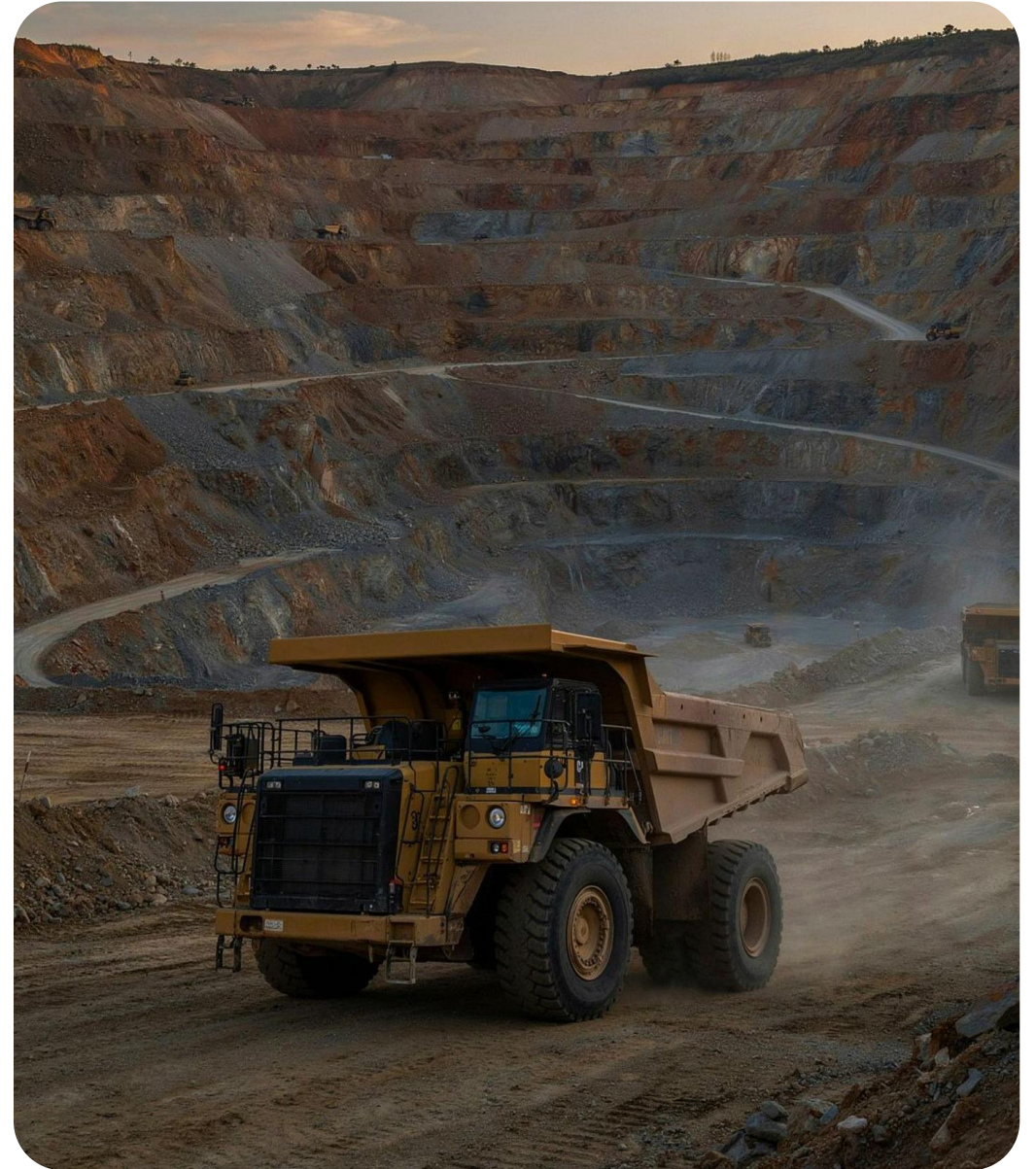


FutureBridge

5 Signals that Mining is Becoming Software-Defined

A FutureBridge Executive Insight Report examining how the world's most capital-intensive industry is undergoing a fundamental architectural shift from mechanically optimized assets toward interconnected, software-governed operating systems.



EXECUTIVE FRAMING

The Next Battle in Mining is over what runs the Mine

For over a century, mining's competitive edge rested on geology, metallurgy and mechanical engineering. Moving more material at lower cost defined success. That still matters, but software is changing the equation.

- By January 2026, Caterpillar's nearly 700 autonomous trucks had hauled over 11 billion tons of material.
- Komatsu had surpassed 900 commissioned autonomous trucks by October 2025.

Across five converging signals fleet autonomy, real-time optimization, digital twins, software-defined radio, and platform-based operating models, the industry is transitioning from a hardware-defined paradigm to a software-governed one.

The implications for capital allocation, talent strategy, vendor relationships, and competitive positioning are profound and immediate.

15–25%

Productivity Gains

Unlocked on existing asset bases through software-defined operations

827

Autonomous trucks operating

Caterpillar's operating autonomous fleet hit 827 trucks in 2025, alongside its first major mixed-fleet autonomy deal.

1,000

Autonomous trucks commissioned

Komatsu reached 1,000 commissioned autonomous ultra-class haul trucks in April 2026, with its FrontRunner system surpassing 11.5 billion tons moved.

Caterpillar and Luck Stone reported more than 3.5 million US tons hauled during an 18-month quarry pilot, supporting expansion to two additional sites.

Autonomous Fleets are Becoming Standard Infrastructure

- **From pilot to production backbone:** Autonomous trucks now carry most of the production at leading mines, not just trial loads.
- **Adoption is accelerating, with China moving fastest:** Chinese autonomy provider EACON alone runs over 2,000 autonomous mining trucks, more than Caterpillar targets by 2030.
- **The value sits in software, not the truck:** Utilisation gains come from routing, collision avoidance, dispatch and predictive servicing.
- **The battle is shifting to platform control:** At Roy Hill, Epiroc's LinkOA system has converted 78 haul trucks from Caterpillar and Hitachi to autonomous operation on a common platform, demonstrating how software can coordinate mixed fleets without tying miners to a single equipment manufacturer.

❏ **STRATEGIC IMPLICATION:** Autonomous haulage decisions are becoming platform decisions. Mining executives must look beyond equipment performance to assess software interoperability, vendor dependence and long-term control over operational intelligence.

300+

Rio Tinto Autonomous Trucks

About 80% of daily production capacity at 10 Pilbara sites

3x

Caterpillar's Autonomous Fleet Target

From 690 trucks (end-2024) to 2,000+ by 2030

15%

Higher Effective Utilization

At Rio Tinto's autonomous haulage sites

SIGNAL 02

Software Upgrades Are Replacing Hardware Overhauls

- **Upgraded in the field, not just at the factory:** OEMs now update machines already in service. Caterpillar's Remote Flash, for example, updates engine and hydraulic controls remotely, with no technician on site.
- **Software alone now delivers measurable gains:** A 2025 Epiroc drill-rig software update cut fuel use with no hardware change.
- **Software is now part of machine safety:** From January 2027, EU rules treat software updates and cybersecurity as safety requirements.
- **Cyber fixes now have a deadline:** EU rules require exploited vulnerabilities to be reported within 24 hours, so OEMs need a fast, secure way to patch every machine.



Build

Machines ship with central computing and spare capacity so new functions can be added later



Update

Control software reaches field machines remotely, without a workshop visit



Improve

Productivity, fuel efficiency and automation features keep improving across the machine's life

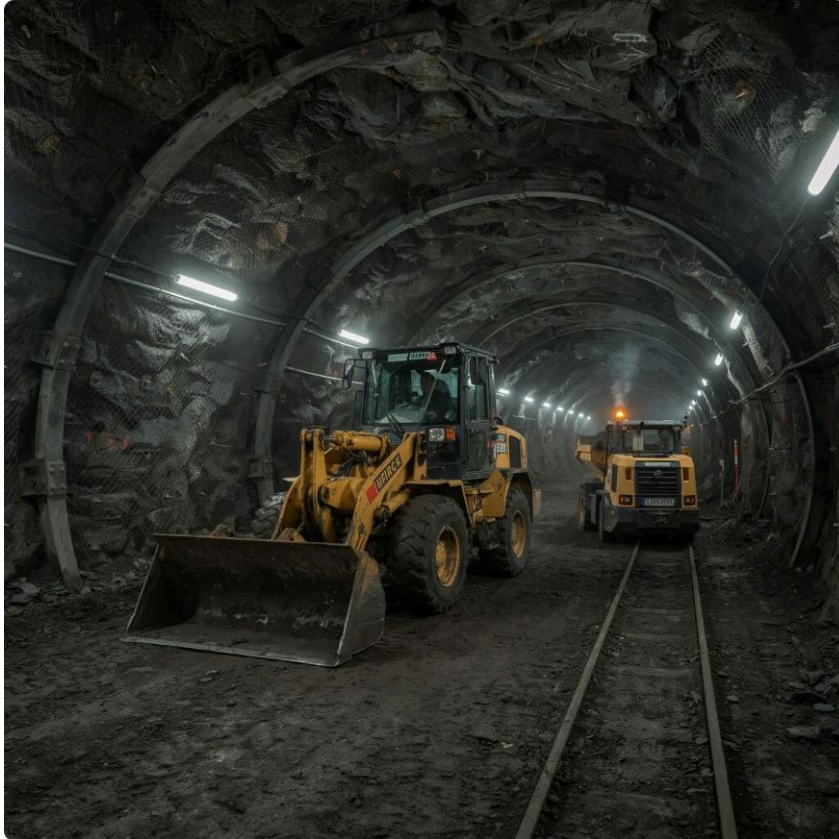


Govern

Each software change is versioned, secured and logged to meet safety and cyber rules

❏ **STRATEGIC IMPLICATION:** A machine's value is no longer fixed at the point of sale. OEMs that can safely update their installed fleet will win on lifetime performance and recurring revenue. OEMs that can't will face a growing compliance burden from 2027.

Mining Revenue is Moving Beyond Machine Sales



- **Services are now the growth engine:** Caterpillar earned \$24bn from services in 2025 and is targeting \$30bn by 2030.
- **Recurring revenue already dominates:** 66% of Epiroc's 2025 revenue came from aftermarket, and 31% of its equipment runs under service contracts.
- **Connectivity has become the sales channel:** Caterpillar now connects more than 1.6 million assets, which lets it monitor machines remotely, prioritise service and sell digitally.
- **OEMs are buying and building software:** Sandvik acquired the mine-planning software company Deswik, and Epiroc launched its InSite mixed-fleet platform in 2025.

Lifetime Value Over Unit Sales

OEM profit is shifting from the machine sale to the 10+ years of service, parts and software that follow

Outcomes Over Equipment

Customers increasingly pay for uptime, meters drilled or tons moved, rather than for the machine alone

Data as the Differentiator

Fleet data lets OEMs predict failures, time service and sell upgrades before competitors can

Private 5G is Rewiring the Mine's Nervous System

- **Legacy networks are the bottleneck:** Autonomy and remote updates need reliable coverage across pits and tunnels. Vale is moving its autonomous trucks to private LTE for this reason.
- **Private wireless is already at scale:** By 2022, Nokia alone was running private wireless networks at 60+ mines.
- **5G is going underground:** Boliden runs private 5G at its Kankberg mine in Sweden, and Finland's Callio test mine has coverage down to 1.5 km.
- **OEMs are building machines for it:** Komatsu's autonomous haulage system was qualified on private LTE in 2019.

📄 **STRATEGIC IMPLICATION:** The mine network is now part of the machine's operating environment. Operators should plan private wireless alongside their autonomy roadmap. OEMs should build machines that run on any site network, whether LTE, 5G or Wi-Fi.

60+

Mines on Nokia Private Wireless

Across 35+ mining customers

1.5 km

Underground 5G Coverage Depth

At the Callio FutureMINE test site, Finland

2019

**1st Autonomous Haulage
System on Private LTE**

Komatsu's FrontRunner, tested with Nokia

SIGNAL 05

Platform Operating Models are Emerging Above the Asset Layer

The most advanced signal of software-defined mining is the rise of integrated operational platforms. These sit above individual machines, systems and vendors, and run the whole production chain through a single software layer.

Rio Tinto's Perth Operations Centre runs 18 mines, 4 port terminals and rail from 1,500 km away. Vale's master operations centre connects 15 sites across its Mariana and Itabira complexes.

Freeport-McMoRan's AI models raised throughput at its Bagdad mine by 10%, which the company says could equal a \$2bn concentrator if applied across its Americas operations. Each shows the same new operating model: intelligence is centralised, while execution stays at the machines and sites. Operators, OEMs and software vendors are now competing to own this integration layer.



Centralized Intelligence

Decisions move from individual sites to one centre that sees every mine, plant and rail link



Distributed Execution

Machines and edge systems act locally, so operations keep running if the network drops



Integration Layer Control

Whoever owns the layer above mixed fleets sets the standards that OEMs and suppliers must connect to

STRATEGIC IMPLICATION

The New Competitive Moat Is the Operating System, Not the Ore Body

Across all five signals, a single strategic conclusion emerges with force: the sources of durable competitive advantage in mining are migrating from physical assets like geology, fleet size, and processing capacity toward software architecture, data governance, and platform control.

The operators and investors who recognize this shift earliest will allocate capital and talent accordingly. Those who continue to treat software as a cost center rather than a capability asset risk being outperformed on the same ore bodies by rivals running superior operating systems.



Audit your software stack

Map current vendors, data flows, and integration gaps against the five-signal framework



Evaluate platform lock-in risk

Assess AHS, twin, and connectivity vendors for interoperability and long-term strategic alignment



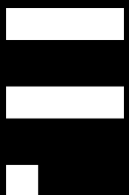
Reframe the talent agenda

Software engineers, data scientists, and systems architects are now core mine operations roles

FutureBridge Perspective

Mining companies are at an inflection point structurally like manufacturing in the early 2000s, when ERP systems and lean digitalization separated the industry leaders from the laggards within a single decade. The window to build software-defined capability before it becomes table stakes is open, but it will not remain so indefinitely.

FutureBridge advises mining and resources leaders on technology strategy, innovation foresight, and competitive positioning across the global energy transition.



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