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Artificial neural network application to predict the sawability performance of large diameter circular saws

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A R T I C L E I N F O

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A B S T R A C T

To predict the performance of a large diameter circular saw (*LDCS*) is among the fundamental steps that are required for determining the practicability of stone production. Natural stone processing plants were visited to measure the areal slab production rate (*ASPR*) of *LDCS* in different operational conditions. Neural network toolbox in MATLAB is applied in order to develop a model to predict *ASPR* of *LDCS*. An artificial neural network is trained with physical and mechanical properties of eleven stones as input parameters and their associated *ASPR* values as the target. Uniaxial compressive strength (*UCS*), Brazilian tensile strength (*BTS*), Cerchar abrasivity index (*CAI*), porosity, and density are the physical and mechanical properties that are used as input parameters. In view of its speed, robustness, and the fact that it is very well renowned compared to the other learning algorithms, the Levenberg–Marquardt propagation algorithm is used to train the network. It is explained in detail that a neural network with the previously mentioned input parameters and only one hidden-layer can successfully estimate *ASPR* for *LDCS*. It is noticed that, while the number of neurons is less than eight in the single hidden-layer, the network generalizes better than when the number of neurons increases. However, beyond that point, not only the number of neurons does not have any positive effect on performance of the network, but it may also cause the network to memorize the results instead of generalizing them. It can be declared that using *ANN* to predict *ASPR* of *LDCS* may lead the engineers toward a more reliable design and planning.

1. Introduction

Large diameter circular saw (*LDCS*) has been the dominant choice in natural stone processing plants for production of stone slabs with different sizes. Relying on only one person as operator, *LDCS* has achieved superb production performance with minimum cost compared to the other commonly used machines in the field of natural stone production. In addition, the slabs produced by *LDCS* are smooth-surfaced and do not require shaping. Nevertheless, depending on geotechnical features of the stone, *LDCS* may have its limitations. Physical and mechanical properties of the stone, machine characteristics, penetration rate, and tool consumption are the factors that have an effect on either the machine selection procedure or machine performance. Machine performance in its own turn, has a direct impact on production planning and cost estimation [1].

Artificial neural network (*ANN*) is a new tool for dealing with geotechnical problems. In the fields of tunneling and mining, *ANN* has been used in performance estimation studies for mechanical excavators (TBMs, Roadheaders, circular saws, diamond wire saws, etc.). Tiryaki [2] exploited *ANN* to create a prediction model for rock cutting. He also used this technique to estimate cuttability performance of drag tools [3]. Bilgin et al. [4] applied *ANN* to estimate

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cuttability performance of rocks based on rock properties. Avunduk et al. [5] built a performance prediction model for roadheader using *ANN*. Salsani et al. [6] conducted a research on prediction of roadheader performance by *ANN*. Alvarez Grima et al. [7], and Benardos and Kaliampakos [8] used *ANN* to model tunnel boring machine (*TBM*) performance. Javad and Narges [9] developed a prediction model for penetration rate of *TBM* by implementation of *ANN*. Samani and Bafghi [10] implemented *ANN* to estimate the sawing quality of Marmarit stones. The sawing performance estimation of diamond wire machines were analyzed by Jain and Rathore [11] using *ANN* approaches. Kahraman et al. [12] used shear strength parameters as predictors in an *ANN* based prediction model to estimate sawability of carbonate rocks. Enayatollahi et al. [13], Ceryan et al. [14], Manouchehrian et al. [15], Dehghan et al. [16], Yilmaz and Yuksek [17], Sonmez et al. [18], Khandelwal et al. [19], Singh et al. [20], Shahin et al. [21], and Yang and Zhang [22] are among the researchers who used *ANN* to solve geotechnical problems. Using a sufficient number of training data, *ANN* learns how to generalize well between input parameter(s) and target. A trained *ANN* can predict the desired parameter using newly presented input parameters that are within the range of input parameters the network has been trained with [9].

This study investigates the application of *ANN* as a tool for predicting the performance of large diameter circular saw (*LDCS*). A data base is generated by gathering samples from different stone processing plants and performing laboratory tests on them. Brazilian tensile strength (*BTS*), Cerchar abrasivity index (*CAI*), uniaxial compressive strength (*UCS*), density, porosity are the selected predictors for an *ANN* model that predicts areal slab production rate (*ASPR*) of *LDCS*. The efficiency of the *ANN* is discussed thoroughly.

2. Previous studies on performance estimation of large diameter circular saws

Kahraman et al. [23], Gunaydin et al. [24], Wei et al. [25], Brook [26], Ceylanoglu and Gorgulu [27], Hausberger [28], and Burgess [29] are the researchers who have previously discussed the relationship between stone properties and performance of the circular saw. Tumac [1] suggested two empirical performance prediction models that use Schmidt hammer rebound values and Cerchar abrasivity index as predictors. The reliability of the models was verified by comparing the predicted and actual areal slab production rates of *LDCS*. Yurdakul and Akdas [30] analyzed the sawing parameters (advance rate, depth of cut, stone properties) and compared them with specific cutting energy (SE_{cut}) of the sawing machines. They developed a model to predict specific cutting energy (SE_{cut}) for block cutters. Using samples collected from five different marble quarries in Mugla province of Turkey, Guney [31] proposed numerous statistical models that relate hourly slab production rate to surface hardness and mineral grain size. Kahraman and Gunaydin [32] found a strong linear correlation between the areal slab production rate of large diameter saws and the indentation hardness index by investigating the performance of *LDCS* on eight distinct carbonate rocks. Ribeiro et al. [33] correlated the sawability of stones with saw properties, machine characteristics, sawing depth, and stone properties. Tutmez et al. [34] exploited the multifactorial fuzzy approach to investigate relationships between *LDCS* performance and stone properties. Their endeavor resulted in classification of performance of diamond saw into three main categories based on the rock properties. Delgado et al. [35] found a strong correlation between sawing rate and micro hardness of pink Spanish granite. Kahraman et al. [12] demonstrated the superior reliability of their proposed *ANN* models over statistical models for sawability estimation for carbonate rocks. Zhang and Lu [36] made an effort to optimize design and rotational application of diamond saw blades. In order to optimize tool consumption and sawing parameters, Konstanty [37] developed a theoretical model for chip creation and removal process. Clausen et al. [38] proposed that the sawability of stone might be classified using acoustic emission tests. Norling [39] stated that grain size had a greater impact on sawability than quartz content.

3. Laboratory and field studies

Block samples with the minimum size of $25 \times 25 \times 30\ cm^3$ were collected from natural stone factories. Physico-mechanical property tests according to the International Society for Rock Mechanics standards [40] were carried out on Afyon tigerskin marble, Afyon white marble, Karacabey black limestone, Manyas white marble, Marmara white marble, Milas white marble, Eskisehir supreme limestone, Karahallı white marble, Karahallı gray marble, Mustafa Kemal Pasa white marble, and Sivaslı purple marble. The method suggested by the American Society for Testing and Materials [41] was used to carry out Cerchar abrasivity tests (*CAI*). Uniaxial compressive strength (*UCS*) tests were performed on grinded NX (54.7 mm) samples having length to diameter ratio of around 2.5–3. The stress rate was applied within the limits of 0.5–1.0 kN/s. Brazilian tensile strength (*BTS*) tests were carried out on grinded NX samples having length to diameter ratio of around 0.5–1.0. The applied load on the samples was 0.25 kN/s. *UCS* and *BTS* tests were replicated 10 times for each natural stone samples. In Cerchar abrasivity index (*CAI*) tests, a steel conical pin was scratched in a direction parallel to a freshly broken stone surface over a distance of 10 mm under a total constant force of 70 N. Wear flats on the pins were measured under a microscope in 0.01 mm increments. 5 individual *CAI* tests were conducted for each natural stone sample to achieve a defined average value. Porosity and density properties of natural stone samples were determined using saturation and caliper techniques. At least six test samples with the form of a cylinder, representing the body of the natural stone were tested. Table 1 summarizes the physical and mechanical properties of natural stone samples. In order to determine the texture of the natural stone, thin section petrographic analysis was carried out by using the photographs taken in plane polarized light (Fig. 1). The obtained results are given in Table 2.

The outcomes of the performed tests show that uniaxial compressive strength (*UCS*) values vary between 63.8 and