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A discrete-event model to simulate the effect of truck bunching due to payload variance on cycle time, hauled mine materials and fuel consumption

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ABSTRACT

Data collected from truck payload management systems at various surface mines shows that the payload variance is significant and must be considered in analysing the mine productivity, energy consumption, greenhouse gas emissions and associated cost. Payload variance causes significant differences in gross vehicle weights. Heavily loaded trucks travel slower up ramps than lightly loaded trucks. Faster trucks are slowed by the presence of slower trucks, resulting in 'bunching', production losses and increasing fuel consumptions. This paper simulates the truck bunching phenomena in large surface mines to improve truck and shovel systems' efficiency and minimise fuel consumption. The study concentrated on completing a practical simulation model based on a discrete event method which is most commonly used in this field of research in other industries. The simulation model has been validated by a dataset collected from a large surface mine in Arizona state, USA. The results have shown that there is a good agreement between the actual and estimated values of investigated parameters.

1. Introduction

Improving the efficiency of haulage systems is one of the great challenges in mining engineering and is the subject of many research projects undertaken in both study and industry [1–9]. For mining, it is important that haulage systems are designed to be as efficient as possible, in order to minimise haulage cost, improve profitability and increase the total mine value. Haulage system inefficiency is typically derived from inadequate engineering, which results in poor haul road design, machinery standby and downtime, and circuit traffic [10–12]. According to the literature, haulage costs can be some of the largest in a mining system [13,14]. In various case studies it was found that material transportation represents 50% of the operating costs of a surface mine [15].

The main effective parameters on material transport when a truck and shovel system is used in surface mines are mine planning, road condition, truck and shovel matching, swell factors, shovel and truck driver's ability, weather condition, payload distribution and payload variance [16–19]. Based on the literature among all above mentioned parameters, truck payload variance is one of the most important parameters in this field [7,20,21]. The payload variance not only affects the production rate, but also it is an important parameter in the analysis of fuel consumption. The main source of the payload variance in truck and shovel mine operation is the loading process. Loading is a stochastic process and excavator performance is dependent on factors such as swell factor, material density and particle size distribution [22]. Variation of these factors causes variation of bucket and consequently truck payloads, affecting productivity. Reducing truck payload variance in surface mining operations improves productivity by reducing bunching effects and machine wear from overloaded trucks [23]. In large surface mines having long ramps, bi-directional traffic and restrictions on haul road widths negate the possibility of overtaking. Overloaded trucks are slower up ramp in comparison to under-loaded trucks. Thus, faster trucks can be delayed behind slower trucks in a phenomenon known as truck bunching [20]. This is a source of considerable productivity loss for truck haulage systems in large surface mines.

There are some investigations about the payload variance simulation and the effect of this event on other mining operational parameters. A project completed by Hewavisenthi, is about using a Monte-Carlo simulation to investigate the effect of bulk density, fill factor, bucket size and number of loading passes on the long term payload distribution of earthmoving systems [21]. The focus of their study is on simulation of payload distribution and variance in large surface mines. A study conducted by Knights and Paton

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concerned with truck bunching due to load variance [20]. This study was conducted to provide an analysis of the effect of load variance on truck bunching. In this project, a GPSS/H model was constructed which simulates a haulage circuit designed using data inputs from a real mine site. The model was used to run haul circuit simulations with different levels of payload variance. From empirical data, haul route travel times were estimated to be dependent on payload based on a linear relationship with an additional stochastic component modelled by a normal distribution. The data was insufficient to determine the dependence of changes in haul route travel time on changes in payload variance. In this project, a simulation was also conducted to investigate the haul circuit throughput difference if single truck overtaking was permitted. Webb investigated the effect that different bucket load sizes had on truck cycle times and the inherent costs [24]. The research project being undertaken will focus primarily on the effect of load variance on truck bunching.

Based on the condition of truck and shovel mining operations in surface mines, the best simulation for this event can be simulated by discrete event methods. Discrete event simulation can be used to model systems which exhibit changes in state variables at a discrete set of points in time [26]. The models can be static or dynamic. Static models represent a system at a specific time, while dynamic models represent a system as it evolves over a period of time [26]. A mining operation is a dynamic system which is very difficult to model using analytical methods. When simulation is used, the model input can be based on probabilistic data which better characterise the input variables and a given number of variables can be described by selecting appropriate distributions [27].

The trucks utilised in the haulage operations of surface mines consume a great amount of fuel and this has encouraged truck manufacturers and major mining corporations to carry out a number of research projects on the fuel consumption of haul trucks [28]. There are many factors that affect the rate of fuel consumption for haul trucks such as payload, velocity of truck, haul road condition, road design, traffic layout, fuel quality, weather conditions and driver skill [1]. A review of the literature indicates that 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 [29].

This paper aims to present a new simulation model based on the discrete event methods to investigate the effect of truck bunching due to payload variance on average cycle times, the rate of loading materials and fuel consumption.

2. Payload variance

Loading performance depends on different factors such as bench geometry, blast design, muck pile fragmentation, operators' efficiency, weather conditions, utilisation of trucks and shovels, mine planning and mine equipment selection [21,30]. 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 [20]. The payload variance can be illustrated by carrying a different amount of overburden or ore by the same trucks in each cycle. The range of payload variance can be defined based on the capacity and power of the truck. The increase of payload variance decreases the accuracy of the maintenance program. This is because the rate of equipment wear and tear is not predictable when the mine fleet faces a large payload variance [23]. 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. The payload variance can be shown by variance of standard deviation σ. Standard deviation measures the amount of variation from the average. A low standard deviation indicates that the data points tend to be very close to the mean; a high standard deviation indicates that the data points are spread out over a large range of values. This parameter can be calculated by

$$\sigma = \sqrt{\frac{1}{Z}\sum_{i=1}^{Z}(x_i - \mu)^2} \quad (1)$$

where Z is the number of available data for each parameter; i the counter of data; x the value of parameter; and μ the mean which can be calculated by following equation.

$$\mu = \frac{1}{Z}\sum_{i=1}^{Z} x_i \quad (2)$$

Fig. 1 shows the different kinds of normal payload distribution (the best estimation function for payload distribution) based on the difference σ for one type of the mostly used truck in surface mines (CAT 793D).

In Fig. 1, gross vehicle weight (GVW) is the total weight of empty truck and payload. Based on the CAT 793D technical specifications, the range of GVW variation is between 165 (empty truck) and 385 tonnes (maximum payload). Hence, the maximum σ for this truck can be defined as 30; that is because for higher standard deviations, the minimum GVW is less than the weight of empty truck and the maximum GVW is more than the maximum capacity of truck.

3. Discrete simulation modelling

Based on the condition of truck and shovel mining operation in surface mines, the best simulation for this event can be by discrete event methods. Discrete event simulation can be used to model systems which exhibit changes in state variables at a discrete set of points in time [25,31]. The models can be static or dynamic. Static models represent a system at a specific time, while dynamic models represent a system as it evolves over a period of time [32]. A mining operation is a dynamic system which is very difficult to model using analytical methods. There are different kinds of discrete simulation models used for modelling the systems in industrial projects. In this study, some of the most popular models have been investigated and a new model to simulate the truck bunching event in surface mining operation has been developed.

The first investigated model is AutoMod. This model is a simulation system which is designed for use in material movement systems developed by Applied Materials, USA [33]. It can be used for

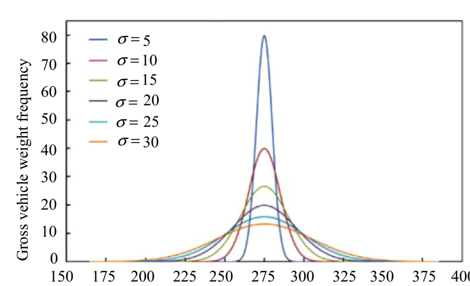

Fig. 1. Normal payload distribution for different standard deviation σ (CAT 793D).

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