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OPTIMIZATION OF BLENDING OPERATION FOR ASWAN PHOSPHATE MINES USING LINEAR PROGRAMMING

Mahrous A.M. Ali[1*], H.S. Wasly[1], W.R. Abdellah[2], Hyongdoo Jang[3]

[1]Al-Azhar University, Qena, Egypt
[2]Assiut University, Assiut, Egypt
[3]Curtin University, Perth, Australia
**Corresponding author: e-mail mahrous_mining@yahoo.co.uk, tel. +20963210223, fax: +20963210223*

ABSTRACT

Purpose. The economic value of phosphate is reduced when randomly blending raw phosphate produced from different mines. Therefore, the blending process of different raw phosphate ores to produce economic percentage of P_2O_5 is essential to maximize the profit of a mine as regards suitable mine design.

Methods. This paper presents an application of Linear programming (LP) method to determine the optimum quantities of phosphate ore needed per each mine for blending process. Three phosphate operations, located in Aswan province south of Egypt, have been chosen for this study namely B1, B2 and C.

Findings. The results of LP methods reveal that the phosphate ore of 24% of P_2O_5 will be produced by blending 16.8% of phosphate ore from operation B1, 9.42% of phosphate ore from operation B2 and 73.78% of phosphate ore from operation C. Whilst the phosphate ore of 22% P_2O_5 will only be obtained by blending 66.43% of phosphate ore from operation B1 and 33.57% from mine B2.

Originality. Estimating the suitable height of benches according to stability, safety of work place and efficiency of work place. The suitable height of benches was found according to the efficiency of work place ranged from 12 m to 30 m. Sub benches were divided to keep the assays of the phosphate ores from dilution and the result is that the height of sub bench for overburden ranged from 7 m to 11 m, for the third layer from 0.2 m to 0.3 m, for the upper layer from 0.4 m to 0.6 m and for the lower layer from 0.3 m to 1 m.

Practical implications. Applied linear programming in mining as regard mining operations to obtain the optimum solution in mining sites.

Keywords: *linear programming, blending operation, profit optimization, phosphate ore deposit*

1. INTRODUCTION

Phosphate is a non-detrital sedimentary rock which contains high amounts of phosphate bearing minerals, where considering the phosphorite rock (e.g. calcium phosphate) comprises only 15 – 20% of phosphate. The content of phosphate in the phosphorite rock would vary upon the contents of hydroxyapatite and fluoroapatite. For example, if the phosphorite rock contains 20% of these primary minerals, then the percentage of phosphorous will be 18.5%. On the other hands, comparing with the typical sedimentary rock, which consists less than 0.2% of phosphorous, the phosphorite rock is considered as a phosphorous enriched mineral as well, when it contains more than 3.7% phosphorous (McClellan, 1980).

The total phosphate production of the world is 137 million tons annually, 28.1% have been produced by United States (40.87 million tons), 21.1% China (30.75 million tons), and 15.1% Morocco (22 million tons). The rest of phosphate is produced from various countries, such as Brazil, Russia, Jordan, and Tunisia. Phosphate is one of the common ore deposits in Egypt as it extends to a distance of 750 km from the coast of Red Sea in the east to the west of Dakhla Oasis (Stowasser, 1983).

1.1. Study area

Most of sedimentary deposits are formed in offshore marine conditions on the continental shelves. Such deposits are exhibited in a wide variation in the chemical composition and physical nature. Phosphate rocks contain distinct phosphate particles that can be separated from the unwanted gangue minerals. Insular deposits (e.g. a type of sedimentary deposit that associated with

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oceanic islands) have been considered as the main source of phosphate rocks for more than hundred years.

However, most of these deposits are totally depleted. From economic point of view, the valuable phosphate in Egypt is located in three main areas. The first locations are called Sibaiya and Mahameed where are part of Nile Valley (in between Idfu and Qena). The geological reserve of phosphate ore in this region is estimated by 200 million tons in Mahameed only, where the percentage of phosphorous oxide is 22%. The second place of phosphate ore is located between Sagafa and Quseir (e.g. Mount Dawi, Thirsty and Hamrawein) (Said, 1962; Issawi, 1968; Dabous, 1980). The estimated phosphate reserve in this area is 200 – 250 million tons where P_2O_5 ranges from 27 to 30%. Abu-Tartur is the third place which is one of the largest phosphate deposits existed in Egypt. The estimated phosphate reserve in this area is 1 billion tons where P_2O_5 is 25%. Although the percentage of P_2O_5 ranges between 22 and 30% in the Egyptian phosphate, however, production is very costly due to the proportion of impurities.

In the present study, nine samples of phosphate rocks have been obtained from three operations named B1, B2, and C of El-Gera mines located in Aswan, south of Egypt. The studied area lies between latitudes 32°34′44.9″ North, bearing 45°, Longitude 25°10′48.8″ and at 4-kilometer west of Idfu, Aswan Governorate (Issawi, 1979). The location map of the study area is shown in Figure 1 and the stratigraphic column of the phosphate deposit is shown in Figure 2. Table 1 lists the surface geological reserve of phosphate ore and percentage of P_2O_5 in the three operations. To maximize the profit of El-Gera mine, optimizations of a blending process of phosphates produced from the three operations and optimum height of a bench design are essential.

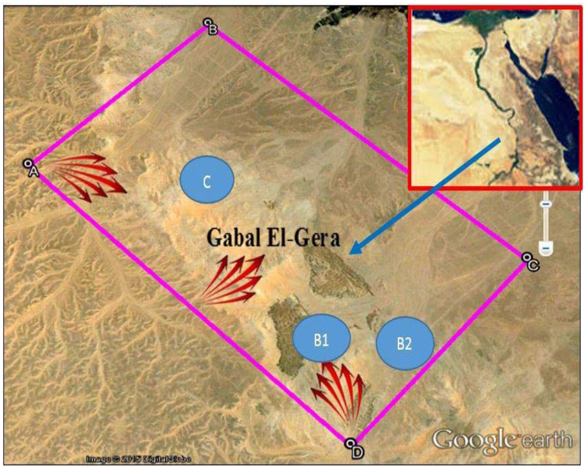


Figure 1. Location map of the studies area

Table 1. Phosphate ore reserves in Egypt and percentage of P_2O_5 of three operations (The Egyptian mineral resources authority, 2015)

Area	Reserves, million tons	Percentage of P_2O_5 (range)
Quseir – Safaga Region	250	21 – 36
Idfu – Qena Region	850	20 – 33
Abu Tartur Plateau	1000	22 – 36

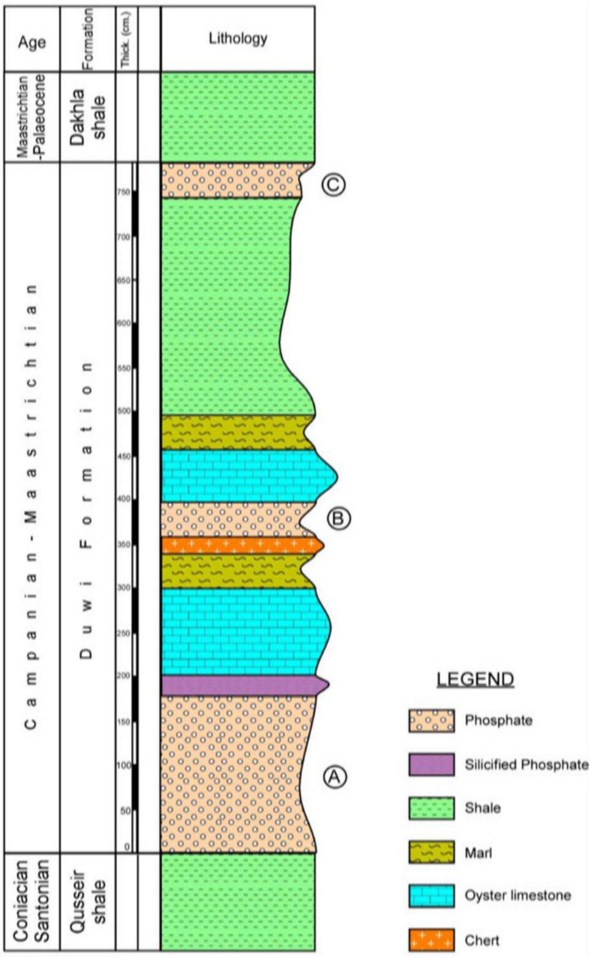


Figure 2. Stratigraphic column of phosphate facial zones (Shams et al. 2015)

In the following sections, the phosphate reserves are estimated and are given in Table 2 (section 1.2).

Table 2. The total quantities of phosphate ore in three operations

Operation		Quantities, ton
B1	Third	67400
	Upper	215311
	Lower	192096
B2	Third	19441
	Upper	112374
	Lower	132127
C	Upper	801150
	Lower	1115627
Total		2655527

Applicable bench heights has been recommended in section 1.3. The significance of ore blending operation is discussed in section 3 and optimum quantities of ore from three different operations are examined by LP method in section 4. In section 5, the study is concluded in discussion with results in section 4.

1.2. Estimating phosphate reserve

In this study, ore reserves estimation are calculated according to the borehole data by using statistical calculations, volume and total amounts of ore reserves based on the thickness of boreholes, assay and topographic information of the study operations of B1, B2 and C. Each location of the study area is classified into upper, lower and third strata. Table 2 gives the estimated surface geological reserve of phosphate ore in the three operations and the life of the mine has been determined (David, 1977; Hustrulid & Kuchta, 1995).

1.3. Mine design and planning

Several factors affect the design of open pit such as geometry (e.g. size and shape), characteristics of ore/rock mass (e.g. strength properties, ore extent/dip angle, cut-off grade, etc.), design parameters (e.g. height of bench, slope angle, berm, etc.) and operational costs (e.g. cost of extraction, milling/processing, transportation, storage, market prices, etc.) (Hustrulid, Kuchta, & Martin, 2006; Adilson, Marcos, Wilson, & Valdir, 2013; Aitsebaomo, Ngerebara, Teme, & Ngah, 2015).

Height of the bench is considered as one of the prominent parameter which has a great effect on the overall mine profit. It is defined as the vertical distance between two horizontal levels of open pit. It could be fixed for all benches unless geologic conditions dictate otherwise, such as height should be designed according to characteristics of ore deposit, degree of selectivity, size of equipment, climatic conditions and rate of productions (Ulusay, 2014). In large phosphate mines, height of bench normally varies from 12 to 20 m and is divided to sub-benches. Figure 3 demonstrates vertical section of a bench in the operations B1, where the heights of overburden, third, upper and lower layers are 7, 0.2, 0.41 and 0.38 m respectively.

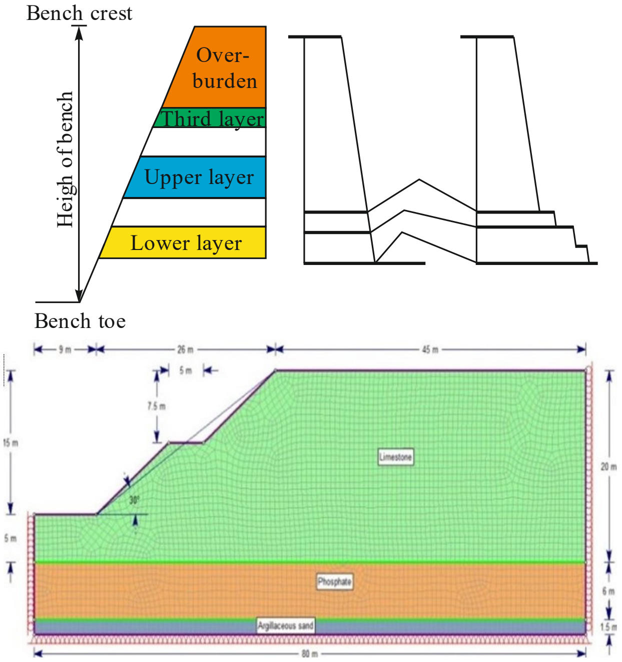


Figure 3. Bench height divided into sub-benches in the operations B1

Table 3 give the characteristics of phosphate ore deposits in the three operations, while Table 4 illustrate the calculated height of benches using various formulas accordance with slope stability, safety and efficiency of work place.

Table 3. The physical and mechanical properties of the tested phosphate samples

Location	σ_c, t/m^2	T_s, kg/cm^2	Density, gm/cm^3	Water absorption, %	Internal friction, deg.	Remarks
B1	104.3	65	1.97	16.4	30	All data calculated using statistical analysis
B2	120.6	50	2.20	12.8	29	
C	117.8	75	2.15	13.7	25	

Table 4. Calculated height of bench for the three phosphate operations

Methods	Equation	Bench height, m		
		B1	B2	C
A-1	$H = 4\cdot\dfrac{C}{\delta\cdot\sin 2\alpha}$	131.9	90.9	139.53
A-2	$H = 0.985\cdot 4\cdot\dfrac{C}{\delta}$	126.4	87.09	133.67
A-3	$H_v = 2\cdot C\cdot\dfrac{\cos\phi}{\delta(1-\sin\phi)}$	126.4	87.09	133.67
A-4	$H_v = \dfrac{\sigma_c}{\delta}$	131.8	65.76	109.55
B	$H_v = 1.5\cdot H_{d_{\max}}$ (a super 6030 FS hydraulic shovel)	52.9	54.81	54.79
C	$H = 0.7^{a}\sqrt{\dfrac{\sin\alpha\sin\beta}{k\xi^{/}\left(1+\xi^{//}\right)\sin\left(\beta-\alpha\right)}}$	30.75	30.75	30.75

*Note: A – bench height calculation considering slope stability;

A-1 – N.A. Tsykevich; A-2 – Fellenius modified; A-3 – V.V. Sokovsky; A-4 – E.M. Demen;

B – bench height calculation due to safety of work place; C – bench height calculation due to the efficiency of work place;

$H_{d_{\max}}$ – maximum digging height of the excavator, m; $a = 0.8(R_d + R_l)$, where a – is a width of the broken down heap of materials formed after blasting, m; α – slope angle of broken down materials, deg. (e.g. for phosphate $\alpha = 3°$);

β – slope angle of the face, deg.; k – loosening factor of the face material (coefficient of swelling);

$\xi^{/}$ – ratio of length of least resistance line of first row of blast holes face height, usually, equal to 0.55 – 0.70;

$\xi^{//}$ – ratio of distance between rows of blast holes to length of line of least resistance, usually, equal to 0.75 – 0.80;

R_d – digging radius of power shovel, m; R_l – loading radius of power shovel, m.

2. BLENDING OPERATION

This study is adapted to three phosphate operations (e.g. B1, B2, and C) located in the Nile Valley, El-Sibaiya west area. The three operations have variations in amount of phosphate reserve and assay. Consequently, some assays may become waste (when P_2O_5 percentage is beyond the economic value 20% P_2O_5 and cannot compete with global market. Therefore, improving the poor assays by blending phosphate ores is essential to maximize profit of the mine. To determine the optimum quantities of phosphate ore per each mine to optimize profit, LP has been applied Figure 4 depicts the stages of blending operation. The ore is prepared in the first stage using a front-end loader then it is fed to blending plants in the second stage.

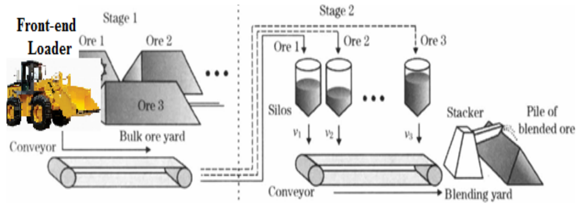


Figure 4. Stages of blending operation

Phosphate rocks widely vary in both chemical composition and the nature of associated principle minerals. Therefore, the big concern in phosphate ore production is blending operation (Ashayeri, van Eijs, & Nederstigt, 1994; Shih & Frey, 1995; El-Arabi & Khalifa, 2002; Gholamnejad & Kasmaee, 2012; Song, Hu, & Li, 2012). Spectrophotometric technique has been used to analyze the chemical composition of phosphate rocks at chemical labs of Nile Valley Company as listed in Table 5. The chemical analysis reveals that the most oxides are existed in phosphate rocks are SiO_2, Al_2O_3, TiO_2, and P_2O_5. Table 6 gives the quantities and assays of phosphate rock per each mine. Table 7 displays the selling prices of phosphate ore based on its P_2O_5 percentage. Thus, it is necessary to blend phosphate ores of different assays to achieve maximum profit (Ali, 2007; El-Beblawi, Mohamed, El-Sageer, & Mahrous, 2007; Ali & Sik, 2012, Yassien & Elameer, 2014).

Table 5. Chemical composition of the phosphate rocks obtained from three operations

Element, %	B1	B2	C
P_2O_5	23.2	22.9	24.1
CaO	48 – 49	47 – 48	44 – 45
MgO	0.3 – 0.4	0.3 – 0.5	0.3 – 0.5
Fe_2O	1.8 – 2.1	1.8 – 2.0	1.8 – 2.0
Al_2O_3	0.2 – 0.7	0.5 – 0.8	0.5 – 1.0
SiO_2	6 – 7	8 – 9	12 – 15
SO	1.5 – 1.8	1.5 – 1.8	1.5 – 1.8
Cl	0.03 – 0.06	0.03 – 0.07	0.08 – 0.1
F	3.0 – 3.1	2.9 – 3.0	2.5 – 2.7
Na_2O	0.3 – 0.5	0.3 – 0.5	0.3 – 0.5
K_2O	0.02 – 0.06	0.02 – 0.06	0.05 – 0.1
LOI	6.5 – 7.5	7 – 8	9 – 11
CO_2	4.5 – 5.5	5 – 6	7 – 9
$CaCO_3$	10.2 – 12.5	11.3 – 13.6	15.9 – 20.4

Table 6. The quantities and assays of phosphate ore per each mine

Operation		Quantities, ton	Average assay, P_2O_5%
B1	Third	67400	22.5
	Upper	215311	23.6
	Lower	192096	23.6
B2	Third	19441	21.0
	Upper	112374	23.5
	Lower	132127	24.3
C	Upper	801150	24.0
	Lower	1115627	24.2
Total		2655527	

Table 7. The selling price of phosphate ore according to assay in global market 2016

Assay, P_2O_5%	Selling price, \$/ton
24	15.5
23	12.5
22	10.5
21	5.0

3. NUMERICAL METHODOLOGY

The first step is to define the decision variables, X_{ij}. Where variable i refers to amount of phosphate ore excavated from operation B1, B2 and C (Saul, 1957; Paul Loomba, 1964). The second variable, j denotes to P_2O_5 assay (e.g. 21, 22, 23 and 24%). Then, the objective function, that maximizes the profit contribution, can be developed by multiplying the selling price and quantities of the phosphate ores, as illustrated by Equation 1:

$$\begin{aligned} &\max 15.5\left(x_{11}+x_{21}+x_{31}+x_{41}+x_{51}+x_{61}+x_{71}+x_{81}\right)+ \\ &+12.5\left(x_{12}+x_{22}+x_{32}+x_{42}+x_{52}+x_{62}+x_{72}+x_{82}\right)+ \\ &+10.5\left(x_{13}+x_{23}+x_{33}+x_{43}+x_{53}+x_{63}+x_{73}+x_{83}\right)+ \\ &+5\left(x_{14}+x_{24}+x_{34}+x_{44}+x_{54}+x_{64}+x_{74}+x_{84}\right). \end{aligned} \tag{1}$$

Equations 2 to 9 are given the constraints should be achieved to attain maximum profit and satisfy the entire product specifications:

$$x_{11}+x_{12}+x_{13}+x_{14} \le 67.400\,; \tag{2}$$

$$x_{21}+x_{22}+x_{23}+x_{24} \le 215.311\,; \tag{3}$$

$$x_{31}+x_{32}+x_{33}+x_{34} \le 192.096\,; \tag{4}$$

$$x_{41}+x_{42}+x_{43}+x_{44} \le 19.441\,; \tag{5}$$

$$x_{51}+x_{52}+x_{53}+x_{54} \le 112.374\,; \tag{6}$$

$$x_{61}+x_{62}+x_{63}+x_{64} \le 132.127\,; \tag{7}$$

$$x_{71}+x_{72}+x_{73}+x_{74} \le 801.150\,; \tag{8}$$

$$x_{81}+x_{82}+x_{83}+x_{84} \le 1115.627\,. \tag{9}$$

Amount of phosphate is blended must be equal to number of targeted assays, as given per Equations 11 to 16:

$$\begin{aligned} &22.5x_{11}+23.6x_{21}+23.6x_{31}+21x_{41}+23.5x_{51}+ \\ &+24.3x_{61}+24x_{71}+24.2x_{81}=24\left(x_{11}+x_{21}+\right. \\ &\left.+x_{31}+x_{41}+x_{51}+x_{61}+x_{71}+x_{81}\right); \end{aligned} \tag{10}$$

$$22.5x_{12} + 23.6x_{22} + 23.6x_{32} + 21x_{42} + 23.5x_{52} + \\ + 24.3x_{62} + 24x_{72} + 24.2x_{82} = 23\left(x_{12} + x_{22} + \right. \\ \left. + x_{32} + x_{42} + x_{52} + x_{62} + x_{72} + x_{82}\right); \tag{11}$$

$$22.5x_{13} + 23.6x_{23} + 23.6x_{33} + 21x_{43} + 23.5x_{53} + \\ + 24.3x_{63} + 24x_{73} + 24.2x_{83} = 22\left(x_{13} + x_{23} + \right. \\ \left. + x_{33} + x_{43} + x_{53} + x_{63} + x_{73} + x_{83}\right); \tag{12}$$

$$22.5x_{14} + 23.6x_{24} + 23.6x_{34} + 21x_{44} + 23.5x_{54} + \\ + 24.3x_{64} + 24x_{74} + 24.2x_{84} = 21\left(x_{14} + x_{24} + \right. \\ \left. + x_{34} + x_{44} + x_{54} + x_{64} + x_{74} + x_{84}\right); \tag{13}$$

$$(\text{Non} - \text{negative}) \sum x_{ij} \geq 0; \tag{14}$$

$$\sum x_{ij} = \text{Total quantities of phosphate ores in 3 mines.} \tag{15}$$

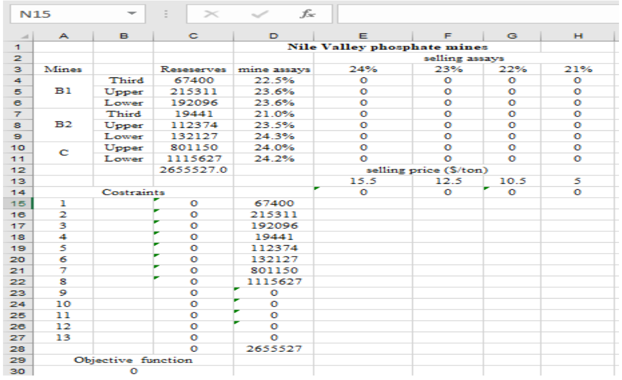
3.1. Spreadsheet model and solver implementation

To implement the problem into excel spreadsheet; the following parameters should be included:

a) cells E4 to H11 represent the twelve decision variables (e.g. according to selling assays) and the cell A30 represents the objective function;

b) cells C15 to C27 represent the constraints left-hand sides and cells D15 to D27 represent the constraints right-hand sides as shown in Figure 5;

c) non-negativity constraints are not implemented in the spreadsheet and can be implemented in the solver.



N15

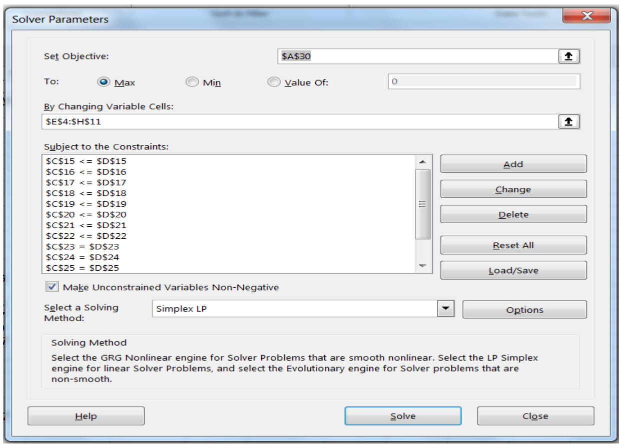
	A	B	C	D	E	F	G	H
1					Nile Valley phosphate mines			
2					selling assays			
3	Mines		Reseserves	mine assays	24%	23%	22%	21%
4		Third	67400	22.5%	0	0	0	0
5	B1	Upper	215311	23.6%	0	0	0	0
6		Lower	192096	23.6%	0	0	0	0
7		Third	19441	21.0%	0	0	0	0
8	B2	Upper	112374	23.5%	0	0	0	0
9		Lower	132127	24.3%	0	0	0	0
10	C	Upper	801150	24.0%	0	0	0	0
11		Lower	1115627	24.2%	0	0	0	0
12			2655527.0		selling price ($/ton)			
13					15.5	12.5	10.5	5
14		Costraints			0	0	0	0
15	1		0	67400				
16	2		0	215311				
17	3		0	192096				
18	4		0	19441				
19	5		0	112374				
20	6		0	132127				
21	7		0	801150				
22	8		0	1115627				
23	9		0	0				
24	10		0	0				
25	11		0	0				
26	12		0	0				
27	13		0	0				
28			0	2655527				
29	Objective function							
30	0							

Figures 5. Input data and description

The complete set of constraints, target cell (e.g. objective function cell); variable cells and whether to maximize or minimize the objective function are identified in the solver parameters box as shown in Figure 6. While, the optimal distribution of phosphate ores in the blending operation is shown in Figure 7. Cell (A30) gives the optimal solution for the objective function.

4. RESULTS

The demonstrated LP allows exploiting all quantities of phosphate ore from the three mines. Blending operation can be done on daily, weekly and shift bases. The results of the proposed solution are converted to percentages since the blending process cannot be done at equal daily portions during the life of the mine.



Solver Parameters

Set Objective: $A$30

To: ● Max ○ Min ○ Value Of: 0

By Changing Variable Cells: $E$4:$H$11

Subject to the Constraints:

```
$C$15 <= $D$15
$C$16 <= $D$16
$C$17 <= $D$17
$C$18 <= $D$18
$C$19 <= $D$19
$C$20 <= $D$20
$C$21 <= $D$21
$C$22 <= $D$22
$C$23 = $D$23
$C$24 = $D$24
$C$25 = $D$25
```

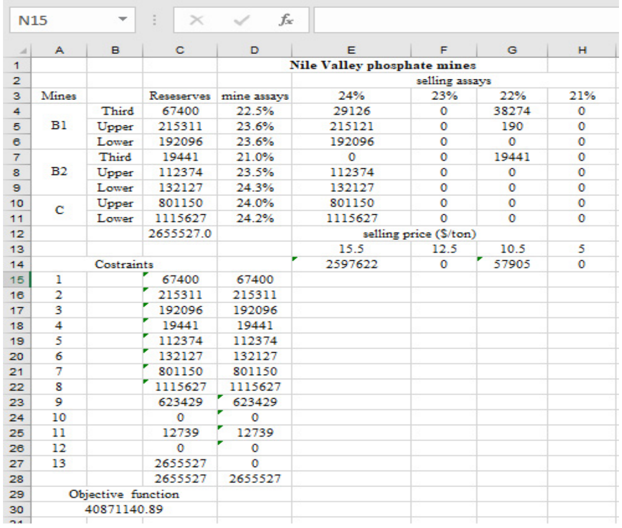
☑ Make Unconstrained Variables Non-Negative

Select a Solving Method: Simplex LP

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Figures 6. Solver dialog box illustrate the objective function, variables, and constraints

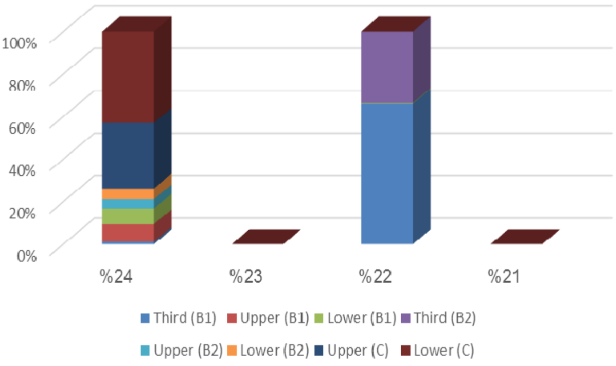


N15

	A	B	C	D	E	F	G	H
1					Nile Valley phosphate mines			
2					selling assays			
3	Mines		Reseserves	mine assays	24%	23%	22%	21%
4		Third	67400	22.5%	29126	0	38274	0
5	B1	Upper	215311	23.6%	215121	0	190	0
6		Lower	192096	23.6%	192096	0	0	0
7		Third	19441	21.0%	0	0	19441	0
8	B2	Upper	112374	23.5%	112374	0	0	0
9		Lower	132127	24.3%	132127	0	0	0
10	C	Upper	801150	24.0%	801150	0	0	0
11		Lower	1115627	24.2%	1115627	0	0	0
12			2655527.0		selling price ($/ton)			
13					15.5	12.5	10.5	5
14		Costraints			2597622	0	57905	0
15	1		67400	67400				
16	2		215311	215311				
17	3		192096	192096				
18	4		19441	19441				
19	5		112374	112374				
20	6		132127	132127				
21	7		801150	801150				
22	8		1115627	1115627				
23	9		623429	623429				
24	10		0	0				
25	11		12739	12739				
26	12		0	0				
27	13		2655527	0				
28			2655527	2655527				
29	Objective function							
30	40871140.89							

Figures 7. Optimal solution for the blending operation

Some technical problems may rise and affect the production rate and blending process. Figure 8 shows the percentages of phosphate assay after blending process using LP. Blending plant may be built in the crusher location where topographic conditions are suitable. Table 8 summarizes the results of the obtained optimal solution for the blending operation.



Figures 8. Percentage of phosphate ores after blending operation

Table 8. Summary of the optimal solution for the blending process

Mine	Layer	Blending percentage			
		24%	23%	22%	21%
B1	Third	1.12	0.00	66.10	0.00
	Upper	8.28	0.00	0.33	0.00
	Lower	7.40	0.00	0.00	0.00
B2	Third	0.00	0.00	33.57	0.00
	Upper	4.33	0.00	0.00	0.00
	Lower	5.09	0.00	0.00	0.00
C	Upper	30.84	0.00	0.00	0.00
	Lower	42.95	0.00	0.00	0.00

5. CONCLUSIONS

Optimization of ore blending operation is crucial to maximize the profit of a phosphate mine. Such optimization requires investigating the physical and mechanical properties of ore, estimating ore reserve and achieving optimal quantity of ores to be blended together. Nine phosphate rocks have been collected from three operations named B1, B2 and C located in Aswan governorate, south of Egypt. Triangular method has been used to estimate ore reserves in the three operations and LP technique is adopted to determine the optimum quantities of phosphate per each mine to obtain economic assay. The results reveal that the phosphate ore of 24% of P_2O_5 will be obtained when blending phosphate quantity of 16.8% (e.g. 1.12, 8.28 and 7.40% from third, upper and lower layers respectively) from mine B1, 9.42% (e.g. 4.33 and 5.09% from upper and lower layers respectively) from mine B2, and 73.79% (e.g. 30.84 and 42.95% from upper and lower layer respectively) from mine C. While, phosphate ore of 22% of P_2O_5 will be produced when blend phosphate of 66.43% (e.g. 66.10 and 0.33% from third and upper layers respectively) from mine B1 and 33.57% from mine B2. Many changes have been applied to the given solution to check the optimal quantity of blending operation. Thus, the empty cells in the spreadsheet will be occupied by 1 ton of phosphate ore from different locations and used to determine the new objective function. Such function will be compared with the first objective function. It is noteworthy that the optimum blending solution is only reached when maximum objective function satisfies all constraints.

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ОПТИМІЗАЦІЯ ОПЕРАЦІЇ ЗМІШУВАННЯ НА АСУАНСЬКИХ ФОСФАТНИХ РУДНИКАХ ІЗ ВИКОРИСТАННЯМ ЛІНІЙНОГО ПРОГРАМУВАННЯ

Магроус А.М. Алі, Х.С. Васлі, В.Р. Адбеллах, Хіонгду Джанг

Мета. Оптимізація операції змішування фосфатних руд, що добуваються з трьох різних рудників родовища фосфатів (провінція Асуан), на основі використання лінійного програмування для максимізації прибутку гірничого підприємства.

Методика. У роботі використано метод лінійного програмування (ЛП) для визначення оптимальної кількості фосфатної руди в процесі змішування, видобутої рудниками на різних ділянках родовища. Для цього розглянуто три фосфатних рудника в провінції Асуан на півдні Єгипту – В1, В2 і С. Для експерименту відібрано три зразки фосфатної руди з кожного рудника, які стадійно перемішувались згідно розробленої схеми. Хімічний склад фосфатних порід, що добуваються з трьох ділянок родовища, визначався спектрофотометричним аналізом.

Результати. В процесі лінійного програмування складена цільова функція з урахуванням відпускної ціни та кількості фосфатних руд певного вмісту P_2O_5, що максимізує прибуток. Виявлено, що у результаті застосування лінійного програмування фосфатна руда із 24% вмістом P_2O5 виходить при змішуванні 16.8% руди з рудника В1, 9.42% руди – з рудника В2 та 73.78% руди – з рудника С, а з 22% вмістом – при змішуванні 66.43% руди з рудника В1 і 33.57% руди з рудника В2. Встановлено, що економічна цінність фосфату зменшується при випадковому змішуванні сирих фосфатів, видобутих на різних рудниках.

Наукова новизна. Вперше для умов фосфатних рудників Ель-Гера (провінція Асуан) застосовано метод лінійного програмування для оптимізації якості фосфатної руди, що дозволило максимізувати прибуток гірничого підприємства.

Практична значимість. Прикладне використання лінійного програмування в гірничій справі дозволяє поліпшити якість видобутої фосфатної руди з різних ділянок родовища провінції Асуан та підвищити її конкурентоспроможність на світовому ринку.

Ключові слова: *лінійне програмування, операція змішування, оптимізація прибутку, родовище фосфатної руди*

ОПТИМИЗАЦИЯ ОПЕРАЦИИ СМЕШИВАНИЯ НА АСУАНСКИХ ФОСФАТНЫХ РУДНИКАХ С ИСПОЛЬЗОВАНИЕМ ЛИНЕЙНОГО ПРОГРАММИРОВАНИЯ

Магроус А.М. Али, Х.С. Васли, В.Р. Адбеллах, Хионгду Джанг

Цель. Оптимизация операции смешивания фосфатных руд, добываемых из трех разных рудников месторождения фосфатов (провинция Асуан), на основе использования линейного программирования для максимизации прибыли горного предприятия.

Методика. В работе использован метод линейного программирования (ЛП) для определения оптимального количества фосфатной руды в процессе перемешивания, добытой рудниками на разных участках месторождения. Для этого рассмотрены три фосфатных рудника в провинции Асуан на юге Египта – В1, В2 и С. Для эксперимента отобраны по три образца фосфатной руды из каждого рудника, которые стадийно перемешивались согласно разработанной схемы. Химический состав фосфатных пород, добываемых из трех участков месторождения, определялся спектрофотометрическим анализом.

Результаты. В процессе линейного программирования составлена целевая функция с учетом отпускной цены и количества фосфатных руд определенного содержания P_2O_5, максимизирующая прибыль. Выявлено, что в результате применения линейного программирования фосфатная руда с 24% содержанием P_2O_5 получается при смешивании 16.8% руды из рудника В1, 9.42% руды – из рудника В2 и 73.78% руды – из рудника С, а с 22% содержанием – при смешивании 66.43% руды из рудника В1 и 33.57% руды из рудника В2. Установлено, что экономическая ценность фосфата уменьшается при случайном смешивании сырых фосфатов, произведенных на разных рудниках.

Научная новизна. Впервые для условий фосфатных рудников Эль-Гера (провинция Асуан) применен метод линейного программирования для оптимизации качества фосфатной руды, что позволило максимизировать прибыль горного предприятия.

Практическая значимость. Прикладное использование линейного программирования в горном деле позволяет улучшить качество добытой фосфатной руды из разных участков месторождения провинции Асуан и повысить ее конкурентоспособность на мировом рынке.

Ключевые слова: *линейное программирование, операция смешивания, оптимизация прибыли, месторождение фосфатной руды*

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ABOUT AUTHORS

Mahrous A.M. Ali, Doctor of Philosophy, Assistant Professor of the Mining and Petroleum Engineering Department, Al-Azhar University, Maskan Osman, 83215, Qena, Egypt. E-mail: mahrous_mining@yahoo.co.uk

Hamdy S. Wasly, Doctor of Philosophy, Assistant Professor of the Mining and Petroleum Engineering Department, Al-Azhar University, Maskan Osman, 83215, Qena, Egypt. E-mail: elwasly_hs@yahoo.com

Wael Rashad Abdellah, Doctor of Philosophy, Assistant Professor of the Mining and Metallurgical Engineering Department, Assiut University, 71516, Assiut, Egypt. E-mail: wre544@gmail.com

Hyongdoo Jang, Doctor of Philosophy, Associate Professor of the Western Australian School of Mines, Science and Engineering, Curtin University, Kent Street, Bentley, WA 6102, Perth, Australia. E-mail: hyongdoo.jang@curtin.edu.au