Extended Abstract

Production planning and management of an ornamental quarry

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Abstract

This study was developed in cooperation with VISA – Consultores de Geologia Aplicada e Engenharia do Ambiente, using Filstone - Comércio de Rochas, S.A. database within the scope of the dimension stone industry.

Nowadays, with the increase of production targets and market competitiveness, the importance of a correct analysis of a quarry's extractive capacity is underlined and fulfilled by the production control. The dimension stone industry is essentially based on small scale quarries and, as such, a specific tool to support the control and production management has not been developed.

The production in a limestone dimension stone quarry is the focus of this analysis, therefore, it was carried out a study based on the quarry Casal Farto nº3 in Casal Farto, Fátima, in which geological terms, is part of the Maçico Calcário Estremanho (MCE). In Portugal, the MCE is the main center of limestone extraction.

The Chinese market is the main client for the cream-colored limestones extracted from Casal Farto nº3. Due to market demands, the goal of this study is to develop a tool that allows planning support and organization for short-term production. Throughout this document, the tool will be described in order to guarantee the analysis of the quarry's extractive capacity and to produce a sensitivity analysis of the quary.

In conclusion, when the predictive results are compared with the real ones, the differences between both are minimum.

Keywords: quarry's extractive capacity; production control; limestone dimension stone quarry; planning support and organization of short-term production; sensitivity analysis.

1. Introduction

Portugal, has a great geological diversity with unique characteristics and opportunities for the appearance of new explorations. In this country, the dimension stone industry has strong traditional roots since the Roman occupation, and the extraction of dimension stones is usually made in small quarries with relatively low production targets.

Nowadays, Portugal is recognized for its ornamental limestones and marbles and the Portuguese companies are betting in the international markets.

In Portugal the explored dimension stones are marbles, limestones, granites and shale rocks. In regions like Alentejo, Fátima and Pero Pinheiro there are rocks with unique characteristics, which consolidates the export capacity of the Portuguese products (Carvalho, Carvalho, Lisboa, Casal Moura, & Leite, 2013).

The *Maciço Calcário Estremenho* (MCE) is the biggest exploitation core for limestones, as regards marbles, its exploitation is mainly in the *Anticlinal de Estremoz*. This study focus in limestones exploited in MCE, in the core

Fátima where the limestone variety is named *Creme de Fátima* (Carvalho, 2009).

Although ornamental exploration in Portugal is promising, there is still much to be done. In addition to the lack of response to the market competition the small size of the quarries is not the ideal scenario relating the Portuguese product market projection. The industry has to respond to the threats of big producers such as China and India and for that is mandatory to invest in technology development, research for new markets, an increased cooperation between companies and creation of new tools to support production management (AEP, 2003).

The dimension stone industry is exploited in quarries with particular characteristics, among them, exploration of fronts with regular faces, circulation of machines at reduced speeds, dismantle by primary blocks or slabs and reduced exploration areas. The production cycle in a dimension stone quarry it's an operations sequence that depend on several variables of human and equipment resources but, in a small scale, the control and planning of the variables are easy. The difficulty in analyzing the quarry's extractive capacity increase with the increasing of quarry's dimensions.

The quarry in study is *Casal Farto nº3*, belongs to Filstone - Comércio de Rochas, S.A. and is a big ornamental limestone quarry with an ambitious production target. Due to dimension there is a need of a structured support in the production planning and control by a tool and that is the main goal of this analysis.

This study is divided in two parts. Firstly, the purpose is the development of a tool that gives support in analysis of big limestone quarry's extractive capacity. Secondly, the goal is to generalize the tool with the creation of an interface. The tool is based on an algorithm developed in Microsoft Excel, their generalization is made through Visual Basic.

In order to create the tool, it is important to understand the production cycle characteristics of a dimension stone quarry. A complete production cycle has many phases, this study the purpose is to evaluate the block exploration sequence that typically is based on the sequence shown in Figure 1.

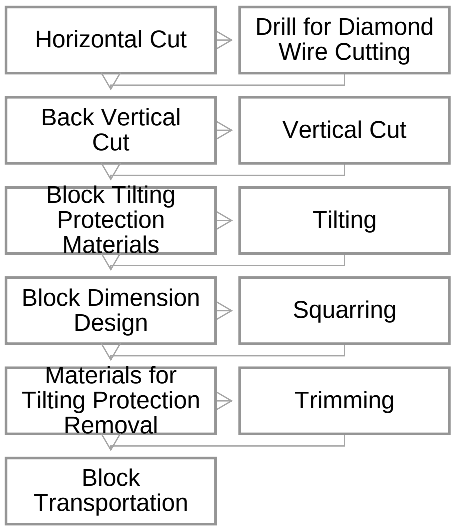

Figure 1 - Cycle of production of an ornamental limestone quarry.

Since the beginning of the 20th century there has been a big investment in tools to provide support in production management. Initially the tools were manual, such as Gantt Charts, Pert Chats and CPM and difficult to keep updated. However with the growth of information and technology the tools are now software based.

In spite of the existence of a lot of software options that could have been used, this study was done through Microsoft Excel. The choice was based on the following characteristics:

- Enables data transformation in simplified information;
- Allows dynamic analysis freely without restrictions;
- Simple data interpretation;
- Easily available to all the computers without associated costs;
- Integrated tool in the daily work of companies.

To sum up the present case study formation three tables are presented with the reasons that led to the existence of the dissertation, its objectives and the solutions found (Table 1, 2 and 3).

Table 1 - Case study formation

Constrains that led to the case study formation	
Big quarries dimensions.	High production targets with restricted time limits. Increased market demands and competitiveness.
Several variables of human and equipment resources.	Difficulty in the equipment and daily task management.
Difficulty in the quarries production control and organization.	A lack of a specific tool to support the ornamental quarries production.

Table 2 - Study purpose.

Study purpose	
Development of a tool that gives support in analysis of big limestone quarry's extractive capacity	Generalization of the tool with the creation of an interface

Table 3 - Solutions found.

Solutions found	
Development of an algorithm in Microsoft Excel	Development of an interface in Visual Basic

2. Methodology

The present analysis can only be performed with input data of the quarry in study. The quarry has to provide information about the primary block and the equipment characteristics. The human resources weren't analyzed in this study. For each operation only the equipment was considered.

2.1 Development of an algorithm in Microsoft Excel

For the first part of the study the purpose was the development of an algorithm in Microsoft Excel. The algorithm is based on the formation of an Excel main page.

In order to engender the main page is essential to create support pages. Not only there's more than one equipment available for each operation, but also they can have different work schedules per day and per equipment type. To integrate both of these variables two support pages were generated. Another variable that needed an independent page was the exploration bench availability. It was with the construction of this three pages (equipment selection, equipment schedule and exploration bench availability) and with the input data (primary block and equipment data) that it is possible to create de main page that reproduce the quarry extractive capacity. The Figure 2 is the structure of the developed algorithm:

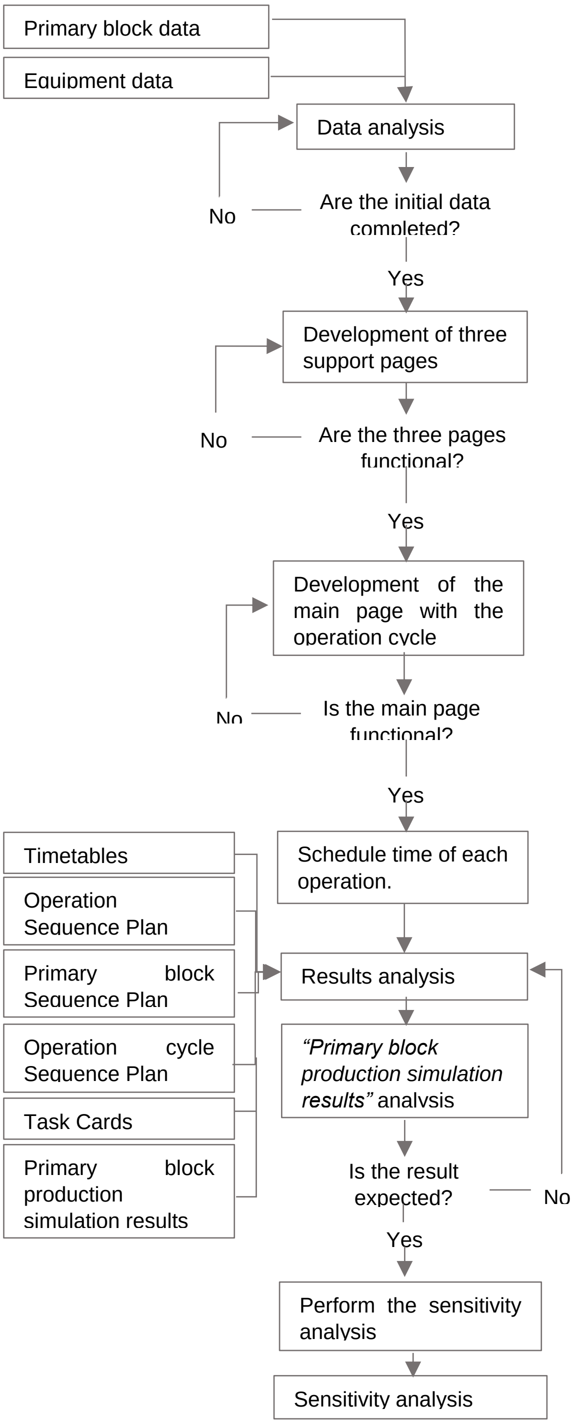

Figure 2 -Algorithm developed.

The main page has integrated the block exploration sequence presented in Figure 1 for the extraction of 30 primary blocks (in other words is a short-term analysis of the quarry).

. As it can be seen in Figure 2 the algorithm produces 6 automatic results and enable the production of a seventh result, the Sensitivity analysis. This last result is the one that allows the drawing of conclusions about the quarry extractive capacity. The other results have the intention to aid the production control and organization. The figure 3 shows the aim of each result.

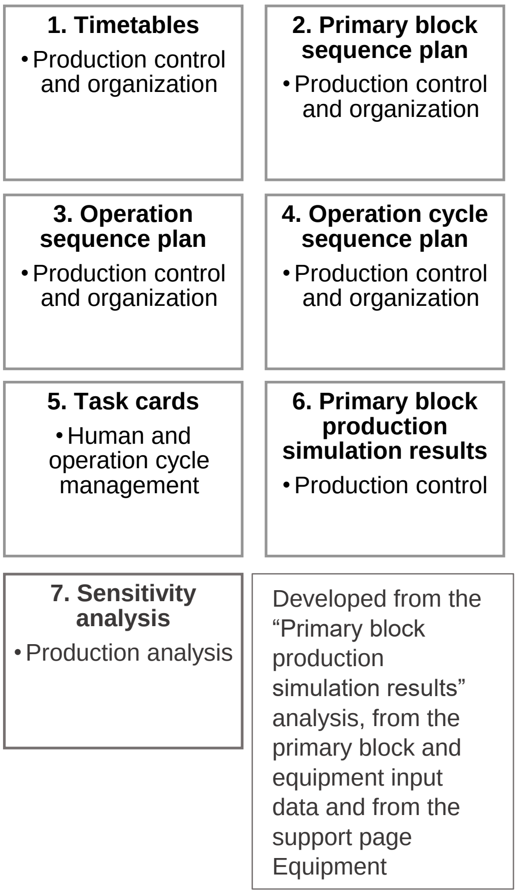

Figure 3 - Aim of the algorithm results.

The creation of the main page with the block exploration sequence has incorporated conditions for the beginning of each operation. The Figure 4 and 5 have the assumptions integrated in the algorithm main page. The Figure 4 is until de "Tilting" and the 5 is after.

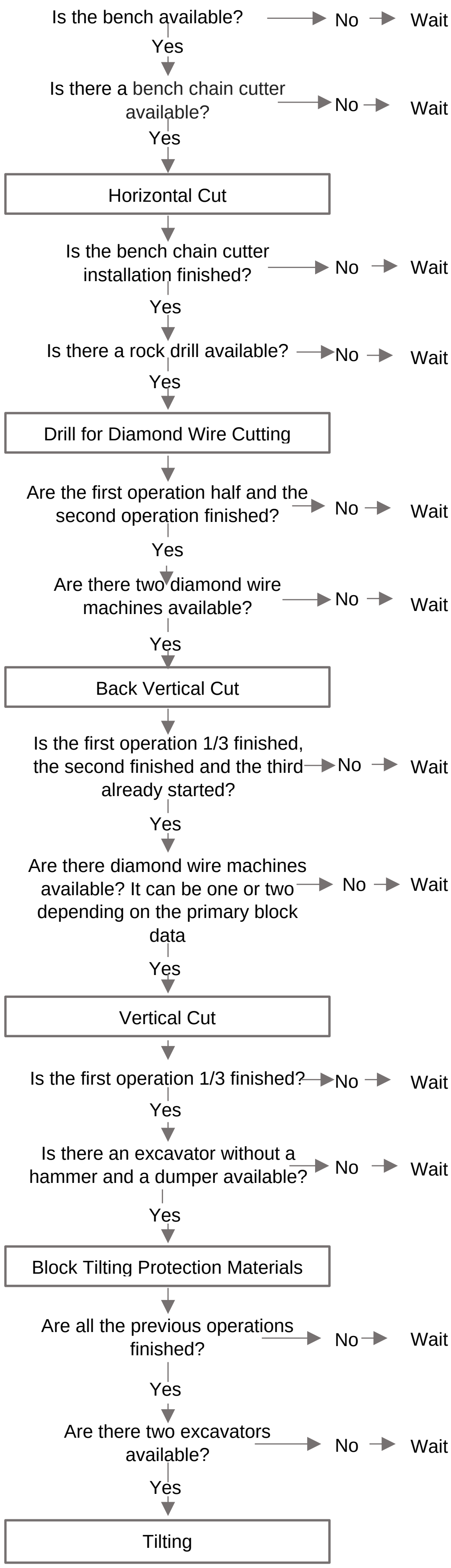

Figure 4 - Conditions for the beginning of each operation.

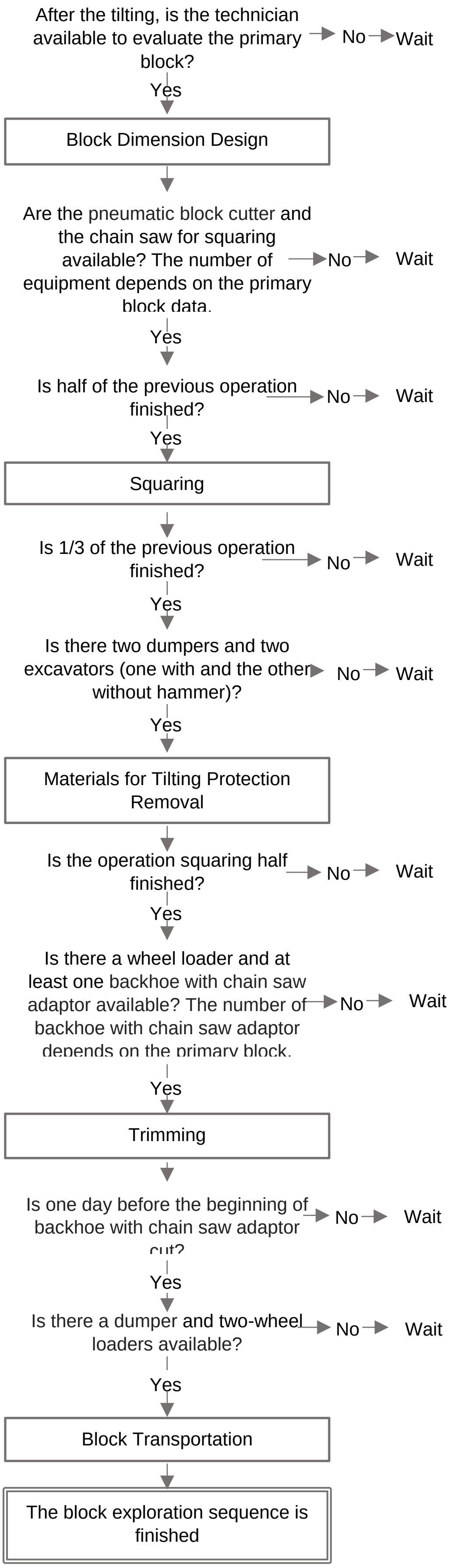

Figure 5 - Conditions for the beginning of each operation, after the operation "Tilting".

To summarize, the first part of the study can be divided in three phases presented in the Table 4.

Table 4 - Phases of the first part of the study.

Phase 1	Phase 2	Phase 3
Input data evaluation and summary in two tables of equipment and primary block characteristics.	Increment of the three support pages.	Development of the main page with the primary block production cycle and algorithm application.

2.1 Generalization of the tool with the creation of an interface

The tool generalization is based on the first part of the study and carried out through Visual Basic. The structure of this part is introduced in the Figure 6.

Figure 6 - Structure of the second part of the study.

The main goal of this part of the study is the development of the eight Visual Basic pages, but for that is required the creation of three support pages in Excel and input data.

The two input data pages are the same as the first part of this study.

The three support pages in excel have the function to save the data introduced in the interface. The first support page "*Initial Data*" has embedded in it a button that, when selected, make the connection between the

Excel and the first page of the interface in Visual Basic.

The eight pages developed in Visual Basic are presented in the Figure 7.

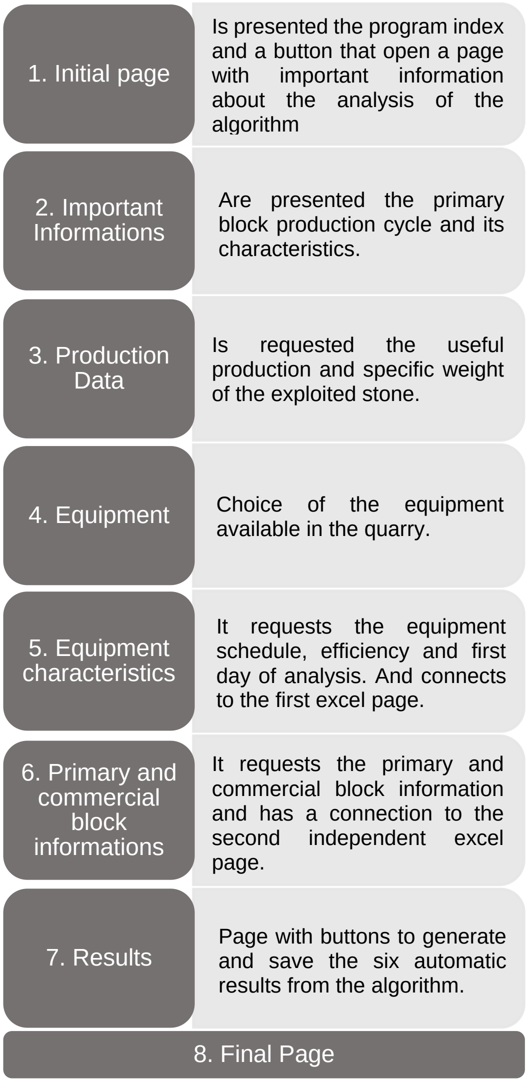

Figure 7 - Interface developed.

The methodology presented here was applied to *Casal Farto nº3* quarry. The quarry understudy will be presented in the following chapter.

3. Study Case

The study case conducted in this dissertation is focused in the quarry *Casal Farto nº3* that is located in Casal Farto, Fátima, county of Ourém, district of Santarém, Portugal, as Figure 8 shows.

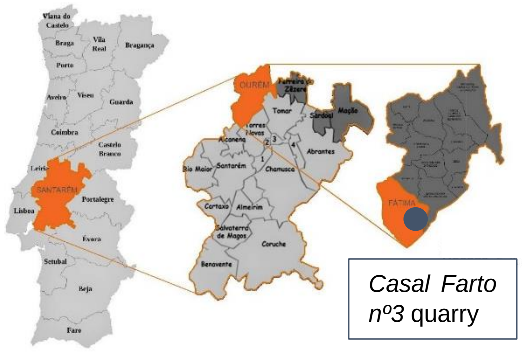

Figure 8 - Localization of Casal Farto nº3 quarry.

Geologically, this quarry is in the Northeast of MCE, located in the Lusitanian Basin belonging to the western zone of the Iberian plate (VISA Consultores, 2015). The MCE is the main mining district of ornamental limestones, is limited by Batalha, Ourém, Rio Maior and Alcanena and is mainly composed by upper and middle Jurassic limestones (Carvalho, Lisboa, Prazeres, & Sardinha, 2012).

The limestones exploited in this quarry has three different designations, non-ornamental limestone, ornamental limestone and *Vidraço* (without market economic value). In order to minimize the environmental impacts and the extraction cost it is important the economic valorization of the non-ornamental material and the *Vidraço.* The material without ornamental competence can be reused for other industries. The Figure 9 shows the end use of the products extracted in *Casal Farto nº3* quarry.

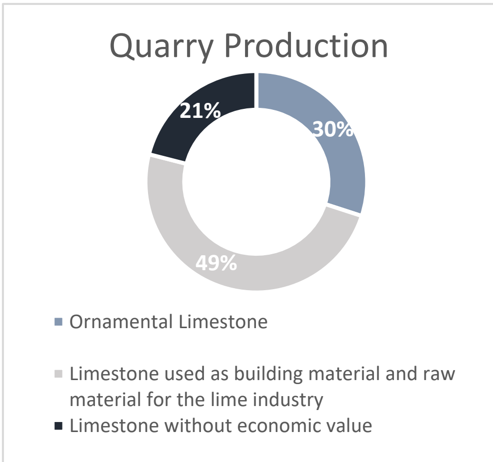

Figure 9 - End use of the products extracted in Casal Farto nº3 quarry.

The quarry block exploration sequence is the same as the one in Figure 1. The equipment used is described in Table 5.

Table 5 - Equipment used in the quarry operations.

Operations	Equipment
Horizontal Cut	- Bench chain cutter
Drill for Diamond Wire Cutting	- Rock drill
Back Vertical Cut	- Diamond wire machine
Vertical Cut	- Diamond wire machine
Block Tilting Protection Materials	- Excavator; - Dumper
Tilting	- Excavator
Block Dimension Design	- Manual
Squaring	- Pneumatic block cutter; - Chain saw for squaring
Materials for Tilting Protection Removal	- Excavator - Dumper
Trimming	- Wheel Loader; - Backhoe with chain saw adaptor
Block Transportation	- Wheel Loader - Dumper

4. Results and Discussion

The results obtained by the application of the algorithm created to the quarry in study is presented in this chapter.

The algorithm developed for the ornamental limestone quarry analysis generates 7 different results, introduced in Figure 2. Six of them are automatic results, which means that the tool generates the results without any extra analyze. The last result, the sensitivity analysis, is dependent on the automatic results. For better understanding the present study, all results presented will be explained with examples.

Timetables

The timetables developed display the operation cycle chronology for the 30th primary blocks exploited. The Table 6 is an example of this result for the first two operations of the first primary block explored.

Table 6 - Example timetable produced by the algorithm.

Operations	Initial Date [Day]	Final Date [Day]	1	2	3
Horizontal Cut	0,00	2,06	606	606	606
Drill for Diamond Wire Cutting	0,12	0,33	606	_	_

Primary block sequence plan

The primary block sequence plan is an intuitive and simple table organized by primary block, exploration bench (named *Local* in Table 7), operation, equipment and initial and final dates. With this result the production control is easier.

The Table 7 is an example of this result for the first two operations of the first primary block explored.

Table 7 - Example primary block sequence plan created by the algorithm.

Primary Block	Local	Operation	Equipment	Initial Date	Final Date
606	A	Horizontal cut	Bench chain cutter *Dazzini*	2-5-18 8:00	4-5-18 9:23
		Drill for Diamond Wire Cutting	Rock drill *Fravizel*	2-5-18 10:54	2-5-18 15:58

Operation sequence plan

The dynamic table originated in this result represents the same data then the previous one (Table 7) with a different organization. In this case the table presents the information by equipment and occupation time. The Table 8 is an example of this result for the first two equipment used from the production cycle first operation.

Table 8 - Example operation sequence plan created by the algorithm.

Equipment	Local	Primary Block	Initial Date	Final Date
Bench chain cutter *Dazzini*	A	606	2-5-18 8:00	4-5-18 9:23
Bench chain cutter *Fantini 4 metros*	B	607	4-5-18 9:23	7-5-18 16:32

Operation cycle sequence plan

The Table 9 represents an example of the third sequence plan automatic result from the algorithm. The main difference between this result and the others is the introduction of delays. This way is possible to compare the predictive results with the real ones.

Table 9 - *Example operation cycle sequence plan created by the algorithm.*

Initial Date	Initial Day	Equipment	Operation	Local	Primary Block	Start Delay	Operation Delay	Real Time [h]	Scheduled Time [h]	Final Date	Final Day
2-5-18 8:00	Wednesday	S1	Horizontal Cut	A	606	0,00	0,00	21,39	21,39	4-5-18 9:23	Friday
2-5-18 10:54	Wednesday	P1	Drill for Diamond Wire Cutting	A	606	0,00	0,00	5,07	5,07	2-5-18 15:58	Wednesday

Operation cards

The operations cards are generated to guide the daily operators work, thus each operator knows his daily task, the equipment to be used and its duration. The Table 10 represents the layout of an operation card created by the tool.

Table 10 - Example of an operation card created by the algorithm.

PRIMARY BLOCK 1		
FILSTONE natural	EQUIPMENT OPERATION	G4
Equipment:	Excavator Komatsu 350	
Local:	606 / A	
Operation:	Materials for Tilting Protection Removal	
Initial Date:	10-5-18 19:13	Thursday
Final Date:	15-5-18 8:51	Tuesday

Primary block production simulation results

The last automatic result allows to understand the monthly production of the quarry by the exploration of the primary blocks analyzed. The Table 11 demonstrate the production of the first six primary block exploited.

Sensitivity analysis

The sensitive analysis is based on *"Primary block production simulation results"* analysis, from the primary block and equipment input data and from the support page "*Equipment selection"*.

The process of analysis was focused on the efficiency and production maximization. For that aim it was necessary to choose a reference month. After that the impact of variables change such as the equipment number and the primary block dimensions were evaluated. The quarry's extractive capacity for the reference month is 12 137t. This value was calculated considering all the equipment available for the operation cycle.

The figure 10, shows the variations of the dimension stone production in result to the change of the number of equipment involved.

The goal was understanding the optimal efficiency per equipment used. The optimal number is the minimum number of equipment were the dimension stone is maximized.

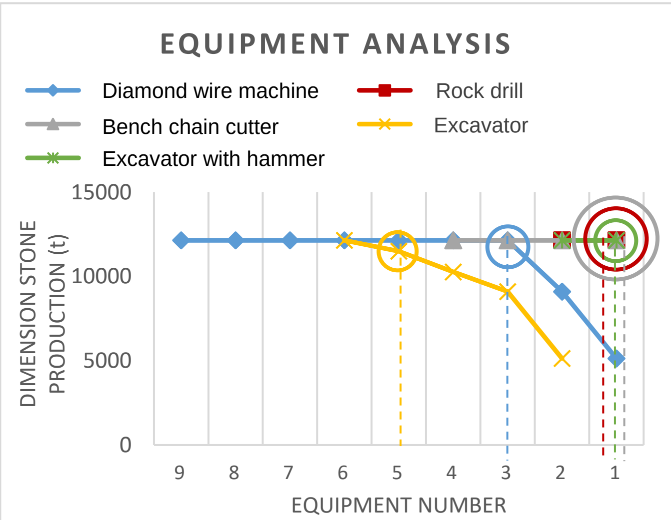

Figure 10- Impact of the variation of the equipment number.

Table 11 - Simulation of the first six primary block exploited.

	Local	Primary Block	Initial Date	Final Date	Total Volume [m3]	Ornamental Stone Volume [m3]	Ornamental Stone Weight [t]	Accumulated Ornamental Stone Weight [t]
1	**A**	**606**	02-05-2018	15-05-2018	2224,80	444,96	1168,02	1168,02
2	**B**	**607**	02-05-2018	17-05-2018	1339,20	267,84	703,08	1871,10
3	**C**	**575**	02-05-2018	19-05-2018	1653,75	330,75	868,22	2739,32
4	**D**	**576**	02-05-2018	22-05-2018	1771,88	354,38	930,23	3669,55
5	**E**	**610**	03-05-2018	23-05-2018	567,00	113,40	297,68	3967,23
6	**F**	**605**	04-05-2018	25-05-2018	2220,75	444,15	1165,89	5133,12

The next graphics (Figure 11 to 15) show the dimension stone production variation with the modification of the different variables. The graphics were created based on the sensitivity analysis.

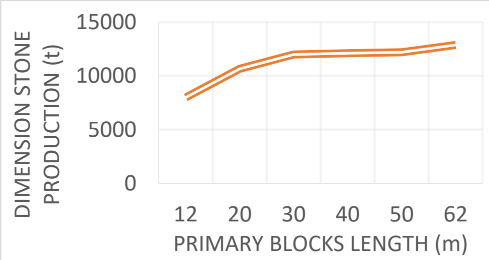

Figure 15 -Impact of the length variation.

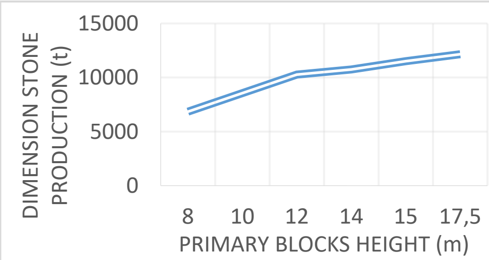

Figure 15 - Impact of the height variation.

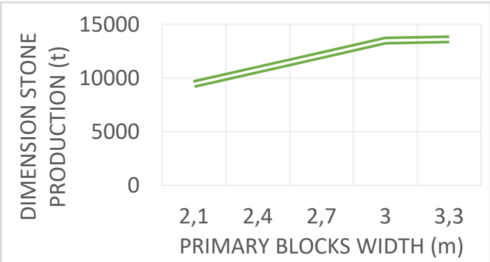

Figure 15 - Impact of the width variation.

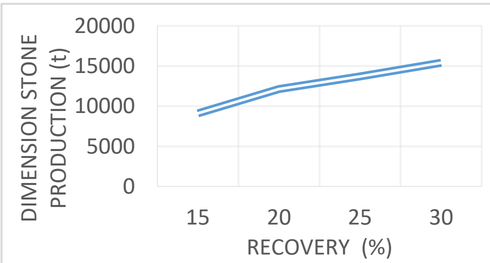

Figure 15 - Impact of the recovery variation.

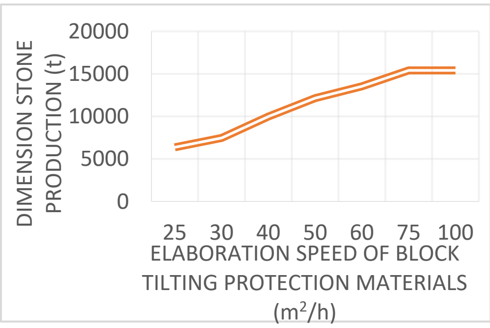

Figure 15 - Impact of elaboration speed of block tilting protection material variation.

In order to understand the information given by the graphics, the Table 12 summarize and identifies the optimal number for each variable. In other words, the Table 12 establishes the variables value that corresponds to the point where the dimension stone production and the operation cycle and equipment resources efficiency are maximized.

Table 12 - Sensitivity analysis results

Variables analyzed	Optimal number
Diamond wire machine	3
Rock drill	1
Bench chain cutter	2
Excavator	5
Excavator with hammer	1
Elaboration speed of block tilting protection materials	75 m^2/h
Height	About 15 m
Length	About 40 m
Width	2,7 m, because of customers agreements
Recovery	25%
Operating benches number	6

According to the seven algorithm results exposed it can be observed that:

- The first result allows a general view of the primary block production cycle timetables. The existence of a chronology is one of the main production planning support and organization parameters needed.

- Three of the results are sequence plans. All of them are developed to the production planning support and organization so that the quarry technicians always have access to the equipment localization and the status of primary block operation cycle in exploration.

- The operation cycle sequence plan has the particularity of presenting delay information. This way is possible to identify problems in the primary block production cycle. The main disadvantage is that the delays has to be manual introduced in the algorithm main page.

- The operation cards support the human resources' daily work, with them each worker is aware of his task, the equipment to use and the schedule time.

- The primary block production simulation result, is the last automatic result and allows to get the expected dimension stone production for the 30 primary blocks analyzed by the tool. With this result (Table 11) is also possible to get the beginning and end of the 30 primary block production cycle.
- The dimension stone production goal for the Casal Farto nº3 quarry, is more than 120 000t per year that means more than 10 000t per month. The last automatic result analysis concludes that the monthly quarry's extractive capacity is 12 137t which means that the quarry's goal is achieved.
- The sensitivity analyzed and summarized in Table 12 allows for the equipment and production cycle global evaluation.

The generalized interface layout tool developed, is not presented in this extended abstract. To see the layout, it is advised to consult the dissertation document.

5. Conclusion

When the predictive results are compared with the real ones, the differences between both are less than 10%, which validates the developed tool. This means that the tool can represent the quarry's reality and forecast the production. Through the interpretation of this document it can be concluded that the purpose of the study was fulfilled.

Taking into account the sensitivity analysis results for the production maximization, 3 setting cases can be created.

Case 1: There is only one team in operation, all the equipment is available. This is the current quarry format. The dimension stone production is 12 137 t per month.

Case 2: There are two independent teams, each would have 3 diamond wire machines, 2 bench chain cutter, 1 rock drill, 3 excavators and 1 excavator with hammer. In this case the dimension stone production would be 9 100t per month per team, which means that for both teams would be 18 200t.

Case 3: There are three independent teams in operation, each would have 3 diamond wire machines, 1 bench chain cutter, 1 rock drill, 2 excavators and 1 excavator with hammer. In this scenario the dimension stone per month, per team would be 5 133t that means 15 399t per month for the three teams.

By the interpretation of the 3 setting cases it can be deduced that the implementation of Case 2 would be the best production choice. In this case is recommended the application of the algorithm developed for both teams.

It was created an interface in Visual Basic to simplify the interaction with the algorithm. The big advantage of the interface is the possibility to save de algorithm results in independent documents with the name of the result and the day and hour of the interface use, for example, Timetables 27/05/2018 12:20.

To sum up the algorithm developed is a specified tool that allows planning support and organization for short-term limestone dimension stone quarry production with a pre-set operation cycle. It should be noted that with the operating cycle adaptation the tool can be generalized for other dimension stones exploration.

6. References

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