MANAGING MINE ROAD MAINTENANCE INTERVENTIONS USING MINE TRUCK ON-BOARD DATA

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ABSTRACT

The management of unpaved mine road networks on large surface mines rarely results in optimal road maintenance strategies and minimised total road-user costs. This is ascribed mostly to the complex and dynamic combination of variable road networks and loading and discharge points. In a dynamic mining environment - typically those mines in which production is managed by a centralised truck dispatch system – there is no guarantee that a particular road maintenance intervention will contribute significantly to reducing total road-user costs or increasing productivity.

Most large surface mines operating ultra-heavy mine trucks rely on an integrated on-board diagnostic data collation, communication and GPS-asset location system as a real-time fleet management tool. By extending this system to incorporate a multi-sensor analytical procedure in which specific truck vital signs are monitored and filtered, a road defect can be recognised and a trigger level set to relay the location of defects on the mine haul road to the centralised truck data management system. Previous work established the feasibility of the multi-sensor approach to road defect recognition on large mine haul trucks, and outlined the defect recognition, analytical and modelling issues and system limitations.

This paper presents the development of the analytical procedure used as a basis for evaluating the truck on-board data to establish maintenance priorities amongst a network of mine roads. Following an introduction to the system architecture, the results of system field trials are analysed and the results discussed in the light of defect density and traffic volume as the primary variables in an approach to prioritising road maintenance. The paper concludes that by supplementing the existing mine communication and asset management systems, road maintenance can be managed on a near real-time basis and maintenance equipment dispatched to where most immediate benefit will realised from a maintenance intervention on the network, thereby generating the maximum improvement in service and reduction in cost per ton hauled.

INTRODUCTION

The design and management of unpaved surface mine haul roads encompasses geometric, structural, functional and maintenance aspects as discussed by Thompson & Visser (1996, 2000, 2003). Design and construction costs for the majority of haul roads represent only a small proportion of the total operating and road maintenance costs and in particular, the use of an appropriate road maintenance management strategy has the potential to generate significant vehicle operating cost savings.

The ideal maintenance strategy for mine haul roads should be the one that results in the minimum total cost since, in the case of mine haul roads, the agency maintaining the haul road network is also affected by user operating costs. Current operating practice however does not always reflect this maxim. An optimal road design will include a certain frequency of maintenance (grading, etc.), within the limits of required road performance and minimum vehicle operating and road maintenance costs. In mine road maintenance, it is the translation of a maintenance frequency concept into a maintenance strategy that is problematic.

Various approaches to 'routine' mine road maintenance have been discussed by Thompson and Visser (2004), including ad-hoc blading, scheduled blading, managed maintenance systems (MMS) and the real-time road maintenance (RT-MMS) approach. Each has its own specific application, ranging from small, low tonnage operations where ad-hoc blading is often appropriate, to large complex and dynamic mining operations where a real-time system is a requirement if haulage costs are to be effectively controlled and minimised.

Exxaro Grootegeluk Coal Mine, situated on the Waterberg coal fields, in the town of Lephahle, Limpopo Province of South Africa, is typical of a large complex surface mining operation. The mine handles in excess of 56 million tons per annum, comprising of various coal types, interburden waste and overburden waste. Mining makes use of a basic truck and shovel operation with 15 x Haulpak 730E, 4 x Euclid EH4500 and 7 x Euclid EH3500 trucks in conjunction with P&H2300 and Demag shovels.

Mining takes place on various benches, which are defined according to geological qualities. The coal seam is divided into 13 different benches with an overall depth of 130m. Each bench has its own road network to a certain destination, which can vary between 1 of 5 coal beneficiation plants and 1 of 4 waste dump destinations. Together with shared ramp access, dump and perimeter roads, the active road network consists of more than 24km at any given time, translating to over 1.48million m^2 (or 148 hectare) of road surface or over 112 000 tkm of daily truck haulage. CAT 16H road graders are used to maintain the road surface, initially on an ad-hoc basis and more recently by using an approximation to a real-time system as described by van Staden et al (2006).

The disadvantages of the current maintenance systems applied at Grootegeluk (or any high tonnage complex network of mine roads) is the necessity to communicate and regularly update the maintenance strategy to road maintenance resources (grader, water-car, support equipment, etc.) and the difficulty in accommodating rapid localised road deterioration, due to structural failure, poor wearing course performance, effects of rain, spillage, etc. A real-time maintenance management system was considered as a solution to overcoming these deficiencies; the road condition being monitored by on-board analysis of truck-pavement interaction, integrated with the mine's existing communication and truck location systems.

Aim and Scope of Paper

This paper presents the development of the analytical procedure used as a basis for evaluating the truck on-board data to establish maintenance priorities amongst a network of mine roads. Following an introduction to the system architecture, the results of system field trials are analysed and the results discussed in the light of defect density and traffic volume as the primary variables in an approach to prioritising road maintenance. The paper concludes that by developing existing mine communication and asset management systems, road maintenance can be managed on a near real-time basis and maintenance equipment dispatched to where most immediate benefit will realised from a maintenance intervention on the network, thereby generating the maximum improvement in service and reduction in total road-user costs.

MATHEMATICAL MODELLING OF TRUCK RESPONSE TO ROAD DEFECTS

The approach adopted was based on the development of a multi-body dynamics model of the truck under consideration, which could then be used to solve the so-called inverse problem that entails finding the road input from measured responses and known system characteristics. This approach also requires a fairly difficult characterisation exercise to determine the specific haul truck system geometry, spring stiffness coefficients, damping coefficients, as well as mass and inertia characteristics. The chief advantage of this characterisationally intense approach is system versatility in the sense that it is possible to computationally correct for varying loads, speeds, and other parameters that change continuously. This may also enable the recognition system to be universally applied across a wide range of truck types and sizes.

Using this approach, further field tests were designed (Hugo (2005) to capture the essential dynamics of a haul truck using a seven-degree-of freedom model. From this seven-degree-of freedom model and in conjunction with further field trial results (Hugo et al 2005), it could be shown that a simple single-degree-of-freedom model of the unsprung mass on an independent front suspension system provided an adequate description of the vehicle response dynamics. One of the important features of this simplified model is that neither elastic structural vibration, nor vibrations induced by other sources on board (such as the engine) significantly contaminate the measured signals in the frequency band below 10 Hz. It is this frequency range that is both typical and characteristic of road-vehicle interactions.

By way of example, Figure 1 depicts three defects that were reconstructed in this way, from field test data described by Hugo (2005). This figure demonstrates the degree to which the defect shapes could be reconstructed. Table 1 lists the physically measured widths W_m and reconstructed widths W_r and heights (height or depth (H_m) and reconstructed value H_r) of these defects. Generally good estimations of the main features of the road defects are clear, both for larger defects (typically defects 4 and 6) and smaller isolated defects (typically defect 5) and it seems as if it might well be possible to identify defect location, type and size from the response measurements of the haul truck.

These field tests confirmed that haul truck response does have potential as a haul road maintenance management tool. Using the proposed methodology, haul road defects can be identified in terms of location, size and type, with an accuracy sufficient for the purpose of haul road maintenance management. To the authors' knowledge, no such practically viable method previously existed. Moreover, the simplicity of this method and the fact that it requires basically no alteration to the vehicle that can influence its primary function are advantageous for real-time implementation.

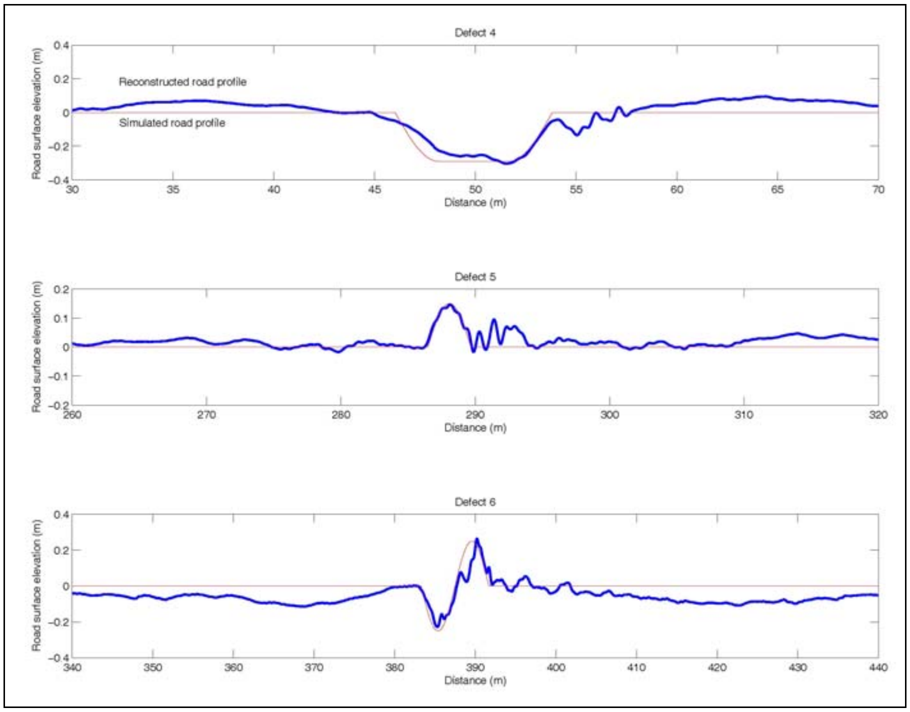
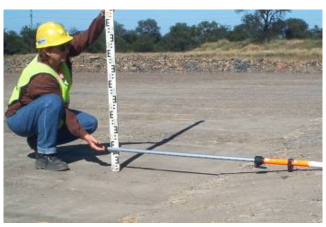


Figure 1 Reconstructed road defects compared to measured defect geometry in haul road

Table 1 Measured and reconstructed defect widths and heights

Defect type		W_m(m)	W_r(m)	H_m(m)	H_r(m)
	Ditch defect 4	7.8	9.07	0.3	0.267
	Hump (small) defect 5	0.6	1.52	0.1	0.070
	Ditch & hump (large) defect 6	8.0	9.15	0.5	0.489

FIELD TRIAL – REAL-TIME ROAD MAINTENANCE MANAGEMENT

To evaluate the utility of the mathematical procedure outlined previously, a field trial was undertaken using a 190t capacity (317t GVM) mine haul truck. The vehicle was instrumented with an accelerometer mounted below front suspension, GPS antenna and data recording unit. The truck was then operated on the existing mine road network according to the prevailing production requirements.. Figure 2 shows the truck type used and the location of the additional instrumentation.

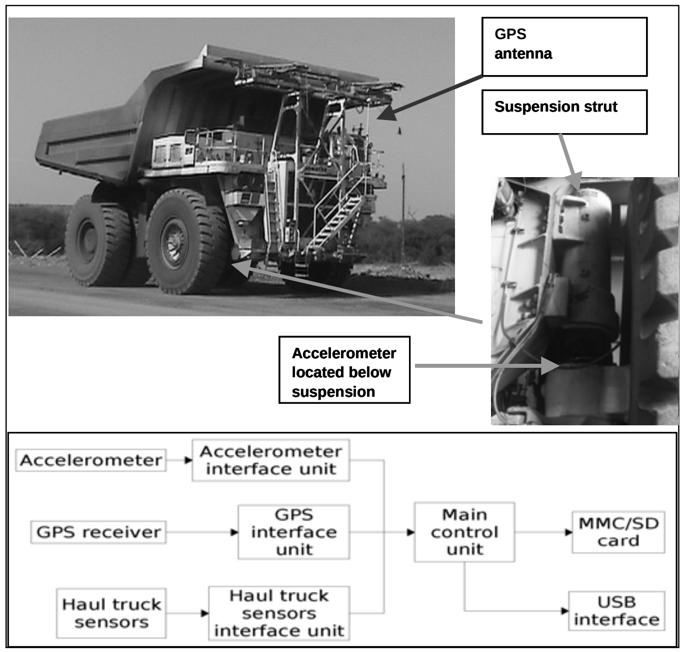


Figure 2 Haul truck used for RT-MMS field testing, showing detail of front suspension cylinder and additional instrumentation interfaces

Over a 2-hour production period, the truck covered 36km of mine road at an average speed of 18km/h. Figure 3 shows the truck runs recorded relative to the most recent mine plan. A total of 69 road defects were recognised, in the range of 0,05m to a maximum of 0,5m in height or depth, as shown in Figure 4 in terms of defect magnitude and 'density'. Defect density refers to the number of defects recorded on a section of road which is indirectly an indication of the number of vehicles encountering the defect, or the traffic volume itself. Clearly, sections of road network where high defect-densities and defect-magnitudes are encountered should enjoy priority when assigning maintenance assets.

To determine the location of a specific defect, unsprung mass accelerations were analysed to locate the maximum or minimum accelerations at a specific recording time interval. To recognise specific defects however, in addition to resolving the speed of the vehicle from the on-board GPS data, a sufficient time lag is required after the acceleration 'event' to allow the vehicle to return to equilibrium. As seen from Figure 1, this distance can be in excess of 20m, even at fairly low truck speeds. At typical production speeds experienced during the field trial (up to 42km/h), the data shows many super-imposed 'events' where one or more defects were encountered whilst the vehicle was dynamically in motion as a result of interactions with an earlier events. This results in very poor resolution of the type of defect encountered in all but a few cases.

To determine the magnitude of a specific defect, the procedure described earlier was applied, subject to a limiting resolution of 0,05m being adopted in the analysis, primarily to exclude defects smaller than this value from reporting an 'event', for the reasons discussed previously and additionally from consideration of the typical aggregate maximum size (37,5mm) normally recommended for a mine wearing course material. A number of truck-related operational issues must also be considered since these can lead to 'false' defect locations. The accelerometer records were filtered according to truck speed, any events occurring below 4km/h (forward or reverse) being associated primarily with slow-speed manoeuvring, loading or tipping as opposed to road defects. Further filtering took place on the basis of truck acceleration or deceleration – where limits of $\pm 0{,}5 m/s^2$ were applied. Using this approach, Figure 5 illustrates a typical accelerometer record for part of the truck run shown in Figure 6. From Figure 5 it is clear that, even when filtering is applied to 'minor' defects as described above, few defects are sufficiently isolated from other defects to allow the type of defect to be resolved.

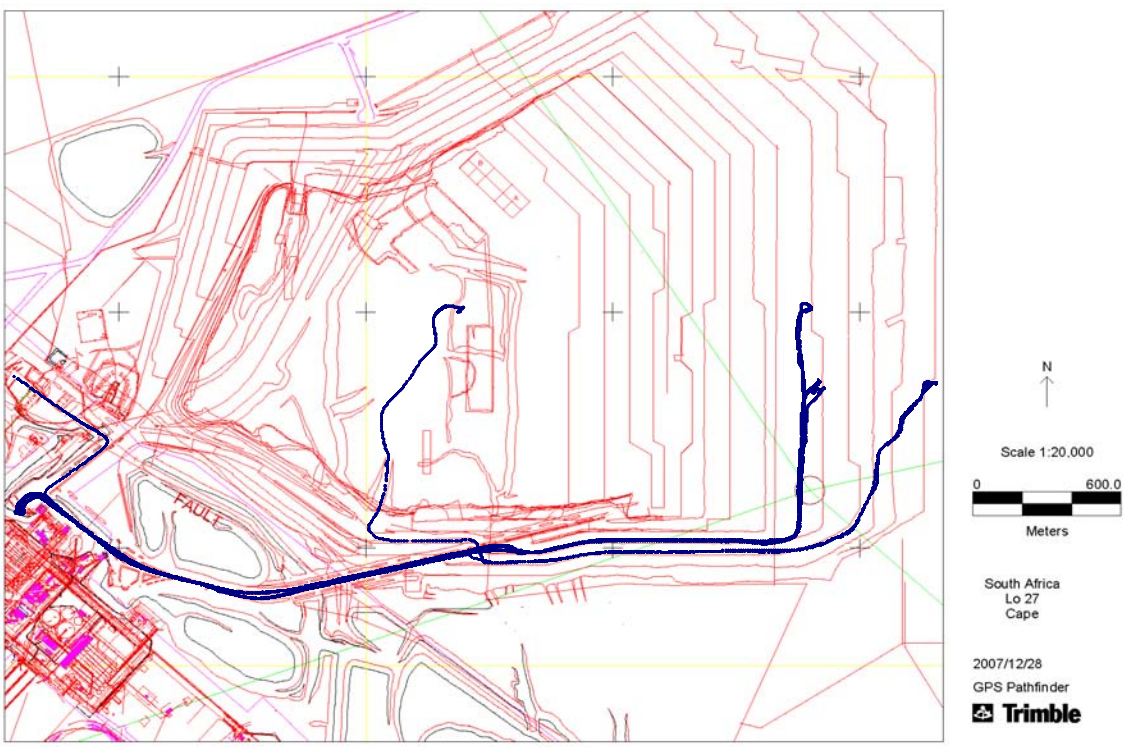


Figure 3 Truck runs recorded during field trials at Grootegeluk Mine

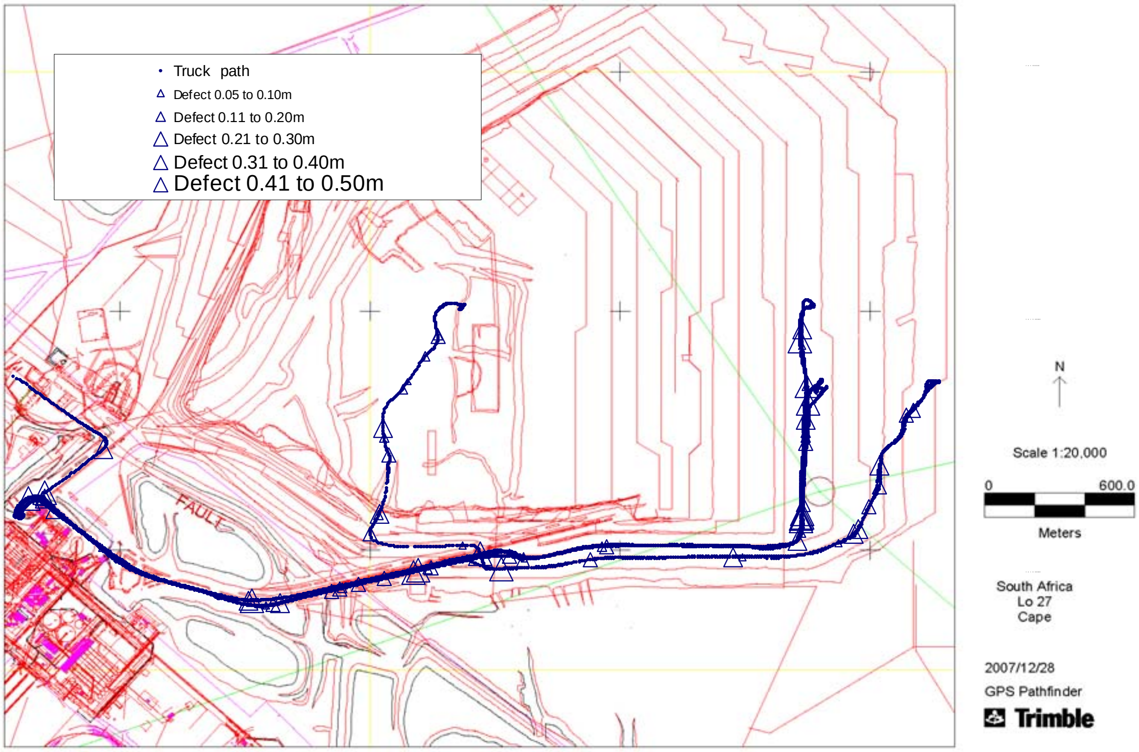


Figure 4 Road defect density map for field trials at Grootegeluk Mine. Symbols represent defect magnitude (depth or height).

The field trials confirmed that road defect locations and approximate magnitudes (in terms of size) can be resolved from mine truck on-board data coupled with measurements of unsprung mass acceleration. A practical limitation exists when attempting to reconstruct the defect as a whole, especially where truck speed is high and or defect density on the road is high. Nevertheless, the defect location and density map concept provides a useful indication of which active haul roads would benefit from a maintenance intervention.

In the field trials described here, only a single truck was instrumented and the defect density map produced reflects the most frequently used routes. When the system is extended to the truck fleet as a whole, defect density will be related to traffic-volumes and as such the resulting defect density map will enable the mine to evaluate road conditions on a real-time basis, and dispatch maintenance assets to the most critical area of the network. This will generate the most significant improvement in service and reduction in total road-user costs, since the intervention is defect magnitude and traffic-volume related.

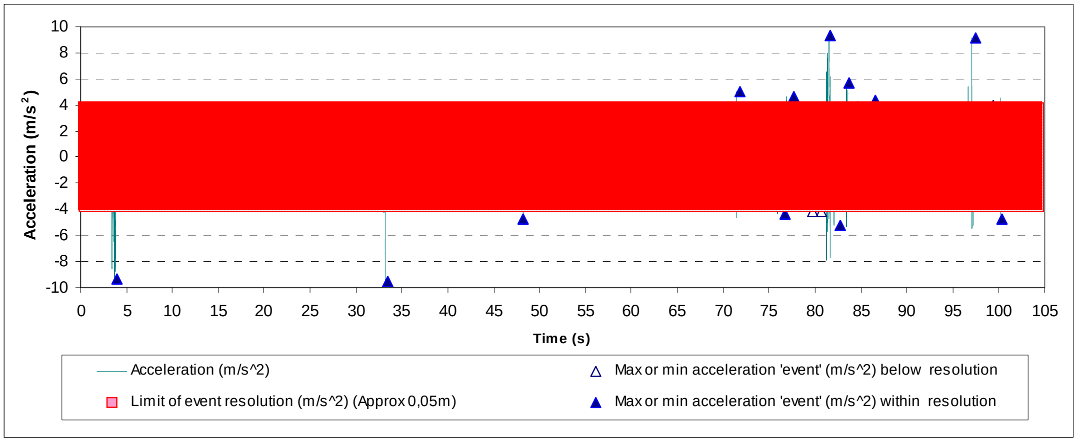


Figure 5 Typical acceleration record, showing acceleration waveform, recognised events above and below resolution and limit of resolution applied, for part of the truck run shown in Figure 6

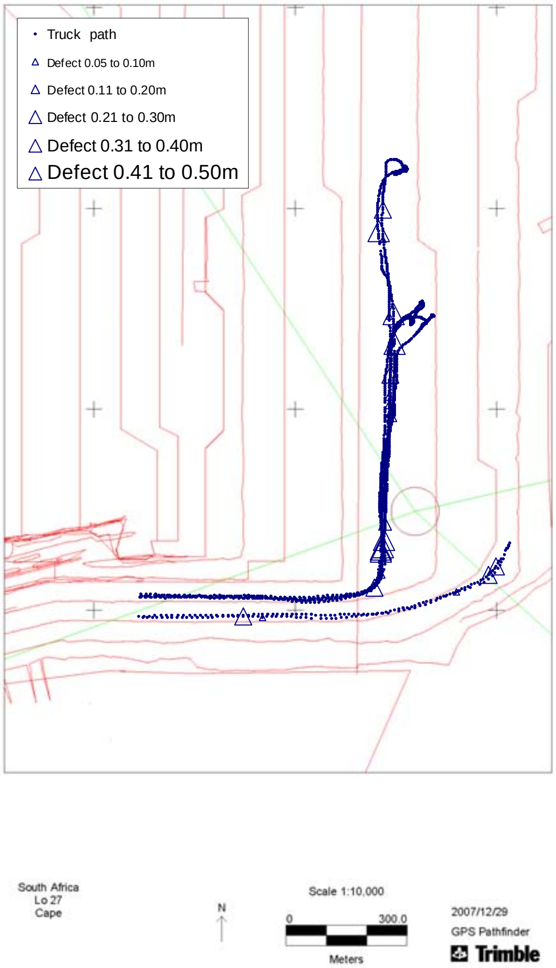


Figure 6 Detail of truck run (from a coal hauling bench) showing defect locations and magnitude.

CONCLUSIONS

For large, complex and dynamic mining operations, road maintenance management systems are often sub-optimal, due in part to the combined effects of rapid road deterioration, inconsistent construction and material qualities, coupled with variable road traffic volumes. The RT-MMS was proposed as a means of road maintenance in a complex and dynamic mining environment - typically those mines in which production is managed by a centralised truck allocation system. The concept is based on the integration of existing truck multi-sensor on-board diagnostic data, coupled with additional accelerometer instrumentation, to recognise the size and location of typical haul road defects requiring a maintenance intervention.

The field trial conducted to evaluate the potential of proposed system under production conditions highlighted that whilst road defect locations and magnitudes can be resolved, a practical limitation exists with when attempting to reconstruct the defect as a whole, especially where truck speed and or defect density on the road is high. However, the defect location and density map concept provides a useful indication of which active haul roads would benefit from a maintenance intervention. When the system is extended to the truck fleet as a whole, the resulting defect density map will enable the mine to evaluate road conditions on a real-time basis, prioritize maintenance interventions and therefore realise an improvement in road performance and reduction in cost per ton hauled.

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