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Sensitivity Analysis for Sawing Cost Model Evaluation. A Review on an Iranian Stone Factory

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Abstract

Stone sawing industry is among the most important mineral industries in Iran. Therefore, special attention to this sector can result in economic growth by providing a healthy condition in competition with other countries. Two important factors, which affect the world market's competition, are the cost operation and the quality of the processed stone. Providing economic advantage by lowering the cost without causing any defect in the quality of the stone is the key point in the industry. Therefore, in this research, an economic evaluation was carried out on the sawing process of a hard stone and a cost model including all cost factors was developed. Then, in order to determine the most effective cost factors, sensitivity analysis was performed on the proposed model. The results of this study showed that diamond disk and energy cost are respectively the most important factors in the operation.

Keywords

Stone Sawing, Cost Model, Sensitivity Analysis, Diamond Disk Cost, Cost of Energy

JEL Codes: C51

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1. Introduction and literature review

Stone sawing disks are significantly used in dimensional stone production factories. Therefore, having enough knowledge about dimensional stones and executive ability of the sawing machines help designers to speed up the process, which consequently results in an increase in the rate of production. For a high production rate, high quality and effective competition in the world markets, the use of advanced, high technology tools is required in the extraction and stone processing steps. The proper use of these devices in one hand and the precise recognition of their performance on the other hand, can significantly help to increase the quality of the processed rocks.

Recently, some good industrial and laboratory tests have been performed on the technology and ability of dimensional stone sawing process in Iran and other countries (Mikaeil *et al*., 2008; Ataei *et al*. 2011; Mikaeil *et al*., 2011; Ghaysari *et al*., 2012; Ataei, 2012; Sadegheslam *et al*., 2013; Mikaeil *et al*., 2013; Mikaeil *et al*., 2014; Mikaeil *et al.,* 2015; Aryafar & Mikaeil, 2016; Mikaeil *et al*., 2016; Akhyani *et al.,* 2017; Mikaeil *et al*., 2017; Almasi *et al*., 2017a; Almasi *et al*., 2017b; Kamran *et al*., 2017; Aryafar *et al*., 2018; Mikaeil *et al.,* 2018a; Mikaeil *et al*., 2018b; Akhyani *et al*., 2019; Mohammadi *et al*., 2019; Dormishi *et al.,* 2019; Mikaeil *et al*., 2019; Haghshenas *et al*., 2019; Hosseini, 2020). However, a limited number of these studies have dealt with providing and developing economic models in the sawing process. For the first time, in 2005, Ayhan (2005) carried out a research by providing an economic model in the sawing process of soft dimensional rocks (marbles) in Turkey (Ayhan, 2005).

Following that, Sadegheslam *et al.* (2013) carried out a similar study and analysed some soft rock samples in Iran (Sadegheslam *et al*., 2013). Due to dealing with various hard rocks in Iran and the lack of a comprehensive model for predicting sawing costs for them, in this study, we have tried to analyze the effective parameters in the hard stone sawing process and develop a model for that.

2. Cost Factors and Cost Model Determination

In general, the sawing cost of a stone block includes five major functions of labour cost, consumption of diamond disks, energy consumption of cutters, water consumption and maintenance costs. Mathematical models for each of these functions can be presented as follows:

Labour Costs Function. By using this function, we can calculate labour-related costs for sawing a square meter of stone blocks. The labour costs can be calculated through Eq. 1.

$$C_L = \frac{P N_w}{H_m P_h} \quad (1)$$

where CL is the cost of labour ($/m2), H_m is monthly working hours (h/month), P stands for monthly gross payment ($/month), N_w represents the number of workers. P_h is production rate (m2/h), which can be determined by Eq. 2.

$$P_h = K D_c F_r \quad (2)$$

In Eq. 2, K is the conversion factor that is equal to 0.036, Dc is depth of cut (mm) and Fr denotes feed rate (cm/s).
Disk consumption cost function. Eq. 3 defines the cost of disk consumption in terms of wear, the unit price of the disk and the disk durability, (the length of consumable segments). By using this function, the disk cost can be calculated for sawing one square meter of the stone block.

$$C_d = \frac{W_r P_d}{L n P_h} \quad (3)$$

Where Cd is disk consumption cost ($/m2), W_r is wear rate (mm/h), P_d stands for disk price ($), n is the frequency that the steel body of the disk is used, and L is the length of useful segment.
It should be noted that after totally using the segments in rock sawing factories, the steel body of the disk is sent to the welding centre for repair and reuse. Therefore, for several times, diamond segments can be welded to the body, and the body of the disk can be ready to be used again. On average, a steel body can be reused for 4 to 6 times. Thus, the unit price of a diamond disk can be calculated from the Eq. 4:

$$P_d = P_p + [n(S_p + G_p)] \quad (4)$$

Where P_p, S_p and G_p are steel body cost ($), segment cost for disk recycle ($), and the cost of segments' welding to the steel body ($), respectively.
Energy expenditure function. The cost of energy consumption, per unit cut surface of the stone block, can be determined through Eq. 5 by putting energy consumption and unit price energy parameters in it.

$$C_E = \frac{E_{co} E_p}{P_h} \quad (5)$$

where C_E is energy consumption cost ($/m^2), E_p is Energy unit price ($/Kwh), and Eco is energy consumption rate (Kwh/h)
Water consumption cost function. Eq. 6 shows the amount of water consumed per unit area cut for a block of stone.

$$C_w = \frac{W_{co} W_p}{P_h} \quad (6)$$

Where, C_w is water consumption cost ($/m^2), W_{co} is water consumption rate (Lit/h), and W_p is water price per litre ($/Lit).
Annual maintenance cost. Eq. 7 shows the cost of maintenance per unit area cut of the stone block:

$$C_M = \frac{M_p}{P_h d_y H_d} \quad (7)$$

where, C_M is maintenance cost ($/m^2), d_y is the number of working days per year, H_d is the number of working hours per day, and M_p is annual maintenance cost ($/year).
Total production cost per unit area cut for a stone block is presented in Eq. (8). According to this relation, the total cost function is equal to the sum of cost functions including disk consumption, energy, labour, maintenance and water consumption costs.

$$C_T = C_L + C_d + C_E + C_w + C_M \quad (8)$$

In this equation, the total production cost, C_T, is given in dollars per square meter. Eq. (8) can be rewritten in terms of all cost functions as below:

$$C_T = \frac{P N_w}{H_m P_h} + \frac{W_r P_d}{L n P_h} + \frac{E_{co} E_p}{P_h} + \frac{W_{co} W_p}{P_h} + \frac{M_p}{P_h d_y H_d} \quad (9)$$

These equations are obtained from tests performed on different carbonate rocks under actual production conditions. They can easily be applied to carbonate rocks due to their efficiency, which is proven by doing a sensitivity analysis as below.

3. Sensitivity Analysis

Sensitivity analysis is a method for measuring the impact of a function relatively to the change of the other function variables. In order to determine the most sensitive economic parameters in the sawing process of stone blocks, sensitivity analysis was carried out at a stone sawing factory in the Shams Abad industrial town. For this purpose, the process was performed according to the flow chart of Figure 1. The required economic information was first gathered and shown in Table 1. Working hours were estimated to be 11 hours per day and 286 hours per month. The maximum disk consumption rate was 130 Amps and the used voltage was 400 volts. Regarding the cumulative working hours, the cost per kilowatt was evaluated to be 0.013 $.

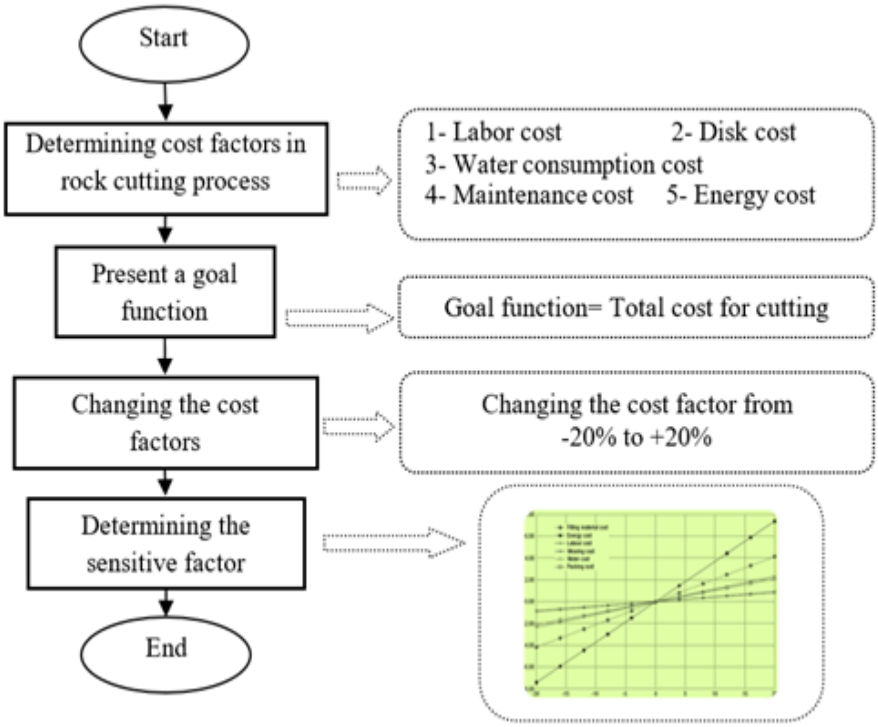

Figure 1. Steps for analysing the sensitivity of costing factors

Water is mostly evaporated at the time of evacuation of the ponds or mud resources. Disk cost is due to the usage frequency of an intact disk body and its segmentation cost after complete wear. After completing the economic data gathering process, the costing function values including water consumption, energy, disk, labour and maintenance per each square meter of the stone were calculated. Finally, the total production cost for sawing a square meter of the block was obtained. Figure 2 shows the estimated costs for sawing process of one square meter of the analysed block.

Table 1. Information and characteristics recorded from a stone sawing factory for sensitivity analysis

Economic parameters					
M_p	[$/year]	2105.2630	D_p	[$]	47.3684
N_w		1.0000	d_y	[days/year]	312.0000
P	[$/month]	315.7895	E_c	[$/m^2]	0.1897
P_h	[m^2/h]	3.0240	E_p	[$/kWh]	0.0132
TPC		1.8052	E_r	[kWh/h]	43.6000
W_a	[m^2/h]	0.0215	H_d	[h/day]	11.0000
W_c	[lit/h]	600.0000	H_m	[h/month]	286.0000
W_c	[$/m^2]	1.0260	L	[mm]	10.0000
W_p	[$/lit]	0.0001	L_c	[$/m^2]	0.3651
W_r	[mm/h]	0.6550	M_c	[$/m^2]	0.2029

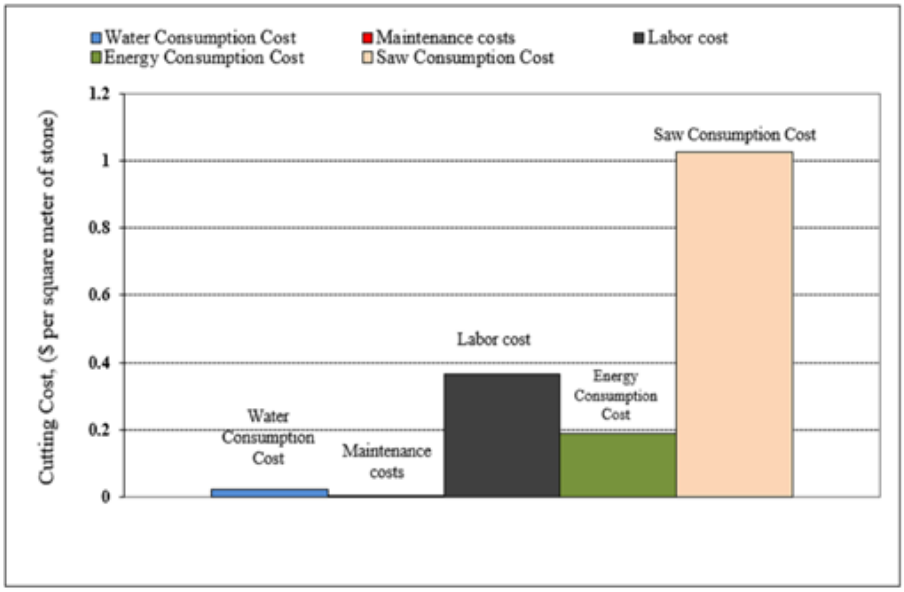

Figure 2. Values obtained from the costing function for sawing a square meter of red granite block.

It is clear that a high percentage of the total cost is due to wearing diamond tools, which is a function of cost of the disk. Because of the nature of granite, it was predictable that this factor is the most effective one. It should be mentioned that the values of these factors are determined under constant economic conditions. The question here is that what effect economic transformation will have on the economic structure of the process (in other words, change in the price of energy carriers, diamond tools, labour forces, etc.). To answer this question, it is necessary to examine changes in the total cost function relative to the variation of the variables of the problem. In other words, it is necessary to determine the sensitivity of the total cost function to the cost factors.

3.1. Sensitivity analysis of the total cost function relative to cost-making factors

In this section, we try to examine the total cost function under variable economic conditions (analysing the effects of variation in the value of each factor on the total cost). For this purpose, first the domain of the changes of each effective variable was determined (the range of change of each variable was considered from -20% to +20%) and, then, the total cost was calculated based on the new input values. The results of the sensitivity analysis are presented in Figure 3.

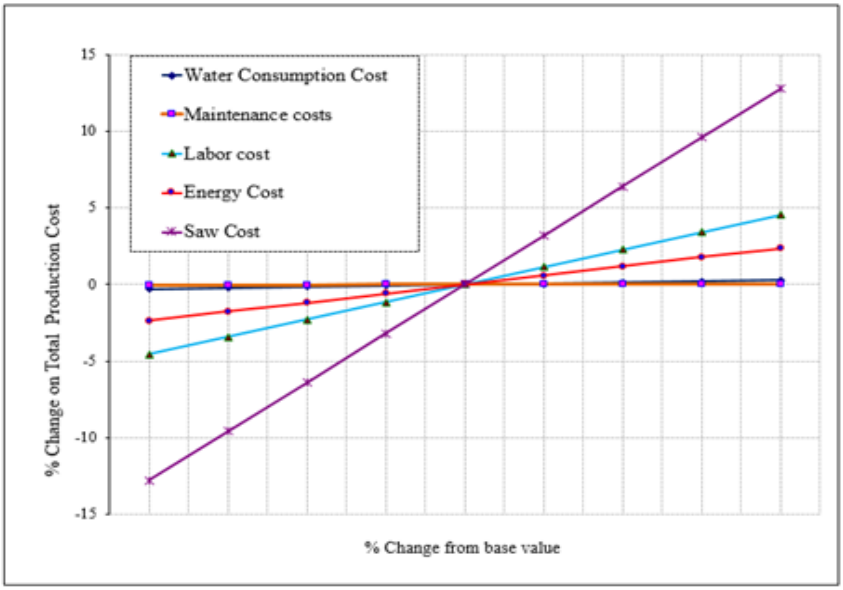

Figure 3. Sensitivity analysis of costing factors for sawing a hard stone block

In Figure 3, change on total production cost is plotted vs change from the base value for all factors. Sawing cost with the highest slope is the most effective factor. The cost of this factor covers more than 80% of the total production costs. After this factor, the two factors of energy consumption and labour costs have the greatest impact on the overall sawing costs and due to increase in the cost of energy carriers in Iran and its increase over the coming years, energy consumption will be one of the most influential factor along with cost of disk.

3.2. Sensitivity analysis of the total cost function relative to the effective rates in the sawing process

According to the studies from the previous section, it was found that energy and wearing diamond costs are among the most important factors affecting the final product price. The point to be considered is that in addition to the examined factors other important factors also affect the production cost. These factors that can be related to the operation and are not affected by economic factors of the market and the price of the energy carriers. Among these factors, the most important one are the production rate, disk wear rate and energy consumption. So that a small change in these parameters can lead to overall changes in production costs. Therefore, complete evaluation of these factors is necessary for the sawing cost assessment of a stone block. For this purpose, in this section of the study, we tried to analyse the sensitivity of these factors including production rate, wear rate, water consumption rate and energy consumption rate per cut price for a square meter of stone block. The results of this study are presented in Figure 4.

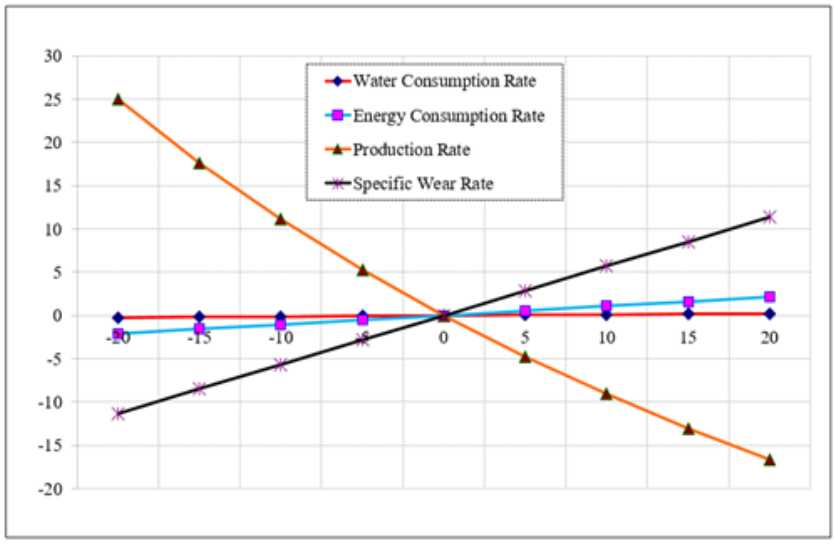

Figure 4. Sensitivity analysis of effective rates in the process of sawing a hard stone block.

Figure 4 shows that the production rate has the highest effect. It is clear that the sawing cost have has inverse relationship with the production rate. But it should not be forgotten that increase in the production rate is only be allowed to a certain extent, and its optimal amount is always a desirable option for stone factory.

5. Discussions and conclusions

The stone sawing industry is among the most important mineral industries in Iran. Therefore, special attention to this sector and providing solutions for its problems can result in rapid growth of the country. One of the most important criteria in the worldwide markets is the cost of commodities. Therefore, regarding the high cost of sawing operation of stone blocks, it is necessary to carry out precise economic studies such as sensitization and related risk analysis. Sensitivity analysis is one of the available methods for determining the sensitivity of the economic model to cost factors. Determining the impact of the objective function in different situations during the life of a project can significantly help the managers to choose the most appropriate economic orientation over the life of a project. In this research, after analysing and determining cost factors, the sensitivity analysis for the proposed economic model was studied. Generally, the results of this research can be summarized as follows:

1. The diamond tool wear cost is the most effective factor in the total cost function. After that, energy consumption and labour costs have the highest impact on the overall sawing costs. Because of increase in the cost of energy carriers in the country and its definite increase in the coming years, this factor is considered to be one of the most influential factors beside the disk consumption costs. Therefore, it is necessary to provide solutions to reduce energy consumption. One of the most useful ways in this regard is to present a suitable sawing pattern with an approach to reduce energy costs and increase production. Such a model, in addition to increasing production efficiency and reducing its costs, can help to reduce

the per capita consumption of energy throughout the country. Also, as a simple solution, in order to reduce the energy cost, it is possible to change the working shifts from mid-peak hours to low-peak hours. According to the ministry of energy low-peak hours are hours from 11pm to 6am and mid-peak hours are between 6am and 6pm and peak hours in winter are between 6pm to 11pm. Thus, if the managers of rock factories shift most of their activities to low-peak hours, they will benefit considerably from electric costs.

2. In the second part of this study, we analysed energy consumption rates, wear rates, production rates and water consumption rates on total production costs. The results showed that total production cost was significantly affected by the rate of production (operating characteristics of the sawing and mechanical and physical characteristics of the stone block). And this shows the importance of providing a suitable sawing pattern to achieve optimal economic conditions.

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