Making the grade

A summary of a presentation on haul-road planning, design and safety, given by Caterpillar's Pete Holman at its 2007 Global Mining Forum in Peoria, attended by *Mining Magazine*

Two generations of Caterpillar graders at its Illinois test area – the 163H and the latest 14M joystick-controlled machine

CATERPILLAR is the world's leading manufacturer and supplier of mining haul trucks. Years of experience in working with customers have resulted in many practical lessons being learned, in terms of optimal operating procedures and haul-road management, in order to maximise the life and availability of trucks and their components, particularly tyre life in the current climate.

Haul roads are important because they are one of the key elements that drive truck-haulage costs in mining operations and can genuinely be either a mine's greatest asset or its greatest liability. Their importance should be reflected in the realisation that investment in the haul road is money well spent and it has a major influence on both cost and production.

In both surface and underground mining, poorly-designed and maintained haul roads can lead to dramatically higher costs in the form of lost production, equipment repair/replacement, reduced tyre longevity, increased fuel spending and safety issues.

Caterpillar 785C, Apatity mine, Russia

ECONOMICS OF CONSTRUCTION

To fully understand haul-road economics, entire lifecycle costs must be considered, including: road construction and removal, and the impact on fleet productivity and operations; road maintenance; the effect of any additional fleet-operating and maintenance costs; and any extra stripping costs (to alter haul-road width and/or grade). Also the 'cost' of money needs to be seen in a long-term sense – it may be costly in terms of today's money to design and construct an efficient haul-road system, but it will more than pay for itself over the life of the mine.

Haul roads can be divided into temporary, semi-permanent and permanent roads. Temporary roads have inferior construction, with a higher rolling resistance (3-20%), and may only be used for days or weeks, mainly as access routes to shovel-and-dump areas. The initial construction of semi-permanent roads is of higher quality, meaning they have less rolling resistance (1.5-5%) and service lives, measured in months or years. Permanent roads could include the final route to the processing plant and sections of the main route out of the pit.

Before a road is built, pre-road construction preparation can include: sub-grade preparation; ditching/water-control design; and determining the final grade and design of safety berms. Actual construction costs mainly consist of: sub-grade preparation; sub-base material placement and preparation; base placement and preparation; surface-material placement and prep-aration; berm placement and ditching. These will be discussed in more detail.

The additional cost of fleet operation on poor roads is often ignored as it can be hard to quantify in a narrow timeframe, but this includes increased fuel and component wear, higher costs of fuel, and drive-line components. The level of stress on the truck frames and suspension is increased and tyre life reduced.

Other considerations for road construction are climate, as this will control the water volumes that the road will have to endure (or dust in the case of arid climates), and the size of the trucks to be used as the largest ones will carry higher loads and have more contact with the road surface. They will also require wider roads for safe operations. Finally, particularly with semi-permanent roads, ore contained in the road area might not be accessible for a long time, so this must be factored in during design.

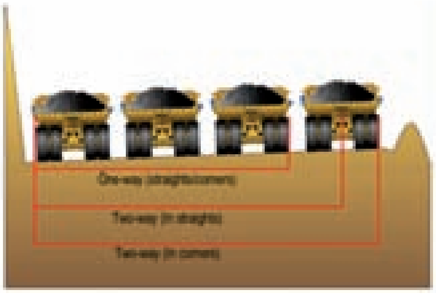
HAUL-ROAD PLANNING

Temporary, semi-permanent and permanent roads all have applications in most surface mines. The appropriate selection is a combination of the road-building and maintenance costs, the road's predicted lifespan and how it will be used over that time. This process of road-selection type can be confirmed by using a full-lifecycle economic evaluation.

The design itself must factor in aspects such as the road grade, the likely traffic layout and estimated traffic patterns, plus any required curves, super-elevations, intersections and switchbacks.

As a rule of thumb, if you can comfortably travel your haul roads at 60 km/h in a light vehicle, this is an indicator of good conditions. It is also important to remember that the haul road actually begins at the loading face and ends at the dump, so it is crucial to maintain good floor conditions at the dump and load areas, and for operators to travel at reasonable speeds in the dump zone.

The machine-stopping distances for the fleet to be used is also a primary consideration in road design. Each vehicle in the fleet should be evaluated, and the road alignment adjusted to the machine with the longest stopping distance.

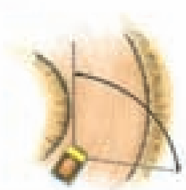


Sight distance is another key element in this determination – it must be sufficient to allow the machine to safely stop before encountering obstructions or hazards. In the case of sight distances for horizontal and vertical curves, the extent of peripheral area visible to the machine operator must be sufficient for the vehicle to stop before reaching a hazard or obstacle, and the distance from the operator's eye must equal or exceed the required stopping distances.

Minimum road width is an important design issue. On one-way straights and corners, a minimum of three truck widths is recommended. For two-way traffic, in straights, a minimum of 3-3.5 truck widths is advised. In corners, it is a minimum of 3.5-4 truck widths. Road width affects safe operating speeds, and can help minimise tyre contact with safety berms and spilled rocks. The table shows some minimum road-width calculations for the major Caterpillar truck models. A left-hand traffic pattern gives better visibility of the ditch line (and improved tyre life) and is safer in wet conditions as there is a reduced risk of truck collision.

Cross-fall (the transverse slope of the road) is important, both on flats, to maintain the minimum slope for drainage; and on grades due to the forces on the truck chassis. On flats, a 2% constant cross-fall is recommended for loaded trucks on the 'uphill' side of the road. If a constant cross-fall is not possible, then one solution is a crown haul road – a convex road surface (opposite slopes meeting in the middle) that allows runoff to drain to either side, but it should still be designed with the minimum slope angles. On grades, minimal cross-fall is required unless the mine is subject to heavy rainfall.

Vertical alignment concerns the design of grades and vertical curves (ie curves that incorporate a grade) to allow adequate stopping and sight distances on all segments of the haul road. Grades and curves must be designed for equipment-braking limitations and hill crests must not impede operator visibility to hazards within stopping distances.



Horizontal alignment concerns the design of the elements necessary for safe operation around curves. Proper width and super-elevation, as well as appropriate turning radius and sight distances, are all factors.

SWITCHBACKS, SUPERELEVATION, BERMS

Switchbacks (zigzagged roads) are used to achieve rapid elevation from deeper open-pits. They should have as wide a curve as is practical, as well as safety berms and, if possible, a constant grade. Tight switchbacks can result in significantly higher costs. For both curves and switchbacks, truck performance is the main part of the equation.

Operators should strive for consistent truck speed for optimal performance, and recognise that poorly-designed curves produce slower cycle times and higher overall costs. It is worth remembering that trucks are moving in both directions and empty trucks travel faster.

Superelevation is the increase in the outer part of the transverse slope on corners, and can be employed if speeds exceed 15 km/h, but greater than 10% superelevation should only be used with caution. The concept is similar to banking curves on a racetrack and counteracts centrifugal forces, allowing higher speeds on curves. It also reduces stress on frame and tyres, and reduces the chance of spillage from loaded trucks. The limiting factors are higher loads on the inside of the wheels, additional frame stresses and potential sliding in slippery conditions.

The recommended minimum height of a conventional safety berm is half the wheel height of the truck. The recommended placement of berms is along the edge of the dump area, along all haul-road edges with gaps for drainage and, where possible, between the lanes on curves.

Berms serve as marking devices for haul-road edges and as drainage channels to prevent uncontrolled erosion. They also act as fixed points of reference for machine operators and safety devices for smaller, maintenance machines using haul roads.

OPTIMAL GRADE

The main goals of road grade are to maintain proper weight distribution of the load and minimise lateral forces on tyres. The same design that minimises tyre wear also enhances truck productivity as the truck remains stable at optimum speeds.

The steeper the grade, the more weight bears on the rear tyres. The goal is to keep the weight distribution at about one-third on the front tyres and about two-thirds on the rear duals. Ideally, the grade should not exceed 8% – eight units of rise per 100 units of horizontal distance. The grade should be constant and the road smooth to minimise rapid weight-distribution changes, minimise transmission shifts and maintain higher average speeds. Such a road also promotes smooth braking when trucks are returning to the loading area.

The optimal grade means the number of transmission shifts is minimised and the operator can maintain higher average speeds. It also allows for

more constant braking effort on returns, as well as reducing load-spillage and fuel consumption.

Choosing the optimal grade requires consideration of both haul-road geometry and truck performance. The grade is a factor of both time and distance, with the basic indicator of optimal grade being the cycle time. Caterpillar recommends targeting haul roads with a grade of 8-10% or less, and minimising haul-road rolling resistance wherever possible. Part of ensuring optimal performance on grades is maintaining consistent payloads. Caterpillar has what it calls the 10-10-20 Truck Payload Policy, which means no more than 10% of loads should exceed 10% over the target payload, and no loads may exceed 20% over the target payload.

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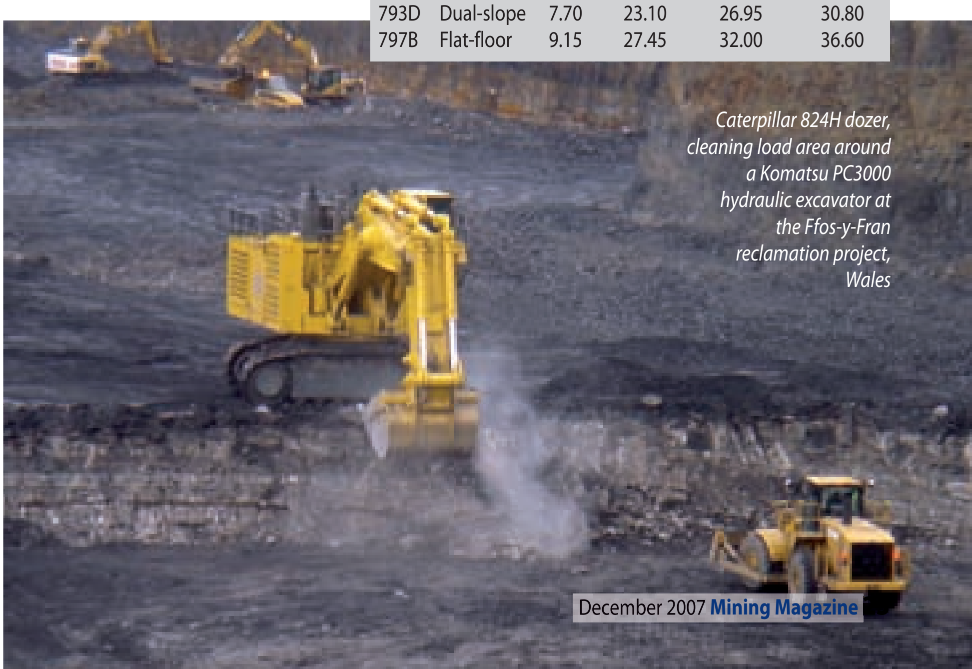
HAUL-ROAD WIDTHS – CATERPILLAR

Model	Accessories (body)	Width (m)	One-way (straights /corners) x3	Two-way (straights) x3.5	Two-way (in corners) x4
777F	Dual-slope	6.50	19.51	22.75	26.00
785C	Dual-slope	6.64	19.92	23.24	26.56
789C	Dual-slope	7.67	23.01	26.85	30.68
793D	Dual-slope	7.70	23.10	26.95	30.80
797B	Flat-floor	9.15	27.45	32.00	36.60



Caterpillar 824H dozer, cleaning load area around a Komatsu PC3000 hydraulic excavator at the Ffos-y-Fran reclamation project, Wales

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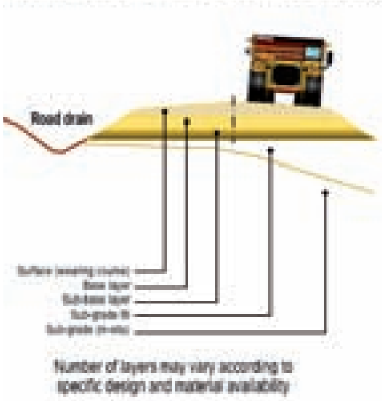
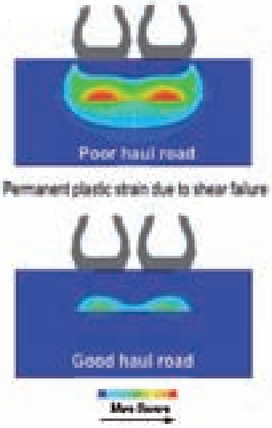




CROSS-SECTION DESIGN

The number of layers may vary, according to the specific design and material availability. On a poorly-constructed haul road, permanent plastic strain can result due to shear failure, which is very difficult and expensive to correct. The haul road has four basic layers: sub-grade; sub-base; base course, and surface course. The sub-grade consists of native rock or soil, landfill, mine spoil, or even muskeg or marsh, over which the road is placed. The rock or compacted gravel sub-grades require little fill, but soft clays and muskeg will require substantial fill. Sub-grades lacking adequate bearing capacity may need additional work, such as compaction or the use of geotextiles.

The sub-base consists of cemented or untreated granular material between the sub-grade and base course, and it is primarily composed of run-of-mine and coarse rock. It is this layer that provides structural strength to the haul road. It also serves to prevent intrusion of sub-grade soil into the base course, and vice versa. The sub-base helps to minimise the effects of frost and water accumulation, as well as providing a working platform for the construction equipment. The thickness of this layer is determined by the bearing characteristics of the sub-grade.

The base course lies directly beneath the road surface and usually consists of high-quality, treated or untreated material with proper size distribution. It has more stringent material specifications as it provides the main haul-road's structural strength.

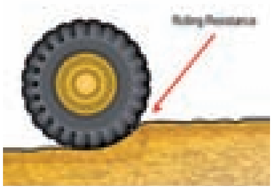
Finally, the surface course is the uppermost layer, which has direct contact with the machine tyres. The surface is generally constructed with fine gravel, but other choices include asphaltic concrete, specialty surfaces and stabilised earth. Besides creating a smooth running surface, it also helps distribute the load for the course below.

Several primary methods are used for determining the required layer thickness, the most common being the California Bearing Ratio (CBR) and Resilient Modulus Method.

The CBR used to be the standard for the mining industry and involves measuring the pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard, crushed-rock material. The Resilient Modulus Method is newer and considered more reliable, but it is expensive.

SURFACE CONSIDERATIONS

Primary haul-road considerations include the surface material itself – usually crushed gravel – but also the roughness of the surface, which will affect the level of impact force transferred from tyres to truck. Excessive impact will significantly reduce truck-component life.



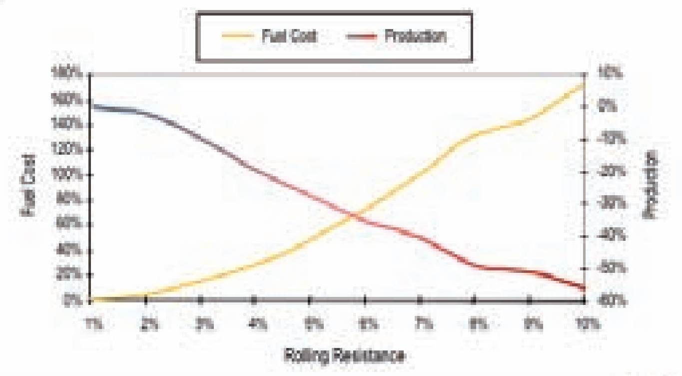
Most truck-frame shock-loads occur within 150 m of the face and dump. Because of this, it is vital to properly match bucket and truck size to minimise rock spillages, as well as carefully designing and maintaining dump zones. Truck frames have an impact-fatigue life, which is cumulative – the highest 10% of impacts are more damaging than the remaining 90%.

Rolling resistance affects safety, productivity and component life. Proper compaction is the key to maintaining a smooth, long-lasting surface. This is

Two Caterpillar 777Fs, part of a fleet of 28 at Ffos-y-Fran, the largest to date in Europe

ROLLING RESISTANCE

	Wheel gp/diff life	Wheel gp/diff cost/hr	Engine life & cost/hr	Production	Fuel efficiency
Payload increase	Significant decrease	Significant increase	Insignificant change	Slight increase	Insignificant change
Haul-road resistance increase	Very significant decrease	Very significant increase	May or may not be significant	Significant decrease	Significant decrease
Haul-road grade increase	Very significant decrease	Very significant increase	No change	No change	No change



the tractive effort required to overcome the retarding effect between tyre and ground, and it is overcome by the machine power exerted to pull the tyre up and out of its own rut. Rolling resistance is expressed as a percentage of road grade. For off-highway trucks running radial tyres, it is generally possible to assume a minimum rolling resistance, as follows:

- 1.5% for a hard, well-maintained, permanent haul road.
- 3% for a well-maintained road with little flexing.
- 4% for a road with 25 mm tyre penetration.
- 5% for a road with 50 mm tyre penetration.
- 8% for a road with 100 mm tyre penetration.
- 14% for a road with 200 mm tyre penetration.

In practice, a 5% increase in rolling resistance can result in up to 10% lower production and 35% higher production costs. Wet conditions can also badly affect haul roads, so it should be a priority to remove soft and wet spots completely as soon as possible, refilling them with good dry material. Without good repair, these spots will continually deteriorate.

Poorly-maintained haul-roads increase operating costs in terms of tyres (one tyre failure at 50% of typical longevity equals more than 250 hours of 16G motor grader operation). Rough haul-roads also dramatically increase component wear, increasing maintenance costs.

The three main factors in road deterioration are weather, repetitive routes and spillage. Various measures can be taken to reduce deterioration over time. Keeping ditches and culverts clear of obstructions minimises potential erosion, as does using different areas of the haulage lane to avoid rutting.

Motor graders, wheel dozers and other vehicles help to maintain cross-slopes, remove spills, and fill and smooth surface depressions. Operator training is another key element in maintaining superior haul-road surfaces.

Poor drainage increases the potential for tyre cuts and causes rut formation and therefore high rolling-resistance conditions. Culverts are the most efficient and effective way to control drainage flow as they reduce potential for standing water on road surfaces. Culvert integration in drainage design is affected by their location, sizing and inlet/outlet control.

In dry conditions, dust can become a major maintenance and safety factor. Watering using a water truck removes the dust hazard and maintains compaction. A 'checkerboard' or 'spot' intermittent pattern on slopes is recommended to reduce the risk

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> "The three main factors in road deterioration are weather, repetitive routes and spillage"

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of slippage on braking grades, as well as minimising water use in areas with a limited water supply.

Other options include the use of chemical dust suppressants – liquid stabilisers that give a stronger surface course and provide some waterproofing. Common suppressants include emulsified asphalt, calcium chloride and calcium lignosulfonate.

Safety provisions may include the addition of median or collision berms, escape lanes and dedicated small-vehicle roads. Appropriate signage is as important on mine roads as public roads. Options include speed-limit signs, stop signs, curve and intersection-warning signs, culvert-crossing markers, limited-access designators and safety-access indicators. Signs can also indicate the optimum gear selection on certain sections of the road.

GETTING THE MOST FROM TYRES

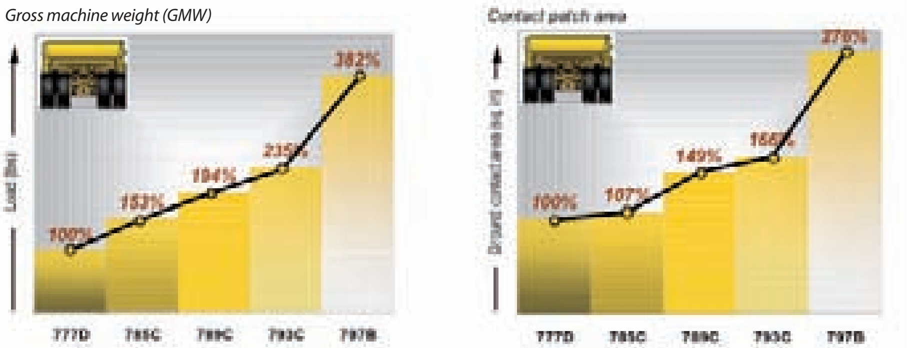
Approximately 80% of all large tyres fail before wearing out. Proper design and construction of optimal grade, cross-slopes and superelevation of corners all act to maintain proper weight distribution of the load and minimise the lateral forces on truck tyres. The same design that minimises tyre wear also enhances truck productivity, as the truck remains stable at optimum speeds. Avoiding spillage is key – about 75% of tyre failures are estimated to be caused by cuts from rocks and impacts with rocks.

Machines to remove spillage and a communication system that promotes fast action are needed at every mine. But, in addition to good mine design, proper loading and operating techniques should reduce the need for cleaning up.

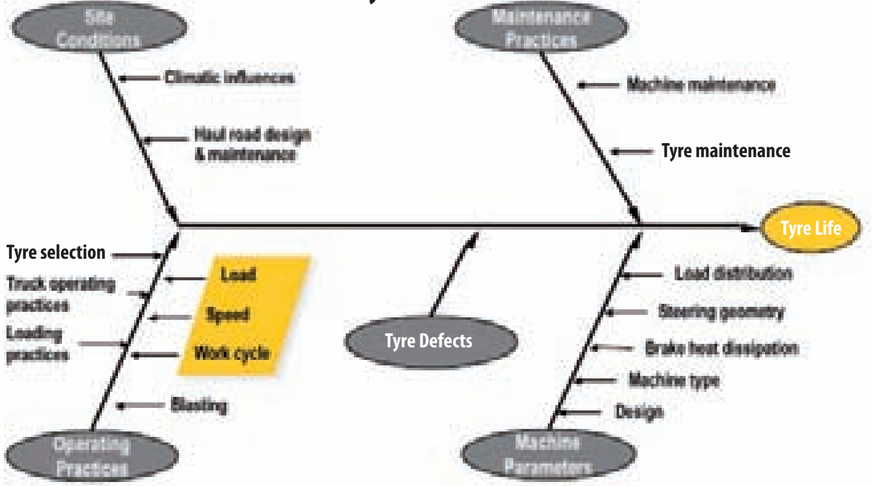
The loading-machine operator plays a key role in getting a long life from truck tyres. Centering the load properly in the truck body, and not overloading, allows the tyres to work within their intended load limits. A correctly-sized, properly-placed load is less likely to lose rocks onto the roadway.

Front-end loader operators are generally responsible for maintaining the floor of the loading face. Shovels are usually assisted by a dozer. Consider that a wheel dozer can move in and out quickly to remove debris, and can help reduce truck-exchange time. Keeping trucks from backing over rocks that have fallen from the face or dropped during loading is an important aspect of tyre care. Additionally, stopping the truck on rocks reduces the accuracy of payload-measurement systems.

Effect of load and contact area



Influencers of tyre life



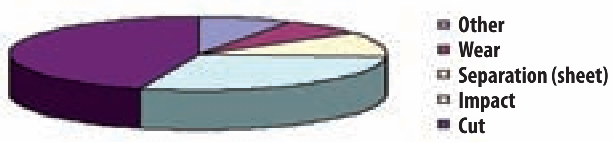
Maintaining strut pressure by ensuring cylinders are properly charged, as per manufacturer's recommendations, will maximise tyre and frame life. The correct tyre-inflation pressure provides an optimum shape to the tyre. This has its own benefits as it maximises the ground contact area, giving optimal traction and braking. It also improves cornering. Optimum sidewall-flexibility minimises the effects of road irregularities, and controlling heat levels inside tyres reduces fatigue.

SUPPORT EQUIPMENT

The final pieces in the haul-road jigsaw are the support vehicle, which can be a combination of crawler and wheel dozers, motor graders and water trucks. Motor graders are typically more cost-effective and offer greater speed than crawler dozers in light applications. Favourable applications include haul-road construction/maintenance, selected load-area clean-up, selected dump maintenance, blasting clean-up, reclamation and snow removal. They help to keep rolling resistance to a minimum and maintain superelevation on curves.

Wheel dozers are typically more cost-effective and offer greater speed than crawler dozers in light applications. Applications include many similar areas to graders, but they are the principal machine for loading-area clean-up, dump maintenance and blasting clean-up. Crawler dozers are most cost-effective when production-dozing at distances up to 500 ft. They have also proven highly effective in utility-type applications. Key usage areas include dedicated waste-dump operations, stockpile operations/steep slopes, haul-road construction, reclamation and ripping.

Actual large OTR tyre failure data from world-class metal mine



SOFTWARE-AIDED ROAD DESIGN

Caterpillar's exclusive Vital Information Management System (VIMS) integrated system monitors machine performance to provide critical information on a real-time basis. This data can be integrated with Application Severity Analysis (ASA) and Road Analysis Control (RAC) systems to quantify haul-road conditions. This often results in better payload management to optimise speed on grade. Checking VIMS event logs shows up any high braking temperatures, engine over-speeds and other variables.

Integrated with VIMS, RAC is a Caterpillar monitoring tool that uses onboard pressure sensors and RAC monitors, and logs haul-road severity to increase truck life and reduce cost/tonne. The system sensors measure component-loading and impact shock, and use this data to identify any haul-road problem areas to avoid and correct. The system can transmit real-time data and GPS locations to maintenance teams.

Another tool, Fleet Production Optimisation (FPO), quantifies the severity of the haul using strut-pressure data. It documents transmission-shift frequency and gear on grade. It also identifies the frequency and location of brake/retarder use.