Journal of Environmental Management 172 (2016) 177–185

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

New approach for reduction of diesel consumption by comparing different mining haulage configurations

Edmo da Cunha Rodovalho [a, *], Hernani Mota Lima [b, 1], Giorgio de Tomi [c, 2]

[a] Institute of Science and Technology, Federal University of Alfenas, Brazil
[b] Department of Mining Engineering, Federal University of Ouro Preto, Brazil
[c] Department of Mining and Petroleum Engineering, University of São Paulo, Brazil

ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form
25 February 2016
Accepted 26 February 2016
Available online xxx

Keywords:
Fuel consumption
Statistics
Mathematical modelling
Mining haulage operations

ABSTRACT

The mining operations of loading and haulage have an energy source that is highly dependent on fossil fuels. In mining companies that select trucks for haulage, this input is the main component of mining costs. How can the impact of the operational aspects on the diesel consumption of haulage operations in surface mines be assessed? There are many studies relating the consumption of fuel trucks to several variables, but a methodology that prioritizes higher-impact variables under each specific condition is not available. Generic models may not apply to all operational settings presented in the mining industry. This study aims to create a method of analysis, identification, and prioritization of variables related to fuel consumption of haul trucks in open pit mines. For this purpose, statistical analysis techniques and mathematical modelling tools using multiple linear regressions will be applied. The model is shown to be suitable because the results generate a good description of the fuel consumption behaviour. In the practical application of the method, the reduction of diesel consumption reached 10%. The implementation requires no large-scale investments or very long deadlines and can be applied to mining haulage operations in other settings.

1. Introduction

In large open pit mines, load and haul operations are commonly performed by haul trucks and excavators. Among the operations performed in an open pit mine, haulage has the highest operating cost. Over the past years, this method has been widely discussed due to the significant increase in its operating costs (Curry et al., 2014). This is justified on the basis of inputs such as diesel oil and tyres. According to Bozorgebrahimi et al. (2003), transport operations account for 46% of the mining operation costs. In addition, the fuel ranks first in the composition of these costs.

Against this background, mining companies seek to reduce operational costs by controlling the consumption of these inputs. By applying techniques that reduce the consumption of supplies, the mining industry can become more economical and sustainable (Gomes et al., 2015). Therefore, assessment of the variables that influence diesel consumption becomes essential to ensure the competitiveness of the mining industry. However, the mining industry lacks a methodology able to select and measure the operational aspects that have more or less influence on fuel consumption. Filling this gap would represent a tangible method of management and control of the operating costs of haul trucks. Effective control of the consumption of fossil fuels also improves mining companies' environmental performances, reducing their greenhouse gas emissions.

The purpose of this paper is to build a methodology to identify and classify the operational variables that influence the fuel oil consumption of haul trucks. In addition, it aims to develop actions that reduce fuel consumption. With the use of statistical analysis and multivariate linear regression tools, which are applied to the modelling of fuel consumption behaviour, it is possible to manage

* Corresponding author. Universidade Federal de Alfenas, Instituto de Ciência e Tecnologia, Rod. José Aurélio Vilela, 11999, BR 267 km 533, Cidade Universitária, 37715-400, Poços de Caldas, MG, Brazil.
E-mail addresses: edmo.rodovalho@unifal-mg.edu.br, edmo.rodovalho@gmail.com (E.C. Rodovalho), hernani.lima@ufop.br (H.M. Lima), gdetomi@usp.br (G. de Tomi).
[1] Permanent address: Universidade Federal de Ouro Preto, Escola de Minas, Departamento de Engenharia de Minas, Campus Universitário Morro do Cruzeiro, 35400-000, Ouro Preto, MG, Brazil.
[2] Permanent address: Universidade de São Paulo, Escola Politécnica, Departamento de Engenharia de Minas e de Petróleo, Av. prof. Mello Moraes, 2373, Laboratório LAPOL, Cidade Universitaria, 05508-900, São Paulo, SP, Brazil.

http://dx.doi.org/10.1016/j.jenvman.2016.02.048
0301-4797/

the mining operation costs. After the identification and classification of these variables by degree of influence, it will be possible to use prioritization tools to establish the management actions. These actions should be applied on an industrial scale to seek to validate the management method. This study used real data from a large open pit mine. The results obtained were validated at the same open pit mine.

2. Methodology

In large iron mines the overburden and ore transport costs have a direct relationship with the diesel consumption. Due to the growing production demand, it is becoming necessary to use off-road trucks with increasingly large capacities, leading to increased energy consumption. Shafiee and Topal (2012) claim that the estimation, cost simulation, and operating performance analysis can be done through the use of graphical analysis of tables and equations. All of these features are intended to identify a pattern linked to a particular operating configuration. This pattern is used as a reference to estimate indicators and support decisions in similar operating conditions. In order to identify and investigate the aspects that affect fuel consumption in haulage operations is necessary to delimit a period of one year for data collection. The studies were developed in a large iron mine in the Quadrilátero Ferrífero (Brazil). After this step, prioritization tools were applied to identify actions which can reduce the diesel consumption.

The development of this methodology is not limited to addressing the economic aspects but also has great potential to promote sustainability in mining operations. The key to reducing greenhouse gas emissions and, therefore, reducing diesel consumption begins with the development of management tools able to identify and address issues that strongly influence consumption (Levesque et al., 2014).

2.1. Driving and human factors related to fuel consumption

In order to understand the behaviour of fuel consumption in mine haul operations, one should not be limited to mechanical parameters (Australian Government, 2010). However, it is necessary to evaluate the influence of the human factor on the behaviour of this variable. Operators' performance is supported by their driving style. This feature differs under conditions of acceleration, breaking, cornering, speed variations, and manoeuvres. Besides these, there are other associated conditions that influence the performance of the production process, such as weather and topographic conditions (Shafiee and Topal, 2012). It is clear that all of these points are addressed in specific operational training for driving haul trucks. However, mine operation teams comprise a heterogeneous group with respect to the capability to execute each of the process steps in the most safe, economical, and productive way possible.

The first step of this study seeks to establish a method to measure the variability in fuel consumption between the teams by considering their heterogeneity regarding the experience and ability to operate equipment. This condition exists within each team or between one team and another. In addition, teams are subjected to diverse operating circumstances such as weather and haul road conditions, night shifts, visibility, and availability of resources.

A period of one year was assumed for assessment in order to consistently cover all subject teams, variables, and operating conditions. One year was considered sufficient to submit all teams to the climate seasonality that occurs during the year. An onboard system of sensors in trucks has been developed for evaluating the equipment performance and operating conditions regarding diesel consumption. A report by the Australian Government (2010) indicates that the diversity of haul road conditions has a direct effect on fuel consumption. Fig. 1 illustrates the topographic surface of the operating mining area where the studies were developed.

The lines represent the active haul roads used by trucks, with their grades, between load and dumping points. The segment formed by the points A and B forms the route AB, while the points C and D form the route CD. These routes were selected so that the influence of the operators' performance could be evaluated in a broad and representative way. The route CD represents the waste rock flow and the route AB the iron ore flow. Fig. 2 illustrates the elevation profile of the route AB, while Fig. 3 shows the elevation profile of the route CD. Points A and C are loading points and B and D are dumping ones. Haul route AB is considered a favourable gradient because the trucks are loaded down the ramp and gravity helps the movement. The CD profile is considered unfavourable because the loaded trucks go up the ramps. On these roads the trucks must overcome rolling resistance, generated by the friction of the tyres with the pavement, and gradient resistance. The performance of the haul trucks depends on the design of the mine haul roads and gradient variations (Thompson and Visser, 2006). In this way all the teams and operators are subject to different types of haul roads.

The studied mine operation has a transport fleet of mechanical and electromechanical trucks, both of which have the same load capacity. All truck drivers are able to operate both fleets' equipment. The evaluation of the human factor was performed considering mechanical trucks on routes AB and CD for one year. Descriptive statistical analysis was the first step in assessing the data generated by the five mine operation teams. Boxplot graphics were used to perform this analysis and check for outliers. It is also necessary to evaluate whether there are significant differences in terms of absolute diesel consumption between teams. For this it is necessary to perform a normality test to assess the p-value. This standard defines the use of parametric or non-parametric methods to measure the relevance of variability between samples (Montgomery and Runger, 2007). If the variability between teams is not significant, one can consider that there is no difference in consumption between them. Thus, technical heterogeneity between operators does not correspond to different consumption patterns, which eliminates the influence of the human factor.

For the route AB, 239 measurements of the five teams were performed. Each measurement represents an absolute consumption of diesel in a 6-h shift. Fig. 4 shows a graphical representation of descriptive statistics using a boxplot graph corresponding to the fuel consumption on the AB path. Fig. 5 illustrates the graph referring to the route CD boxplot. In Fig. 4 one can observe the absence of outliers and that the B team had the lowest median. Fig. 5 also shows no presence of outliers. Outliers are points that indicate consumption above normal during the research. Each point represents a shift with consumption above normal. On this route team D showed lower variability. From the boxplot graphics one can observe the variations of the median between the teams. But it is not possible to state that the variability between the teams is relevant. According to Oskouei and Awuah-Offei (2014), further analyses such as normality tests are required to determine whether the variability is significant. After this test, it is necessary to apply parametric or non-parametric analysis to measure the significance of the variance.

The normality test for the population assessed in Fig. 4 gives a p-value < 0.05. According to Devore (2000), for p-values lower than the significance level of 5%, the null hypothesis that the data follow a normal distribution is discarded. Since the data distribution is not known, the application of parametric procedures is not recommended. The alternative is to use distribution-free procedures,