Short-term mining operations in limestone mines – diagnosis and proposition for improvement

Operações de lavra de curto prazo em mina de calcário - diagnóstico e proposição de melhoria

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Abstract

This paper deals with a study conducted in a limestone mine located in Caçapava do Sul in the state of Rio Grande do Sul. Themes related to short-term operational planning and unit operations are discussed. We conducted a diagnosis of the practices observed in the mining company under study and recommendations were proposed for change and innovation regarding mining operations. We sought to identify factors that affect productivity as well as actions that could increase the overall efficiency of the unit operations in the "peak" production period so that increased market demand could be met without the need for investing in new equipment. The article highlights the difficulties associated with the lack of planning for the mining cycles and with the organization of daily activities. An assignment of daily production to each piece of equipment that is part of the unit operations is suggested in order to optimize operations, thus contributing to the sustainable management of the company.

Keywords: mining operation, mining planning, sustainable management, production optimization.

Resumo

Este trabalho trata de estudo realizado em mina de calcário, localizada em Caçapava do Sul, no Estado do Rio Grande do Sul, no qual são abordados temas sobre planejamento operacional de curto prazo e operações unitárias. Foi realizado um diagnóstico da prática observada na empresa e propostas recomendações de modificações e inovações quanto às operações de lavra, buscando identificar os fatores que interferem na produtividade e propor ações que poderiam aumentar o rendimento global das operações unitárias no período de "pico" de produção. Assim, poder-se-ia atender o aumento da demanda do mercado sem a necessidade de investimentos em novos equipamentos. São apontadas as dificuldades relacionadas à falta de planejamento dos ciclos de lavra e de organização das tarefas diárias. Sugere-se, ainda; uma atribuição de produção diária a cada equipamento que compõe as operações unitárias para buscar a otimização das operações, o que contribuiria para uma gestão sustentável da empresa.

Palavras Chave: *operação de lavra, planejamento mineiro, gestão sustentável, otimização de produção.*

1. Introduction

The Caçapava do Sul region has the largest reserves of dolomitic marble of the state of Rio Grande do Sul, with around 200 million tons of the material that when crushed and grinded accounts for 85% of the material used in corrective soil treatment for agriculture purposes. There are seven mining sites, with an installed capacity of approximately 4,400,000 tonnes/

year, that are located next to the BR-392 highway, and the production flow runs through the junction of this highway with the BR-290 and BR-153. These companies operate different mining fronts located within a radius of no more than 8 km from the city center.

In general, the mining operations are very similar; they start with the preparation of the area to be disturbed and uncovered – usually performed with the use of mechanical equipment such as loaders, excavators, and trucks. Then, in a cyclical manner the other unit operations occur that include drilling, blasting, loading, and hauling. As the dolomitic marble ore has low added value, the company's profit comes from selling on a large scale, making it imperative to reduce the costs, 40% of which correspond to the mining operations.

In general, mining is recognized as being an industry involving high initial investment and high associated risk, in which the decision-making process is very complex due to the stochastic characteristics of the system (Pinto, 1999). Thus, before the implementation of mining operations, it is necessary to conduct planning for the mining in relation to the optimized pit, among other aspects, as well as establishing a sequence of mining operations and direction for advancement in order to maximize the financial return (Hustrulid & Kuchta, 1995). The importance of this planning is related to basic aspects such as the definition of the useful life of the mine, equipment selection, and the size of the fleet. Studies of these aspects will serve as a basis for analyzing the economic feasibility of the project.

What can be observed in most dolomitic marble mining operations in the region being studied is that, due to the size or the way in which companies are formed - most of them are of familial origin and still maintain this structure - there is a distinct lack of operational planning and adequate technical organization. Additionally, there are many mining activities in areas previously operated by another company or in areas arising from disputes, and these also have inadequate prior planning.

In this scenario it becomes essential to undertake short and medium-term planning that contemplates the production scale, orders the mining operations, shows the progress to be made over time, and sequences extraction from the pit. Likewise, it is imperative to define routines for monitoring production of each mining front in order to allow the definition of quality control for run-of-mine (ROM) production. These measures would allow for improvements in safety conditions and slope stability, monitoring of the unproductive material to mineral ratio, minimization of costs associated with the use of loading and transport equipment, and an adequate fire plan for blasting of the rocks.

Thus, this study was conducted in one of the dolomitic marble mining companies in the municipality where the operations are concentrated in the production of material for soil correction for agricultural use. Based on a diagnosis of the mining operations, a series of proposals were sought that would enable the reduction of losses which occur in the process of extracting the ore (ROM) and are a result of a lack of short-term extraction planning.

2. Object of the case study

The mine analyzed in this case study, located in the municipality of Caçapava do Sul as shown in Figure 1, is an open-pit mine with bench heights of 6 to 15 meters, in which dolomitic marble has been extracted since the 1970s for the production of agricultural lime on a production scale that is heavily influenced by the seasonality of the agricultural market.

Despite no technical and/or economic evaluation of the deposit currently existing, the exposure of rocks at the mining fronts and planialtimetric surveying information suggest that there are mineral resources of approximately 9,000,000 tonnes of dolomitic marble within a licensed area of 49.49 ha, which at current production levels of about 320,000 tonnes/year, would allow the mine to operate for about 25 years.

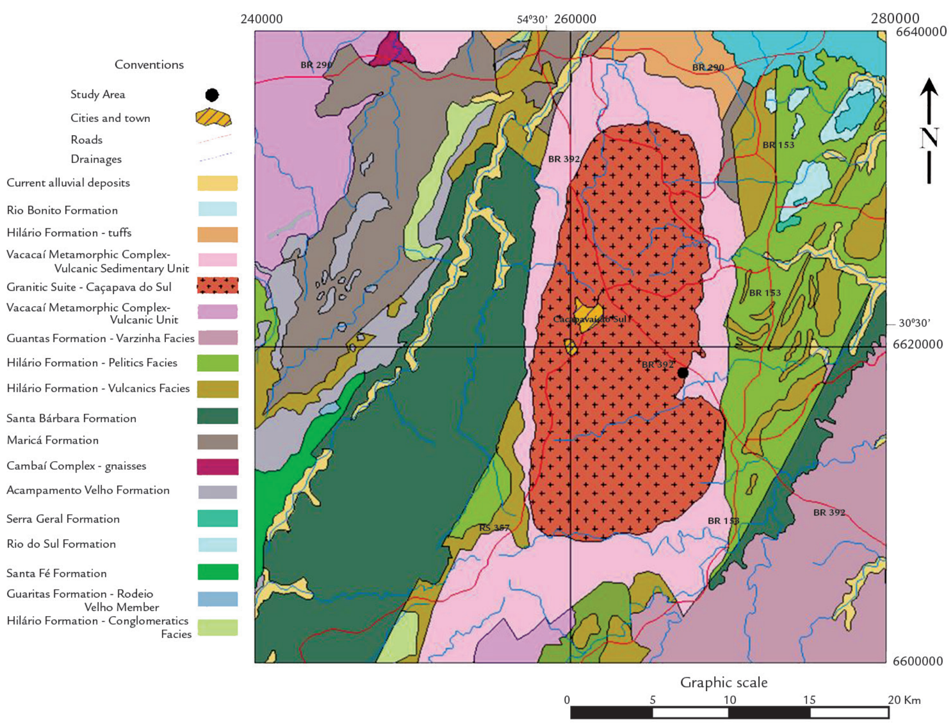

Figure 1
Location map of the study area and the geological context in which it operates

The marble has a color that ranges from milky white to grey/light-blue with a medium grain that pertains to the Vacacaí Metamorphic Complex (Figure 1). There are also known occurrences located about 6 to 10 km east and southeast of the city of Caçapava do Sul. They are big bodies with the position of the deposit in the preferred direction (NE 0° to 10°) and the SE dip ranges from 24° to 37° - in some places the deposits are outcropping.

The deposit consists of very fractured metamorphosed dolomitic marble, which prevents its use as ornamental stone. The material has average grades of 19% MgO and 32% CaO, with a high resistance to excavation. The in situ density is 2.45 tonnes/m³, the swelling factor is 1.25, and the disaggregated density is 1.96. In some places the deposit shows intrusion of diabasic bodies, granitic apophyses, and interbedded shale. These materials are part of the unproductive area of the mine and are placed in piles located to the north of the licensed area.

3. Methodology employed

As noted above, from identification of the losses and bottlenecks in the unit operations of the mine, this study proposes to develop a diagnosis of the current practices in the dolomitic marble mine. This would enable identification of problems related to production so that the efficiency of the processes could be improved, and minimum practices could be established in relation to short-term planning and the ordering of mining operations and processing.

The diagnosis was based on the estimation methodology, statistical data analysis, and correlations of cycle times for unitary operations, whose application is justified because the model is easily constructed and is used in small and medium-sized mining.

The application of this basic methodology involved the following steps:

i) data collection during the harvest period, from April to September in 2011;

ii) processing and analysis of the information;

iii) verification of the correlation between the performance parameters, production targets, and efficiency of the equipment.

This approach involved field surveys of cycle times, transport distances, mechanical availability of the equipment, as well as interviews with employees and managers to know more about the company and identify bottlenecks in the productive system that could assist in this work.

4. Characterization of the problem

The planning of mining operations in open-pit mines is a problem of great practical relevance, since control of production has an impact on many indicators that are considered critical for the activity and for an adequate mining cycle. During the high demand of the harvest period which runs from May to September, the mining operation seeks to exploit the best areas, without concern about meeting the technical parameters regarding the angle of slopes, size of squares, drilling, blasting, loading, transport, or the safety standards related to these aspects such as the construction of windrows.

The situation is aggravated by the poor condition of access roads to the mine that impair the transport due to the effect of overhang and holes caused by the water, as well as floods, mud, loose rocks, tight curves, and ramps with inclinations of up to 16°.

Another complicating factor that significantly impacts the transport cycle is the existence of a federal highway, BR-392, which passes between two adjacent areas of the Company and means that special attention is required for crossing equipment, thus increasing the cycle time.

Therefore, in order to meet the current production demands during the harvest season, besides verifying the ability of the fleet to meet any increase in the production rate, it is necessary to program the mining progress and the sequence of operations, optimize the mining cycle, ensure cost control, introduce improvements in safety conditions and slope stability, and reduce environmental impacts.

5. Diagnosis of the operations

During the production monitoring period, the operation was being performed in a daily eight-hour shift from Monday to Saturday. In the special periods of peak production, due to the high demand for the product from the agricultural sector, every day of the week is worked, including Sundays and holidays. In the months of May, June, and July, two 8 hour shifts were worked per day. The results of the summation of the hours worked, the hours programmed, the hours available, and the hours utilized, as well as the availability coefficient, are shown in Table 1. It also shows the results obtained in the peak season for 2012 during which only one shift was utilized and measures suggested by our work were used.

Table 1
Summary of the hours worked during the peak period, in 2011 and 2012.

	2011	2012
Days worked in the period	152	152
Days worked with 2 shifts	91	0
Hours programmed in the period	1944	1216
Sum of lost time	2h	1h
Mechanical availability	90%	90%
Availability coefficient	0.675	0.7875
Hours avaiable in the period	1312	958

In 2011, production of lime for agriculture use (soil correction) was 328,638.75 tonnes, with monthly variations that can be seen in Figure 2. The months from May to September correspond to the peak period which is marked in gray in the figure.

As noted earlier, the peak demand occurs in the months from May to September, a period that coincides with the highest incidence of rain in the state. Since most companies do not have a culture of working with large stocks of finished product or with piles of ore, these climatic conditions negatively interfere in all mining unit operations and may cause stoppages. Moisture in the ore from the rain makes processing more complex and slower because the sieves become clogged and there is a loss of efficiency in the mills resulting from physical agglomeration of the material.

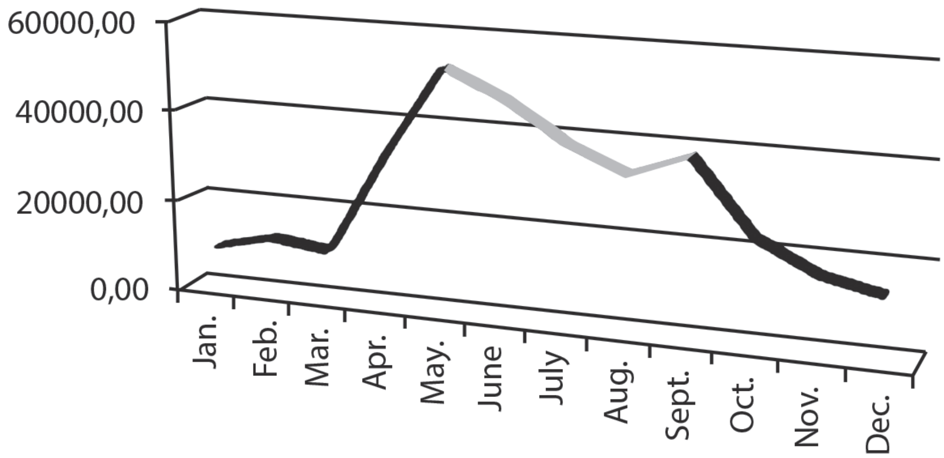

Figure 2
Change in the rate of monthly limestone production for 2011. The peak production period is marked in blue.

In this period of increased demand, production reaches 72% of the total production for the whole year. Table 2 shows the mining activity in this period, for both 2011 and 2012.

Material (tonnes)	2011	2012
Unproductive	22,020	6,860
Run of mine (ROM)	234,500	249,000
Rejects	21,260	11,020
Limestone production	211,464	226,360

Table 2
Movement of material in the mine up to the month of September for 2011 and 2012.

6. Short-term mining planning

With the lack of long-term mining planning, there is neither production sequencing nor an anticipated definition of the advances in the mining. During operation, the advances are defined empirically, directing the mining activity only by the ease of access to the material and without quality control in relation to what is being mined, a practice that involves obvious losses related to geotechnical parameters and, consequently, leads to unsafe operating conditions.

As established by several authors (Pinto & Merschmann, 2001; Merschmann, 2002; Costa, 2005), short-term planning refers to operational aspects of the mining such as the determination of the extraction rate at the various fronts and allocation of loading and transport equipment for time intervals of up to 30 days, in addition to including the definition of the sequence of unit operations which make up the mining cycle over the course of a week.

Short-term mining planning should be done based on an annual plan, so as to meet the target set for supplying the processing plant that, in turn, is subject to the targets for sale of limestone to the agricultural sector. Given this, the complexity of the mining assumes large proportions due to limitations both in terms of accessibility to the ore that meets the quality parameters and also in relation to the quantity of existing equipment and its availability.

During the survey of information gathered in this study, it could be seen that high losses occurred due to the lack of synchronization between the schedules for detonations and the schedules for work shifts, in addition to the fact that without planning for the start of activities in the subsequent shifts, considerable losses kept occurring (Table 3).

Ore extraction is performed based on the premise of "bigger is better", not taking into account a projection of sales and operational capability of the equipment. Thus, there is no minimum programming of the daily advances in the mining.

Daily Losses	Minutes per shift	Total minutes per day
Detonation	30	60
Stop to eat	15	30
Start of activities	15	30

Table 3
Daily losses in the mining operations for 2011.

7. Discussion of the results

To enable verification of the reasons for the high daily losses, monitoring of all the operational activities was done and the stoppage times that directly influenced the operational cycle of the extraction activities were recorded. The main losses were detected and listed, as shown in Table 3, where the time losses related with mobilization and removal of mining equipments from detonation site were significant.

With the identification of the biggest losses, it was proposed that the time of the shifts be changed so that they would finish at 11:30 am and 5 pm in order to eliminate the losses from the daily stoppages for blasting of rocks which occur at 11:45 am and 5:15 pm.

Because the stoppage to eat is a result of union negotiations, there was no change to it; however, it was agreed that in relation to the start of activities it is necessary that the person in charge receives in advance the list of services for each shift so that it reaches all the unit operations and the associated employees.

Even this program of immediate activities to be performed during the shift requires operational planning, with minimum short-term production targets established. Thus, from using the production targets for the harvest period, shown in Figure 2, and with the knowledge of the operational capacity of the equipment, one can assign a daily production target for each piece of equipment, as shown in Figure 3. It is, therefore, possible to define the size of the daily advances based on the operational capacity of the enterprise and, based on this decision, the short-term operational planning of the mining was done for a time interval of 30 days.

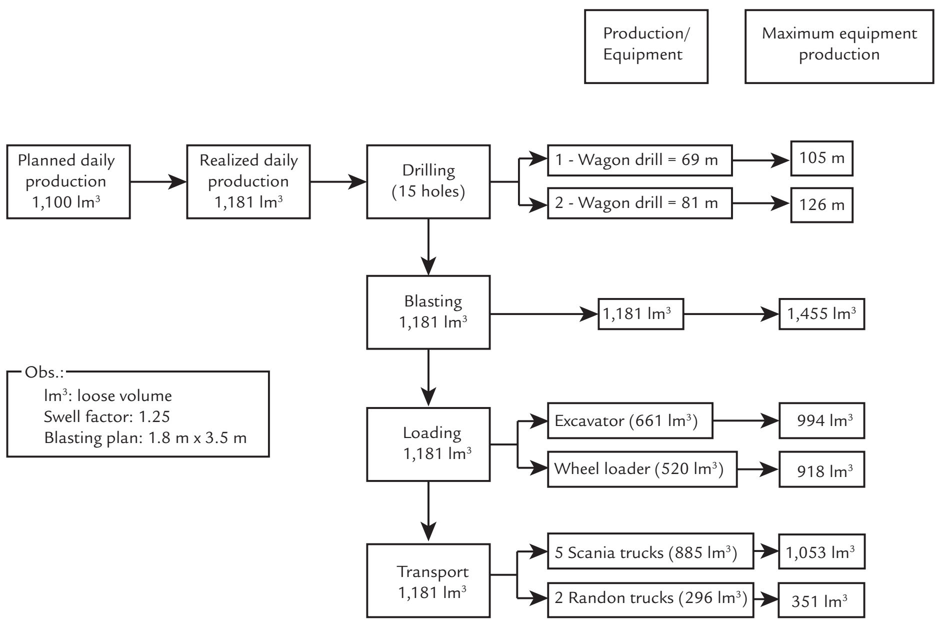

Figure 3
Production targets for the major unit operations, with the daily advances of the mining and the maximum production that each machine can attain.

8. Conclusions

From the survey of information and the times of the unit operations, it was possible to identify where the main losses occurred for the programmed hours in relation to the available hours and, based on the use of the production goals established for the unit operations, it was possible for the company to keep the mining activities to a single shift, obtain better use of the scheduled hours, and reduce staff (Table 4).

Year	Programmed hours	Available hours	Availability coefficient	Losses (%)
2011	1944	1312	0.675	32.51
2012	1216	958	0.7875	21.21

Table 4
Reduction of losses in the programmed hours – a comparison between 2011 and 2012.

The proposed operational planning established the daily advances and production targets for equipment that, with the deployment of some practical controls, assisted in the execution of short-term planning. Some examples of this are:

i) the minimization of production deviations by monitoring the planned volumes of ore for the daily mining advances and the actual production achieved;

ii) the control of the productivity limit of the loading equipment by daily checking of the differences between the production target attributed to the equipment and the actual production achieved by the equipment;

iii) the establishment of an index for controlling losses in production resulting from waiting times and smaller or larger loads. This was achieved by analyzing the expected daily productivity and the actual productivity that is effectively achieved.

Thus, as shown in Table 5, it was possible to meet the production desired by the company for 2012, with an increase in productivity of around 36.6%.

Year	ROM (t)	Unproductive (tonnes)	Total (tonnes)	Tonnes/hour
2011	234,500	22,020	256,520	195.52
2012	249,000	6,820	255,860	267.08

Table 5
Productivity for 2012 in relation to 2011.

Even with the positive results obtained in terms of productivity, there is a clear need to implement other changes and innovations that would certainly result in significant gains for open-pit dolomitic marble mining. For example:

(i) conduct medium and long-term mining planning - establish a sequence until the exhaustion of the mining, taking into account periods of peak production and periods of excessive rain;

(ii) train employees and eliminate empirical practices;

(iii) create stockpile of ROM and increase the covered area for storage of recrushed ore.

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