps Dodge).

Over the same period, output at the Bagdad operation
has increased from 167 to over 220 million pounds per annum
(Cyprus Minerals Company 1985-1989). The latest expansion
at Bagdad, a $21 million expansion of the mill that
processes copper sulfide ore, is expected to reduce
production costs through added processing capacity and
improved productivity.

Copper deposits are classified into three major types:
porphyry, sedimentary, and massive sulfide. The American
southwest porphyry copper district (into which the Bagdad
deposit is placed) constitutes the second largest
concentration of world copper (after that in Chile). At
Bagdad, Cyprus mines copper sulfide ore and a small amount
of oxide ore. The result is the production of copper with
both molybdenum and silver byproducts. The operation
consists of an open-pit mine, a 55,000 ton per day sulfide
ore concentrator producing copper concentrates and
molybdenum concentrates, and an oxide ore heap leaching
system with a solvent extraction electrowinning plant
producing copper cathode.

Cyprus Minerals Company was spun off from Amoco
Corporation in July 1985. At that time the Bagdad mine was
the company's only copper producer, and economically the mine was marginal at best. The mine was closed and supervisors went to work reviewing every step taken in the production of copper. Eventually the facility was reopened with 60 percent of the original work force producing the same amount of copper. Production costs were whittled 35 percent and the mine continued to produce throughout the copper market slump. Production costs were continually reduced and currently, with the relatively high copper price, the mine and the company are enjoying record profits.

The analysis of the Bagdad operation which follows is attributable to personal interviews with various company personnel on-site.

3.2.1 First Half of the Reduction

The cost reduction at Bagdad of roughly 30 cents per pound following 1985 was achieved in equal measure by two changes (consult Table 3.4 for a depiction of these changes). Approximately one-half of this reduction resulted from a renegotiation of the power and smelting contracts. It is well understood that these inputs, most obviously power, are extremely large and important for a mining operation. In the case of the power contract, this was restructured into the form of an "interruptible service" contract (along the lines of that described later
Table 3.4

Primary Cost Reductions at Bagdad

I. Total Operating Cost Decline\(^1\) \(35\%\) 30c/lb (1984-1989)

II. Cost Reductions

A. Renegotiation of the power and smelting contracts \(17.5\%\)^2

B. System of operation \(17.5\%\)
   - ore blending \(4.4\)
   - blasting technique \(1.4\)
   - economic grade control \(2.6\)
   - dual process ore \(2.1\)
   - equipment usage \(2.3\)
   - maintenance \(3.5\)
   - other (labor, et. al.) \(1.2\)

III. Total (A+B) \(35\%\) 30c/lb

Note These are strictly this author’s estimates, based upon personal discussions and company literature. They are meant to be used for comparative analysis and not as absolute figures. These are not official company numbers.

\(^1\) Nominal dollars.

\(^2\) These "percentages" and those which follow below are percentage point contributions to the overall reduction detailed above.
at the Henderson operation). Power costs are markedly reduced with such a contract and the few requirements for a constant power flow (flotation cells, etc.) are maintained by an on-site generator. Power interruptions average a very manageable two brief outages per month. The new smelting contracts with various other copper companies are each individually structured but they all highlight cost considerations as well as output goals. The result, as expected, is lower and more manageable unit production costs. There has been some speculation, however, that these new lower toll charges may be revised upwards. Therefore the bulk of the reductions attributable to the new contacts (i.e. the power contracts) will be permanent; however, some (those resulting from the revised smelting contracts) may not be.

3.2.2 Second Half of the Reduction

The final half of the reduction was achieved by a change in the system of operation at the mine. Such changes are most attributable to the mine department. Perhaps the most instrumental change, however, resulted when a standard milling procedure was enhanced by better control of the overall mining process. The specific change was a blending of ore before it entered the crusher. In this manner ore heavy in clay material or talc was no longer a problem in plugging the crusher or the screens. A
secondary benefit was that this change allowed autogenous grinding in the mills to be possible. This type of grinding is unique in the milling of porphyry copper deposits - normally ball mills are required (the difference being that autogenous grinding circuits rely on the churning ore to crush itself while ball mills rely on steel balls to accomplish the grinding). In addition to the obvious lower usage of external grinding media, autogenous grinding facilities use less power than their alternatives. This is the case since the heavy ball distorts the weight equilibrium of the rotating mill.

As indicated, this milling improvement was made possible by improved mining techniques. Detailed blasting records are now maintained. Holes are continually being drilled and blasted on a 9" x 26' pattern. In addition to the above described milling changes that this better understanding permits, such records increase the powder factor or loading ratio (the number of tons of rock blasted per pound of explosive) at the mine and allowed additional mining improvements.

One such improvement goes by the acronym EGC, or more formally, economic grade control. This is, in effect, a variable cutoff grade system and it requires economic analysis on every blast hole to be successful. Such a system allows an optimal cutoff grade to be determined and
one which, as economic conditions dictate, can vary over time.

A second process goes by the acronym DPO, or dual process ore. This involves marginal ore (in terms of grade) which previously was classified somewhere in the range between mill ore, leach ore, and waste. The process entails the construction of leach dumps near the crusher. The ore is placed onto these dumps, it is then treated with acid, and finally it is sent through the conventional mill. Although the DPO must be handled twice, the enhanced recoveries more than compensate in the form of lower unit costs.

These improvements in mining have clearly reduced production costs. Interestingly, the mine was able to show a profit because of these (and additional) changes when the price of copper was at 57 cents per pound - now, as indicated earlier, this price is much higher. More importantly, these reductions should be permanent and can be placed into the first category of sustainable reductions having no deleterious side effects.

An important contributor to production costs, especially at a large mine, concerns the use and handling of equipment. Previously, this vital function was mismanaged and, as a result, costs suffered. After the mine was reopened, two shovels were eliminated, 10 of 31
trucks were idled, and the work force was cut by one-third. Despite these cuts the mine is operating at full strength and, as the increased throughput indicates, "full strength" is now much greater.

A substantial reason for this is an improved maintenance component. The maintenance system is in the process of being computerized and this has permitted an improved usage of equipment. A tangible example is seen in the mill where a 95.5 percent availability rate (much higher than normal) is a direct result of this improved maintenance system. The most obvious facet of this system, however, is illustrated by the repairing and the rebuilding of mine equipment. The new system employs "glider kits" in which essentially everything is rebuilt except the frame. The cost savings have been dramatic - a "new" (i.e. rebuilt) 170-ton truck costs only $260,000 versus over $900,000 for a new truck and in many cases the original warranty still applies. Such successes, and a strong commitment to better communication, are making this new emphasis on maintenance feasible.

Improvements in the maintenance system have resulted in cost reductions which should prove to be sustainable. A continued cognizance of the importance of the maintenance function (illustrated in a clear fashion by its prominence in the budget) will ensure that this results.
The reduction in the labor force at Bagdad came from both management and labor. It is well known that the outflow of money can be reduced by dropping a shift. The changes went beyond this, however, and were concentrated on the scheduling of manhours worked. The objectives were to reduce overtime and to curtail the short changes between shifts (every shift change requires an estimated 50-60 minutes) when no productive mining work is accomplished. A shift schedule (six days on, two off; seven on, four off; seven on, two off) was implemented with this in mind. Currently the mine is experimenting with trial 12-hour shifts to see whether improvements can be realized. The results, which show up in labor productivity, have been less time worked with more ore moved.

In addition, a vigorous program of cross-training allows the opportunity (the program is entirely voluntary; however, participation is high) for workers to learn more than one trade. The result is that now many positions can be filled by in-house transfers with less dependence on outside hirings (this, of course, reduces the necessity of expensive company training and on-the-job start-up requirements). The nonunion status at Bagdad makes such a program more feasible. The program is strengthened by classroom training, which the company provides. And finally, all employees are eligible for a bonus in addition
to their wage which is tied to profitability as well as to production goals.

It is difficult to envision these labor changes resulting in anything less than permanent cost reductions. They have and they should continue to result in increased productivity, thus producing sustainable reductions of the first type.

These are only some of the most visible methods which successfully reduced costs at Bagdad. Others include an increased byproduct recovery of almost 20 percent which, due to the assignment of cost, is usually a significant profit enhancer; a focus on power management, including shifts to greater power usage during off-peak periods; heavier reliance on competitive bids for most goods; and the maintenance of stripping ratios. All of the above simply represent good management decisions.

The mill expansion at the Bagdad facility will increase capacity by 22 percent, or 20,000 tons per year, to 110,000 tons per year (Cyprus Minerals Company 1989). The $21 million capital cost will reduce the mine costs by 3 to 4 cents a pound, improve productivity, and expand capacity. Previous expansions anticipated additional growth and existing buildings and infrastructure will accommodate this mill expansion. Construction is expected to take 12 months (commencing May 1, 1989) and these cost reductions will
come into effect over this time period.

The project will increase grinding capacity 14,000 tons per day to 71,000 tons without requiring significant changes at the mine. The cost reduction, primarily achieved through additional economies of scale, alone should save Cyprus $6.3 million per year. At a selling price for copper of a dollar a pound, the added capacity would earn Cyprus an estimated $17 million (pretax). Including both cost saving and expansion, this investment should realize an 11-month payback at the aforementioned copper price (Atwell 1989). Although the concept of payback period can be misleading as an indicator of economic differences in investment alternatives, the calculation is extremely useful when conducting financial analyses (Stermole and Stermole 1987). With this in mind, this investment by Cyprus is justified.

Such an investment is a clear example of brownfield costs. As stated earlier, for such investments total unit costs are relevant. These include the cost of capital, additional fixed costs, and the operating costs. The $21 million capital expense is perhaps only one-half the cost for a similar capacity virgin grinding facility. Thus, capital costs, in addition to operating costs, will be favorably impacted. The cost reduction achieved by such an expansion will be permanent and it should not have any
unanticipated side effects.

The above examples detail the principal methods employed by the Bagdad operation in its successful curtailment of production costs (a summary of these methods and their impacts is presented in Table 3.4 - the mill expansion at Bagdad is not included because the cost reductions have not been realized yet). This curtailment has been successful in the immediate term, which has witnessed an almost 30 percent reduction, and into the future as well, since the bulk of these reductions will be sustainable. Both Tables 3.2 and 3.3 are again relevant.

3.3 The Henderson Operation

Henderson is a molybdenum mine located in Empire, Colorado, owned and operated by AMAX, Inc. through its wholly-owned subsidiary, the Climax Metals Company. Molybdenum is a metallic element whose versatility has assured it a significant role in modern technology and thus, throughout industry. It is used principally as an alloying agent in steels, cast irons, and superalloys, either by itself or in combination with other alloymetals. It also finds significant use as a refractory metal and in numerous chemical applications (U.S. Bureau of Mines 1988).

Henderson is a large underground molybdenite mine, employing a continuous panel-caving mining system. The
massive (230 million short tons) (Jensen N.d.) porphyry orebody is well suited to this mining method. Production start-up at this mine occurred in mid-1976. The period of 1976-1981 was one of rapid growth in production levels, manpower, and equipment in response to prevailing market conditions for molybdenum during that time. With a general decline in the sales of molybdenum in the early 1980s, Henderson was forced to react by adjusting production levels frequently; sometimes up but most often down. Accompanying these changes were manpower reductions and a concentrated effort to increase efficiencies and to reduce production costs.

The early 1980s were a difficult period for most mineral producers. Molybdenum is one of those all too familiar commodities whose price (both in real and nominal terms) plummeted throughout this period. Henderson, producing 50 million pounds per year of molybdenum, witnessed its considerable profit margin disappear. This led in mid-1982 to the mine's initial shutdown, albeit only a temporary one of two months. Then, in the third quarter of that same year, the mine was shut down again, this time for 15 months.

During this second shutdown, Henderson initiated a major program to identify potential areas of cost reduction. For the mine to operate, let alone to compete,
such reductions were necessary. At present, total operating costs have been reduced by 70 percent and the mine is producing 41 million pounds a year of molybdenum. The significant methods of cost reduction are highlighted in Table 3.5.

3.3.1 Power Management System

This cost reduction program initially developed a power management system. This was not surprising given the knowledge that AMAX has always been extremely energy conscious, perhaps the result of its direct involvement in the natural resource industry. In an era when energy costs have escalated dramatically and when energy availability in the required forms and quantities is increasingly uncertain, the substantial power requirements demanded by a mining operation are important factors in the determination of both total and operating costs. AMAX recognized this and installed many energy saving devices in the initial construction of the mine. Because of topographic and environmental constraints, the Henderson mill and concentrator are located 24 km (15 mi) from the mine on the west side of the Continental Divide. All ore from the mine is transported to the mill by an electrified rail haulage system. Over 15 km of the trip is underground through a double-track tunnel. The loaded rail cars require great amounts of energy to traverse uphill.
Table 3.5

Primary Cost Reductions at Henderson

I. Total Operating Cost Decline\(^1\)  \hspace{1cm} 70\% \hspace{1cm} 4.50/lb
(1982-1987)

II. Cost Reductions

A. Decline in labor compensation  \hspace{1cm} 0\%\(^2\)

B. Increase in output/employee  \hspace{1cm} 70\%
   
      i. Power management system
         a. power bill
         b. renegotiation of power contract
         c. heating and ventilation
   
      ii. Supplies
   
      iii. Maintenance
   
      iv. Operational - mining method
   
      v. Labor
         a. work scheduling
         b. employee reductions

IV. Total (A+B)  \hspace{1cm} 70\% \hspace{1cm} 4.50/lb

Note: These are this author’s estimates. They are meant to be used for comparative analysis and not as absolute figures. These are not official company numbers.

\(^1\) Nominal dollars.

\(^2\) These "percentages" and those which follow are percentage point contributions to the overall reduction detailed above.
Conversely, the unladen cars travelling downhill do not have the same energy requirements. Thus, a system was developed whereby the trains travelling downhill would regenerate and store power and, at appropriate times, transfer this power to those moving uphill. Such a system is indicative of the energy consciousness that went into the development of the Henderson mine.

In light of this energy awareness, it is not surprising that the initial cost reduction plans were centered around the development of a power management system. Much of this system is not ingenious. For instance, unneeded outside lighting has been shut off and underground ventilation to unused parts of the mine has been curtailed. The power bill at the mine is now running $1 million a month versus a previously estimated $2 million a month. In addition, shutdown costs (the mine has been closed temporarily a number of times since 1982) have been reduced significantly.

The power management system also entailed a renegotiation of the contract to provide electricity to the mine. This contract was, and it still is, an "interruptible service" contract but the terms have been restructured. Previously, service could be halted because of capacity or economic constraints (economic constraints come into play when it becomes economical for the power
provider to furnish service elsewhere). Opting to continue power service (which generally is necessary at a mining operation) was extremely costly. The new contract allows only power interruptions which are the result of capacity overloads. This new arrangement is much more manageable and from the mine’s perspective it has been cost effective. Clearly, reductions of this type can be placed into the first category of permanent cost reductions with no deleterious side effects. The following principal focuses of this power management system can also be classified as such.

3.3.2 Heating and Ventilation

A major focus of this system was directed towards heating and ventilation. Being a mine situated in the Rocky Mountains, a need for heat was always present. Greater control in this area was necessary and the power management system implemented a scheme of manual observation and operation of portal heaters serving the haulage tunnel. As a result of this operation (simply switching off the heaters whenever the air becomes too warm) an estimated $100,000 a year was saved. The magnitude and the relative ease of these savings has led to the development of a sophisticated ventilation and air heating process that has reduced these costs by over 80 percent, a very critical savings in the competitive
molybdenum marketplace (Keskimaki N.d.). The rudiments of this system were put into place when the mine was developed and improvements have since been implemented.

The present mine ventilation system utilizes three sources of fresh air and two exhausts. The primary fresh-air intake is No. 3 shaft. An airflow of 755 m$^3$/s (1.6 x 10$^6$ cfm) is supplied to this shaft and distributed within the mine by means of fresh-air distribution vents connected to production and development levels by raises.

A secondary source of fresh-air (165 m$^3$/s) is provided throughout the mine by No. 2 shaft, which is also the primary man and material access. Downcast airflow in this shaft is induced by a pressure differential produced by the fans in the system such that net intake and exhaust volumes are identical. Such an arrangement is not only less expensive to operate but also allows for expansion at a reduced cost (both operating and capital) by ensuring that the system is always in balance.

Exhaust air is moved from the various working levels through connecting raises to collection levels which return the air to No. 1 shaft. Three exhaust fans are located at the collar of this shaft and these support a flow of 755 m$^3$/s. In addition, an airflow of 71 m$^3$/s is exhausted from the intake distribution level via the haulage tunnel at No. 4 shaft. The flows handled by this system were
structured with cost and safety as primary concerns.

The necessary heating of the mine is transported through this ventilation system and this arrangement also exhibits a degree of cost effectiveness. In the early design phase of No. 3 shaft it was recognized that air heating would be required to maintain underground temperatures above 0°C (32°F). The No. 3 shaft heat plant was put into operation and represents an economic alternative to plants that rely on conventional energy sources because the heat source is essentially free. The primary heat source is the 29.4°C water which is pumped from the mine at No. 2 shaft. The geothermal gradient at Henderson is such that at the lowest mine level the virgin rock temperatures approach 32.2°C. Mine water must be cooled in any case because of stringent stream discharge temperature requirements (making heat generation in a sense "free").

Warm mine water is pumped from the No. 2 shaft to an insulated 110,000 gallon tank from which it flows by gravity to the No. 3 shaft heat plant. The water is strained and passed through a series of exchangers and then discharged. The heat is transferred to a glycol solution. Each heat exchanger is equipped with a fan to compensate for the additional air resistance that such a system generates. By design, the mine water enters the plant at
26.7°C and is discharged at 4.4°C. At a water flow of 1,000 gallons per minute, energy is transferred to the glycol solution at the rate of \(20 \times 10^6\) BTU/h. This heat will raise the temperature of the air in the mine by 9.4°C (Jensen N.d.). Although the use of mine water as a heat source is not novel in the mining industry its use at the Henderson mine exhibits an energy awareness and ultimately a cost awareness. The viability and the cost reductions achieved by such a glycol heat exchanger mine ventilation system have been verified and are given added credence by similar installments in other mines (Echo Bay Mines Ltd. 1989).

Helpful as it is, the system at Henderson does not always provide sufficient heat in the cold Rocky Mountain environment. Supplemental heat is required and is provided by a hot-water boiler fueled by waste oil collected throughout the year and stored in a 47,000 gallon tank adjacent to the heat plant. The oil, with a heat value of 150,000 BTU/gallon, is generated in a quantity of 40,000 gallons a year and thus represents a significant energy source. In previous years the Henderson operation sold this used motor and lubricating oil to a commercial recycling company. With the changing energy picture, the oil is now of greater value as a fuel, with relatively minor amounts of filtration being the only treatment
required. This alternative use of spent oil solves a problem of waste management and is also a cost effective method of reducing operating expenses.

The power management system has clearly reduced costs in a permanent fashion. The structure of the Henderson operation (i.e., always maintaining the system in balance) and the evident planning that went into this phase of its construction insures that, in addition to operating cost reductions, capital expenditures necessitated by this system are minimized. As indicated earlier, annual mine heating and ventilation operating costs are believed to have been reduced by 80 percent. It is difficult to separate the two, given the nature of the operating system. In any event the heating system throughout the mine is an integral part of the ventilation system and costs, both operating and capital, are in many cases indistinguishable (just as in the case of byproduct mineral production).

3.3.3 Supplies and Equipment

The Henderson mine also reduced costs by reassessing its supply and equipment needs. As all are aware, such an emphasis need not be on the least expensive supplies but rather on the most cost effective. In this regard the theories concerning just-in-time inventory were implemented (to a limited extent), as was a major effort on fleet
control. This new control (established by nothing more than an increased focus) made it possible to reduce the mining fleet from 29 units to 10 units (Jensen 1989). In addition to obvious capital cost savings and lowered maintenance requirements, the reduction has increased annual cash flows. Trimming the fat has been instrumental in the overall cost reduction at the Henderson complex. Eliminating the fat will obviously have some side effects. The mine management believes that these side effects will not be negative, but, if they are, their effects will be minimal. Nonetheless, without specific knowledge as to what these side effects may be or as to what extent they may result, such reductions may at least in part belong in the second category of cost reductions, which do have some adverse effects.

3.3.4 Maintenance

A substantive program has been developed to optimize maintenance procedures at the Henderson operation. The high degree of mechanization at Henderson, and the accompanying high maintenance costs, focused increased attention on the maintenance function as a cost center with the potential for vast reductions. The value of preventive maintenance as an alternative to breakdown or emergency repair is widely accepted. At the time of production start-up in July 1976, few people at Henderson had
experience with maintaining diesel-powered, rubber-tired equipment (such as used at Henderson) since AMAX's other underground operations relied primarily on rail and slusher technology. Therefore, a maintenance consultant was hired to establish the first formal preventive maintenance program.

Four separate preventive maintenance services, labeled A through D. These ranged from the most frequent, the so-called A-service consisting of a general inspection and greasing, to the D-service, a comprehensive inspection and testing of major component systems. Experience with this new program soon highlighted the following:

-the key to a successful preventive maintenance program is compliance by the operators to the agreed-upon schedule of work. This can be achieved only with full commitment by the highest level of management to the program (such a commitment is evident at Henderson);

-the D-service was taking longer and longer to complete because most identified problems were felt to require immediate attention before reactivating the equipment. In fact, the D-service was evolving into a minor rebuild in many cases.
The result of this experience led to the current program which modifies (the only substantive change being that the so-called C-service was incorporated into the other stages of service) the initial preventive maintenance program. Each operating department is responsible for bringing its equipment to the preventive maintenance service area at the designated date and time. Mainly as a result of the demonstrated success of these efforts towards reducing costs, compliance to the service schedule is now routinely close to or equal to 100 percent (Timmons and Jensen N.d.).

In order to minimize cost and to maximize maintenance effectiveness, the time interval between services is quite clearly the factor which needs to be optimized. Too frequent and/or unnecessary maintenance is costly and harmful. For example, air filters changed too frequently can expose the engine intake manifold to additional contaminants during the filter change itself (Timmons and Jensen N.d.). The program at Henderson recognizes this and attempts to balance the two conflicting effects.

The D-service, unique to the Henderson operation, is extremely costly in that typically several hundred maintenance man-hours are involved. The company determined (in an economic analysis designed to optimize) that the best interval for this comprehensive service was 2,000
hours.

The type of analysis undertaken is straightforward. It relies on a graphical comparison of the cost of the D-service with the benefits derived from it. Two costs, the cumulative routine cost per cumulative operating hour and the D-service cost per cumulative hour, and their sum are plotted (Figure 3.1 gives a visual interpretation of this). As the operating hours accumulate after the service, the routine cumulative cost per hour tends to increase, while the fixed D-service cost is spread over more hours, thereby reducing the service cost per hour. The minimum cost per hour is attained when the sum curve (total cost) bottoms out and begins to increase; this is the economic (optimal) time to perform another D-service and, as mentioned earlier, at the Henderson operation it is 2,000 hours (Timmons and Jensen N.d.).

At the core of any effective maintenance operation is access to timely and accurate information regarding equipment cost and performance. Those at the mine recognized this (and they also realized that the optimization process just described would be worthless without such access) and this is achieved through an on-line computer system, the present form of which was created in 1984 and improved upon since (Timmons and Jensen N.d.). The system maintains a master file with all
Figure 3.1

Economic Analysis of D-service Maintenance

the basic data necessary to identify the equipment. All equipment subject to preventive maintenance is in this system. Equipment components are input directly permitting component tracking and maintenance history. Thus it is possible to track viable components from one piece of equipment to another, and the system also can be used to determine the current location of spare components. This not only directs attention to areas where maintenance is required, it also provides records of prior maintenance completed and the overall availability of equipment. This equipment history is also invaluable in evaluating the results of changes in mining operations and equipment suitability.

Maintenance, especially at a large underground operation, is an extremely important cost center. The treatment of these costs has evolved over time at the Henderson operation into a very sophisticated process. The reductions in cost stemming from this process are permanent and some of the more important contributors to the overall reductions in cost experienced at Henderson.

3.3.5 Mining Method

Operating changes at Henderson have focused on the method of mining rather than on the ore being mined. The mine is a panel block-caving operation. This method of mining necessitates the construction of drawpoints for the
recovery of the ore. In all draw systems the spacing of drawpoints is instrumental in affecting the results. Close spacing requires more development work, but minimizes the tonnage of ore stranded on the sill after the stope is emptied and such a pattern maintains a more even work platform of broken muck in the stope. The converse is the case with wide spacing. Henderson has economized by spacing the needed drawpoints at 53-foot intervals instead of the previous 40-foot intervals. This move has been justified on production grounds - i.e., under the new spacing regimen, no production drop offs have occurred.

As all economists are (or should be) well aware, such a tradeoff demands an economic optimization (such as with the maintenance service problem). It is entirely possible that the optimal spacing at this mine will be different—larger or smaller—from the 53 feet chosen. Considerations of safety, upon which it is difficult to place economic worth, further complicate the decision. The spacing of drawpoints materially affects "cavability." If the process is not engineered correctly the cap of ore will form arches. From a safety standpoint these arches must not form over long distances for a long time. The formation of stable arches not only disrupts the caving operation, but very likely will cause air blast and concussion in the mine when these arches suddenly collapse. The classic example recounted in
the literature is the Urad molybdenum mine (located adjacent to the Henderson mine). An arch 300 x 400 ft in area formed over the entire mine and violently collapsed (Hartman 1987). Up until that time production had not been adversely affected by the spacing of drawpoints. This example indicates that cost reductions resulting from operational changes may be made without affecting production, but in the long run these reductions might become overshadowed by other events.

The cost reductions described immediately above are obviously permanent. However, they come with side effects that in the long run can make them illusory. The collapse of the Urad mine was extremely costly in terms of the extensive property damage that it caused and the loss of production that resulted. The same result could conceivably occur at Henderson.

3.3.6 Labor

Labor costs depend upon wage rates and labor productivity (manhours per ton). The management stressed that at no time were wages at Henderson cut. This is true in a nominal sense; however, wages did not rise with cost-of-living increases, so that when measured in real terms, wages fell). New technology has not been significant in molybdenum mining (to the same extent, for example, as was the case in copper mining). Rather cost
reductions have been achieved by the elimination of, or reduction in, certain job activities. For instance, at one time 24 guards were employed at the mine. Today none are. The number of safety engineers has been reduced from 59 to 5 (incidentally, the mine now boasts a better safety record). An example with greater long run implications is the reduction in the engineering department from roughly 100 employees to only 12 at present (Jensen 1989). These, and similar reductions, were more easily made because the mine employs non-union labor.

The company pays a bonus to its employees based upon coming in below budget rather than upon a production target. Thus the employees are attuned to making money. Such an outlook harkens back to the previous example of an expanded view towards mining money rather than mining ore.

It is difficult to categorize these labor reductions. They were certainly made by the company with the belief that they would be permanent reductions. However, some may turn out to be temporary. Further mining may require additional engineers. At best we can only note that certain labor reductions may not be permanent and in time, without reinstatements, competitiveness may be duly affected.

Methods of cost reduction at the mine have included conventional austerity programs, innovative operating
improvements, and creative work schedules. Traditionally, most mines have been operated 24 hours a day, seven days a week. High product demand coupled with low unit costs and rapid return on capital investment have motivated management to operate plants continuously and at maximum rates of production. Also, the milling-flotation circuits operate more efficiently at steady state, without start-ups and shutdowns. However, when product demand dictates a reduction in metal produced (as occurred at Henderson following 1980), alternatives must be considered. These include:

(1) operate continuously at low rates of production;
(2) operate continuously only a portion of the available equipment;
(3) operate only part of the time.

Options 1 and 2 may reduce manpower slightly, but both require four operating crews. Option 3 was selected at Henderson because only three crews are required.

A noncontinuous operating schedule must consider wage premiums such as overtime and weekend pay and, in Colorado, time-of-day power billing. Public Service Company of Colorado has various charges for both usage and demand for
peak, off-peak, and shoulder-peak billing periods.
Following thorough evaluation of the above factors, a 7-6-7 operating schedule was adopted. Over a 28-day period, the mill operates seven days, off two, operates six days, off two, and operates seven days, off four. This schedule allows for three operating weekends per month (off-peak power), no scheduled overtime, and three start-ups/shutdowns per month. The reduced power costs far outweigh weekend pay increases. Some maintenance personnel work an offset 7-6-7 schedule to accomplish major mill maintenance work during nonoperating hours. Mill availability has increased from 92 to 97 percent with only one percent of downtime attributable to mill start-ups/shutdowns (Hegerle and Roop 1986). Adverse performance caused by frequent start-ups/shutdowns was anticipated. However, with practice, both are now accomplished quickly and routinely with nearly undetectable negative effects in metal recovery, product quality, or grinding efficiency.

The reductions attributable to more efficient scheduling is only permanent over a range of production. This range necessarily has an upper limit which, at some point, the buoyant molybdenum market may dictate as too low. Hence the down-scaled operation at Henderson, while efficient at the current level, may require expansion.
This expansion will most likely be accompanied by greater operating costs per unit of output. Capital costs may increase as well.

The above presentation details the primary efforts responsible for the 70 percent reduction in operating costs effected at the Henderson operation (over the relevant time period). An attempt was made to categorize each into one of the three areas of cost reduction. Unfortunately it proved impossible to divide up the total reduction and assign percentages to each category for the following reasons:

(1) much like a jigsaw puzzle, the overall 70 percent reduction is comprised of a number of interlocking pieces that individually have very little merit. Only when these pieces are combined is the true effect felt;

(2) much of the data is proprietary, and, while it probably exists, it is not publicly available.

The above reasons, especially the first, were emphasized by company personnel. Even given this caveat this exercise has been instructive.
Chapter 4
CONCLUSIONS

The concern that the cost reductions achieved by domestic mineral producers are merely short term or are likely to undermine the long-run viability of the industry appears largely unfounded. All three case studies analyzed in this thesis showed fairly clear-cut results in terms of the cost reductions achieved. The Bingham Canyon operation whittled operating costs 40 percent over the 1985-1989 period. Bagdad, another significant copper producer, saw its operating costs fall 35 percent (over the 1984-1989 period). The previously alluded to studies of the copper industry by the U.S. Bureau of Mines (Porter and Thomas 1988) concluded that a similar (36 percent) reduction occurred over the 1981-1986 period in domestic copper production costs. Thus, in this very critical sense, these two mines appear typical (it must be kept in mind that in other regards these two mines may be atypical. For example, neither employs to any great extent the new leaching technology which is becoming more prevalent throughout the copper industry). The Henderson operation experienced a much larger (70 percent) reduction in operating costs, however, this operation mines a different
commodity. This congruence with the published literature lends credence to these findings and should allay some of the misgivings concerning the generalities drawn from this study.

The evidence collected suggests that most of the operating cost reductions achieved at the two copper mines will be permanent and were achieved without serious side effects on the long-run economic viability of the industry (probably 80 percent or more at both Bingham Canyon and Bagdad).

These findings have important ramifications for the domestic mining industry. Specifically, they suggest that the recently won gains in competitiveness are "real" and not transitory.

4.1 Profit Maximization?

This thesis has highlighted a number of additional areas which deserve further consideration. The concept of profit maximization is the backbone of conventional economic theory, yet each of the three case studies considered in this thesis suggests that mining companies are not always profit maximizers. Cost reductions as large as those documented in the three case studies raise the obvious question, "Are not mining companies profit maximizers?" Certainly some reductions, for example those
associated with the introduction of new technology, are made possible only with the passage of time and thus are consistent with profit maximization. It is possible to theorize how other reductions may be consistent with this doctrine: for example, concessions on wage rates by organized labor are much more likely when a mine is threatened with closure.

That being understood, it does not seem plausible for the magnitudes of the reductions achieved in these three case studies to coexist with this doctrine. For all firms, reducing unit costs clearly increases profits, yet in these examples it took crises to galvanize the companies into action. This simple fact seems to indicate that these operations may not have been operated in a profit maximizing fashion.

Fortunately, research has provided a number of alternatives to this basic economic doctrine. A thorough review of this work is beyond the scope of this thesis; in this regard, however, recent researchers have developed a number of supplemental concepts to augment the doctrine of profit maximization. These include concepts which highlight the maximization of a mine's life, sales (revenue) maximization, "satisficing," among others. Perhaps the case studies considered in this thesis will prove fertile ground to these researchers.
In addition, all three case studies were of mines which constituted only limited portions in an overall corporate structure (re the Henderson mine and AMAX Inc.). This means that there may exist a profit maximizing function for the corporation as a whole which may not appear to be profit maximizing for the mine itself. If this is, in fact, the case, the situation is further complicated.

It is apparent that further work on this subject is called for. Many examples, for instance the juggling of work schedules at both the Bingham Canyon and the Bagdad operations, quite clearly (for the simple reason that profit maximization implies cost minimization) call into question the applicability of the profit maximization assumption. It would appear that if those within mineral economics continue to make this assumption, better incorporation and acknowledgment of this recent research is justified.

4.2 Suggestions for Further Research

This thesis, through its case studies, has highlighted a number of obvious areas which warrant further study. Each of the three case studies analyzed involves the mining of a massive orebody. This type of orebody permits cost reductions to be achieved rather easily by the manipulation of ore grade. Although this will result in a shorter mine
life, the concept of net present value discounts this future diminishment to such an extent that, to a large mine, it may, in fact, be inconsequential. A simple solution would be a similar analysis conducted on a mine with a small orebody. In this respect, this thesis may be biased by choosing a non-representative sample in terms of case studies (although in respect to copper mining it appears that this bias may be small).

Another area demanding further research and one in which data certainly exists concerns technology. As mentioned, two of the case studies involve the mining of copper. In the copper industry the recent advent of leaching extraction methods has had a sizable impact on production costs (this impact has been actual in some cases and only potential in others). Other mineral commodities have not all undergone such significant changes during the period in question. A glaring example concerns aluminum in which its stages of production have remained largely unchanged since the metal first became available in commercial quantities about a hundred years ago (U.S. Bureau of Mines 1985). This provides an obvious counter to copper production in which significant technological changes (not merely refinements) have taken place. Again it could be argued that a bias exists.
4.3 Summary

The line of reasoning used throughout this thesis has been quite straightforward. The methods outlined in the preceding paragraphs isolate specific cost reduction efforts and the relevance of each in an overall cost reduction program. These, and similar methods, can be utilized for many of the cost reduction endeavors identified throughout this paper. By the application of the classification system developed (i.e., the three types of cost reduction), this analysis has allayed much of the concern regarding the sustainability of many of the recent cost reductions achieved by domestic mineral producers and thus those apprehensions surrounding their competitive gains. This suggests that the health of the industry is intact, perhaps to a greater degree than most believe. Furthermore, an avenue for additional research has been provided. The logical move is to continue this study in the pursuit of a better understanding of the U.S. mining industry.
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