Evaluation of the operational costs for chain saw cutting

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ABSTRACT

Chain saw cutting technology has been widely described by the author those last years in several scientific and technical articles. The main problems encountered on chain saw machines have been described. Several experimental approaches have been developed in laboratory to better understand the stone cutting mechanisms and to improve the efficiency of the machines. New cutting designs have been developed increasing the performances of the machines. Monitoring systems have been introduced on the machines to follow their performances while operating in quarries. Even if the technology is well described, very few information can be found on the costs of the technique.
This paper overcomes this lack of information and introduces a rigorous methodology to estimate the real costs of the sawing operations with chain saw machines. The technological parameters introduced and described in the literature have been implemented in a cost evaluation program developed by Stone Assistance, in order to evaluate their influence on the chain saw operational costs. The objective of the paper is to present some interesting results that should be considered by the engineers or operators working with chain saw machines, and that could help them to manage the operations with chain saw machines in quarries.

KEYWORDS

Chain saw, tools, optimization, efficiency, operational cost, profitability

INTRODUCTION

Stone Assistance is working since several years on the improvement of the sawing technique with chain saw machines in quarries. The technology has been revisited thanks to a research program undergone at University of Mons in collaboration with PMDS sa, a manufacturer of diamond tools for chain saw machines, and granted by the Walloon Region.

At the very beginning of the project started a serious discussion with operators regarding the profitability of the chain saw process. Two different points of view were identified on the evaluation of the operational costs of the chain saw technique. From an operational point of view, the purchasing cost of the tools was crucial; from the R&D point of view the cutting speed of the tools was fundamental. Those points of view raised a serious question: do we have to keep using lower price tools, or is it more profitable to use more expensive tools? To answer this question, a complete research program has been performed in order to collect any important information that would help answering the question.

The research program has been focused on the understanding of the cutting mechanisms and improvement of the sawing technique. An experimental approach has been followed in laboratory to better understand the stone cutting mechanisms [1]. Based on the experimental results obtained in laboratory, a new cutting typology has been designed in order to increase the performances of the machines (higher production rate, increase of the tool life span) [2]. The new cutting concept has then been validated in quarry thanks to a monitoring system that has been developed to record cutting parameters while sawing and to evaluate the performances of the machine [3]. An evaluation method of the life span of the chain links and tools has also been developed [4] [5].

Many different types of information have been collected in order to determine the most realistic cost of the sawing operations with chain saw machines. And finally, a simple cost evaluation program has been developed in order to compute the operational costs.

1. THE COST EVALUATION PROGRAM

Advanced cost evaluation methods are rarely used in the stone industry to accurately determine economic gain of using high technology tools. Most of the stone processors evaluate the performances of their tools using a basic formula:

$$\frac{\text{Tool cost}}{\text{m}^2 \text{ of material cut}} \tag{1}$$

Unfortunately, such formula does not take into account several hidden costs related to the efficiency of the tools, or the cutting speed of the machines.

The cost evaluation program developed by Stone Assistance is based on a classical cost evaluation methodology for heavy construction equipments [6]. For instance, the cost computation methodology in use in the Caterpillar® Fleet Production and Cost analysis software [7] has been adapted for chain saw machines.

The program takes into account a large number of characteristics of the chain saw machines (purchase price, estimated residual resale value, depreciation period, electrical power, etc.), and integrates the performance parameters measured while operating (chain speed, cutting speed, working efficiency, staff efficiency, etc.) or other information related to machine maintenance (tools and chain life span, maintenance frequency, etc.). Those data enable to assess both the fixed costs (depreciation, interest on loans, equipment insurance, various taxes...) and the variable costs (chains, tools, other consumables, energy consumption, and labor).

Note that the program currently incorporates the main economic parameters, but the calculation model could be very easily adapted to take into account any other specific parameters. We will not detail the all calculation method in this article. However, anyone interested in more information, or in a practical implementation for his quarry or processing plant should contact the author.

The main objective of such a method of assessment is to get a correct evaluation of the true operational costs which should allow the process engineer to quantify the potential benefits of strategic decisions to optimize the stone processing (modification of the technical parameters, use of high-tech tools, replacement of a machine, etc). On another hand, the method also gives the opportunity to the stone processors to size the fleet of machines to achieve the annual quarry and plant productivity. The use of very similar concepts already allowed significant improvements of sawing techniques for plant processing [8].

2. THEORY OF PRODUCTIVITY

The theory of productivity is not recent in process engineering. Coromant-Sandvik, for example, is one of the main instigators of this theory for metal machining. It is well known in this industry, and in metal turning for example, that the cost of the cutting tools represents only a very small part (on the order of 3%) of total production cost. The major gains in productivity and on the operational cost are obtained by adapting the working methods. Choosing the right tool and applying it correctly allows, in metal turning, to increase significantly the productivity and to bring down the operational cost by 10 to 15% [9].

The theory of productivity should also be applied to stone processing. From the experience in metal turning, it can be expected that the technological parameters of the tools, such as cutting speed and depth of cut, are variables that have the largest impact on the improvement of the productivity and on the reduction of the costs. The paper will try to quantify their influence on the operational cost.

3. INFLUENCE OF SEVERAL VARIABLES ON THE OPERATIONAL COST

The objective of this study is to demonstrate the importance of some variables of the cost evaluation program and to illustrate the range of possible gains that could be reached by modifying them. For each study case, the operational cost will be divided in six costs categories: fixed costs, chain costs, tool costs, consumable costs, energy costs, and man power costs.

In any case, the main variables will be listed in front of the cost diagrams for each study case. The stone considered is the Belgian Blue Limestone which has been studied in the research program.

By reason of discretion, the costs provided by the evaluation program will be normalized by the maximum one of each study case.

3.1 CUTTING SPEED

The cutting speed of the chain saw machine ($v_{machine}$) depends on the chain speed (v_{chain}), the depth of cut (*d*), the length of the cutting typology (*n.step*, with *n* the number of cutter holders in the configuration and *step* the distance between successive cutter holders), and the inclination of the arm of the machine (α) [1]:

$$v_{machine} = v_{chain} \frac{d}{n \cdot step} \sin\alpha \tag{2}$$

The increase of the cutting speed of the machine can be obtained by increasing either the depth of cut or the chain speed, or by decreasing the length of the cutting typology. No detailed discussion will be done in this article on the change of the different variables that may affect the cutting speed of the machine. Just remind that the depth of cut results from the thrust applied by the arm of the machine on the stone to be cut and the length of the typology is a characteristic of the cutting design.

The example presented in Fig.1 illustrates the influence, on the operational cost, of a change in cutting speed from 1 to 5 cm/min. At any other settings kept constant, the only variation of the cutting speed enables to significantly reduce the total operational cost. Cutting speed has a direct effect on the fixed costs of the machine, the energy and labor costs. This example shows the interest to increase cutting speed of the machine regardless of the design of tools used. More than 60 % of cost reduction may be expected in the example.

Note that if the rotational speed of the chain has been correctly set up, the cutting speed has no immediate effect on the tools and chain costs. But a bad choice of rotational speed of the chain will have a non-negligible consequence on the tool life span. Several rotational speeds are indeed critical as they generate vibrations that may be responsible for the breakage of tools. However, we do not consider this parameter in this example.

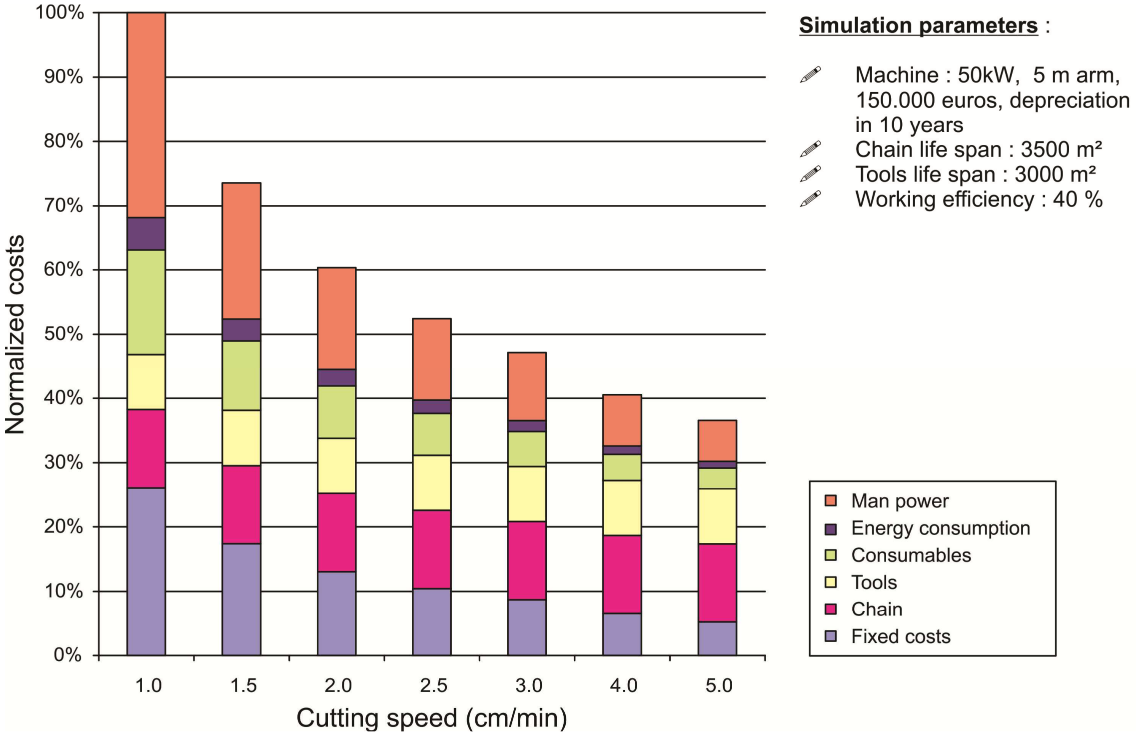

Fig.1 : Example of the influence of the cutting speed of the machine for the same cutting configuration, and any other setting kept constant.

3.2 WORKING EFFICIENCY

The working efficiency (η_w) is a performance parameter which reflects the amount of time lost in machine immobilization due for example to breakdowns and repairs, or to any other organizational reasons. These time-outs are therefore affecting this performance:

$$\eta_w = \frac{\text{effective working time}}{\text{theoretical working time}} = 1 - \frac{\text{time-outs}}{\text{theoretical working time}} \qquad (3)$$

Whatever the industrial sector, it is not uncommon that machines operators spend more than 20% of their time to search or wait for their tools. This is not without consequence on the productivity and the operational cost.

The site-specific organizational aspects (working methods, preventive maintenance or not, etc.) are not the topics of this paper and will not be discussed. Keep in mind that the tool selection will have consequences on the final process organization. A non suitable cutting tool choice can be responsible for breakdowns that require handling and immobilization of the machines.

From the monitoring of the machine [3], the working efficiency of chain saw machines have been estimated in a first approximation to 45%. The example presented in Figure 5 illustrates the influence, on the operational cost, of the increase of the working efficiency of the machine from 30 to 60 %.

The benefits are mainly obtained on the fixed costs. Depending on the initial and final working efficiency, the operational cost may decrease up to nearly 20 %.

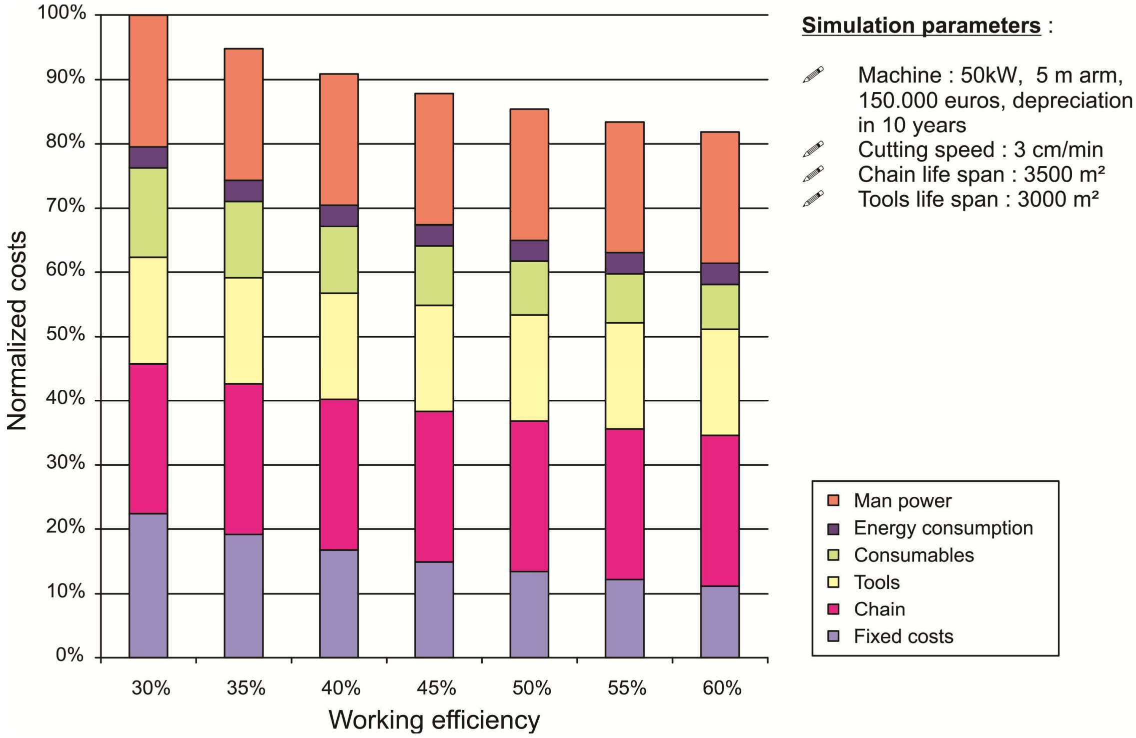

Fig.2 : Example of the influence of the working efficiency for the same cutting configuration, and any other setting kept constant.

3.3 LIFE SPAN OF THE TOOLS AND CHAIN LINKS

The tools and chain links life spans are not intrinsic characteristics. They strongly depend on the conditions of use of the machines. For instance, a non appropriate rotational speed of the chain can cause vibrations of the machine and tool breakage [3]. A bad force distribution on the cutting configuration can generate fatigue phenomena leading to the ruin of the chain links [4].

The example presented in Fig.3 shows the influence, on operational cost, of the increase of the life span of the chain from 3000 to 6000 m^2. In the example, the increase of chain links life span allows to reduce the operational cost up to 15%.

The example presented in Fig.4 illustrates the influence of the increase of the tools life span from 3000 to 6000 m^2. In this example, the reduction the operational is around 10%.

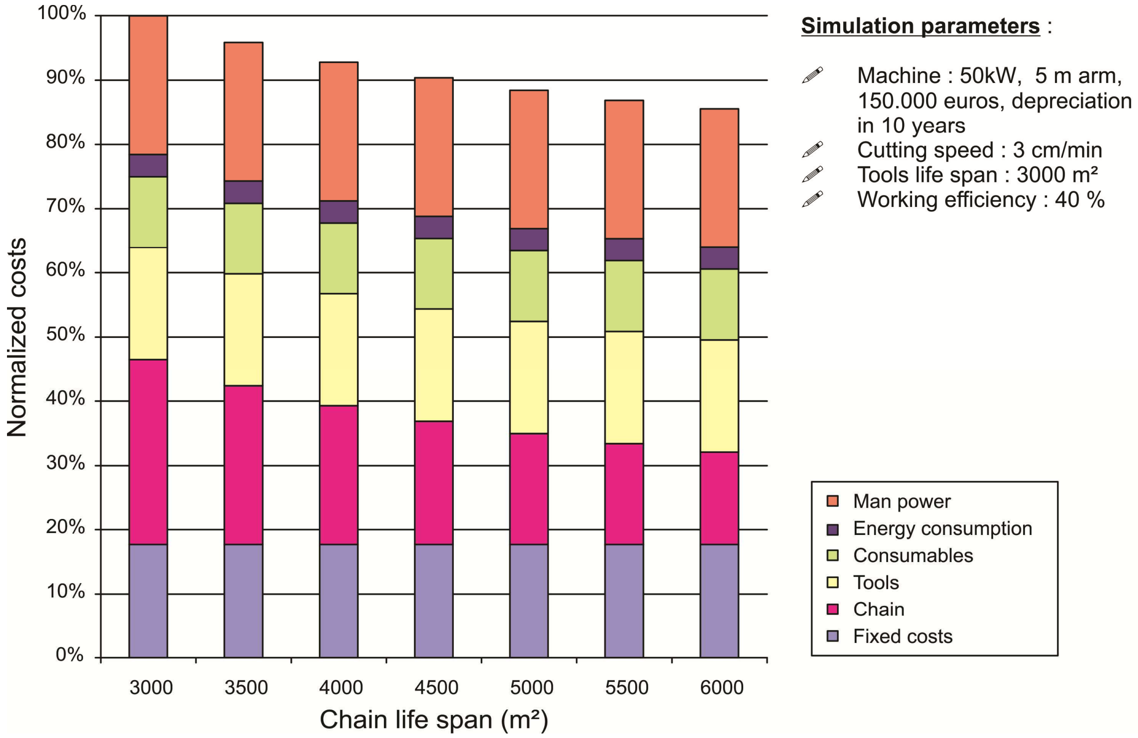

Fig.3 : Example of the influence of the chain links life span for the same cutting configuration, and any other setting kept constant.

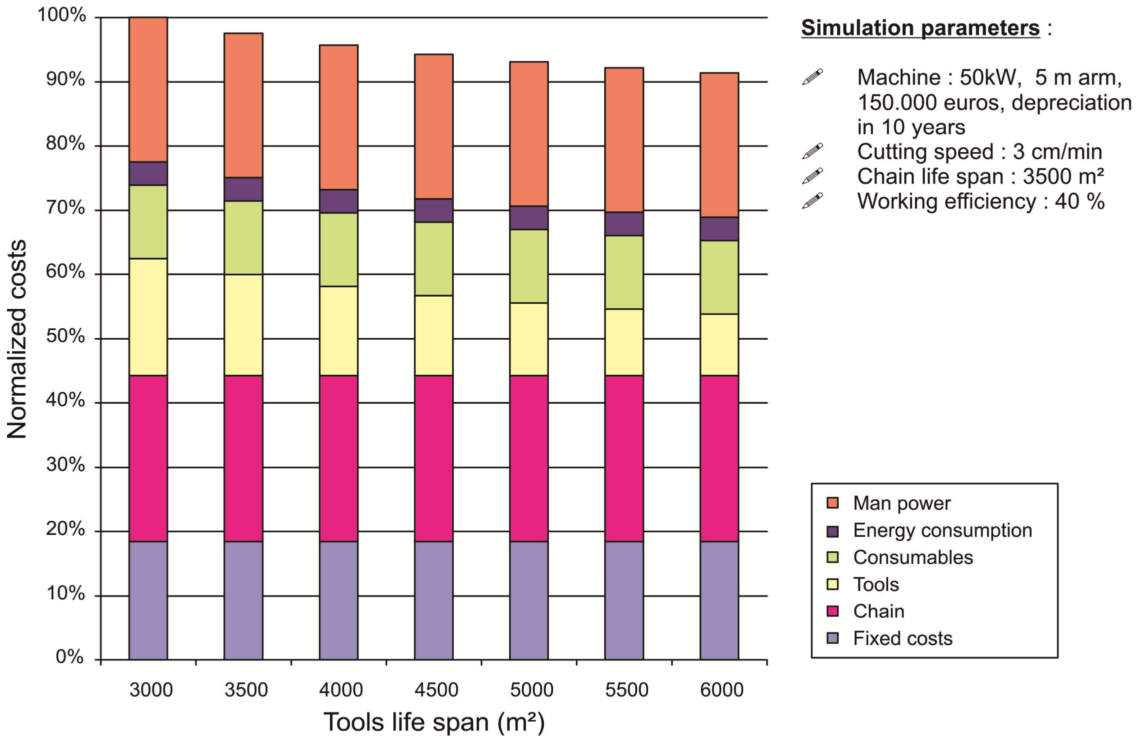

Fig.4 : Example of the influence of the tool life span for the same cutting configuration, and any other settings kept constant.

3.4 TOOL PRICE

The tool price is of course a variable that influences directly the operational cost. And it is generally the variable that will be taken into account when buying the tools.

The example presented in Fig.5 illustrates the influence, on the operational costs, of a price reduction from the full price to 60% reduction. The reduction of the operational cost is less than 10%.

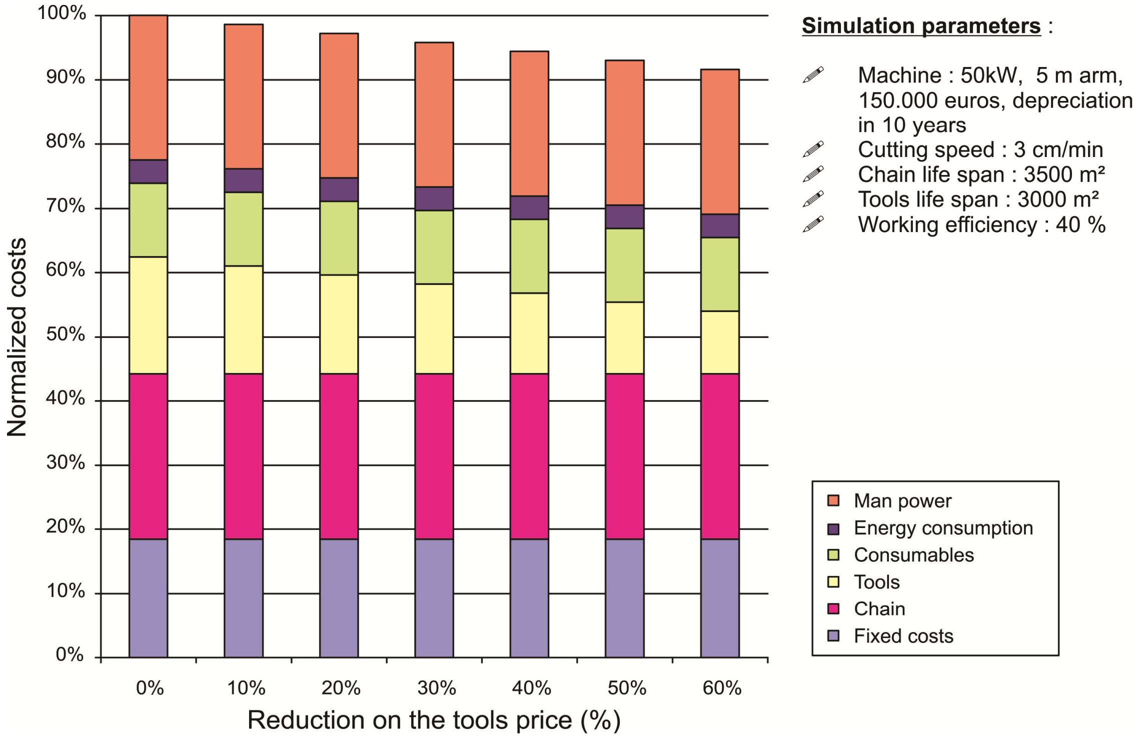

Fig.5 : Example of the influence tool price for the same cutting configuration, and any other setting kept constant.

4. APPLICATION OF THE COST EVALUATION PROGRAM

Several cutting configurations have been studied in the previous articles (see Fig.6) :

1. a configuration with 9.4 mm width squared cutters,
2. a configuration with 8 mm diameter circular cutters,
3. a configuration with 13 mm diameter circular cutters,
4. the new concave cutting configuration with 10 mm diameter circular cutters.

Most of the technical parameters and economic variables have been measured or determined and introduced in the evaluation program.

Fig.6 presents the different operational costs estimated with the cost evaluation program for the different cutting configurations studied. The last simulation corresponds to the new concave configuration working at the maximum chain speed without generating vibration.

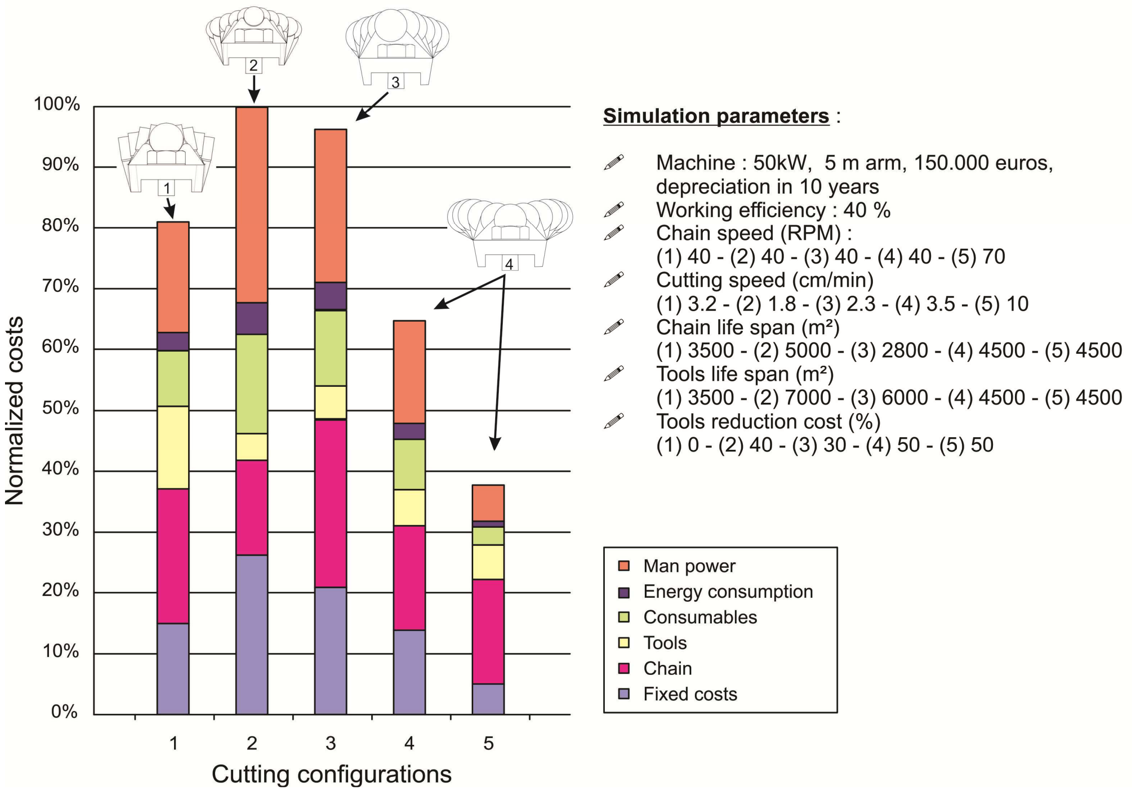

Fig.6 : Comparison of the three cutting configurations in use in the Belgian Blue Limestone quarries (1,2 and 3), with the new concave configuration developed (4) and the same configuration working with the maximum chain speed of the machine without vibration (5).

Based on the different data, the fleet of machines necessary to reach the productivity of a quarry has been defined. Fig.7 illustrates the number of identical machines that should be needed for an annual quarry productivity of 40.000 m³, actual volume extracted in the Blue Limestone Quarry which has been studied.

It can be clearly observed that the tools choice and its final performances has an effect on the operational cost and the amount of machines necessary to achieve the productivity.

5. CONCLUSION

The research project on chain saw machine technology has been initiated in order to understand why problems were appearing in hard stone cutting. The experience acquired during the project allows the design of an innovative cutting typology. The use of a cost evaluation program specially developed for chain saw machine in combination with the experimental approach in laboratory and the monitoring of the machines in quarry gives the opportunity to stone processors to evaluate the benefits of using new high-tech tools to optimize chain sawing operations.

From the evaluation of several variables implemented in the program, it has been shown that the cutting speed of the machine is the main variable which allows significant decrease of the operational cost. The development of new efficient cutting configuration based on a scientific approach allows the increase of the working efficiency, and the increase of the tools and links life spans which finally also induces additional decrease of the operational cost. The effect of the tool price reduction on the operational cost stays marginal in comparison to what can be expected from the other variables. Evaluating the performances of tools based only on their direct cost should be disregarded. However, the cutting tool must be correctly chosen based on the expected cutting speed, the life span of tools and machine parts, or the energy consumption.

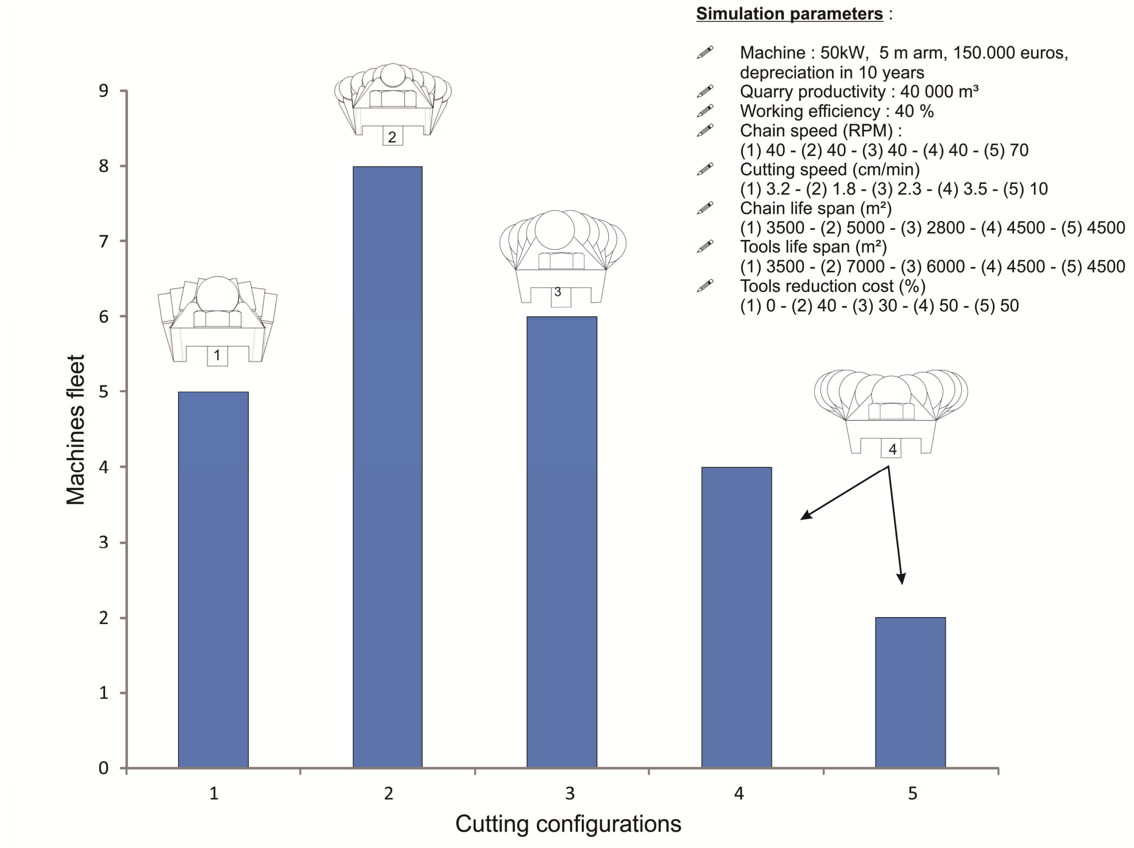

Fig.7 : Evaluation of the machine fleet necessary to reach a productivity of 40 000 m³ with identical machines for the different cutting configurations evaluated.

The experimental approach in laboratory and the continuous monitoring of the machine combined with an efficient cost evaluation program is an innovative methodology that helps increasing the productivity and reducing the operational cost in the stone industry. Their use will bring additional innovations. Working methods and tasks organization will also allow additional gains in terms of working efficiency.

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