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A comprehensive investigation of loading variance influence on fuel consumption and gas emissions in mine haulage operation

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ABSTRACT

The data collected from haul truck payload management systems at various surface mines show that the payload variance is significant and must be considered in analysing the mine productivity, diesel energy consumption, greenhouse gas emissions and associated costs. The aim of this study is to determine the energy and cost saving opportunities for truck haulage operations associated with the payload variance in surface mines. The results indicate that there is a non-linear relationship between the payload variance and the fuel consumption, greenhouse gas emissions and associated costs. A correlation model, which is independent of haul road conditions, has been developed between the payload variance and the cost saving using the data from an Australian surface coal mine. The results of analysis for this particular mine show that a significant saving of fuel and greenhouse gas emissions costs is possible if the standard deviation of payload is reduced from the maximum to minimum value.

1. Introduction

Mining industry consumes a large amount of energy in various operations such as exploration, extraction, transportation and processing [1]. A considerable amount of this energy can be saved by better managing the operations [2–5]. The mining method and equipment used mainly determine the type of energy source in any mining operation [6]. In surface mining operations, haul trucks use diesel as the source of energy [7–10]. Haul trucks are generally used in combination with other equipment such as excavators, diggers and loaders, according to the production capacity and site layout. Haul trucks use a great amount of fuel in surface mining operation; hence, mining industry is encouraged to conduct a number of research projects on the energy efficiency of haul trucks [11–13].

There are many kinds of factors that affect the rate of fuel consumption for haul trucks such as payload, truck velocity, haul road condition, road design, traffic layout, fuel quality, weather condition and driver skill [14–18]. A review of the literature indicates that the understanding of energy efficiency of a haul truck is not limited to the analysis of vehicle-specific parameters; and mining companies can often find greater energy saving opportunities by expanding the analysis to include other effective factors such as payload distribution and payload variance [17,19–21].

Loading process in truck and shovel operations is a stochastic process [20]. An analysis of the haul truck payload data obtained from a number of mine sites around the world shows that the payload distribution can be estimated by a normal distribution function with a satisfactory error; and the variance associated with haul truck payloads is typically large [19–21]. The payload variance depends on a number of parameters such as the particle size distribution, the swell factors, the material density, truck-shovel matching, number of shovel passes and the bucket fill factor [19,20,22]. Many attempts have been made to reduce the payload variance by using the latest developed technologies such as truck on-board payload measurement system, direct connection between this system and the shovel control system and on-line fleet monitoring system [19,20].

The payload variance not only affects the production rate and fuel consumption, but it is also an important parameter in the analysis of gas emissions and cost. Many research studies have already been conducted on the measurement of the haul truck gas emissions in the mining industry [23–27]. In addition, several numbers of economic models have been presented to predict the cost of diesel and gas emissions [28].

In this paper, the effects of payload variance on fuel consumption for a mostly used haul truck in Australia surface coal mines (CAT 793D) are investigated. A model is presented to estimate the effect of payload variance on the gas emissions and the total cost associated with fuel consumption and gas emissions. The corresponding energy saving opportunities to the reduction of payload variance is also investigated.

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2. Theoretical analysis

2.1. Haul truck payload variance

Loading performance depends on different factors such as bench geology, blast design, muckpile fragmentation, operators' efficiency, weather conditions, utilisation for trucks and shovels, mine planning and mine equipment selection [19,20]. In addition, for loading a truck in an effective manner, the shovel operator must also strive to load the truck with an optimal payload. The optimal payload can be defined in different ways, but it is always designed so that the haul truck will carry the greatest amount of material with lowest payload variance [15]. The payload variance can be illustrated by carrying different amount of ore or overburden by same trucks in each cycle. The range of payload variance can be defined based on the capacity and power of truck. The payload variance in a surface mine fleet can influence productivity greatly due to truck bunching phenomena in large surface mines [19]. The increasing of payload variance decreases the accuracy of maintenance program. This is because the rate of equipment wear and tear is not predictable when the mine fleet faces with a large payload variance. Minimising the variation of particle size distribution, swell factors, material density and fill factor can decrease the payload variance but it must be noted that some of the mentioned parameters are not controllable. Hence, the pertinent methods to minimise the payload variance are real-time truck and shovel payload measurement, better fragmentation through optimised blasting and improvement of truck-shovel matching.

2.2. Haul truck fuel consumption

The fuel consumption for haul trucks is determined based on the following parameters (see Fig. 1):

- The Gross Vehicle Weight (*GVW*), which is the sum of the weight of an empty truck and the payload.
- The Haul Truck Velocity (*V*).
- The Total Resistance (*TR*), which is equal to the sum of Rolling Resistance (*RR*) and the Grade Resistance (*GR*) when the truck is moving against the grade of the haul road.
- The Rimpull Force (*RF*), which is the force available between the tyre and the ground to propel the truck.

Caterpillar trucks are the most popular vehicles amongst all different brands of trucks used in Australian mining industry. Based on the power and capacity of haul truck and mine productivity, CAT 793D was selected for the analysis presented in this study. The specification of selected truck is presented in Table 1.

Fig. 2 presents the Rimpull-Speed-Grade ability curve extracted from the manufacturer's catalogue for CAT 793D.

The rate of haul truck fuel consumption can be calculated by the following equation [24].

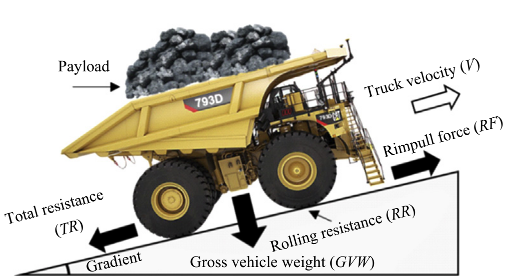

Fig. 1. Haul road and truck key parameters.

Table 1
CAT 793D haul truck specifications [28].

	Specification	Value
Engine	Engine model	CAT 3516B HD
	Gross power (kW)	1801
	Net power (kW)	1743
Weights-approximate	Gross weight (tonnes)	384
	Nominal payload (tonnes)	240
Body capacity	Struck (m^3)	96
	Heaped (m^3)	129

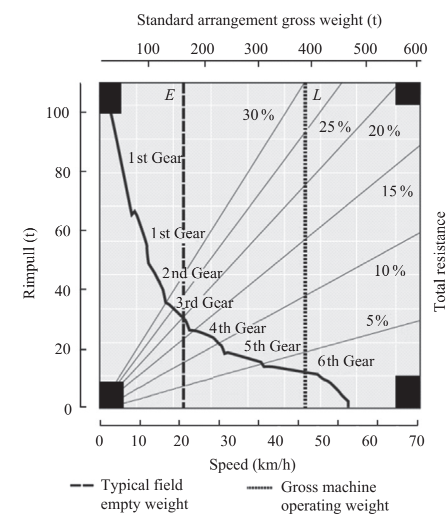

Fig. 2. Rimpull-Speed-Grade ability curve for truck CAT 793D [28].

$$FC = 0.3(LF \cdot P) \quad (1)$$

where *LF* is the ratio of average payload to the maximum load in an operating cycle. The percentage of *LF* in different condition is presented in Table 2 [24] and *P* is the truck power (kW).

For the best performance of the truck operation, *P* is determined by:

$$P = \frac{1}{3.6}(RF \cdot V_{max}) \quad (2)$$

where *RF* is the force available between the tyre and the ground to propel the truck. It is related to the torque (*T*) that the truck is capable of exerting at the point of contact between its tyres and the road and the truck wheel radius (*R*).

$$RF = \frac{T}{R} \quad (3)$$

In this paper, the fuel consumption by haul trucks has been simulated based on the above mentioned formulas.

Table 2
Load Factors (*LF*) for different conditions [22].

Operating conditions	*LF* (%)	Conditions
Low	20–30	Continuous operation at an average *GVW* less than recommended, no overloading
Medium	30–40	Continuous operation at an average *GVW* recommended, minimal overloading
High	40–50	Continuous operation at or above the maximum recommended *GVW*

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