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Development of a multi-layer perceptron artificial neural network model to determine haul trucks energy consumption

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ABSTRACT

The mining industry annually consumes trillions of British thermal units of energy, a large part of which is saveable. Diesel fuel is a significant source of energy in surface mining operations and haul trucks are the major users of this energy source. Gross vehicle weight, truck velocity and total resistance have been recognised as the key parameters affecting the fuel consumption. In this paper, an artificial neural network model was developed to predict the fuel consumption of haul trucks in surface mines based on the gross vehicle weight, truck velocity and total resistance. The network was trained and tested using real data collected from a surface mining operation. The results indicate that the artificial neural network modelling can accurately predict haul truck fuel consumption based on the values of the haulage parameters considered in this study.

1. Introduction

The reduction of energy consumption has gradually become more important worldwide since the rise of the cost of fuel in the 1970s. The mining industry annually consumes trillions of British thermal units (BTUs) of energy in operations such as exploration, extraction, transportation and processing. A large number of research studies and industrial projects have been carried out in an attempt to reduce energy consumption in mining operations [1–4]. Current investments in the improvement of mining equipment have resulted in a significant reduction of energy consumption [5,6]. A large amount of energy can also be saved by improving mining technologies and energy management systems [7,8]. Energy saving is also associated with the reduction of millions of tonnes of gas emissions because the major energy sources used in the mining industry are petroleum products: electricity, coal and natural gas [9,10]. The type of fuel used on a mine site is greatly dependent on the type of mining method and the equipment used. Most of the equipment used for the handling of materials in mining is powered by diesel engines [11], which are highly energy-intensive, accounting for 87% of the total energy consumed in material handling.

Service trucks, front-end loaders, bulldozers, hydraulic excavators, rear-dump trucks and ancillary equipment, such as pick-up trucks and mobile maintenance equipment, are examples of the diesel equipment used in mining operations. Trucks in surface mines are used to haul ore and overburden from the pit to the stockpile, the dumpsite or to the next stage of the mining process. They are used in combination with other equipment, such as excavators, diggers and loaders, according to the production capacity and the site layout. The trucks used in the haulage operations of surface mines use a great amount of energy and this has encouraged truck manufacturers and major mining corporations to carry out a number of research projects on the energy efficiency of haul trucks [12–16].

The study conducted by Antoung and Hachibli [13] is concerned with the implementation of power-saving technology to improve the motor efficiency of mining equipment. The focus of their study is on the technical performance of motor components and how they contribute to the reduction of friction and the improvement of the motor efficiency. Beatty and Arthur [14] investigate the effect of some general parameters, such as cycle time and mine planning, on the energy used by haul trucks. They determine the optimum values of these parameters to minimise fuel consumption in hauling operations, but they do not consider the three technical key parameters of gross vehicle weight (GVW), total resistance (TR) and truck velocity (V). The research presented by Carmichael et al. [15] is concerned with the effects of haul truck fuel consumption on costs and gas emissions in surface mining operations; however, the simulation used in their research does not include the pertinent factors affecting the fuel consumption.

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Chingooshi et al. [16] study the smart energy mining strategy and identify the effective key parameters involved in energy efficiency opportunities in the mining industry as a whole; however, their research excludes the technical aspects of the parameters that affect fuel consumption for haul trucks. The scope of the present paper differs from the above-mentioned studies because it aims to determine how the fuel consumption of a haul truck varies with the truck payload, truck tyre rolling resistance (RR) and the haul grade resistance (GR) when the truck is travelling with the best engine performance.

The understanding of the energy efficiency of a haul truck is not limited to the analysis of vehicle-specific parameters and mining companies can often benefit by expanding the analysis to include other factors that affect the energy use of trucks, such as payload distribution; however, reasonable progress has not yet been made in this field of research due to the complexity of the parameters involved. There are a number of key parameters that influence the energy used by trucks in a mine fleet, all of which need to be taken into account simultaneously for the optimisation of fuel consumption.

Artificial neural networks (ANNs) can be used to determine fuel consumption by taking into consideration a number of parameters that influence the fuel consumption of trucks. ANNs have been used in many engineering disciplines, such as materials, biochemical engineering, medicine and mechanical engineering [17–30]. ANNs are desirable solutions for complex problems as they can interpret the compound relationships between the multiple parameters involved in a problem. One of the main advantages of the ANNs is that they can simulate both linear and nonlinear relationships between the parameters using the information provided to train the network. This paper presents the development of a multi-layer perceptron artificial neural network model to determine the fuel consumption of haul trucks in surface mines.

2. Haul truck fuel consumption

Haul truck fuel consumption is a function of various parameters, the most significant of which have been identified and categorised into seven main groups (Fig. 1). The key parameters that affect the energy consumption of haul trucks include the payload management, the model of the truck, GR and RR, according to a study conducted by the Department of Resources, Energy and Tourism. That study examines the best truck ratio (BTR) and the diesel consumption for a fixed production of 20 million tonnes of moved material and finds an optimal payload associated with the minimum BTR and diesel consumption. The BTR is defined as the ratio of actual consumed energy to the theoretical best use of energy by haul trucks. It is also shown that the model of the truck and the haul road condition affects the BTR and the diesel consumption.

In the present study, the effects of the GVW (representing the sum of the empty truck weight and the payload), the maximum truck velocity (V_{max}, representing the truck model at a fixed payload) and the TR (representing the haul road condition) on the energy consumption of the haul trucks were examined. The TR is equal to the sum of RR and GR when the truck is moving against the grade of the haul road.

$$\mathrm{TR} = \mathrm{RR} + \mathrm{GR} \tag{1}$$

The RR depends on the tyre and hauling road surface characteristics and is used to calculate the rolling friction force, which is the force that resists the motion when the truck tyre rolls on the haul road (Fig. 2).

For typical haul roads, the RR is 2% if the road is hard and well-maintained; on the bench and close to the dump end, the road quality deteriorates and the RR is expected to increase to 3%; during wet periods when the road conditions are worsened, the RR might increase to 4%; finally, under very poor conditions, the RR may rise to 10–16%, however, this would only be over very small sections of the haul road and for short periods of truck operations. In this study, the haul road is considered to have the same conditions as the dirt-dry, but not firmly packed, road and, therefore, a RR of 3% is used in the analysis. The typical values for RR are presented in Table 1.

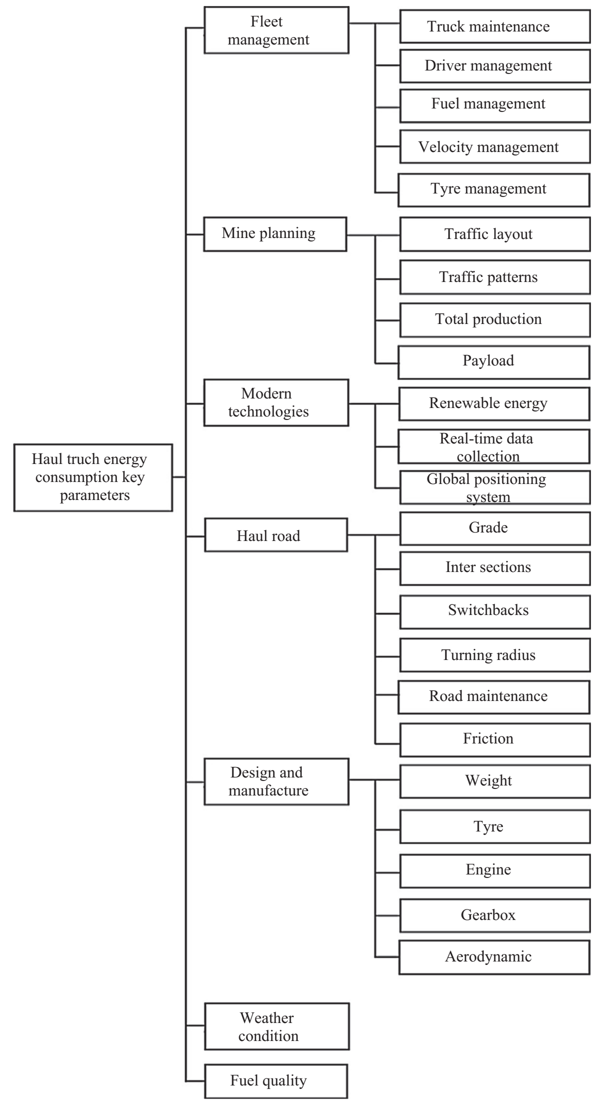

Fig. 1. Haul truck energy consumption key parameters.

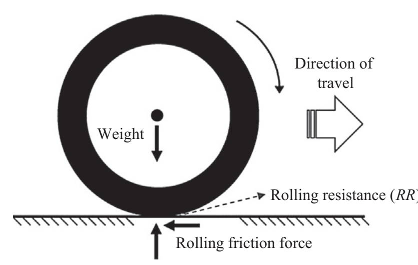

Fig. 2. A schematic diagram of a truck tyre showing the force.