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UNDERGROUND MINING

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Economic benefits of load volume scanning of underground mining trucks

P. Knights and M. Reuter

School of Mechanical and Mining Engineering, The University of Queensland, Brisbane, Australia

ABSTRACT

This paper examines the economic benefits of employing a portal-mounted load volume scanner (LVS) system to manage payload and optimize fuel consumption of haul trucks. It does so through the analysis of LVS and fuel transaction data collected over a seven-month period from a Central Queensland gold mine. A high incidence of carry back (62% of all cycles) was detected in trucks entering the mine portal. The mean carry back was 0.24 m^3 or approximately 0.4 tonnes (t) per cycle. Possibly as a result of carry back, truck load volumes were skewed to the high side: 9.4% of loads exceeded +10% of the mean. The total carry back was estimated at 1,780 t of ore worth $370k (Australian dollars). Assuming a gold grade of 2.5 g/t and an all-in mining cost of $1,400/oz, this equates to an opportunity cost of slightly more than $300k/year: $290k in lost production plus $12k in additional fuel costs.

RÉSUMÉ

Cet article examine les avantages économiques de l’utilisation d’un système de balayage de volume de charge (LVS, de l’anglais *load volume scanner*) monté sur un portique pour gérer la charge utile et optimiser la consommation de carburant des camions de transport. Pour ce faire, il analyse les données des LVS et des transactions de carburant recueillies sur une période de sept mois dans une mine d’or du centre du Queensland. Une forte incidence des reports de charge (62 % de tous les cycles) a été détectée dans les camions entrant dans le portail de la mine. La moyenne de report du minerai était de 0,24 m^3, soit environ 0,4 tonne (t) par cycle. Il est possible que les volumes de chargement des camions soient biaisés vers le haut en raison de l’effet de report : 9,4 % des chargements dépassaient +10 % de la moyenne. L’ensemble du report de charge a été estimé à 1 780 t de minerai d’une valeur de 370 000 $ (en dollars australiens). En supposant une teneur en or de 2,5 g/t et un coût minier total de 1 400 $/oz, cela équivaut à un coût d’opportunité d’un peu plus de 300 000 $/an : 290 000 $ de production perdue plus 12 000 $ de coûts de carburant supplémentaires.

KEYWORDS
Carry back, Payload, Underground truck, Volume scanning

MOTS-CLÉS
balayage de volume, camion souterrain, charge utile, report de charge

INTRODUCTION

Low-profile, articulated haul trucks are commonly used in many underground mines to move production ore and waste rock from development headings. Although battery and trolley-assist versions are emerging as commercial options, the majority of existing truck fleets are powered by diesel internal combustion engines. Truck haulage not only represents a major cost to underground mining operations, it is also a major source of energy consumption and contributor to greenhouse gas emissions. With attention switching to decarbonization of truck haulage, it is therefore essential to ensure that truck haulage operations are run at maximum efficiency.

The productivity of truck haulage systems is measured by the average payload divided by the cycle time. Cycle times are calculated from the cumulative sum of the times involved in a sequence of actions. First, the unloaded truck enters the portal and trams down the decline to the loading location. Blasted material is removed from the stope via a load-haul-dump vehicle and loaded into the truck tray in a series of dumps or passes. Finally, the loaded truck proceeds back up the decline, exiting the portal to dump material at the run-of-mine stockpile (Figure 1). In order to optimize productivity, truck payloads should not exceed a recommended 10% above the rated payload. Overloaded trays cause trucks to be slower on the decline, extending cycle times and increasing fuel consumption. Underloaded trucks are associated with an opportunity cost for not carrying correct load and CO_2 emissions per tonne (t) will increase. Carry back (also known as haul back) is the material that adheres to the tray following dumping and is carried back into a mine during a return cycle. This increases truck fuel consumption and causes accelerated tire wear and the potential for hydraulic retarder brakes to overheat.

Loadscan is a New Zealand-based, small to medium enterprise that manufactures laser volume scanning

CONTACT Peter Knights p.knights@uq.edu.au

Figure 1. Photograph of loaded truck exiting the portal and portal-mounted load volume scanner

equipment. The technology has applications in mining operations, civil construction, quarries, sand and gravel pits as well as bark and mulch production. Loadscan's Mine Payload Technologies division uses The Mine Payload Scanner^{TM} to identify underloading, carry back, and off-center loading to increase productivity, improve accountability, and maximize business profit.

The objective of this paper is to examine the economic benefits of employing a portal-mounted load volume scanner (LVS) system to manage payload and optimize fuel consumption. It presents an analysis of LVS and fuel transaction data collected over a seven-month period from a Central Queensland gold mine. The scope does not extend to quantifying additional fleet uptime benefits as a result of potential improvements in tire, component, engine, and retarder brake lives due to payload management.

PAYLOAD VOLUMETRIC AND MASS MEASUREMENT SYSTEMS

There are several alternative approaches for measuring payload mass and volume in underground haul truck tubs. Payload measurement systems available on the market can be divided into two classes: (1) those requiring physical contact to measure loads (weighbridges and onboard payload monitoring systems) and (2) contactless systems (vision- and laser-based).

Weighbridges

Perhaps the oldest means of weighing payloads is using truck weighbridge scales. Weighbridges can be installed temporarily or permanently in part of the haul route outside the portal. They measure gross vehicle weight and then subtract empty vehicle weight to derive payload mass. Measurement requires physical contact between the truck and the weigh scale. Weights are derived via measurement of either hydraulic fluid pressure or beam deflection (the latter with strain gauges). The systems are very adept at measuring variance in payload distribution. However, trucks must come to a halt to measure truck load, which can add up to 30 s to cycle times. This delay is a further disincentive to monitor for residual carry back in tubs as empty trucks head back into the mine. Strain gauge and pressure measurement instrumentation also require frequent recalibration. A final drawback is the overhead associated with maintaining moving mechanical parts.

Vaziri, Haas, Rothenburg, and Haas (2013) developed a weigh-in-motion scale for use in the construction industry using reinforced concrete slabs and strain-gauge load cells. The system consists of a "set of sensors and instruments that measure the dynamic tire force, axle spacing, speed, time, and wheelbase, which then processes and displays the data without interrupting regular traffic flow."

Onboard payload monitoring systems

Onboard payload monitoring systems typically measure hydraulic strut pressures. However, truck design is such that the tray rests on physical stops during loading and transport phases. Lift cylinder pressure only reflects payload in the dump stage of the cycle. This offers a relatively small window of time in which to take measurements and also requires transient pressures to be filtered to account for lift dynamics. The Canadian company, Newtrax, recently purchased by Sandvik Mining and Rock Technologies, markets a Mobile Equipment Telemetry system capable of integrating with a custom payload management system for load-haul-dump vehicles and underground trucks. The system has been installed on five trucks at Glencore's Matagami mine in Quebec, Canada (Gleeson, 2019). Haulage distances are relatively long at approximately 8 km. It is essential to optimize payload to the rated 60 t in order to maximize productivity. Gleeson (2019) reports that the mine has seen a:

- 4–6% increase in utilization of ore haulage,
- 4% increase in overall equipment effectiveness, and
- 5% increase in loads per cycle.

Vision-based systems

Volumetric measurement systems based on stereographic camera images are less precise than LIDAR

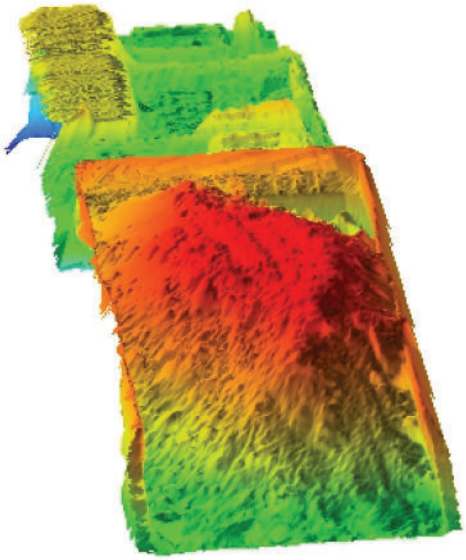

Figure 2. Loadscan image of a fully laden underground truck; the red area is the highest area of muck within the tray; orange delineates the outline of the tray

(light detection and ranging)-based systems. A major drawback is the presence of dust that degrades images.

Laser-based systems

Laser-based volumetric scanning methods offer a contactless and cost-effective means of monitoring payloads. They are associated with relatively low supply, installation, and maintenance costs. The Loadscan LVS is a noncontact, drive-through truck measurement instrument for the volumetric measurement of bulk materials (International Mining, 2016). An advantage is that it does not need regular servicing or calibration. Further, there is no need to outfit an entire fleet of trucks with onboard weighing systems or install a fixed truck scale. It can be a single installation with no major earthworks or calibration. Low running costs, full automation, and low maintenance requirements enhance the attractiveness of the LVS system (International Mining, 2016).

LiDAR sensors measure the load volume of dump trucks in a single pass without the need for the vehicle to come to a stop. The three-dimensional model created from the collected data (Figure 2) serves as a basis to calculate the load volume. Knowing the loose density of the loaded ex-situ material allows the payload to be estimated. Discrepancies between mass and volume measurements can be used to make specific gravity corrections.

The Loadscan Mine Payload Scanner provides data in real time, livestreaming three-dimensional imaging of every load to allow fill factors and incorrect loading to be monitored. "It provides a picture with ±1% accuracy of the quantity of material being extracted/hauled and scanning trucks on their return route will allow mines to monitor and manage in a timely manner inefficient haul cycles and carry back" (International Mining, 2016).

Table 1. Mining equipment fleet from a gold mine in Central Queensland, Australia

Equipment	Model	No.	Rated capacity (t)
Trucks	Epiroc MT6020	3	60
	Epiroc MT65	1	65
Jumbos	Sandvik DD420–60	1	–
	Sandvik 422i Dual Control	1	–
Loaders	Cat R2900G	2	17.2
	Cat R1700G	1	12.5
	Sandvik LH517i	2	17.0
Drills	Epiroc H1257	2	–
	Epiroc S7D	1	–

Dashes indicate drill data in units of m/h (not available).

CASE STUDY

Underground mine details

The underground gold mine that provided data for this study is located in Central Queensland, Australia. It is a narrow vein operation comprising a number of satellite orebodies, some of which are located up to 7 km from the portal. The mine employs an underground open stoping mining method in the form of a modified Avoca. The mine must produce approximately 1,600 t/day to feed the 600 kt/year carbon-in-pulp plant, which produces 50–75 koz/year of gold (grade dependent). The operation fleet includes four trucks: three 60-t capacity Epiroc MT6020s and one 65-t capacity Epiroc MT65 (Table 1).

The mine installed a Loadscan LVS in 2021. It is mounted on the wall of the box cut directly above the main portal to the mine (Figure 1). A digital message board informs drivers that the LVS is "ready to scan." The driver must slow to a walking speed to ensure successful scanning. Another digital board informs the driver whether the scan was successful or not. The Loadscan data are integrated with the Underground Digital Terrain database, where scans can be related to trucks, operators, or crews.

Data provided

The mine provided the following data covering a seven-month period:

- 14,531 LVS records for all trucks from 21 Dec., 2021 to 22 Aug., 2022

- 2,133 truck fuel transactions from 21 Dec., 2021 to 22 July, 2022

The mine does have a weighbridge installed, however, it was not in service during the period of study. It was therefore not directly possible to determine loose material densities. To overcome this problem, the mine provided a range of material densities for the latter half of 2021. On the basis of this data, a density of 1.82 t per loose cubic metre was assumed for all material transported.

Data processing

The preliminary summary of the LVS “in” data in Table 2 indicate that scanner errors accounted for 18.5% of all readings and were caused by trucks either moving too fast or at uneven speed (i.e., being outside or moving diagonally across the target area).

Analyzing the difference between entry and exit times enables calculation of truck cycle times. Hence, the combination of LVS and fuel consumption data enables the calculation of the following parameters:

- Volume of material in truck tray leaving the portal
- Volume of material in truck tray entering the portal
- Volume of material delivered to the Run of Mine
- Cycle time of truck entering and leaving the portal
- Weekly fuel consumption
- Weekly fuel consumption per (tonne × operating hour) per cycle

RESULTS

Underground truck material output

Truck output metrics for the seven-month period can be seen in Tables 3 and 4. Scanner errors within the data were replaced with volume output averages. It should be noted that truck model MT65 has a greater tray volume than the MT6020 models. Total diesel consumption for the truck fleet over a one-year period was estimated to be 1.1×10^6 L.

Payload distribution

The average load volume for MT65, the 65-t class truck, was 29.6 m^3, corresponding to 54 t (Figure 3). This is 17% below the maximum SAE International heaped capacity of 35.7 m^3, which corresponds to the full rated load of 65 t. Three-pass loading with the larger Cat 2900 G or Sandvik LH517i loaders would achieve 51–51.6 t payloads, respectively, better matching the 60-t MT6020 trucks. It is likely that the loaders were having to make a partial load pass in order to fill the 65-t MT65. It is also evident from Figure 3 that 7.5% of load volumes were below −10% of the mean, whereas 9.4% exceeded +10% of the mean. Load volumes were skewed to the right side, possibly as a result of the high incidence of carry back.

An opportunity exists to better utilize the capacity of the MT65 truck by increasing the average load. It is estimated that a 10% increase in the average load volume is worth approximately $0.9 million/year (all values presented are Australian dollars) in enhanced profit before tax. However, in order to achieve this, improved control of load variance is required. This in turn is controlled by the particle size

Table 2. Summary of load volume scanner “in” data collected from four Epiroc haul trucks over a seven-month period

Variables	MT6020 1	MT6020 2	MT6020 3	MT65	Total[a]
Time period (days)	212	216	217	214	**859**
Total scanner “in” readings	1,417	1,974	1,478	1,746	**6,615**
Total scanner measurements	1,117	1,684	1,216	1,373	**5,390**
Total scanner errors	300	290	262	373	**1,225**
No. carry back cycles	729	1,259	1,010	1,126	**4,124**
Cycles with carry back (%)	51	64	68	64	**62**

[a] Value is average for cycles with carry back.

Table 3. Average ex-mine output for four Epiroc haul trucks over a seven-month period

Output variables	MT6020 1	MT6020 2	MT6020 3	MT65	Average
Average volume (m^3)	27.36	27.27	24.65	29.64	**27.23**
Average tonnes	49.80	49.63	44.86	53.94	**49.56**

Table 4. Total ex-mine output for four Epiroc haul trucks over a seven-month period

Output variables	MT6020 1	MT6020 2	MT6020 3	MT65	Total
Total volume (m^3)	39,432	53,777	36,727	53,524	**183,460**
Total tonnes	71,766	97,874	66,843	97,413	**333,896**
Total fuel consumed (L)	156,467	183,980	140,374	173,237	**654,058**

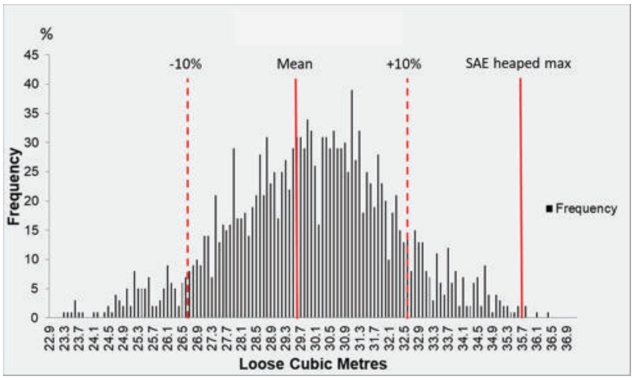

Figure 3. Volumetric distribution for the Epiroc MT65 65-tonne-class haul truck

distribution of the muck pile. Therefore, it is recommended that a study be conducted to quantify the current muckpile particle size distribution and, if necessary, investigate means for improvement. One such improvement could be a review of ring drilling and blasting parameters to better control muckpile fragmentation characteristics.

Truck carry back

A portal-mounted LVD has the advantage of being able to scan empty truck trays as they enter the mine. This can be used to detect the presence of any carry back caused by material compressing and sticking in the tub (see Figure 4 for an example).

Carry back was detected in 62% of all haulage cycles (Table 2). On long declines, this can contribute to overheating of hydraulic retarder brakes. Figure 5 shows the high incidence of carry back recorded for the “in” data for the MT65 truck. Similar trends were identified for the other trucks. The amount of material delivered to the mill is also affected by the presence of carry back. Of the 333,898 t hauled from the mine during the seven-month study period (Table 4), 1,784 t (0.54%) were recirculated as carry back. This is a source of error between the mined and milled tonnes. All recirculated load readings greater than 3 m^3 were assumed to be intentional payloads related to mine haul route maintenance or backfill. These were excluded from further analysis.

A density factor of 1.82 t/m^3 was applied to the volumes to attain a tonnage. Assuming an average gold grade of 2.5 g/t and gold price of $2,580 per troy ounce ($83k/t), the revenue loss over the seven-month period was estimated at $370k (Table 5). Over a one-year period, the revenue loss due to carry back is estimated at just over $634k. If we assume a conservative estimate for all-in cost of production of $1,400/troy ounce, then the annual opportunity cost of carry back was $290k in lost before-tax profit.

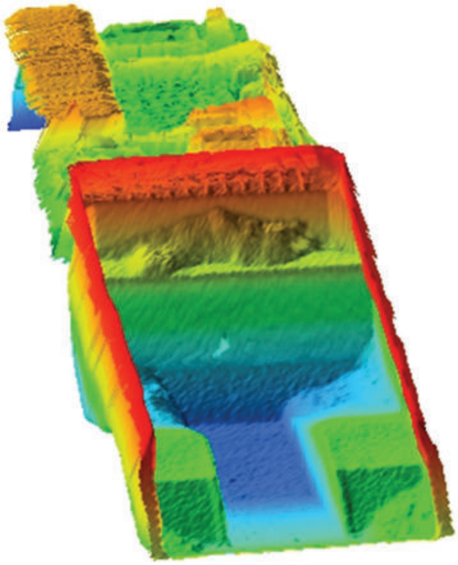

Figure 4. Loadscan image of carry back in the truck tub

Excess fuel consumption due to carry back

Using estimates for the average fuel consumption per loose cubic metre, the fuel consumed for carry back was calculated and total fuel costs were estimated assuming a diesel price of $2/L. On a pro-rata basis, carry back accounted for approximately 5,400 L/year of fuel, costing approximately $11,800 (Table 6). This represents slightly over 0.53% of the total fleet diesel consumption.

Payload optimization for fuel consumption

To attempt to obtain a payload set-point to optimize fuel consumption, weekly fuel consumption expressed as litres per (loose cubic metres × average cycle time) was plotted against average payload. Here, cumulative (loose cubic metres × operating hour per cycle) was used as a proxy for t-km, or the amount of work done by the truck on a cycle by cycle basis. Weeks were chosen as data intervals to minimize variations in underground loading conditions, material densities, and tramming distances. The first and last week of records were excluded because the number of loads was deemed insufficient to form accurate data.

There was no relationship between weekly fuel consumption expressed as litres per (loose cubic metres × average cycle time) and average payload (Figure 6). The mean fuel consumption remained largely invariant, likely due to large haulage distances (i.e., round cycle distances of up to 14 km), where variations in speed due to payload variance had little overall cycle time effect. There was also considerable variation in weekly fuel consumption, which is likely due to variable density of loose material.

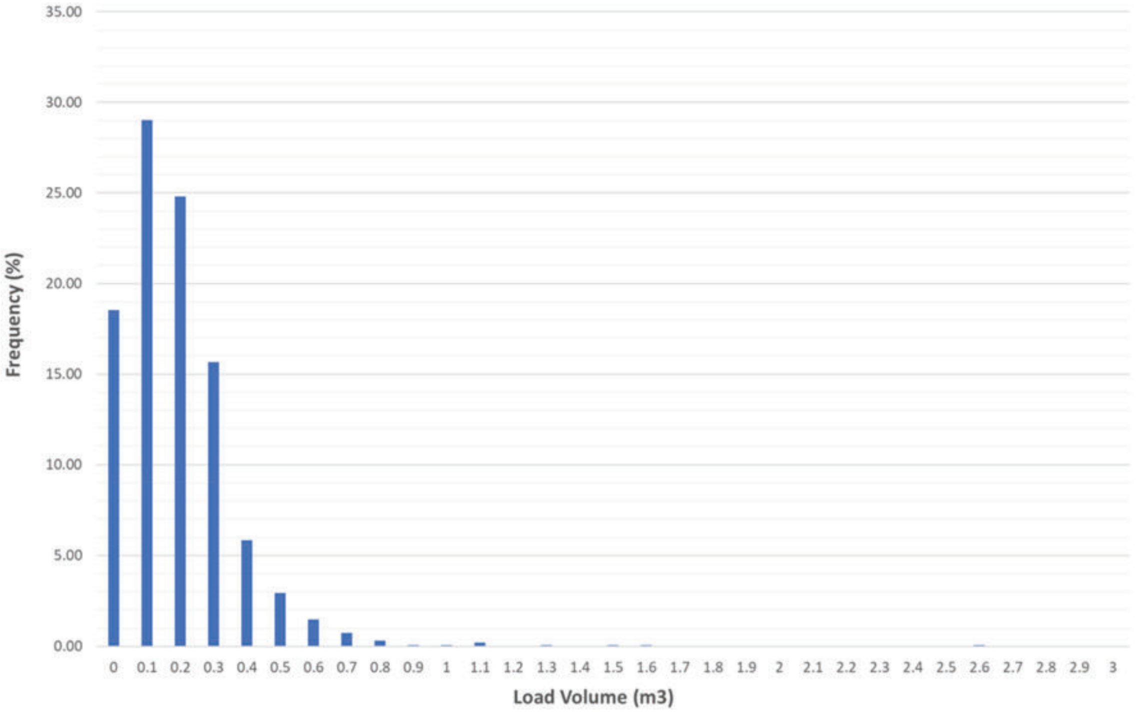

Figure 5. Frequency of load quantities entering portal for the Epiroc MT65 haul truck

Table 5. Carry back metrics for four Epiroc haul trucks over a seven-month period

Carry back variables	MT6020 1	MT6020 2	MT6020 3	MT65	Total[a]
Carry back (m^3)	0.27	0.22	0.18	0.29	**0.24**
Total volume (m^3)	199.43	276.07	181.16	323.36	**980.01**
Tonnage	362.96	502.45	329.71	588.51	**1,783.63**
Gold @2.5 g/t	0.91	1.26	0.82	1.47	**4.46**
Revenue loss (AUD)	75,315	104,258	68,414	122,116	**370,103**

[a] Value is mean for carry back.

Table 6. Fuel consumption for carry back material for four Epiroc haul trucks over a seven-month period

Inefficiency	MT6020 1	MT6020 2	MT6020 3	MT65	Total
Fuel consumed for carry back (L)	791	944	692	1,047	**3,475**
Fuel cost (AUD)	$1,583	$1,889	$1,385	$2,093	**$6,950**

CONCLUSIONS

A high incidence of carry back (62% of all cycles) was detected in trucks entering the mine portal. This carry back averaged 0.24 m^3 or approximately 0.4 t/cycle. It may have caused truck load volumes to skew to the high side, with 9.4% of loads exceeding +10% of the mean. Total carry back was estimated at 1,780 t ore worth $370k. Assuming a gold grade of 2.5 g/t and an all-in mining cost of $1,400/oz, this equates to an opportunity cost of a little over $300k per year, comprising approximately $290k in lost production plus $12k in additional fuel costs. The carry back was estimated to provide a reconciliation error of 0.54% between mined and milled tonnes.

It was not possible to detect a relationship between fuel consumption and payload volume. Having reliable payload data via a functional weighbridge would be beneficial in reducing load volume variance and determining whether a local minimum exists for fuel consumption efficiency.

Increasing the average payload would present an opportunity to better utilize the capacity of the MT65 truck. However, improved control of load variance is required to achieve this. It is recommended that a study be conducted to quantify the current muckpile particle size distribution and, if necessary, investigate means for improvement.

It is recommended that the mine investigate the feasibility of using Loadscan data to provide a real-time

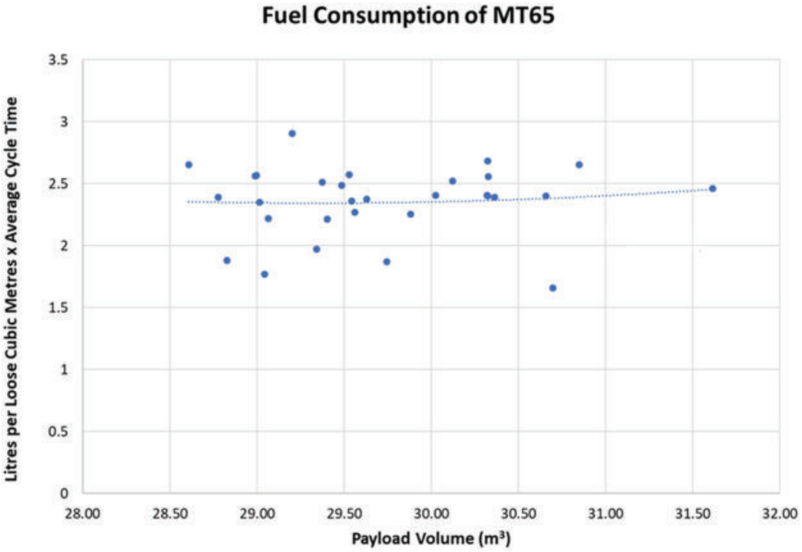

Figure 6. Weekly fuel consumption of the Epiroc MT65 haul truck in litres/(loose cubic metres × average cycle time) versus payload volume

alert of the presence of significant (> 0.3 m^3) carry back. Installation of a high-pressure water spray system or similar, could be used to dislodge carry back material at the end of a shift or as required.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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NOTES ON CONTRIBUTORS

Peter Knights is Professor and Head of Discipline Mining for the School of Mechanical and Mining Engineering at The University of Queensland, Brisbane, Australia. He holds a BE (Mech) from the University of Melbourne, a MEng (Systems) from the Royal Melbourne Institute of Technology, and a PhD (Mining) from McGill University, Canada. His research focuses on mine-mechanical systems, with an emphasis on systems safety, maintenance, and reliability engineering. He is currently leading a project to experimentally determine factors of safety associated with moving large haul truck tires with tire handling equipment.

Maximillian Reuter graduated with a BE (Mech) from the University of Queensland in 2022. He is currently employed as a project engineer by the mining contractor, Byrnecut Services Pty Ltd. This project was conducted as part of his final year engineering honors thesis.

REVIEW STATEMENT

Paper reviewed and approved for publication by the Underground Mining Society of the Canadian Institute of Mining, Metallurgy and Petroleum.

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