Optimization of Final Pit Limit with Regard to Effect of Commodity Price (Case Study: Se-Chahun Iron Ore Mine, Iran)

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ABSTRACT: According to the ore grade reduction and increasing the depth of the ore deposit, final pit limit optimization and long term mine production planning to the optimal pit limit (OPL) determination in large open pit mines has globally become of a high importance. Nowadays, companies have focused their activities on maximizing the profitability and minimizing the undesirable effects of final product cost swings in order to access the whole minable reserves. In this research, a study has been done on the metal price fluctuations, particularly iron ore in the anomaly *XI* of Se-chahun iron mine of Iran during 2012 to 2016. The unfavorable impact caused by the 67.5% concentrate price decline and its side effects on final pit limit and amount of the mineable ore reserve has been analyzed. Scenario comparison that has been done on both northern and southern pit during 2012 to 2016 shows that the pit final depth has been shortened 50 and 40 meters for northern and southern sides, respectively. Comprehensive studies in plan economic assessment shows that by reducing the amount of proved and possible reserve within pit efficient span, the annual mining capacity will scale down from 3.4 million tons to 2-2.5 million tons and the amount of final product will also decrease as a result of the recovery reduction which has a certain strong impact on project profitability.

KEYWORDS: Final pit limit, Price effect, Optimization, Se-chahun iron ore mine

1. INTRODUCTION

One of the important issues in *"Mining Engineering"* which is achieved by economical and safety factors consists of optimization of final pit limit and long term production planning of the large open pit mines. For this purpose, the studying of economic and geo-mechanic issues are significant as two parts of open pit mine planning. There are many methods for the open pit mines design. This difference of mine design is resulted in differences of ore deposits size, quantity and quality of data, software usage and engineer's assumptions during the operations. According to the definition, the final pit limit is an area where the extraction of amounts of ore and waste have maximized Net Present Value during the mining life (Kennedy, 1990). Geometry and situation of final pit limit is so important to design the stockpile of low grade materials, waste embankment, accessing roads, mineral processing plant, all facilities and surface buildings. Final pit limit design should have reconsidered and optimized by combination of technical and economical parameters during the mine life. Nowadays, it is necessary to gather all of the geological, exploratory, geo-mechanical, hydrological and economic data to present a successful long term plan regard to final pit limit design.

Uncertainty and stability of mining final product, increasing the stripping ratio, increasing the hauling distance, increasing of environment damage, non-utilization of modern technology and also increasing the concentration and processing costs are the main challenges for mining engineer (Gholamnejad & Osanloo, 2007). Mine closure has been occurred for many small scales iron ore mines because of recession which has resulted from drop of mining final product price in recent years especially since 2013 up to now. Mining capacity has been decreased strongly for many open pit mines so that mine production has become less than half. The increasing of enrichment and concentration costs for iron ore has been other significant issues that will have major impact on final pit limit determination. At the present time, in Se-chahun mine, extracted ore with average grade (Fe=35%) is usually enrichened by crushing system and its grade is increased to 7 percent and then it will be entered to processing plant to provide the concentrate with 67.5 percent and therefore it has increased the processing costs.

2. SE-CHAHUN IRON ORE MINE- ANOMALY XI EQUATIONS

Anomaly XI of Se-chahun iron ore mines is located in southeast of Yazd city and 50 kilometers from north of Bafq township included two northern and southern part where its exploitation has been started since 2003 with focus on its southern pit (Figure1, 2). With the amounts of geology resource about 145 million tons of iron ore by average grade 37 percent, this mine is one of the largest mines in the central area of Iran. The mining capacity was assumed 3.4 million tons of iron ore by grade 37±5 percent of iron ore regard to extract in mineral processing plant. The objective of this paper was the determination of the optimal pit limit according to impacts of final price of iron ore during 2012 to first half of 2016 and impacts of mining and processing costs per one ton of ore on the mineable ore deposit. *NPV-Scheduler software* was applied for this purpose. This software is able to determination of the optimal pit limit by Lerches & Grossmann's algorithm (Lerchs & Grossmann, 1965) and extraction planning under consideration of determined aims and increasing of the *NPV*. Geo-mechanical studies were applied on faces of the mine based on zoning by geological and geotechnical experts in order to the optimal pit limit determination. Predicted mineable area may be changed according to dispersion distribution for three dimensional model of measured and indicated ore deposit, increasing of stripping ratio in middle years of the mine life, decreasing of grade of iron blocks and changes of iron ore price specially concentrate as a final product of mining. Final pit limit will be changed based on the changes of economical parameters especially final commodity price (Kumral, 2012).

Figure 1. Se-chahun mine (Anomaly XI) aerial view

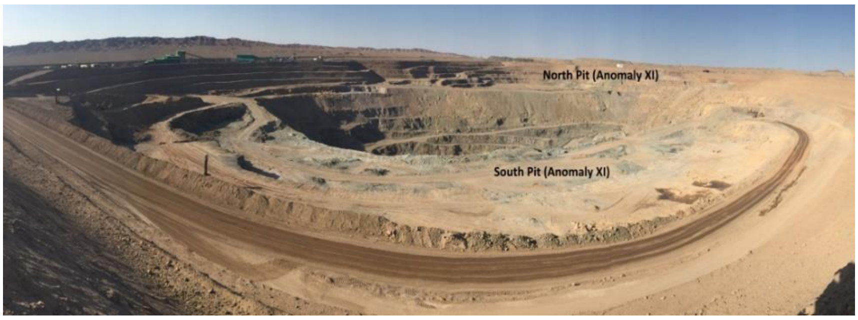

Figure 2. Se-chahun mine (Anomaly XI) panorama view, (Jun 2016)

3. METHODOLOGY

Geological block model has imported to "NPV-Scheduler software" for economic model calculation. After the determination of economic model, the data of pit diagram like final slope and pit limits which should have been optimized based on certain purpose have entered to the software. Finally, the price changing, mining and processing costs and recovery are applied on the block model and different limits will be created.

3.1. Geological Block Model ethodology

Geological block model of Se-chahun mine was made based on the results of supplementary explorations boreholes and Datamien Studio software (Figure 3). The dimensions of blocks and their quantity are 25×25×10 and 76×97×45, respectively. This mine has two northern and southern masses and the amounts of remained iron ore deposit was evaluated 79 million tons in the northern mass according to its cut off and average grades are 20 and 33.5, respectively. Also the amounts of remained iron ore deposit was evaluated 25 million tons in southern pit according to its cut off and average grades are 20 and 37 percent, respectively. Therefore the total measured ore deposit were predicted 104 million tons for the anomaly XI in Se-chahun iron mine.

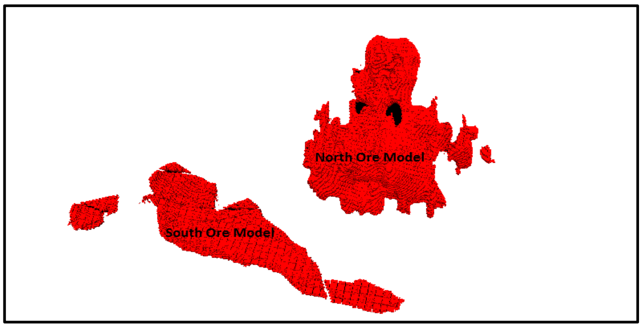

Figure 3. Ore block model (plan view)

3.2. Economic Block Model

Economical block model is known as a guide to design the final pit limit. According to the grade, (Fe) recovery and price, the value of each block are calculated and the block which fits to stability slope of faces is determined based on the sequence of extraction in different zones. In this study, five economical block models are made during 2012 to 2016 according to the changing of final product price, mining and processing costs and recovery in ore blocks. Break even and overall stripping ratio are main parameters on the final pit limit determination. It is obvious that the final pit limit will be smaller when the price of iron concentrate is decreased and so on the depth of mineable ore deposit may be decreased. It is worth nothing that stripping ratio is very important criteria for economical evaluation (Abdel Sabour, 2002).

4. METHODOLOGY

The optimization of Se-chahun iron ore mine block model has done by the results of exploratory and geotechnical studies. The objective function of optimization is the maximization of the NPV according to the least deviation from break even stripping ratio of this mine. In this step, prepared geological model has been made based on measured, indicated and inferred categories. Measured and indicate categories have been selected as a base of calculations and determination of mineable ore deposit for optimization and selection of the best optimal pit limit.

In this study, optimization of the final pit limit are done by NPV Scheduler.V.4.24 according to the following figure and setting.

- Optimization criterion: Max cash flow
- Optimum phases criterion: Profit factor
- Max revenue factor: 100%
- Incremental factor: 5 %

Also, charts of valid sites are applied for statistical evaluation of iron ore price. The changes of price for ten recent years was shown in figure 6. According to this figure, the peak price has been occurred in 2010 and approximately decreasing trend is shown after 2011 to 2016. According to periodic changes of metals price, additive trend will be started after a seven year period (Figure 4).

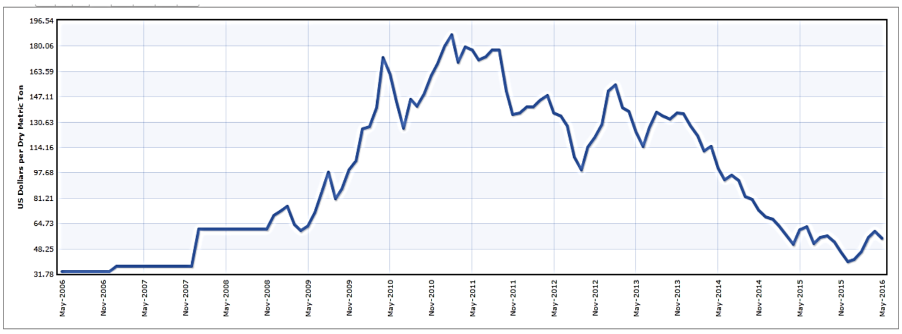

Fig 4. Iron ore price during 2006 -2016

4.1. Optimization Parameters

In order to optimization studies, basic data were evaluated denotatively and were shown in Table 1. Then a comprehensive analysis was done on the final pit limit according to intense changes of price from 2012 to 2016. According to this issue, its results were shown in Table 1. According to this table, optimum phases are changed with to changes of final product price and mining and processing costs in every years. This optimum phase is selected based on present value, amount of stripping ratio that maximize ore in it. Thus, after running of the model and value calculation of blocks, optimum phase is considered executively. According to the figure 6, when the price of mining final product is decreased, mineable ore deposit will be decreased so that break even limit of the mine will be decreased too. The difference of indicate mineable ore deposit has been 93 million tons in 2012 whereas it has been decreased approximately to 12 million tons. Of course, this reduction has been caused to decreasing of the mine depth too. According to Table 1, pit depth is changed fix to drop of price.

It should be noted that the amount of the ore deposit is provided of feed of factory for 4 to 5 years in 2016 (12 million tons of ore which its grade is 48 percent). This extraction plan can due to deduction of the mine stripping ratio and also shows the least amount of deviation of the long term plan as a short term plan.

Table 1. Input Data

Technical Parameters	Time step	Value	Unit
Final Product Price (Iron Price)	2012	128.5	$/tone
	2013	135	
	2014	97	
	2015	55	
	2016	51.5	
Selling Cost	2012-2016	15	$/tone
Annual Discounting	2012-2016	12	%
Base Mining Cost	2012	2.1	$/m^3 ore
	2013	1.81	$/m^3 ore
	2014	2.12	$/m^3 ore
	2015	2.34	$/m^3 ore
	2016	2.5	$/m^3 ore
Mining CAF	2012	1.55	-
	2013	1.46	-
	2014	1.64	-
	2015	1.67	-
	2016	1.65	-
Processing Cost	2012	6.9	$/t ore
	2013	6.4	$/t ore
	2014	9.1	$/t ore
	2015	12.5	$/t ore
	2016	13.2	$/t ore
Mining Recovery	-	95	%
Processing Recovery	2012-2016	84	%
Dilution	-	5	%
Scheduled Mining Limit	2012-2016	3200000	Tone/year
Scheduled Mill Limit	2012-2016	1400000	Tone/year
Workable Days	2012-2016	360	Days/year
Rehabilitation Cost	2012-2016	0.03	$/t ore

4.2. Optimization Result

Final pit limit optimization will be done after entering of economic and technical data contains of commodity price, mining and processing costs, recoveries and slope angles in each zone. Its primary results were shown in table 2a and 2b. Figure 5 (A to E) shows revenue model and according to this figure A, B model which their prices are 51.5 and 55 dollar per ton respectively, have a little block with positive value and negative value for many blocks. But in C, D, E, model has gone to extraction of positive value blocks. It shows that the pit depth of the mine can be increased in both of northern and southern pits. The changes of 2012 and 2016 were shown in figure 5 by achieved models of different years. Optimal pit limit is look like to primary push back and according to previous statement, it can be selected as a short term plan to achieve to long term aims. Indeed, in 2016 (figure 5.A) it is impossible for open the pit mining economically. At this time, the best decision is to use the ore dumped in stockpile. This research showed that, one of the most effective elements to OPL is the processing cost. In addition, iron ore price devaluation between 2012 and 2016 have affected specially on low grade ore deposit such as this case study.

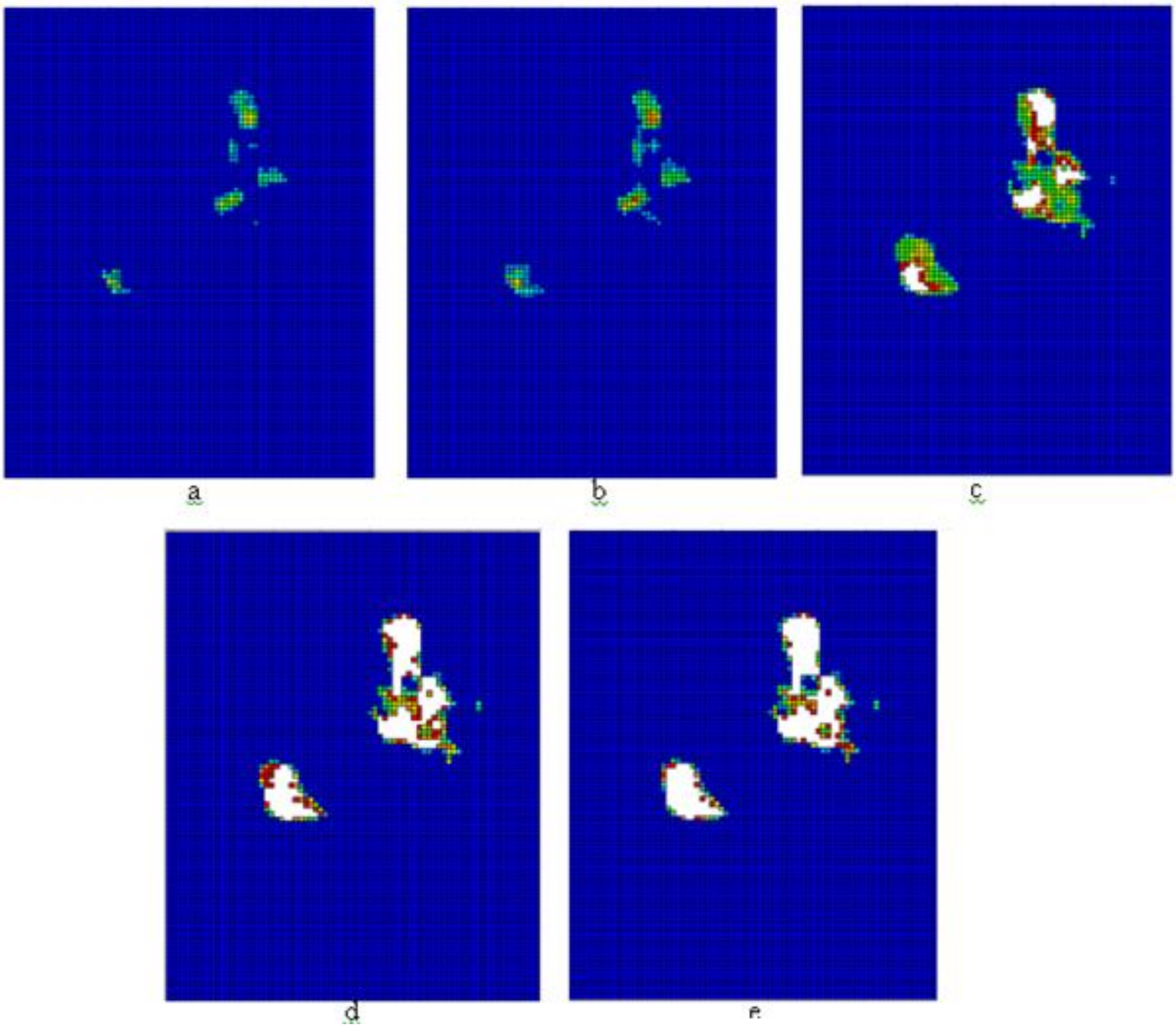

Fig 5. Revenue Models of Optimization result A) (Price: 51.5$/ton) B) (price: 55 $/ton) C) (price: 97$/ton) D) (price: 128.5 $/ton) E) (price: 135 $/ton)

Table 2a. Optimization result of Se-chahun iron ore mine based on price effect during 2012-2016

Alterna tives	Price ($/tonne)	Data Type	Optimum Pit	Years	Rock tonnes	Ore tonnes	Fe tonnes	FeO tonnes
A	128.5	Incremental Data	Pit 3	2012	60,826,000	7,394,000	2,181,000	923,875
		Cumulative Data			41,683,000	93,611,000	32,470,000	13,027,000
B	135	Incremental Data	Pit 3	2013	53,053,000	5,502,000	1,489,000	666,538
		Cumulative Data			452,770,000	96,780,000	33,312,000	48,244
C	97	Incremental Data	Pit 4	2014	65,957,000	8,969,000	2,693,000	1,183,000
		Cumulative Data			384,772,000	89,438,000	31,314,000	12,520,000
D	55	Incremental Data	pit 7	2015	26,158,000	4,816,000	2,068,000	795,329
		Cumulative Data			79,596,000	23,813,000	10,240,000	3,716,000
E	51.5	Incremental Data	pit 8	2016	5,972,000	1,305,000	570,000	215,000
		Cumulative Data			42,745,000	12,361,051	5,935,000	2,021,000

Table 2b. Optimization result of Se-chahun iron ore mine based on price effect during 2012-2016

Alternatives	Fe Recovery %	Grade %	Strip R	Years	Profit $	Best Case NPV $	Worst Case NPV $
A	0.798	29.5	7.2	2012	125,500,000	4,314,000	-
		34.7	3.5		2,360,000,000	736,000,000	573,000,000
B	0.798	27.1	8.6	2013	90,000,000	2,633,934	-
		34.4	3.7		2,680,000,000	812,000,000	655,000,000
C	0.798	30.0	6.4	2014	76,400,000	3,135,000	-
		35.0	3.3		1,324,000,000	444,000,000	298,000,000
D	0.798	42.95	4.4	2015	9,380,000	4,000,000	-
		43.00	2.3		89,313,000	63,750,000	47,000,000
E	0.798	43.7	3.6	2016	1,130,000	708,000	-
		48.0	2.5		45,000,000	38,500,000	33,000,000

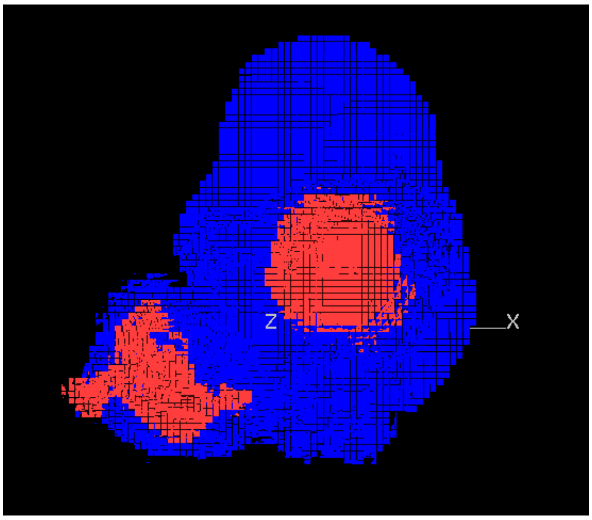

Fig 6. Comparison Between two economic models (Red: 2016, Blue: 2012)

4.3. Optimization Result

Final pit limit is a physical area that has the most net present value. Mine design will be done for accessing to mine levels and exploitation operations after the optimization of ultimate pit limit. In this step, possible largest pit is designed for consideration of pit limits and indicate limitations. For this purpose, geological block model was determined for mining constraint consideration.

Figure 7 shows a total image of designed pit in both of northern and southern pits. The most important concept for open pit mine design is prevention of increasing of stripping ratio in modeling with consideration of safety situation and according to different slopes stability in mine faces, width of roads and safety benches are almost controllable parameters. Also the plan of this mine have to supply required grade for processing plant.

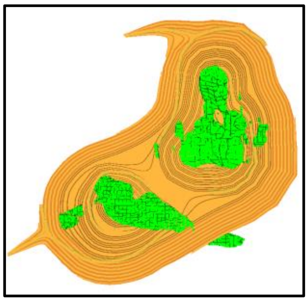

Fig 7. Se-Chahun (Anomaly XI) final pit limit

5. CONCLUSIONS

The influence of mining final product (Fe concentration= 67.5 %) shows the strongly changing in the final pit limit during 2012 to 2016. This change dues to decreasing of mineable ore reserve, production limit and if the price is constant, mine closure will be observed. Anomaly XI in Se-chahun mines is one of the important iron ore deposit in central of Iran where is a provider of feed for "Choghart" plant and it has forced to use of the high and low grade dumps to provide entered for the plant during 3 recent years. For this purpose, it has provided required grade and tonnage for the plant by blending. At the present time, northern pit is located in 1590 where it is closed because of price drop and mining is executable just only in southern pit. This study shows break even stripping ratio is at about 3.5 for Se-chahun mine in current situation which it was half in compared with 2013. Also weight recovery has been at about 52 percent in effect of decreasing of mineable ore amount and increasing of achieved grade which this issue shows if mine capacity is 2 million ton per year, the amount of achieved product is about 1.045 million tons which this issue shows dropping is at about 37 percent. (It means the factory works with its capacity which is 63 percent). According to figures 8 and 9, the influence of processing cost and price of mining final product was determined on determination of optimal pit limit as two main factors. Decreasing of production amount and increasing of operation and overhead costs for the processing plant due to increasing of processing cost per tonnage of ore. This issue will have negative impact on economic potential of the plan. As a result, the long term plan is revision and new technical and economic studies are done. Mining with breakeven capacity of production is able to done possibility because of mine development in previous years, easy accessing to ore blocks, low depth and increasing of average grade ability which is 7 percent.

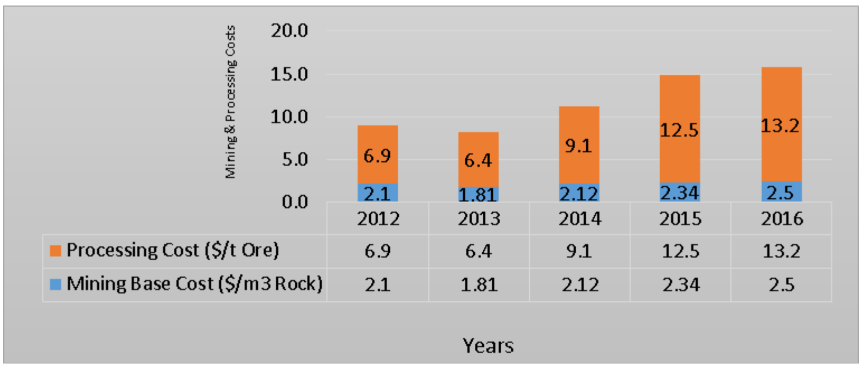

Fig 8. Mining & processing costs during (2012-2016)

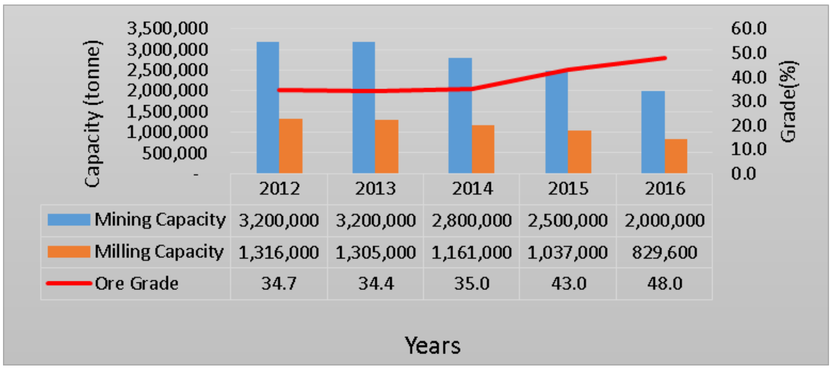

Fig 9. Mining and milling capacity (2012 – 2016)

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