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ECONOMICS OF MINE PLANNING

AND EQUIPMENT SELECTION - PART 1

Dr. Ian Runge
Founder, Runge Ltd

This newsletter is the first of two articles written by Ian Runge, founder of Runge Limited, on the fundamental economics of mining decisions. In this article, he looks at marginal costs, and suggests that some of our investment choices for start-up of new mines might be incorrect – if we apply simple pit optimization criteria, the "optimum" production rates derived from these models may be too high. The second article, which will appear in the May issue of RPMGlobal Perspectives, extends this example and also looks at the economics of reserve estimation. The articles are an edited version of a keynote address presented by Dr. Runge at the International Mine Planning and Equipment Selection Symposium in 2010.

Introduction

Formulating and making decisions has never been easy in the mining industry –there is always a paucity of information, and commonly there is insufficient time to analyze something thoroughly. Nevertheless, with the computer tools now available, analysis of even day-to-day decision choices using real economic numbers is becoming easier. But use of these tools also introduces risk. In the"good old days" (was there ever

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such a thing?) the decision-maker was probably an experienced practitioner, whereas when the work is done inside a computer program the basic economic calculations and data inputs can easily become buried and used without due consideration. This article examines the economics that should underpin the logic in these systems.

In my book Mining Economics and Strategy the notion of marginal cost gets frequent mention. It is one of the most important concepts in economics. To operate mines efficiently – optimally – then "marginal cost" and its partner, "marginal revenue" have to take center stage in our calculations. There is no "optimum" mine plan without consideration of marginal costs. Equipment selection cannot be"optimized" without consideration of marginal costs. This next section reviews a simple marginal cost example and provides the foundation for the following section which extends the concept to look at alternative life-of-mine production rates and mine development decisions.

Simple Marginal Cost Example

Every production process involves fixed and variable costs. As production expands, the fixed costs are unchanged, so the average per-unit cost of production attributable to this component declines. If this were the only trend, then the highest production case would be the lowest overall cost of production. However, few production processes work this way. The fixed parts of the process can only service a limited range of variable parts. Trucks interfere with each other if there are too many of them in a confined space. Bigger mines are also deeper, and each increment of production means longer haulage distances. As production expands the efficiency of the system declines. Each increment of production incurs variable costs that are proportionately more than the variable costs incurred in the previous increment.

Figure 1 shows idealized trends associated with an economic assessment of this style of production process. The figure does not relate to any particular mine, but the numbers are somewhat in line with some of the new large scale iron ore or coal mines being proposed in various parts of the world. Costs per unit of production include return on capital using discount rates at the weighted average cost of capital.

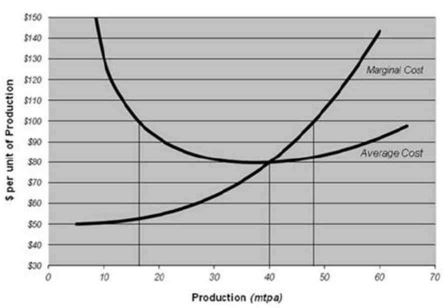

Figure 1: Average and marginal costs

The average cost of production is initially high at low levels of production because of the cost of servicing the capital associated with port and rail infrastructure and in servicing the initial acquisition and development costs of the mine. Each increment of production initially has low costs, representing just the operating cost of the equipment and little more. But with increasing production these costs also increase. If the marginal cost is less than the average cost, the average cost declines with increases in production. The production rate that yields the lowest average unit cost of production occurs where the marginal cost curve crosses the average cost curve (40 Mtpa in Figure 1).

Although the lowest average unit cost of production is a desirable objective, usually the objective is to maximize profits or Net Present Value (NPV). If the selling price is $100, for example, production can be expanded to 48 Mtpa and the additional production still yields a return higher than the marginal cost. Indeed, this is the rule: Expand production until the marginal cost equates to the marginal revenue (selling price). If in this pricing scenario the production was expanded to (say) 60 Mtpa, with an average cost of about $91/tonne, then the mine would still be profitable. However, the production from the first 48 Mtpa would be subsidizing the last 12 Mtpa. Profits cannot be improved by increases in production rate where the marginal cost exceeds the marginal revenue. The same style of calculation applies whether you are optimizing a truck/loader fleet or a pit design. From some initial starting position, the marginal cost for some expanded production is compared with the marginal revenue. The theory is simple, but the task is difficult, as anyone who has ever tried to undertake these sorts of calculations can attest. The marginal cost is not just the extra cost of some expanded production scenario. The marginal cost is the change in total cost. That is: it is necessary to design and calculate a complete case for each production scenario. For complete mine studies, the cost curves are hardly ever continuous smooth curves or upward sloping lines like shown in this figure. In practice there will be a style of mining and development scenario that is well suited to a certain production rate, and then a different style of mining and development scenario will be needed for a higher production rate. A complete mine analysis will likely have step functions, not smooth curves. Nevertheless, the principles still apply, albeit not so easily applied for most cases. Marginal costs have to be calculated, they cannot be measured.

Take, for example, a simple truck/loader marginal cost/productivity calculation. Assume that a loader is currently working with a 5-truck fleet, and that each truck hauls (say) 15 loads in a shift for a total of 75 loads per shift. Now let's assign a 6th truck to the fleet. Production improves by 12%for a total of 84 loads in the shift, or 14 loads per truck each shift. Adding the extra truck only resulted in an additional 9 loads in the shift: the productivity of the additional truck –the marginal productivity – is only 60% of the productivity of the fleet before the change. But this marginal productivity does not appear anywhere in the production records!All trucks, including the extra truck, will achieve similar production (in this case, 14 loads per shift). There is no way of knowing just from the production records what the productivity would have been if a different fleet had been selected. The marginal cost calculation is a planning tool, not a tool for operational decision-making. It is the mine planner who must examine what the expected costs and revenues will be under one scenario, and compare them with the expected costs and revenues for the alternate scenario. The choice is then based on the change in total productivity or change in total cost as the case may be. Operations personnel, production statisticians, and mine accountants can only record average production and average costs, not marginal cost.

Decisions on Mine Investments

Now let's look at a proposed investment in a new mine development using the same average and marginal cost model used in the previous section. conclude with a financial analysis and discounted cash flow (DCF) followed by a series of sensitivity analyses. Prior to any final feasibility study, most technical work is complete and, at least to a non-technical person, subject to little uncertainty.

The selling price throughout the life of the mine is also one of the inputs to the DCF, but because this is always an unknown, most studies use sensitivity analysis to examine its impact on the project return. Indeed, the selling price, internal rate of return (IRR), and NPV are linked: a nominated selling price and rate of return will yield the project NPV; if the [required] rate of return is set, the selling price necessary for project viability (NPV set to zero or greater) can be calculated, or the IRR can be calculated for any selling price by calculating whichever rate results in an NPV equal to zero. Most DCF analyses use the company weighted average cost of capital as the discount rate, and undertake sensitivity analyses on the results from this starting point. Figure 1 has been prepared using this form. It works out, for each production rate, what selling price yields a zero NPV when discounted at the cost of capital. The value of this form of presentation is that it allows a lot of analysis of a project without necessarily requiring knowledge of the selling price in advance Referring again to Figure 1, at a selling price of $100 per tonne, the mine is viable at annual production rates ranging from 16 Mtpa to 48 Mtpa. A "pit optimization" would suggest the mine be developed at 48 Mtpa for maximum NPV. However, for most mines this answer is wrong because it does not consider marginal revenue and marginal costs of capital (and a few other subtle elements that we won't explore in this article).

Marginal Revenue

In the example shown in Figure 1 the calculation of the "optimum" production rate yielding the greatest NPV (48 Mtpa) was based on a selling price that was assumed constant, and independent of the mine itself. This assumption is a very common one in economics, and usually correct, because in most markets with large numbers of buyers and sellers, any one producer affects the price very little. Demand curves are flat.

In mining, except for perhaps gold and silver producers, this is rarely the case. There are standardized prices ("benchmark" prices, or prices from the London Metal Exchange (LME)) but these are not the prices that a new producer can rely on receiving for new products on offer in the market. For bulk commodities like iron ore and coal, new mine production has to be explicitly sold to individual customers, and with variations in mineral content and impurities, not to mention that individual customers might already have contracts in place with other suppliers, only a limited number of new customers will be in a position to use the products directly and pay the "market" price. Over time, assuming competitive market pricing, other customers will adapt, but at the time of project commitment the products can be sold to this broader set of customers only at a discount. The demand curve slopes downwards. The optimum production occurs not when the marginal cost equates to average selling price, but when it equates to the marginal revenue. At the time of project commitment – and that is when we are making the decision – this marginal revenue may be substantially less than the average selling price.

Even for base metals that are marketed on the basis of LME pricing, the "marginal revenue" impact is relevant. The LME price is a reference price, but the trading of base metals doesn't necessarily require products to conform to these LME specifications. Nickel, for example, is frequently sold with Fe impurities, but this "impurity" is a bonus when used in stainless steel production because the nickel is mixed with Fe anyway. So new nickel production sold into the stainless steel market may attract the full LME pricing for its Ni content, but the same nickel placed in some other market where the Fe impurity isn't a benefit may be sold only at a reduced "marginal" revenue. For assessing the economics of any new or expanded mine production, each increment in production has to be considered alongside the selling price associated with that increment.

Figure 2 shows this situation with a declining marginal revenue curve. Thus, in this example, the correct start-up production rate (where the marginal revenue equates to the marginal cost) is actually 35 Mtpa, not 48 Mtpa.

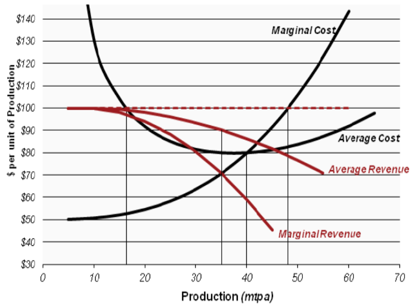

Figure 2: Impact of Declining Marginal Revenue on Optimum Production Rate

The mine is still profitable –the average revenue exceeds the average cost. However, the production rate that should be adopted – the rate that will yield the highest return on investment – is substantially reduced.

The slope of the demand curve, and this marginal revenue effect, is time dependent. Initial operations are commonly faced with a steeply declining demand curve, but, depending upon the speed at which the marketplace can adapt, the slope of the curve reduces over time. Thus, although the marginal revenue effect constrains initial production rates, over time the economic forces favor expansion. The impact of a declining marginal revenue curve is substantial. However, this is only one side of the equation. As planned production rates increase, so too do capital requirements. And, for most mining enterprises, this results in increasing marginal costs of capital. The next article will examine this effect.

