Cut-off Grade and Hauling Cost Varying with Benches in Open Pit Mining

Siwei He[1,*], Xianli Xiang[2], Gun Huang[2]

[1]CAMCE Mining and Tunneling, Lougheed Hwy, Burnaby, Canada
[2]Guizhou University of Engineering Science, Bijie, Guizhou, China
[3]Resource and Environmental Sciences, Chongqing University**,** Shapingba Zhengjie, Chongqing, China
*Corresponding author: jhe@procongroup.net, swjhe118@gmail.com

Abstract One of the most challenging problems geologist and engineer encountering in open pit mining is how much ore at benches can be extracted and sent to mill at the same time. Cutoff grade is playing an important role in solving this problem. The author, in this paper, presented a hauling cost-bench model, which directly impact cutoff grade. The cost model indicates that hauling cost, increasing with bench depth, largely depends upon the dynamic stripping ratio, representing the fundamental nature of resource and economic requirements of mineable ore at benches. The overall ore grade at benches is calculated according to operating cost model provided, while cutoff grade is found using trial-and-error technique based on resource model of a deposit. An example representing cut-off grade-bench curve is given, illustrating what relationship among cutoff grade, average grade and tonnage at benches and how much ore can be extracted and sent from these bench to mill. The example also shows how a way is found to mine out low-grade ore from one bench in a desired cut-off grade for an expected profit of the company. The cutoff grade vs. bench curve is a simple but useful tool for engineers to facilitate sound decision on how much ore tonnage at benches can be extracted and sent to mill at a time.

Keywords: cutoff grade, bench, average grade, expected profit, ore tonnage, stripping ratio

Cite This Article: Siwei He, Xianli Xiang, and Gun Huang, "Cut-off Grade and Hauling Cost Varying with Benches in Open Pit Mining." *American Journal of Mining and Metallurgy*, vol. 3, no. 2 (2015): 54-57. doi: 10.12691/ajmm-3-2-3.

1. Introduction

Mineral resource is naturally occurring, but mineable reserve is created by human effort, which is varying with times and places (R.V. RAMANI at al., 1995) [1]. In mine investment or project assessment, analysts focus more on ore reserve varying with times for a long-term planning and financial model purpose. But in mining operation, mine geologist and engineer are much interested in mineable ore varying from bench to bench for creating a better short-term plan to generate an expected profit (such as CF)in open pit(Peter Darling, 2011; Hustrulid at al., 2001; William A at al., 2013;Xinming Tang, at al., 2007; G. Matheron, 1987) [2,3,4,5,6].

In mining operation, we need to extract ore from one to six benches at a time. The main problem that mine geologist and engineer are encountering is how much ore is sent from these benches to mill. Cut-off grade is the key to success in solving this problem. The cut-off grade could be varying greatly from bench to bench due to two reasons below:

- Mineral nature occurrence such as resource grade distribution, thickness, dip and strike and weathering of a deposit varying from bench to bench (A.E. Annels, 2012) [7]
- Ore hauling cost increasing with depth.

Therefore, delineating a cutoff-depth chart at benches will be significant in mining operation. It should be, at least, a tool for engineers to facilitate sound decision on which portion of ore can be immediately sent to millfor an expected profit. To create this chart, first, we need to builda hauling cost model at benches. Using the model, we can calculate the hauling cost varyingwith bench depth and tonnage-grade distribution in any bench of the pit. Second, we need to look at the inter-relationship between operating or hauling cost, average grade and cut-off grade

2. Hauling Cost Model (Varying with Benches)

Here the hauling cost includes two parts: ore hauling cost and waste dumping cost.

(1) Ore hauling cost

An open pit is divided into benches (i) from the top (surface) to the bottom. The hauling cost (Coi) at each bench can be expressed as:

For i=1 (first bench), $Co1 = L*r + (\frac{h}{2})/1000/\beta*r$

For i= 2 (second one) $Co2 = L*r + (h + \frac{h}{2})/1000/\beta*r$

Or in general,

$$Coi = L*r + [(i-1)*h + \frac{h}{2}]/1000/\beta*r \qquad (1)$$

Then the cost increases in benches: $\Delta C = C_i - C_{i-1}$

$$\Delta Co = \frac{h \times r}{1000\beta} \qquad (2)$$

Where i: bench number counting from top to bottom (1, 2 ….n), h: bench height (m), β: hauling road slope (%), r: hauling cost rate ($/t.km), L: the hauling distance from first bench to mill (km),G&A and mill costin operation.

Normally, ore is extracted from one to six benches at a time in mining operation. The average hauling cost/t can be determined as follow:

$$C(h) = \frac{1}{n}\sum_{i=1}^{6}\frac{[(i-1)h + \frac{h}{2}]r}{1000\beta} + L*r \qquad (3)$$

Obviously, the hauling cost changes with depth, similar to what happen in underground mining(S.M. Rupprecht, 2012) [8]

(2) Waste hauling cost

It is supposed that waste dump is located beside pit, and then for any bench, the waste hauling is simply expressed as:

$$Cwi = SR*[(i-1)*h + \frac{h}{2}]/1000/\beta*r \qquad (4)$$

Where SR: stripping ratio (waste tonnage /ore tonnage)

It is important to note that the SR may vary from bench to bench due to both the fundamental nature of resource and economic requirement of reserve. This is an important variable in determining ore-waste hauling cost.The SR is given below:

$$SR = \frac{t0 - tj}{tj} \qquad (5)$$

Where $t0$ material tonnage above 0 cut-off, tj: ore tonnage at any cut-off grade in a bench

The SR depends, mainly, on ore tonnage-grade distribution; it also depends, to some extent, upon thickness, dip and strike of a deposit and different mining methods employed.

Therefore Cwi is solved by using eq. (4) and (5):

$$Cwi = \left(\frac{t0 - tj}{tj}\right)*\left[(i-1)*h + \frac{h}{2}\right]*\frac{r}{1000\beta} \qquad (6)$$

(3) Hauling Cost and Operating Cost

The hauling cost ($/t) for ore and waste is yielded using Eq.1 and 6:

$$C = L*r + \left(1 + \frac{t0 - tj}{tj}\right)*\left[(1-i)*h + \frac{h}{2}\right]*\frac{r}{1000\beta} \qquad (7)$$

And total operating cost is expressed as:

$$C = L*r + Cf + \left(1 + \frac{t0 - tj}{tj}\right)*\left[(i-1)*h + \frac{h}{2}\right]*\frac{r}{1000\beta} \qquad (8)$$

Where Cf: fixed cost including drilling, blasting, mucking cost, G&A and mill cost.

3. Cutoff Grade and Average Grade Varying with Benches

On each bench the ore tonnage above the break-even cutoff grade are measured and the average grade of the ore is calculated (*Bruce A. Kennedy, 1990*) [9]. It is important to note that profit generated in operation such as net smelter return or NSR depends upon average grade, while the average grade solvedis theoretically based on cut-off grade, which is geology and economy constraint of ore reserve. Normally, for an assigned cut-off, the average grade can be quickly calculated based on resource model provided by resource geologist; on the other hands, if the average grade is known, we can also easily find the cut-off grade using this resource model.

(1) NSR model and average grade

NSR can be given below:

$$NSR >= G*D*R*S$$

Where G: average grade (recovered), D: overall geology and mining dilution in the bench, R: mill recovery (%), S: metal price after deducting the market cost,

If the profit NSR is greater than or equal to the operating cost previously mentioned (C), then the average grade required at benches will be given below:

$$G >= \frac{L*r + Cf + \left(1 + \frac{t0 - tj}{tj}\right)*\left[(i-1)*h + \frac{h}{2}\right]*(\frac{r}{1000\beta})}{D*R*S} \qquad (9)$$

The average grade is an expected mean value of ore grade for reserve reporting purpose. It is also expressed as:

$$G = \frac{1}{n}\sum_{k=1}^{n}gk \qquad (10)$$

The grade value, *gk,* is assigned to any block in a bench, which is sorted from lowest to highest, and then Eq. 10 can be expressed as:

$$G = \frac{1}{n} \times (g1 + g2 + ...gn) \qquad (11)$$

These grade values from g1 to gn are clearly displayed from plan to plan or from section to section based on resource model provided.

(2) Relationship between Cut-off grade Gc and average grade G

The cut-off grade in a bench can be quickly selected if an expected average grade is determined using Eq.9. and then four relationships between cut-off and average grade are summarized below.

- Gc = Cifall value in blocks are: g1= g2 =…gn
- Gc = 0 if any grade value in blocks, *gk,* is at a profit
- Gc = g1 if g1< g2 <…gn
- Gc could be any selection between g1 and gn for achieving the company's expected profit.

4. Delineating a Cutoff (and the Overall Grade)-depth Chart at Benches

An Example given for Cutoff Grade (and the overall grade) vs. Bench Curve at Benches

An operating mine located in China is going to change cutoff grade at benches because it was found that a 1% Zn cut-off grade given on the basis of FS study was not suitable for generating an expected profit. This example is used to demonstrate how a cutoff-bench curve is created using the method proposed in this paper. The procedure can be generally divided into four steps below:

Step 1: Bench Ore info prepared

The basic ore information from bench to bench, which is based on resource model (blockmodel), is illustrated in Table 1 below:

Table 1. bench ore info

Cut-off Grade %Zn	0	0.5	1	1.5	2	2.5
Bench1-tonnage t	4720275	4046125	3811563	3434575	2873650	2113263
Bench2-tonnage t	4567725	3920912.5	3693775	3270550	2697475	1976575
Bench3-tonnage t	3786750	3215875	3071763	2600175	2181000	1536713
Bench4-tonnage t	338850	234463	211850	163925	139800	119425
Bench5-tonnage t	1508625	1091750	445850	666300	389788	221475
Bench6-tonnage t	90450	79775	58425	34713	13913	9400
Bench1-grade %Zn	2.71	2.89	3	3.28	3.6	3.83
Bench2-grade %Zn	2.59	2.68	2.78	3.46	3.95	4.54
Bench3-grade %Zn	2.83	2.88	2.96	3.16	3.37	3.71
Bench4-grade %Zn	2.33	2.35	2.46	2.68	2.97	3.26
Bench5-grade %Zn	2.33	2.56	2.68	3.4	3.11	3.39
Bench6-grade %Zn	3.19	3.21	3.24	3.33	3.56	3.86

In Table 1, red and black colors represent tonnage and grade respectively.

Step 2: SR calculation

The SR is calculated based on the data from Table 1 and Eq. 5, summarized in Table 2 below:

Table 2. SR varying with average grade at benches

Cutoff grade g/t	0.5	1	1.5	2	2.5
Bench1_SR	0.17	0.24	0.37	0.64	1.23
Bench2_SR	0.16	0.24	0.40	0.69	1.31
Bench3_SR	0.18	0.23	0.46	0.74	1.46
Bench4_SR	0.45	0.60	1.07	1.42	1.84
Bench5_SR	0.38	2.38	1.26	2.87	5.81
Bench6_SR	0.13	0.55	1.61	5.50	8.62

Step 3: The parameters used for cutoff (break even and optimum) calculation at benches

The parameters needed for the calculation of cut-off at benches is summarized in Table 3 below:

Table 3.

Item	Value	Unit
Fixed Mining cost (not including hauling cost)	5	US$/ mined t
Processing cost	15.00	US$/ milled t
G&A	5.00	US$/ milled t
Ore recovery (inside the pit)	100.00	%
Ore dilution	15.00	%
Mill recovery	85.00	%
Zinc Price	0.95	US$/lb
refining	95.00	%
Sales Tax	12.00	%
road slope	8.00	%
ore mining bench height	10.00	m
distance from first bench to mill	4.00	km
Waste dump from pit first bench	3.0	km

Step 4: Average grade calculation and cutoff grade determined

The Eq. 9 above is used for calculating average grades and determining cut-off grade. The calculation is carried out using iterative techniques in excel.

Step 5 Cut-off –Bench curve

Data from the tables above is used to generate the cut-off grade (also ave. grade) vs. bench grapics as shown in Figure 1.
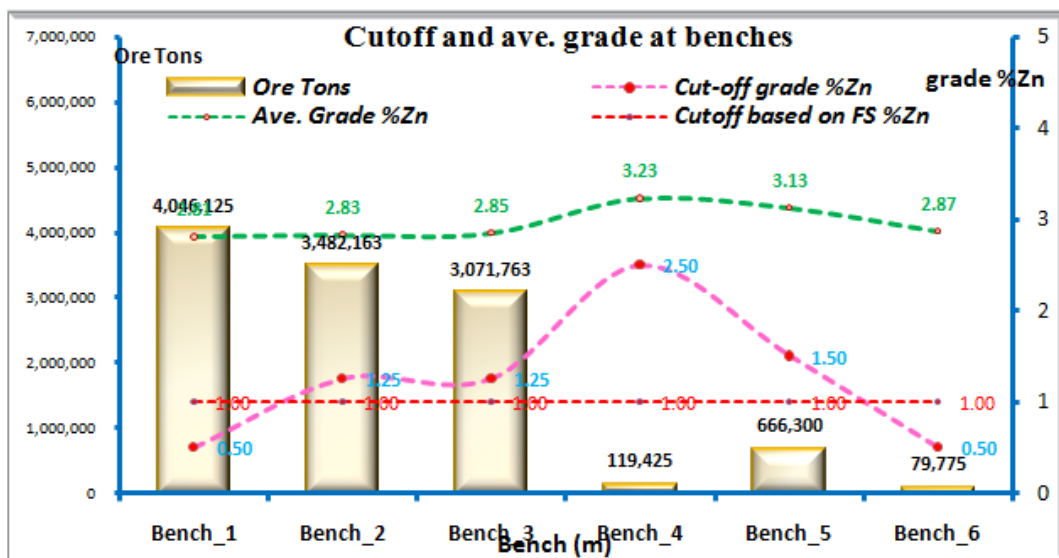

Figure 1. Cut-off grade moving at benches

Figure 1 illustrates that the cut-off including break-even and the overall grade varies from bench to bench, and the previously given 1% cut-off grade is too low to generate the lowest profit at bench 2-5. The example also shows the low-grade material with bench 4 and there is no way to extract ore from the bench in a desired cut-off grade. The best solution would be to remain the low-grade material in its original place or transport it to some place beside the pit after blasting. This is a way reducing waste hauling cost so that we may have a desired cut-off and average grade for a higher production with the bench.

5. Summary

The author presented a hauling cost model to facilitate the dynamic hauling cost calculation. The model indicates that hauling cost increases with depth, but largely depends upon the dynamic stripping ratio, representing the fundamental nature of resource and economic requirements of mineable ore at benches.

The overall grade (and average grade) at a profit can be calculated using the formula presented in this paper, then cut-off grade quickly selected using trial-and-error technique.

The author believe that, by following a five-step procedure as shown in the given example, the cutoff gradevs. bench curve is easily delineated, which will be a simple but useful tool for engineers to facilitate sound decision on how much ore at benches can be extracted and sent to mill.

References

[1] R.V. Ramani, K.V.K. Prasad, and R.L. Frantz, (March 1995),"Ore Reserve estimation: Myth and Reality of Computer Models", *Min. Res. Eng.*4 (2), 15-28

[2] Peter Darling, (2011), *Mining Engineering Handbook, Third Edition,*SME, USA, 401-403.

[3] William A. Hustrulid, (2001), *Underground Mining Methods: Engineering Fundamentals and International Case Studies,*SME, 293-296.

[4] William A. Hustrulid, Mark Kuchta, Randall K. Martin, (2013), *Open Pit Mine Planning and Design,*CRC Press*,* 334-496.

[5] Xinming Tang, Yaolin Liu, Jixian Zhang, Wolfgang Kainz, (2007), *Advances in Spatio-Temporal Analysis,* CRC Press, 840-860.

[6] G. Matheron, (1987), *Springer Science & Business Media,* Geostatistical Case Studies, 239-241.

[7] A.E. Annels, (2012), *Mineral Deposit Evaluation: A practical approach,* Springer Science & Business Media, 321-323.

[8] S.M. Rupprecht, (2012), "MINE DEVELOPMENT – ACCESS TO DEPOSIT", the Southern African Institute of Mining and Metallurgy, 101-120.

[9] *Bruce A. Kennedy,(1990), Surface Mining, Second Edition,* SME, 466-467.