

SHRINK STOPE DESIGN USING AN INVENTORY MODEL

Danny Taylor

Mackey School of Mines, University of Nevada

Reno, Nevada, 89557, U. S. A.

And

Robert E. D. Woolsey

Mathematics Department, Colorado School of Mines

Golden, Colorado, 80401, U. S. A.

ABSTRACT: This paper addresses the fact that current practice in shrink-stoping in hard rock mining invariably ignores the inventory holding cost of the blasted ore. We believe, and show by example, that ignoring this cost could make the difference between profit and loss in an industry that, at present, needs all the help it can get.

1. INTRODUCTION

This paper treats a real-world problem in hard-rock mining in a unique way. In shrink stope mining, the broken ore remaining after a blasting operation stays in the stope and is usually considered an inventory. We will model this quantity with the classical Economic Order Quantity method. We do not assert that the EOQ method is the best, or even a good

model for this situation. It is just a first step in bringing management's attention to possible trade offs between the holding and set-up costs in this problem. We wish to define an optimum stope size that will both minimize the sum of holding costs and development costs. After some analysis, we show that ignoring the holding cost of the above inventory, can cause significant underestimation of the actual total cost of shrink-stoping.

2. PROBLEM STATEMENT

Consider a shrink stoping operation with the following data:

Q= size of the stope block in tonnes

R1= rate at which ore is broken in the stope

S= % swell for broken ore expressed as a decimal fraction

T1= time needed to break all of the ore in a stope, = $Q/R1$

Q*= tonnes of broken ore in stope after T1, = $Q(1 - S)$

T2= time to pull the stopes after all ore is broken

R2= draw rate of ore during T2, = $Q^*/T2$

R= average rate of production for the stope = $(T1 R1 + T2 R2)/(T1+T2)$

Then the maximum inventory in a stope is Q* and the average inventory is $QAVE = Q^*/2$, so that the average inventory holding cost is $CiQ^*/2$. We define Ci as the "part-period" holding cost with units of Rand per ton per unit time. Since the broken ore as a stock on hand represents a lost opportunity cost, Ci will be the company's cost of money times the cost to break the ore.

The other part of the total expected cost equation is the average set-up cost or development cost $(Cs R)/Q$ where Cs is the cost to develop a block of size Q. Operating costs over the

range to be considered are most dependent on outside factors such as vein width, dip, ore hardness, etc., and will not vary significantly with the size of the stope block. We then have the usual cost equation to be optimized as:

$$TEC = C_i \cdot Q \cdot (1 - S)/2 + C_s \cdot R/Q, \quad (1)$$

If C_s could be determined as a constant, this equation could be easily solved, giving the well-known square-root Economic Order Quantity, below:

$$Q_{opt} = \sqrt{(2 \cdot C_s \cdot R)/(C_i \cdot (1 - S))}, \quad (2)$$

$$TEC_{opt} = \sqrt{2 \cdot C_i \cdot (1 - S) \cdot C_s \cdot R}, \quad (3)$$

However, C_s is *not* a constant and depends on the stope geometry. We can break down the development costs into three components: vertical costs, horizontal costs and fixed costs. Vertical costs are those varying directly with the height of the stope, such as raise construction. Horizontal costs are those varying with the length of the stope such as undercutting and drawpoint construction. Fixed costs include stations at the top and bottom of raises and all other stope development that does not vary with the size of the block. If we represent these costs as C_h , C_l and C_f , and the block height and length as H and L , then:

$$C_s = C_l \cdot L + C_h \cdot H + C_f, \quad (4)$$

and

$$Q = L \cdot H \cdot W \cdot D, \quad (5)$$

where W is the vein width, and D is the density of the ore. Then our objective function

becomes:

$$\text{Min } TEC = Ci \cdot (1 - S)WDHL/2 + (C1 \cdot L + Ch \cdot H + Cf) \cdot R/(WDHL), \quad (6)$$

Expanding and simplifying, this becomes:

$$TEC = Ci \cdot (1 - S)WDH/2 + Ch \cdot R/WDL + C1 \cdot R/WDH + Cf/R/WDHL, \quad (7)$$

CASE I. VERTICAL LEVEL INTERVAL IS FIXED

We first assume that the vertical interval level is fixed. Such a situation would occur in an existing operation where the working level interval has already been established or in a new operation where this vertical distance is fixed by factors such as rock mechanics, hydrology, structural control, etc. In this case H is a constant and total expected cost is then:

$$TEC = Ci \cdot (1 - S)WDHL/2 + (Ch \cdot R + Cf \cdot R/H)(WDL) + C1 \cdot R/(WDH), \quad (8)$$

Since the last term is a constant, we can define $TEC' = TEC - C1R/WDH$. So that:

$$TEC = Ci \cdot (1 - S)WDHL/2 + (Ch \cdot R + Cf \cdot R/H)WDL, \quad (9)$$

This is a "by inspection" problem with geometric programming, which gives:

$$TEC'_{opt} = \sqrt{(2 \cdot Ci \cdot (1 - S) \cdot H \cdot (Ch + Cf/H) \cdot R)}, \quad (10)$$

$$TEC_{opt} = TEC'_{opt} + C1 \cdot R/WDH, \quad (11)$$

$$L_{opt} = \sqrt{\frac{(2 \cdot (Ch + Cf/H) \cdot R)}{(Ci \cdot (1 - S) \cdot W^2 \cdot D^2)}} \quad (12)$$

$$Q_{opt} = D \cdot W \cdot H \cdot L_{opt} \quad (13)$$

EXAMPLE I.

Let us assume that we have a width of 10 meters, a vertical dip, a density of .083 tonnes/cubic meter, a swell of 33%, and a level interval of 100 meters. The deposit is to be mined by longitudinal shrink stopes developed by 6 by 10 meter raises in 10 by 36 meter ore pillars with access from the raises on 25 meter intervals. Horizontal development is from an in-vein system with a 10 by 10 meter undercut located 30 meters above the haulage sill. Loading will be through chutes connected to the undercut by finger raises on 25 meter centres.

We also assume the following costs:

Ch, (costs relating to block height): raise construction, conventional @ R100/meter equipped; stope access, stub drifts @ R1000 each or R40/meter.

C1, (costs relating to block length: undercut construction @R150/meter, finger raise and chute construction @ R1250 each or R50/meter.

Cf, (fixed costs): raise station construction @ R5000

In short Ch= R140/meter, C1= R200/meter, and Cf= R5000

Finally, let the company's discount rate be 12% and the breaking cost of the ore is R50/tonne, then $Ci = 50 \times 0,12/12 = R,50$ /tonne/month. Further, let the average production rate per stope be 2000 tonnes/month. Solving we have:

$$TEC'_{opt} = R5046, TEC_{opt} = R5046 + R4800 = R9846$$

$$L_{opt} = 180 \text{ meters}, Q_{opt} = 15100 \text{ tonnes}$$

The contributions to monthly costs are:

Cost Source	%	% x TEC
Inventory	25	2523
Vertical Development	18	1892
Raise Stations	07	0631
Horizontal Development	50	4800
Total	100	9846

In this example, we can note that the horizontal development cost per month are constant at $C1R/DWH = R4800$. Therefore since this is a zero degree of difficulty geometric programming problem, *the variable actual development costs are always equal to the inventory holding costs at optimality. It should be noted that most shrink slope designs are done ignoring an inventory cost equal to the cost implied by the physical layout.*

CASE II.

Next consider the situation where the vertical level interval is *not* predetermined, that is, H is *also* a design variable: We now have two variables and four terms giving a 1 degree of difficulty geometric programming problem. (For a discussion of geometric programming methods, see Woolsey [2].) Such 1 degree of difficulty problems, although complicated, can be solved, and easily evaluated on a small computer or even a programmable calculator. This formulation is shown below:

$$TEC = C_i \cdot (1 - S) \cdot WDHL/2 + C_h \cdot R/(WDL) + C_f \cdot R/(WDHL) + C_1 \cdot R/(WDH), \quad (14)$$

The authors will send anyone requesting it, a copy of the FORTRAN program to evaluate

this case, using geometric programming. Solving the previous case for *both* L and H, as design variables, we have:

$$L_{opt} = 126\text{meters}, H_{opt} = 180\text{meters}, Q_{opt} = 19,000\text{tonnes}, TEC_{opt} = R9030/\text{month}$$

In this case, the contributions to monthly costs are:

Cost Source	%	% x TEC
Inventory	35	3185
Vertical Development	30	2660
Raise Stations	05	0525
Horizontal Development	30	2660
Total	100	9030

CONCLUSION

From the above we conclude that at optimum dimensions, the inventory costs in this situation are over 50% of the total monthly development costs. It therefore appears that the planning of shrink stope sizes with this approach could significantly reduce the "hidden" inventory costs usually ignored in shrink stope planning.

References:

- [1] H. W. Turnbull, *Theory of Equations*, 5th ed., Oliver & Boyd Publishers, Edinburgh, 1952, p. 166.
- [2] R. E. D. Woolsey & H. S. Swanson, Two Tutorials on Geometric Programming, in *Operations Research For Immediate Application- A Quick & Dirty Manual*, Harper & Row Publishers, NY, NY, 1975, pp. 84-99.