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Artificial neural network model for forecasting energy consumption in hot mix asphalt (HMA) production

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HIGHLIGHTS

- Predicting energy consumption in the production of hot mix asphalt.
- ANN model (artificial neural networks) was made.
- Schematic view of input variables that provide the most successful prediction was made.

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ABSTRACT

This paper provides an overview of the artificial neural network (ANN) model development with the objective of successfully predicting natural gas consumption in the process of hot mix asphalt production. For the purposes of testing, data was collected pertaining to the production of hot mix asphalt during 2014 (155 production days). In total, 77,893 tons of hot mix asphalt was produced during the observed period. The total production for the modeling process is divided into 4 groups depending on the layer (type) of road construction in which the subject mixtures are incorporated: Base, Surf, Bin and SMA. By dividing total production into several groups, an attempt was made to take into account the influence of production and composition of asphalt on the efficiency of predicting natural gas consumption. The following independent variables are used in the modeling process: moisture content, hourly capacity, type of produced asphalt mix and the temperature of produced asphalt. From the obtained modeling results it can be concluded that it is possible to successfully use ANN in the process of predicting natural gas consumption in the production of hot mix asphalt, whereby the composition of asphalt and the specificity of the production itself should be considered.

1. Introduction

The production of hot mix asphalt (HMA) requires significant amount of thermal energy. During the production process it is necessary to heat the integral components of the mixture to the desired temperature, which allows for their mixing and proper installation. Reference mixing temperature for mixtures with paving grade bitumen is in the range from 90 to 180 °C (V1500 – 20/30) depending on the binder penetration (Bituminous mixtures – Test methods for hot mix asphalt – Part 35: Laboratory mixing (EN 12697-35:2004 + A1:2007)). According to various sources (Roberts et al., 1996, Zaniewski and Pumphrey, 2004), the viscosity of bituminous binders should amount to about 170 ± 20 cP for mixing and 280 ± 30 cP for compaction [1,2]. Total worldwide energy consumption in the process of producing asphalt mixtures depends directly on the amount of asphalt mixtures produced and the average energy consumption per produced ton. From the previous researches (EAPA 2013), it is evident that the average production of warm and hot mix asphalt in the EU for the period 2008–2013 amounted to 307.1 million tons [3].

Table 1 displays average energy requirements in the process of producing hot mix asphalt according to different authors [4–6].

1.1. Overview of previous researches

During the production of asphalt mixtures, energy consumption is influenced by various significant factors simultaneously. Authors Androjić et al. (2017) in their paper indicate that energy consump-

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Table 1
Energy requirements.

Authors	Energy requirements
Grabowski and Janowski (2010) [4]	4 L of fuel are needed to dry 1 t of mineral mixture with an moisture content of 6%, and additional 3 L are necessary to spend for heating of dry mixture
BAT [5]	85 kWh per ton
Androjić and Alduk 2016 [6]	Average natural gas usage per ton 8.5 m^3/t

tion in the production process of HMA is affected by the conditions of production and storage of mineral mixture, moisture content and temperature range of heated mineral mixture, the quality of mineral mixture, the asphalt plant and the type of asphalt mixture produced [7]. In the production process of HMA, about 97% of energy is spent in the rotary drum (Jullien et al. 2010) [8]. Fig. 1 provides a schematic illustration of previous researches that cite influential factors on energy consumption in HMA production [6].

Table 2 provides an overview of conclusions of certain researches related to the impact of delays, moisture content, drying process and heating of mineral mixture on the need for energy in the process of producing asphalt mixtures.

From the researches conducted so far it can be concluded that, on average, about 30 kWh of heat energy is needed to remove 4% of moisture. The growing number of production delays also leads to increased demand for energy invested. In addition to reducing moisture content and the number of production delays, from the previous researches (Davidson, 2008, Romier et al., 2006, Self, 2006, Harder et al., 2008, Hassan, 2009) it is evident that warm mix asphalt production requires lower heating temperatures and reduced energy consumption [12–16].

During the actual production of asphalt mixtures, energy consumption is simultaneously affected by several influential independent variables. In order to take into account their simultaneous effect, possible application of neural networks is analyzed in the process of predicting energy consumption.

1.2. Use of neural networks

Neural Networks (ANN – artificial neural networks) are replica of human brain which are aimed to simulate the process of learning and data processing. They represent a set of interconnected processing elements or nodes whose functionality is based on biological neuron. The main construction element of an ANN is the neuron, which receives signals from its input, calculates new activation level and sends it as an output signal. The input can be raw data or outputs from other neurons. Output signal can be input to other neurons or a final solution of a problem. One of most used structures in prediction model development is multilayer perceptron (MLP), which is a feedforward neural network. It consists of an input and output layer and one or more hidden layers. Fig. 2 shows the general view of the construction of neural network.

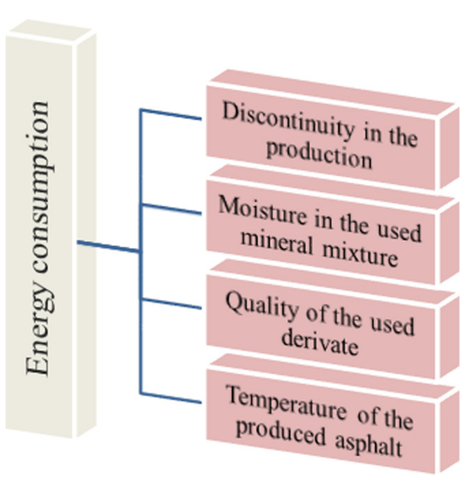

Fig. 1. Influential factors on energy consumption.

Table 2
Effects on energy needs.

Authors	Conclusions
Ang et al. (1993) [9]	number of delays from 5 to 4 leads to 1% reduction in the consumption of diesel fuel and electricity
Ang et al. (1993) [9]	reducing the moisture content for 3% leads to savings in energy consumption by 55–60%
Jenny (2009) [10]	reduction in the moisture content for 2% in the mineral mixture leads to savings in fuel consumption for 1.5 kg/t
Grabowski and Janowski (2010) [4]	4 L of fuel are needed to dry 1 t of mineral mixture with an initial moisture content of 6%
Peinado et al. (2011) [11]	required thermal energy to remove 1% of moisture requires need for energy in the amount of 8.21 kWh
Jenny (2009) [10]	decrease in the mixing temperature from 180 °C to 115 °C during the production leads to the decrease in fuel consumption for 1.5 kg per ton

Neural networks are nowadays used for recognition of patterns, characters, speech, image compression, process control, process optimization, as well as in science and business world. ANN are typical example of modern interdisciplinary subject (Flood and Nabil, 1994, Flood and Paul, 1996) which is used to solve various engineering problems which could not be solved by traditional modeling [17,18]. Many researchers (Lazarevska et al., 2014, Flood, 1990, Jeng et al., 2003) demonstrate in their papers positive effects caused by use of neural networks for process prediction [19–21]. Nowadays, neural networks are not used to predict energy consumption in the rotary drum in the HMA production.

1.3. Objectives of the research

The main objective of the research is the following:

- producing and testing the ANN model with an analysis of influence by individual/total input independent variables on the dependent variable (energy consumption).

This paper shows that moisture content, hourly capacity, type of produced asphalt mixture and temperature of produced asphalt are used in the modeling process as independent variables whose impact is monitored through successful prediction of energy consumption in the HMA production process. By classifying total production on different types of asphalt, the influence of direct/screen production on natural gas consumption and prediction success will be taken into account as well. With successful predictions of daily energy consumption depending on the combined effect of influencing factors we can accomplish lowering the total cost of the produced asphalt mix by correcting one or more influential factors during actual production.

2. Experimental

For the purpose of testing, data (moisture content, hour capacity, temperature of produced asphalt, data about produced mixes and energy consumption) was collected during the production of hot mix asphalt in the period between March 27, 2014 and December 23, 2014. Asphalt was produced on a cyclic asphalt plant (Kov-