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DISTRIBUTION AND IMPLEMENTATION OF DRILLING MACHINES AT THE QUARRY BENCHES

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ABSTRACT

In many times, a good distribution and implementation of equipment and machines along the quarry faces is considered a challenge to the mining engineer or the quarry operator. Quarry equipment includes drilling machines, air compressors, loading equipment including loaders and/or excavators, in addition to the transportation fleet of high-tonnage trucks. These equipment cost large investments in the production processes and need high skill to be efficiently distributed and operated. In this investigation, study of the optimum distribution of the available drilling machines of different specifications and capacities along the faces of the lime stone quarry of Assiut Cement Company has been carried out. A mathematical model has been used to find several alternatives and to choose the best alternative. Calculation of the minimum number of drilling machines that satisfy the annual production plan is an important step to decrease production costs.

Keywords: drilling machines, modeling, quarry.

1. Introduction

Production cycle in most of the quarries includes the processes of drilling, blasting, loading and transportation. Rock drilling is the first operation carried out. Blast holes are drilled with adequate geometry and distribution within the rock mass to accommodate the suitable explosive charges and their accessories [1,7,8].

Considering drilling equipment, most of the drilling cost is time dependent rather than product cost dependent. Hence, higher –priced drilling equipment based on new technologies that save time are economically justified. Rate of penetration (ROP) includes the hours after a bit reaches hole bottom divided by the distance drilled until the time of tripping the bit out of the hole. By this definition, ROP includes actual drilling time plus time spent in reaming, surveying, and making connections. This means that, this drilling time includes time spent in actual drilling (rotating time) in addition to non-drilling (non-productive) time. This is of great importance to the drilling engineer and operation management [2].

There are three basic elements, which must be considered in evaluating a drilling system, they are [3, 4]:

1- Production schedules, operating conditions, and rock types encountered.
2- Equipment productive capacities including pattern size, tons of material effected per hole, drill production rate in meters drilled per shift or hour, and drill availability and utilization %.
3- Capital costs and operating costs including repair, maintenance, and related storage costs of spare parts and drill steel.

It has been advocated that operations research facilities in describing and analyzing the behavior of a system by constructing appropriate models and predicting future behavior

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using these models. Studies on the Queuing, Markov and reliability models lead to the conclusion that with the help of operations research, an appropriate mathematical model for situations, processes and systems can be developed. Then, the model can be tested and operated by changing variable values to implement optimization of the parameters. In the present era, optimal use of resources is essential and operations research can facilitate taking proactive decisions to make the system profitable and competitive [5].

In this investigation, study of the optimum distribution of the available drilling machines of different specifications and capacities along the faces of the lime stone quarry of Assiut Cement Company has been carried out. A mathematical model has been used to find several alternatives and to choose the best alternative. Calculation of the minimum number of drilling machines that satisfy the annual production plan is an important step to decrease production costs [7, 8].

2. Formulation of the problem

In order to formulate any problem as a model, the following parameters must be defined [4, 6]:

1- The variables in the model,
2- The constraints,
3- The objective function.

2.1. The variables

The variables are defined as follows:
TPY is production rate or material mined per year (ton per year)
MPH is material produced per hole, ton/hole
N is the number of holes drilled
MDH is meters drilled per hole = bench height + sub-drilling, m
T_m is total meters drilled = N × MDH, m
DR is drilling rate, m/hr
TDH is total drilling hours in one bench per year
Oh is operating hours
PAT is possible available time (total calendar time – holidays/year), days
AOT is available operating time = PAT – holidays, days
OR are operational restrictions
LDM is long drill moves
PT is personal time
OND is other non-drilling time
NDT is net drilling time
NDT = AOT – OR – LDM – PT – OND

2.2. The constraints

The model has several constraints in form of equations. The equations are formulated basically for the purpose of calculations.

$$\%\ Availability = \frac{AOT}{PAT} \times 100 \qquad (1)$$

$$\%\ Utilization = \frac{AOT - OR - LDM - PT - OND}{AOT} \times 100 \qquad (2)$$

% operated of total time = Availability × Utilization (3)

Oh/shift = Utilization × hr/shift (4)

2.3. The objective function

The objective function of the model is to minimize the number of drills realizing the production plan required. The minimum number of drills needed is expressed as follows:

$$Minimum\ number\ of\ drills\ (MND) = \frac{\sum_{i=1}^{I}(TDh)_i}{PAT/drill \times Avail. \times Utili.} \times 100 \quad (5)$$

Where:

$(TDH)_i$ is total drilling time in one bench, hrs., where i = 1,2,3,… . I, in this case i = 3 benches.

Avail. is the availability %

Utili. is the utilization %

No. of hours per day = 8 hours

3. Collection of field data

The present study has been carried out on limestone quarry of the Assiut Cement Company that operates 300 days per year, one drilling shift per day. It is required to produce 5 million tons of limestone per year to be used in the cement factory. To identify the production plan requirements; the quarry is divided into three benches upper, middle and lower bench. Each bench produces one third of the annual production plan, but they have different bench heights. The height of the upper bench is 26 m, the height of the middle bench is 30 m and the height of the lower bench is 35 m.

The evaluation will start with review of some of the drilling machines available as grouped into three classes based on the drill hole size capability and model of the machine. Table 1, presents rotary percussive blast hole drills that are available and some of pertinent information for the drills listed. Calculations of the drilling patterns, the material effected by each borehole according to the different bench heights and the average drilling rate for the three drills are illustrated in Table 2. Average density of limestone is given to be 2.2 t/m^3.

In case of this quarry, the annual production is distributed between the three classes of drills as follows: 33.76% by Compare, 16.59% by Atlas Copco 660 and 49.65% by Atlas Copco 460. 33% of the annual production is required from each of the upper and middle bench and 34% from the lower bench.

Table 1.
Representative blast hole drills by class.

Class	Name and model	Typical bit size, mm (in)	Tube diameter, mm	Tube length, m
C-1	Compair Holman	111 (4.5)	76	3
C-2	Atlas Copco Roc 606	152 (6)	89	3
C-3	Atlas Copco Roc 460 HF	152 (6)	89	3

Table 2.
Drilling patterns and material effected by each borehole.

Class	Pattern size, m	Material per hole, ton			Average drilling rate, m/hr
		Upper Bench	Middle Bench	Lower Bench	
C-1	6.5 × 4.5	1673	1931	2252	20
C-2	8.5 × 5.5	2674	3086	3600	15
C-3	8.5 × 6	2917	3366	3927	30

4. Application of the model

The procedure for determining drill availability and utilization is outlined in Table 3 and based on the information of a typical operation as used in the present quarry. Equations (1) and (2) are used to obtain the availability and utilization percentages for the drills to be evaluated. Percentage of operation time in relation to total possible time is calculated by using equation (3).

Table 3.
Determination of drill availability and utilization, according to operating time of the present quarry working one 8 hrs-shift/day.

Description	Hours	Days
Total calendar time	2920	365
Less holidays per year	80	10
Possible available time (PAT)	2840	355
Less outages	440	55
Available operating time (AOT)	2400	300
Less operational restrictions (OR)	208	26
Less drill moves and other major interruptions	72	9
Less personal time (PT):		
Travel time	48	6
Lunch	48	6
Other	24	3
Less other non-drilling time (OND):		
Lubrication and inspection	80	10
Short moves	24	3
Running repairs	40	5
Other	40	5
Net drilling time (NDT)	1816	227

$$\%Availabilty = \frac{PAT - outages}{PAT} * 100 = \frac{AOT}{PAT} * 100 = \frac{355 - 55}{355} * 100 = 84.5\%$$

$$\%Utilization = \frac{AOT - OR - LDM - PT - OND}{AOT} * 100 = \frac{300 - 26 - 9 - 15 - 23}{300} * 100$$
$$= 75.5\%$$

$$\%Operated\ of\ total\ time = Availability \times Utilization = 84.5\% \times 75.5\% = 64\%$$

$$Then, operating\ hours\ per\ shift = 8 \times \frac{227}{300} = 6\ hrs/shift$$

In actual practice, the amount of time lost due to operational restrictions can vary from 5 to 40%of the available operating time. In this study, the amount of time lost is about 25%, the amount of time lost is between the lower and higher limit of the possible loss in time [3].

5. Results and discussion

5.1. Calculation of minimum number of drills

For the initial evaluation, it is assumed that all of the three drills have the same availability and utilization values. All the drill productive capacities are given in (Table 2). The minimum number of drills needed in each drill class to maintain supply of broken material according to the annual production plan, can be calculated by using equation (5). The minimum number of drills needed is calculated as shown in Table 4.

Table 4.
Calculation of minimum number of drills according to the current practice in the quarry.

Class of Drills	Bench	TPY, ton	MPH, ton/ hole	N	MDH, m/hole	T_m, m	DR, m/h	TDH, Hrs	MND	Lack(-) - stand by (+)
C-1	Upper	557040	1673	333	28	9324	20	466.2		
	Middle	557040	1931	289	32	9248	20	462.4		
	Lower	573920	2252	255	37	9435	20	471.8		
Total		1688000		877		28007		1400.4	0.77	+0.23
C-2	Upper	273735	2674	103	27.5	2833	15	188.9		
	Middle	273735	3086	89	31.5	2804	15	186.9		
	Lower	282030	3600	79	36.5	2884	15	192.3		
Total		829500		271		8521		568.1	0.31	+0.69
C-3	Upper	819225	2917	281	27.5	7728	30	257.6		
	Middle	819225	3366	244	31.5	7686	30	256.2		
	Lower	844050	3927	215	36.5	7848	30	261.6		
Total		2482500		740		23262		775.4	0.43	+0.57
T.Grand		5000000		1888		59790		2760		

From Table 4, it can be seen that using three drills one of each class leads to very high ratio of standby time. The ratio of standby time is 0.23, 0.57, and 0.69 for class1, class2, and class3 respectively. This is a great loss of operating time which if used can produce 5,702,859 tons annually i.e. greater than the current annual production by about 14%. Hence, the current practice distribution of drills is not suitable and needs improvement.

Now, there are six alternatives suggested, in addition to the case actually applied in the present practice of the quarry as follows:

If we only use one class of the drilling machines, we can calculate the minimum number of drills of this class required to fulfill the five million tons annual production. Hence, we have three alternatives: alternative 1, only using class1; alternative 2, only using class2; and alternative three, only using class3. Table 5 presents calculations of the minimum number of drills for each class that satisfies the annual production.

If we use two drill classes at a time to fulfill the annual production, we have three additional alternatives: alternative 4, using class1 and class2; alternative 5, using class1 and class3; alternative 6, using class2 and class3. Summary of calculations of these alternatives is presented in Table 6.

From Table 5:

Alternative1 suggests using two drills of class1. However, there is a lack of operating time about 14% which can be accounted for by allowing overtime for operating the two drills (about one hour/shift). The quarry has only one drill of class1 at the present time, hence this alternative cannot be applied.

Alternative2 suggests using two drills of class2. There would be standby time about 6% which is an acceptable percentage. However, the alternative is not acceptable because at present the quarry has only one drill of class2.

Alternative3 is very attractive. It suggests one drill of class3 with 14% of standby time. However there is a great potential risk if sudden breakdown happens to the drill. This will lead to a complete stop not only for the quarry operations but also for the subsequent whole system of cement production. This would be much greater economic loss than the saving in the drilling process. Accordingly alternative3 is rejected.

Table 5.

Calculations of minimum number of drills for each class that satisfies the annual production of 5 million ton.

Class of Drills	Bench	TPY, ton	MPH, ton/ hole	N	MDH, m/hole	T_m, m	DR, m/h	TDH, Hrs	MND	Lack(-) - stand by (+)
Alternative1										
C-1	Upper	1650000	1673	987	28	27636	20	1381.8		
	Middle	1650000	1931	855	32	27360	20	1368		
	Lower	1700000	2252	755	37	27935	20	1396.8		
Total		5000000		2597		82931		4146.6	2.28	-0.14/1
Alternative2										
C-2	Upper	1650000	2674	617	27.5	16968	15	1131.2		
	Middle	1650000	3086	535	31.5	16853	15	1123.5		
	Lower	1700000	3600	473	36.5	17265	15	1151		
Total		5000000		1625		51086		3405.7	1.88	+0.06/1
Alternative3										
C-3	Upper	1650000	2917	566	27.5	15565	30	518.8		
	Middle	1650000	3366	491	31.5	15467	30	515.6		
	Lower	1700000	3927	433	36.5	15805	30	526.8		
Total		5000000		1490		46837		1561.2	0.86	+0.14

From Table 6:

Alternative4 using one drill of class1 and one drill from class2 is very acceptable. A very short operating overtime (about 4%) will be needed to fulfill the annual production plan. The two drills are available in the quarry. This alternative will lead to saving one drill of class3 for rent or sale which is a good economic gain.

Alternative 5 suggests that using one drill of class1 and one drill of class3. This will lead to saving one drill of class2 for rent or sale providing an economic gain for the quarry. This alternative will provide a plenty of standby time (about 44%) even after sharing drill1 to satisfy its production share. This can be a good choice if there is a plan to expand the cement production in the near future.

Alternative6 suggests using one drill of class2 and one drill of class3 and saving one drill of class1. It is acceptable because of the economic gain by saving that drill of class1. However there is a plenty of standby time (about 60%) which is not exploited now. It can be available for future expansion.

From the above, alternative 4 (using one drill of class1 and one drill of class2) provides the best option for the distribution of the drilling machines. It provides a complete use of the two drills and save the most efficient drill of class3 for rent or sale. The subsequent options are alternative5 and alternative6 respectively.

Table 6.

Minimum number of drills considering alternative 4, 5 and 6, using two drill classes at a time to produce the annual production.

Alternative 4: Using class 1 and class 2 drills										
Class of Drills	Bench	TPY, ton	MPH, ton/ hole	N	MDH, m/hole	T_m, m	DR, m/h	TDh, Hrs	MND	Lack (-) - stand by (+)
C-1	Upper	825000	1673	494	28	13832	20	691.6		
	Middle	825000	1931	428	32	13696	20	684.8		
	Lower	850000	2252	378	37	13986	20	699.3		
Total		2500000		1300		41514		2075.7	1.14	-0.14
C-2	Upper	825000	2674	309	27.5	8498	15	566.5		
	Middle	825000	3086	268	31.5	8442	15	562.8		
	Lower	850000	3600	237	36.5	8651	15	576.7		
Total		2500000		814		25591		1706	0.94	+0.06
T.Grand		5000000		2114		67105		3804		
Alternative 5: Using class 1 and class 3 drills										
Class of Drills	Bench	TPY, ton	MPH, ton/ hole	N	MDH, m/hole	T_m, m	DR, m/h	TDh, Hrs	MND	Lack (-) - stand by (+)
C-1	Upper	825000	1673	494	28	13832	20	691.6		
	Middle	825000	1931	428	32	13696	20	684.8		
	Lower	850000	2252	378	37	13986	20	699.3		
Total		2500000		1300		41514		2075.7	1.14	-0.14
C-3	Upper	825000	2917	283	27.5	7783	30	259.4		
	Middle	825000	3366	246	31.5	7749	30	258.3		
	Lower	850000	3927	217	36.5	7921	30	264		
Total		2500000		746		23453		781.7	0.43	+0.57
T.Grand		5000000		2046		64967		2874		
Alternative 6: Using class 2 and class 3 drills										
Class of Drills	Bench	TPY, ton	MPH, ton/ hole	N	MDH, m/hole	T_m, m	DR, m/h	TDh, Hrs	MND	Lack (-) - stand by (+)
	Upper	825000	2674	309	27.5	8498	15	566.5		

C-2	Middle	825000	3086	268	31.5	8442	15	562.8		
	Lower	850000	3600	237	36.5	8651	15	576.7		
Total		2500000		814		25591		1706	0.94	+0.06
C-3	Upper	825000	2917	283	27.5	7783	30	259.4		
	Middle	825000	3366	246	31.5	7749	30	258.3		
	Lower	850000	3927	217	36.5	7921	30	264		
Total		2500000		746		23453		781.7	0.43	+0.57
T.Grand		5000000		1560		49044		2502		

Table 7.
Summary

Alternatives	Class of drills	MND	Overtime required(+)/Stand by, hr/year	Remarks
1	C-1	2	####	Inapplicable
2	C-2	2	####	
3	C-3	1	254	Rejected for risk
4	C-1	1	+ 62	The production plan can be accomplished with 113hr overtime, with one drill spare for rent.
	C-2	1	+ 51	
5	C-1	1	0	The production plan will be accomplished. The C-3 drill will be stand by for nearly half of the net drilling time which consider waste of resources.
	C-3	1	940	
6	C-2	1	108	The production plan will be accomplished. The C-3 drill will be stand by for more than half of the net drilling time which consider waste of resources.
	C-3	1	1035	

6. Conclusions

This study has been carried out on the lime stone quarry of Assiut Cement Company (CEMEX). The quarry has three benches and three drilling machines. Namely one drill of Compare (class31), one drill of Atlas Copco Roc 606(class2), and one drill of Atlas Copco Roc 460 HF (class3). A simple mathematical model has been used to calculate the minimum number of drilling machines and their types for six alternatives in addition to the current practice. The following conclusions and recommendations have been drawn.

1- Using one drilling machine of class1 and one drilling machine of class2 (alternative4) is the best option for the quarry. That is because the two drills are operating almost all the time and the drill of class3 is saved for rent or sale.
2- Using one drill of class1 and one drill of class3 (alternative5) will save one drill of class2. Whereas using one drill of class2 and one drill of class3 (alternative6) will

save one drill of class1. However, there will be a plenty of operating standby time, 44% and 60% respectively.

3- Using two drills of class1 (alternative1) and using two drill of class2 (alternative2) are technically acceptable. However, they are rejected because the quarry actually has only one drill of each type.
4- Using one drill of class3 (alternative3) is technically the best option. However, it is rejected because there is a great potential of risk if a sudden break down of the drill takes place. The whole operations in the quarry and the cement producing lines will stop causing great economic loss.

7. Recommendations

1- Alternatives one and two could be reconsidered if new drilling machines will be bought.
2- Alternatives five and six could be reconsidered if expansion of the production is expected.
3- The methodology used in this investigation can be adopted to calculate the minimum number and distribution of other pieces of equipment such as loading units and transportation trucks if their capacities and production targets are known.

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توزيع و أستخدام معدات الحفر على واجهات المحجر

الملخص العربى:

في أحيان كثيرة يعتبر توزيع واستخدام الماكينات و المعدات علي واجهات المحجر بطريقة جيدة تحدي لمهندس التعدين أو مدير المحجر. وتشتمل معدات المحجر علي ماكينات الحفر، وضواغط الهواء ومعدات التحميل من كراكات ولوادر وأيضا أسطول النقل من القلابات ذات الحمولة الكبيرة. وهذه المعدات الثقيلة تشكل استثمارات ضخمة في عملية الانتاج وتحتاج الي مهارة عالية لتوزيعها وتشغيلها بكفاءة. في هذا البحث سيتم دراسة التوزيع الافضل لماكينات الحفر ذات المواصفات المختلفة علي واجهات محجر الحجر الجيري بشركة أسمنت أسيوط وذلك باستخدام نموذج رياضي للحصول علي بدائل مختلفة واختيار أفضل هذه البدائل. حيث أن حساب أقل عدد من ماكينات الحفر الذى يمكن به تحقيق خطة الانتاج السنوي المطلوبه من أهم الخطوات التي تؤدي الى تقليل التكلفه بالمحجر.