A discrete event model to simulate the effect of truck bunching due to payload variance on haul trucks' fuel consumption

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Improving the efficiency of haulage systems is one of the significant challenges in mining engineering, and is the subject of many research projects undertaken in both study and industry.

For mining, it is essential 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 stand-by and downtime, and circuit traffic. Haulage costs can be some of the largest in a mining system. In various case studies, it was found that material transportation represents 50 per cent of the operating costs of a surface mine.

The main effective parameters on material transport when a truck and shovel system is used in surface mines are mine planning, road conditions, truck and shovel matching, swell factors, shovel and truck driver's ability, weather conditions, payload distribution, and payload variance. Among all mentioned parameters, truck

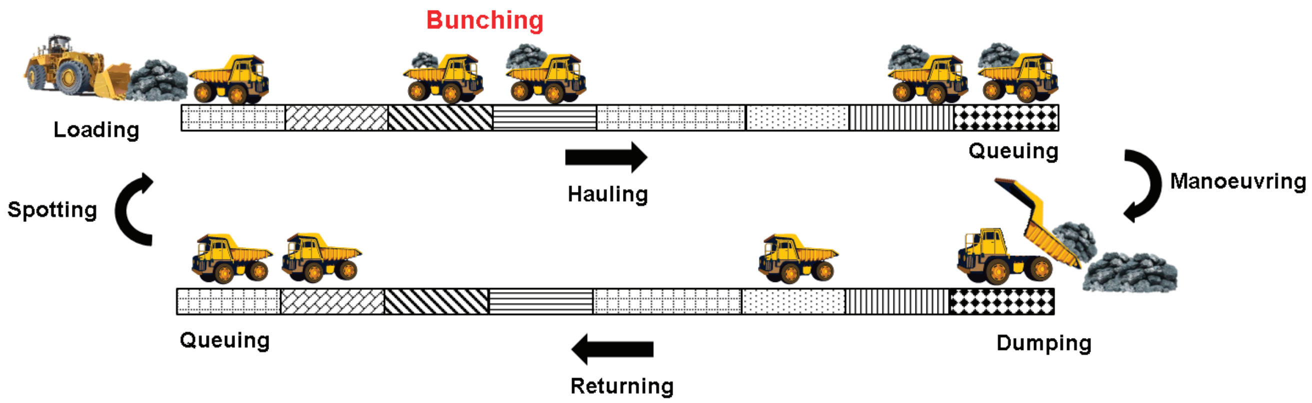

Figure 1. Schematic of hauling operation in surface mines

payload variance is one of the most critical parameters in this field.

The payload variance not only affects the production rate, but is also an important parameter in the analysis of fuel consumption. The primary source of the payload variance in truck and shovel mine operations 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. Variation of these factors causes variation of the 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. In large surface mines, having long ramps, bi-directional traffic and restrictions on haul road widths negates the possibility of overtaking. Overloaded trucks are slower up the ramp in comparison to under-loaded trucks. Therefore, faster trucks can be delayed behind slower trucks in a phenomenon known as truck bunching. This is a source of considerable productivity loss for truck haulage systems in large surface mines.

Based on the condition of truck and shovel mining operations in surface mines, the best simulation of this event can be achieved by discrete event methods. Discrete event simulation can be used to model systems that exhibit changes in state variables at a discrete set of points in time. 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. A mining operation is a dynamic system that is very difficult to model using analytical methods. When the simulation is used, the model input can be based on probabilistic data, which better characterises the input variables, and a given number of variables can be described by selecting appropriate distributions.

The trucks used in the haulage operations of surface mines consume a significant 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. There are many factors that affect the rate of fuel consumption for haul trucks, such as payload, the velocity of the truck, haul road conditions, road design, traffic layout, fuel quality, weather conditions and driver skill. A review of the literature indicates that understanding of the 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.

Hauling operations in surface mines consist of different kinds of components. These components are loading, hauling, manoeuvring, dumping, returning and spotting (Figure 1).

In the standard hauling operation, loading time is the time taken to load the truck, and hauling and returning time is the travel time for each truck between the loading zone and dumping area. Spotting time is the time during which the loading unit has the bucket in place to dump, but is waiting for the truck to move into position. Spotting time will depend on the truck driver's ability and the loading system. Double-side loading should almost eliminate spot time. Dumping time is the time taken for the truck to manoeuvre and dump its payload either at a crusher or dump.

Based on the abovementioned hauling operation components, four main times can be defined: fixed time, travel time, wait time and cycle time.

The fixed time is a summation of the loading, manoeuvring, dumping and spotting time. It is called 'fixed' because it is substantially invariable for a truck and loading unit combination. Travel time is the time taken to haul and return the payload. Wait time is when the truck must wait in a queue for dumping before being served by the loading unit, and the waiting time in line behind the overloaded trucks in large surface mines (truck bunching). Cycle time is the round trip time for the truck. It is the sum of the fixed, travel and wait times.

Figure 2 illustrates the proposed algorithm to complete a discrete event model in this project.

This algorithm consists of four main sub-routines to cover all processes in the hauling operation. These principal components are loading, hauling, dumping and returning. Based on the developed model, each part has a waiting time. The main reason for waiting time in hauling is payload variance.

To validate the developed model, a dataset collected from a large open-pit mine in central Arizona, United States, has been applied. This dataset included measuring average loader payloads, truck payloads, average bucket bulk density, loader bucket fill factor and average swell factor.

In this mine, the volume of material loaded into the bucket was determined by comparing loaded and empty laser-scan profiles of the buckets. Fill factors were calculated by dividing the material volume by the rated volume of the bucket, and bulk densities were calculated by dividing the payload by the loaded volume. Onboard payload monitoring systems were used to measure payloads. The validation of the model was completed for average cycle times and the average mine material hauled by one type of truck (CAT 793D) after truck bunching.

In this case study, the effect of payload variance on haul truck fuel consumption in different haul road conditions for three models of haul truck has been investigated. Haul trucks were selected based on their capacity and engine power. The maximum GVW for trucks is 160, 249 and 383 tonnes respectively. The results of a completed investigation by the developed truck-bunching model are illustrated in Figure 3. This figure presents the FCIndex versus payload standard deviation for three studied model of trucks in same road condition (TR=10 per cent).

This figure shows that by increasing the capacity of the truck, FCIndex can be reduced. In this case, the maximum reduction of FCIndex can be achieved by changing the model of truck from CAT 777F to CAT 793D.

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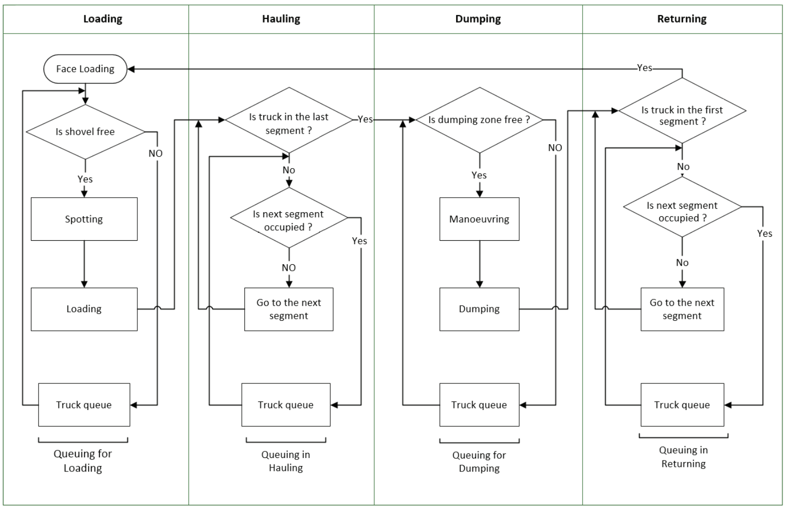

Figure 2. Truck bunching algorithm

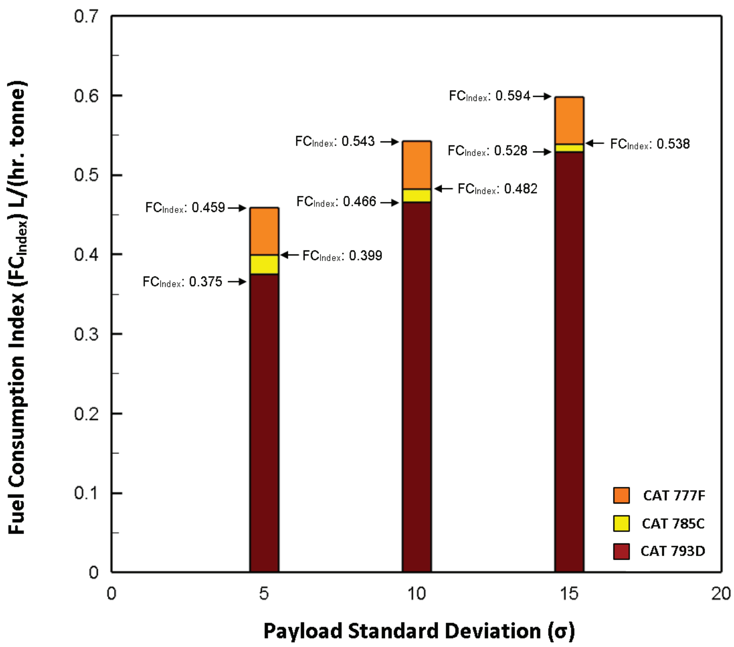

Figure 3. Fuel consumption index for three models of haul trucks, TR=10% (Case Study)