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THE NEW TECHNOLOGY FRONTIER IN MINING

By Matthias Tauber, Jan Philipp Bender, and Adrian Schulte Steinberg

MINING IN THE NOT-TOO-DISTANT future won't look all that different from something out of, say, *I, Robot* or *Battlestar Galactica.* Robots will be shuttled to outer space, where they will mine asteroids. Here on Earth, self-organizing robot swarms will explore and extract ore, while other swarms crush and leach it underground, with minimal environmental impact. Even more fantastic, robots created through 4D printing will be dispatched in flat form to the mine site, where they'll self-assemble once exposed to air. Meanwhile, engineers will monitor all this activity from the comfort of their offices, located hundreds or thousands of miles away.

Only a few years ago, mention of next-generation mining conjured images of autonomous drilling and heavy equipment streaming real-time data to onsite offices. These and other new technologies are already delivering savings, productivity, and safety advances. But even bigger changes are in store—changes that go far beyond optimizing operations.

Emerging digital technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), and new biological technologies promise to revolutionize the industry in almost unimaginable ways. Among them: drones that perform in situ scanning, genetically manipulated bacteria or nanobots that mine at the molecular level, deep-sea robots that mine underwater, big data and algorithms that enable end-to-end tracking and communications as well as real-time supply and demand management, water-neutral processing that eliminates the need for water and slurry ponds.

These new technologies will turn the mining value chain upside down, disrupting both existing business models and the traditional roles and relationships among mining companies and their customers, suppliers, and even competitors. Even the most far-thinking mining executives wrestle with how to proactively address these prospects. Deciding where to stake one's bets is especially challenging in an industry where technological innovation has traditionally involved huge capital outlays.

How do leaders gear up to capitalize on radically new opportunities and ways of doing business? We believe a good place to start is with three fundamental questions: What improvements will the new technologies bring to each step in the value chain? How might the more radical technologies disrupt the value chain? What actions can mining executives take now, without having a clear line of sight, to become successful miners of the future?

Better, Cheaper, Faster, Safer

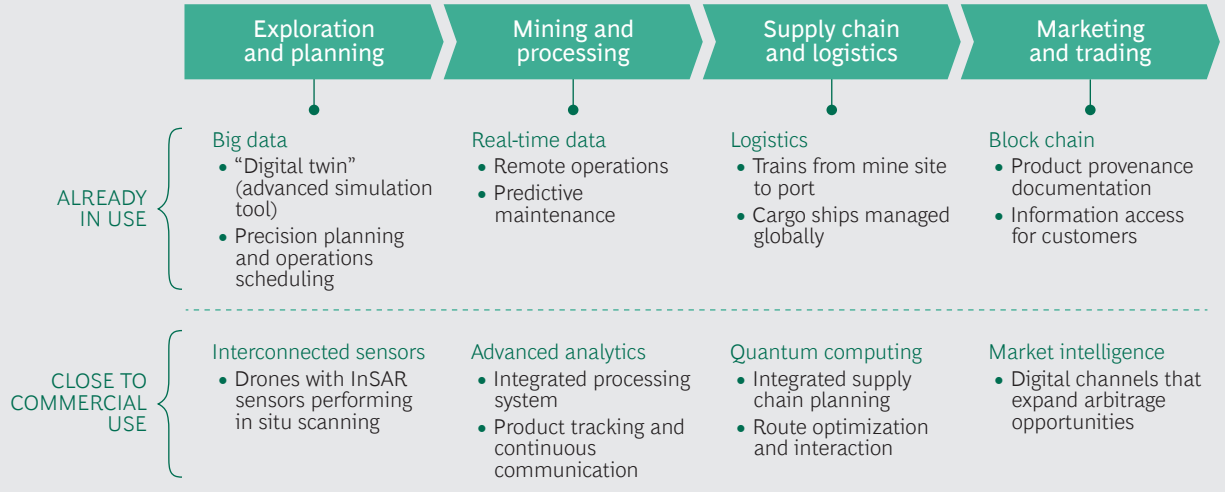
Digital and biological technologies are already enabling companies to operate faster and more efficiently, streamline costs, enhance safety, and reduce their environmental footprint. (See Exhibit 1.) Consider these examples from throughout the value chain; many of these changes are imminent, some are already in use.

Exploration and Planning. Big data will dramatically reduce the cost of exploration—a welcome development, considering that the precrisis spike in exploration spending has only proved how elusive major discoveries can be. (See *Tackling the Crisis in Mineral Exploration,* BCG report, June 2015.) The troves of data being collected digitally—geological, metallurgical, and operational—enable the use of virtualization (or, a "digital twin").

Using data collected from existing equipment and monitoring devices, engineers can create simulations to precisely plan and schedule operations. Even without mobilizing people and other physical resources onsite, they can pinpoint operational requirements, address bottlenecks, and determine likely output. Sensor technology gives extra potency to this approach: contactless molecular sensors can analyze the characteristics of the ores in the ground. Using a digital twin, companies can perform simulations to determine the efficiency and productivity of a future mine. They can do probability modeling, a major advantage in situations where time is a decisive factor, such as meeting permitting deadlines or mollifying public opposition. These simulations save time as well as money, because weather and physical conditions are no longer an obstacle.

Mining and Processing. Real-time data gathering enables companies to manage operations remotely. Boliden, for example, has connected sensors to robotic equipment at its underground Garpenberg mine in Sweden; the sensors feed data to operators in a central aboveground control room. Companies whose fleet equipment has connectivity can take advantage of predictive maintenance and automatic spare-parts replacement, thereby reducing equipment's downtime while facilitating its

Exhibit 1 | Examples of New and Emerging Technologies



Source: BCG analysis.
Note: InSAR = interferometric synthetic aperture radar.

life cycle management. In fact, both 3D and 4D printing will eliminate the need to procure spare parts from afar. Sensors embedded in the materials will make the analysis of each processing step visible, much as is the case with RFID technology.

Autonomous equipment improves drilling precision and efficiency, with the additional advantage of exposing fewer people to dangers in the work environment. Other safety benefits come from smart helmets (powered by augmented reality) that not only provide data to the wearer but also enhance vision and indicate danger zones. Another example: LIDAR (light detection and ranging) sensors on autonomous trucks that measure range and recognize humans within range.

Supply Chain and Logistics. Autonomous rail made its industry debut in early 2017; then, in October, Rio Tinto conducted the first trial run without a driver on board—a nearly 100-kilometer test at the company's iron ore operations in the Pilbara in Western Australia. Giant autonomous cargo ships are not far off; BHP recently announced a vision to deploy them within the next ten years. In addition to vastly expanding supply chain capacity, such carriers will lower labor costs and increase safety and efficiency. New, universal quantum computers, which augment data-crunching capabilities by orders of magnitude, will help to enable this innovation. Together, these advances will allow companies to achieve a whole new level of supply chain optimization, with major improvements in routing and interactions among supply chain participants.

Marketing and Trading. Digital and big data are expanding marketing and trading capabilities, and algorithms are revolutionizing distribution models. (See "Attack of the Algorithms: Value Chain Disruption in Commodity Trading," BCG article, January 2017.) Market intelligence captured through digital channels is already helping mining companies to capitalize on arbitrage opportunities in the commodity markets. Supply chain transparency and downstream integration will enhance both the customer experience and customer engagement.

Take blockchain technology: a tamper-proof digitized ledger can document the provenance and characteristics of the original product, making the information accessible to buyers at every stage—wholesale, retail, and intermediary. (See "Thinking Outside the Blocks," BCG, December 2016.) By ensuring quality and authenticity, it enhances the value of the end product.

How Digital Could Disrupt the Mining Industry's Value Chain

Across industries, digital technologies are removing the barriers to entry and tipping the scales of advantage; consider Google's foray into autonomous cars or Amazon's push to automate more and more of its value chain. These technologies are blurring or shuffling the roles of market participants as they introduce game-changing business models that upset the traditional industry ecosystem. How will they reshape the mining industry?

New Twists in the Value Chain. Universities and data science companies that develop innovations could gain an edge in exploration, and traditional mining companies might be better off either partnering with them or ceding exploration to them altogether. Furthermore, exploration innovation won't come only from engineering or geology; it will also emerge from biochemistry, bioengineering, and computer science—disciplines too complex for mining companies to manage simultaneously in-house.

Mining companies' role in extracting and processing ore could change just as dramatically. In the past few years, more mining companies have switched to leasing rather than owning heavy equipment. In such arrangements, the OEMs handle the maintenance; the mining companies simply purchase hours of productive use. But if the economics make sense, OEMs might very well take over hauling operations. Thus, equipment as a service could mean not just leasing out the asset but also maintaining it—and possibly even providing the labor that operates it. Extracting and processing could conceivably shift to suppliers. In a

more extreme scenario, some steps, such as traditional mineral processing, could disappear altogether. As we described earlier, teams of robots might be programmed to extract and process ore in place, removing the need for crushing and leaching.

Turning Business Models on Their Ear. As data and digital technologies and new types of automation are combined and connected, thereby altering the traditional value chain, mining executives will need to ensure that their organization rests on a sustainable business model. Mining companies are unlikely to wake up tomorrow as software companies, but they should nonetheless explore the potential new sources of revenue and competitive advantage. This includes opportunities derived from establishing a first-mover advantage.

Remember those giant autonomous cargo ships? Imagine mining companies of the future cooperating with one another to create an integrated platform that connects them with shipping companies so that they can achieve maximum efficiencies in shipping and logistics. With visibility into demand, companies could make more informed decisions, reduce costs, and completely manage their global shipping activities. Whoever owns, operates, and controls access to such a platform is positioned to quickly build a new source of advantage and competitive power in the industry.

Shaping the Future Without a Clear Line of Sight

Figuring out which new data can confer competitive advantage or truly create value—or which opportunities suppliers might seize—is no small challenge. Neither is assessing the most promising activities for mining companies to exploit—or those most beneficial to shed. How can companies prepare for a future that is bound to be radically different, and whose outcomes are not only hard to foresee but likely to vary wildly? Mining executives are understandably uncertain about the right way to proceed.

Traditional long-range planning is not the answer. By the time that process is finished, the technologies underlying the assumptions might already be obsolete. And the very uncertainty surrounding the plan makes it difficult to know whether the path one hypothesized is even the right path. But continuing operations as usual is certainly no route to the mine of the future. How best to avoid wrong turns and leapfrog unproductive steps?

Bridge the Gap Between Strategy and Operations. To start with, leaders need to recognize the disconnect in thinking between the C-suite and general managers in the field.

At the corporate center, the focus is, by necessity, on long-term strategy; leaders embrace the exciting possibilities that new technologies and approaches promise.

At the mine sites, though, the focus is more pragmatic, centered on improving operations. To general managers, the dazzling technologies and future vision are all too often “blue sky” thinking or simply too risky to implement.

Both perspectives are, of course, necessary. Operational excellence programs are important, but they are inherently incremental; they cannot lead to a step change. At the same time, a revolutionary vision cannot be realized without a practical game plan that tempers the risks of experimentation through trial, fast failure, and cumulative wins. We believe that the two sides must work together to shape their mine of the future.

The challenge is to develop pilot programs that do more than just test the feasibility of an approach—they must also ensure that the approach delivers value.

Pilot in Place. First, design pilot programs that test a hypothesis in place, demonstrating its validity—or its flaws. Pilots with inadequate results get abandoned, failing fast. If a pilot works, the company can then experiment with another one that can be linked to the first, thus extending the innovation in the value chain and helping to prototype a new business model.

In effect, the company begins assembling pieces of the future mine puzzle. (See Exhibit 2.)

Suppose your company was to launch an autonomous train to transport processed ore from plant to port, as Rio Tinto recently did. In such a test, day-to-day issues and problems could arise, many that engineers thousands of miles away had not anticipated or that would not occur in the laboratory. An emergency breakdown, for instance, might end up costing more to fix because a repair person would have to be flown out, resulting in more downtime than with a traditional train, whose engineer could make the repair on the spot. But if the overall results prove valuable, you might decide to implement autonomous trains across operations.

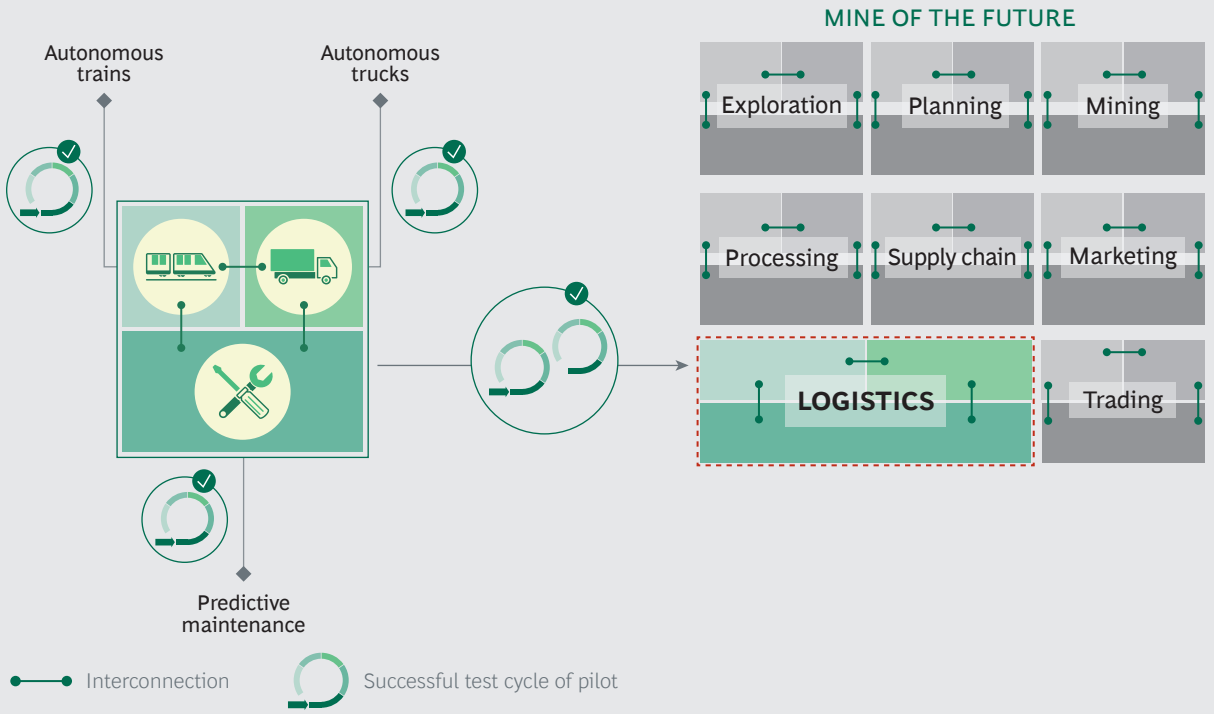
Having now solved the first piece of the puzzle, you might next test autonomous trucks at the mine site. If that test works, you might then combine the two autonomous transportation segments—moving ore around on site and transporting it from mine to port. This would give you an idea of the value of autonomous vehicles in multiple stages of operations.

Conduct Cumulative Pilots. For a second pilot, you might explore predictive maintenance, first with your truck fleet. By testing, say, ten trucks over the course of a year across a few mines, you would get a good idea of sensors' reliability and of the potential savings over and above a standard maintenance regimen. Then, you might move on to test predictive maintenance for the autonomous train cars.

Assuming the results were positive, the next step would be to connect the pilots, resulting in autonomous trains in conjunction with autonomous trucks, both enabled with predictive maintenance. Together, the pilots might completely restructure logistics at the mine site. With these test programs completed, you might move on to implement a processing pilot program, and later a sustainability pilot—and so forth.

This pilot-in-place approach enables companies to test new technologies and new business models in a real-life environment.

Exhibit 2 | Integrating Pilots into the Mine of the Future: Logistics Example



Source: BCG analysis.

Apart from being cost-effective, they also involve the frontline managers—those who routinely face and resolve day-to-day operational challenges. General managers thus become active participants and partners, invested in the success of a new way. This approach brings the "blue sky" down to ground level, helping companies bridge the gap between vision and reality in order to identify and pursue strategic advantage.

Of course, prioritizing the pilots upfront is critical. In identifying worthwhile pilots, companies should undertake a structured process, ranking the choices according to such criteria as their business value, risk, connectibility, and applicability in other settings. Pilots should also be conceived with their integration in mind, as part of the larger puzzle the company is solving. Consider up front the enterprise platform that will ultimately power the programs: the system that digitally integrates and analyzes all the underlying data generated by the massive number of sensors pinging signals every second from all the heavy equipment. Companies might compare platforms by running several pilots on one and then several others on another.

The Technology Quest Is Big but Should Start Small

With mines' average development cycle of ten-plus years, now is the time for mining company leaders to turn their sights to the not-too-distant future. Asteroid mining is only as far off as the next project.

The best approach, in our view, is to start small—and start now. Take Peter Drucker's cue: "The best way to predict the future is to create it." As first steps, collect data, assess your level of digital maturity, and define the areas in which you should take action. Then, devise modular pilots, ensuring that they are built with compatible IT systems so that the successful ones can eventually be scaled and integrated. Invite risk taking and foster a fail-fast culture. Engage people across the business in this exploration while monitoring the evolving industry ecosystem.

We are not suggesting that companies abandon an overall strategy. Instead, strategically steer an adaptive effort and make that effort part of your senior management team's technology agenda. Think hard about where as a company you want to generate value in the future. What will it take to safeguard the strategic assets underlying your value proposition? What resources, capabilities, and relationships will you need? Define the core technologies, set your vision, and draft a high-level roadmap. Above all, keep testing—not only new technologies and ways of working but also your very assumptions about the industry and your role in it.

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