In the view of industry leaders, unit-ops technologies are unlikely to change radically in the coming two decades. What is likely to change is how unit-ops will be managed.

Large productivity gains registered by U.S. industry in recent years are being credited in part to the implementation of IT. Our critical-technologies discussions revealed that the IT revolution is coming to the mining industry as well and will have a significant impact on the productivity of mine operations in the coming years.

While the cost of machinery used in mining has been increasing—especially for metals and coal producers facing thin or negative profit margins—the cost of information has been falling, creating opportunities to use IT to optimize the use of mining equipment and boost returns on investment. Accordingly, observed one participant, technologies to monitor and optimize mining operations are making "huge strides right now." An equipment-supplier representative asserted that electronics constituted the most important developments in the machinery his firm produced, affecting "how you run it, control it, monitor it, and utilize it."

Industry representatives identified a host of IT-based innovations that are converging to support this trend:

- Unit-ops machinery is being outfitted with a growing range of sensors, imaging technologies, and controls for monitoring and managing output.
- Emerging sensor and communications capabilities are enabling real-time and minewide remote monitoring of mine conditions and materials inventories and flows.
• The rapid decline in the cost of computing power has facilitated the growing sophistication of IT hardware and software to monitor, process, and utilize the increasing flows of mine information.

• As more components of a mine operation are brought “on-line,” they can be linked together through minewide communications networks and GPS-based dispatch systems to optimize the entire mining process.

• The installation of minewide communications and data networks will enable external providers to implement a range of mine-planning and management solutions.

Information technologies in mining will have a significant impact on mine operations in the coming decades, giving mine managers and staff much greater understanding of and control over mining processes. Increases in IT capabilities also are establishing the technology base necessary to support remote and autonomous mining operations.

However, the introduction and diffusion of IT in mining has been slower than in other sectors, such as the petroleum and chemicals industries, in part because the mine environment presents unique and formidable challenges:

*Unit-ops machinery such as this continuous miner are unlikely to change radically in the coming two decades. However, information and communications technologies will have a strong impact on how such equipment operates. Photo courtesy of Joy Mining Machinery.*
Mining equipment moves in a three-dimensional environment; the mine environment changes as mining proceeds; the mine environment is hostile to sensitive equipment; and the individual characteristics, and hence the requirements and restrictions for IT, of different mine sites vary widely.

In the following sections, we first outline basic information technologies that are proving critical in mining operations. We then discuss some of the significant capabilities for process optimization enabled by these technologies. We conclude with a review of the present status and possible future developments in equipment remote control and automation—two of the leading objectives of IT integration in mining.

INFORMATION TECHNOLOGIES

Industry participants identified a core set of technologies that are critical to enabling IT capabilities in mining. These technologies include

- Sensors
- Position monitoring
- Ruggedized on-board computer hardware
- Advanced control algorithms
- High-capacity wired and wireless communications

Sensors

A variety of sensors are being developed and deployed for collecting data ranging from ore characteristics to equipment performance and process flows. Sensors generate raw electronic data from the physical environment of the mine that can be used for real-time process monitoring, optimization, and integration.

Several participants involved in both surface and underground mining cited the benefits of on-board sensors that are being developed and deployed to monitor equipment performance parameters such as shovel-bucket and truck-bed payloads, shovel swing angles and cycle times, vehicle speeds, and material flow rates. Advances in digital imaging combined with pattern-recognition software, positioning systems, and computing power are enabling the greater use of cameras to monitor product quantity and quality at different stages of handling.

Sensor technologies traditionally used in exploration, such as shallow seismic monitoring and ground-penetrating radar, were cited in some instances as important new tools for the development and production stages of mining. Bore-
hole tomography, said one user, “has great application in mining” for locating deposits and improving ore-grade quality control during production. These technologies help to define more precisely rock mechanical properties, ore grade, and ore-body location on a local scale. Although the technologies are being used only in isolated cases, the participants who mentioned them felt that they would become an increasingly important part of mine process-optimization systems in the coming years. Two companies engaged in underground metals mining also indicated the importance of microseismic and rock-deformation sensors for monitoring mine environments—for example, to predict roof or wall failure.

**Positioning**

The introduction of the GPS has had a notable impact on surface mining, representing, according to one technology user, “one of the biggest revolutions in the last 20 years.” Two levels of resolution were identified: low (approximately 10-meter) precision for tracking mobile vehicle movement of haul trucks, and high (less than one-meter) precision for precise location of individuals (e.g., during surveying) and machinery such as drill bits, shovel buckets, and bulldozer blades.

A few references were made to positioning technologies for equipment in underground environments. The constrained space within underground tunnels allows for relatively straightforward vehicle tracking via handshaking with radio or infrared beacons positioned along the travel path. Two participants also cited more-sophisticated positioning systems using gyroscopes for maintaining the proper attitude of longwall shearers and for keeping them perpendicular to the coal face, although details on this technology were not provided. The foreseen benefits mentioned included keeping the shearer in the coal seam and maintaining a desired layer of coal on the rock face.

**Computer and Electronics Hardware**

Increasing computing power and decreasing costs of hardware were cited as major drivers of IT innovations in mining. The cost of a computer workstation that can support three-dimensional graphics used in advanced mine modeling and planning applications fell tenfold during the 1990s, reported one executive. This computing power is now available in portable computers that can be used in the field. The decreasing cost of such equipment drove the diffusion of graphics technologies from high-value-metals producers to lower-cost operations such as kaolin and phosphate production.

Several manufacturers have developed data terminals and computers specifically for mining environments. These systems allow remote data acquisition
and manipulation. Important features include improved interfaces, keyless data entry, and compatibility with various wired and wireless communications platforms.

A key challenge is that of developing or acquiring computer and electronics hardware that can withstand the hostile conditions (vibration, dust, heat, physical abuse) characteristic of the mine environment. Accordingly, our discussants noted that several essential IT hardware components—cameras, lasers, radio transmitters, and infrared beacons—are being “hardened” for use in mine environments. One participant, for example, reported the development of a cost-effective, super-hard material that will make camera lenses impervious to abrasion. An equipment manufacturer maintained that developing computers able to withstand nearly nine times the acceleration due to gravity was key to the successful deployment of dispatch systems. Another equipment manufacturer noted that breakthroughs in ruggedization have made greater application of advanced equipment diagnostics feasible.

**Computer Software**

Control algorithms to integrate and process data being generated by mine operations are another critical component in a minewide information network. The goal is to give machine operators on the line as well as facility managers real-time and interactive access to information needed for planning, managing, and optimizing mine operations.

The requirements of such algorithms can vary enormously, depending on the particular task. For example, powering down a piece of equipment when a sensor reaches a threshold level is relatively simple compared to automating the scooping of a shovel bucket. In general, the challenges presented in mining are quite formidable, as they involve dynamic and inconsistent physical environments. Along with unreliable communications and positioning systems, insufficient software development was among the principal causes cited for the late arrival and slow diffusion of IT in mining.

Shareware-based applications, using the Linux scripting language, for example, were seen by one technology developer as a way to increase the efficiency and speed of software development in mining.

**Communications**

The area of underground mine communications is undergoing rapid technological development, and consequently, several generations of communications systems are currently in use at mine sites in the United States. An important
trend is the transition from section-specific to minewide communications systems.

The most basic and most prevalent underground communications system is the hard-wired mine-phone, or “squawk box,” used for essential communications—typically between miners in a section and the surface. These systems require a wired connection, offer limited communications points, and are considered by some to be difficult to maintain.

A more advanced underground communications technology is the leaky feeder.1 Leaky-feeder systems enable continuous contact between mine personnel and the surface, a capability that is particularly valuable in cases of emergency. Although a mature technology, leaky feeders are still relatively uncommon in the United States: One manufacturer estimated that they are installed in only 25 to 35 percent of underground metal mines and that installations in coal mines are far less frequent.

Operating companies noted the contribution of minewide communications systems to enhancing productivity.

• An underground operating company reported the use of leaky feeders in all its mines and noted a major benefit: the ability of personnel to immediately report breakdowns without having to walk out of the section.

• A manager noted the attractiveness of a leaky feeder for his facility, saying it could reduce by up to two hours the downtime from common maintenance problems such as a flat tire.

Although best suited for voice communications, leaky-feeder systems can also transmit data in small batches. Data-based applications include monitoring the location of personnel and equipment and simple remote operations such as powering up conveyors or fans.

A more advanced-generation communications technology is high-capacity, spread-spectrum radio systems. This type of radio is in widespread use in surface mine environments for equipment dispatch, vital-signs monitoring, and remote control. It is also commonly used underground to support point-to-point (i.e., operator-to-machine) remote operations, for example of LHDs. Underground mines can also take advantage of the high capacity of spread-

1A leaky feeder uses a coaxial antenna cable with loosely braided shielding strung throughout the mine works and is connected to operators at the surface. This antenna can support radio communications between personnel and equipment up to 400 feet away and out of the line-of-sight. A leaky coax is an analogous system utilizing high-capacity, spread-spectrum radio transmission over a special coaxial antenna cable having segmented braided shielding.
spectrum radio through leaky-coax communication systems, which operate in a manner analogous to leaky feeders. Still higher-capacity and faster underground communications are possible with multichannel fiber-optics. In this variation, the coaxial antenna is replaced with a fiber-optic cable connecting strategically located radio beacon interfaces. Underground leaky-coax systems are relatively uncommon in the United States, and fiber-optic-based systems are very rare. Both are more common in Canada. According to discussion participants, the future development and extent of use of leaky coax are uncertain and likely to progress faster abroad in newer and larger operations (for example, in large-vein metals production). Standardization of system components was said to be a barrier to the technology’s development and acceptance.

Ultimately, the development and diffusion of robust, high-capacity wired and wireless minewide communications networks will be necessary to support the sustained data transmission required for continuous and real-time process monitoring and optimization, remote controls, and autonomous operations.

**IT-DRIVEN PROCESS MANAGEMENT AND OPTIMIZATION**

The technologies described above combine to enable a minewide information-sharing capability that encompasses rapid measurement, communication, interpretation, and decision support. This capability provides the potential to monitor and control mining operations in a manner analogous to that used in fixed-infrastructure operations such as manufacturing and refining plants.

**Planning**

Information technologies are making an important contribution to mining by helping decisionmakers model mine development and investment choices with more accuracy over the life of the mine. This capability is proving valuable in the face of thinner operating margins, the advent of larger equipment that can reduce a mine’s production flexibility, and more-restrictive land-use policies.

> Having good mine-planning tools is “absolutely critical” to success in a competitive business climate, as it enables one “to mine the right coal at the right time.”

—Coal-company executive

Recent and emerging data collection and analysis tools, such as the Geographical Information System (GIS), three-dimensional graphical representation, and computer-aided design, enable decisionmakers to quickly manipulate and understand complex spatial information that was formerly committed to paper
blueprints and linen cross-sections. Such technologies give management the ability to develop and analyze scenarios based on variables such as initial mine design, operation plans, stockpile scheduling, equipment utilization, and expansion options. These capabilities speed up the planning process, allow companies to optimize capital investments in both plant and equipment, and anticipate facility closure and reclamation needs.

Many benefits of recent and emerging modeling and planning technologies were cited during the RAND critical-technologies discussions.

- Computer-aided geological and geomechanical modeling helps speed the design of initial mine layouts, support requirements, and expansions, thereby reducing up-front investment costs.
- Dispatch simulations help determine the best way to route haul roads and locate waste dumps.
- GPS-based data on material quality and location are helping mines to control the geochemistry of spoil banks and thus better plan and optimize the reclamation and closure process.
- A fire-simulation planning tool expected to become available in the near future will enable firms to minimize fire risks through better ventilation design, conduct virtual modeling of fire incidents, and design emergency-response strategies.
- Blasting simulations incorporate a number of inputs such as rock type and state; face height; hole spacing, depth, and directional deviations; chemistry of explosives; and detonation timing. These data help simulate and optimize blast parameters such as strength, fragmentation, throw distance, and collateral impacts.
- A manufacturer of roof supports is now using finite-element modeling to design comprehensive ground-control strategies in underground coal mines. Demand for this new service has been so strong that the firm opened a subsidiary company devoted solely to this business.

As mine communications and computing algorithms improve in the next few years, said one technology provider, mine-planning tools will be automated, and mine plans will be continuously updated with real-time GPS and sensor data feeds.

**Dispatch**

One of the major manifestations of IT integration in mining has been the introduction of dispatch systems that use GPS to monitor mobile equipment positions; to direct truck flows to shovels, crushers, stock piles, and dump points; and to optimize equipment use and material flows in real time. Another benefit of automated dispatch is the ability to better monitor and control ore grades being delivered to processing facilities.
Dispatch use appears to be approaching standard practice at larger surface operations: Nearly all relevant participants are either already using it or planning to install it in the near future. The concept is being extended to track all mobile equipment, including drills, pickup trucks, and even customer deliveries via highway trucks and rail cars.

Dispatch systems can increase equipment utilization rates by as much as 30 percent. Users have found that initial investment costs could be recovered through reduced operating costs in just weeks or months after installation. “The payoff is astronomical,” especially at production-limited facilities.

—Technology supplier

**Surveying**

New information technologies are turning surveying activities into “a one-man show,” in the words of one representative, doubling labor productivity. High-precision, dynamic GPS, for example, allows surveys to be conducted quickly and accurately from a moving survey vehicle or excavator. This reduces the need to send survey crews as well as supervisors into the mine on a regular basis and mitigates safety concerns such as trips and falls on loose rock. In addition, it eliminates the need for survey stakes, greatly improving earthmoving accuracy, particularly under poor visibility conditions, e.g., at night or during rain, snowfall, or fog.

Reflectorless laser and infrared surveying technologies enable the remote (up to hundreds of meters), rapid, precise, and three-dimensional profiling and mapping of drifts, stopes, pit walls, and waste piles in surface and underground environments. These technologies allow surveyors to work at safe distances from blast piles, highwalls, slopes, and landslides. Lasers are also being used to scan stockpiles, thus conducting inventories on a regular basis. Three executives said that GPS- and laser-based surveying technologies were helping their operations better establish the proper contours and gradients needed for reclamation.

Electronic survey data can be entered into mine information systems, such as GIS databases or planning tools, and automatically updated during earthmoving operations.

Laser-based survey technologies can be used to map a drift at 3,000 times higher resolution and 100 times greater speed than manual methods.

—Technology supplier
Equipment Positioning

Integration of high-precision (one-centimeter accuracy) GPS-based surveying, equipment positioning, and ore-body maps is enabling managers to automatically monitor and direct earthmoving activities such as shovel-bucket and bucket-wheel scooping; blast-hole drilling positioning, alignment, and depth; ore stacking; and bulldozer grading. One of the principal benefits of this technology is a greatly reduced dependence on manual surveying. Once an initial survey is conducted, information systems can update maps in real time as earth is moved, and updated information can be continuously shared throughout the mine site. For example, monitors in operator cabins can be fed continuously updated, color-coded maps showing topography, locations of ore and waste, and tool positions.

In addition to decreasing surveying requirements, increased precision can result in better blast control, decreased ore dilution, more uniform bench heights, and greater operating speed. This can generate large productivity increases: “Customers typically see significant improvements on the order of 25 percent,” said one supplier. A manufacturing firm claimed that its customers realize 30 percent improvements in productivity from these technologies. According to literature provided by a technology supplier, one mine estimated a 90 percent reduction in survey time from implementing GPS-guided bulldozer grading.

High-precision GPS positioning appears to be growing in popularity, with initial installations preferentially applied to drilling systems. Overall, they are still in relatively limited use, however; one manufacturer estimated that high-precision shovel positioning was in use at about 30 sites worldwide.

Performance and Productivity Monitoring

Performance monitoring integrates data from equipment sensors with variations in operating-costs to quantify the effects of different operational choices. Parameters such as number of vehicles, haul distances, maintenance scheduling, operating hours, loads, swing angles, cycle times, particle sizes, speeds, flow rates, and operator scheduling can be compared with various productivity metrics such as labor, maintenance, consumable costs, downtime, and ore-production rates to help make informed decisions about how best to operate a particular mine or production technology. Productivity monitoring is particu-

2GPS is available at a range of resolutions. Standard autonomous receivers have an accuracy of one- to 10-meter resolution. Differential GPS, which uses base reference stations or pseudolites (to correct for variations in the GPS signal), has accuracies down to 20-centimeter resolution and is used for dynamic positioning and automated dispatch. Real-time kinetic provides one-centimeter-accuracy GPS positions and is used for surveying and machine guidance.
larly beneficial for situations where mine operations vary with time due to expansion, addition of new technology, or transient variations in product demand. One equipment supplier noted that his company uses productivity monitoring to analyze repair claims. Another supplier reported using performance monitoring to verify the legitimacy of warranty claims.

Operating-company and technology-supplier representatives illustrated many uses and benefits of performance monitoring.

- Through the use of bar-code readers to input operator ID, a coal-mining operation monitors equipment performance by work shift. Management can ascertain when equipment is turned on and off, equipment performance, and volume of coal produced per shift.

- Unsatisfied with the performance of its new investment, a metals producer scrapped its vertical impactors (a newer technology) and reverted to the use of cone crushers (an older technology) outfitted with enhanced control systems that automatically optimize hydrostatic pressure and close size and thus maximize crusher throughput and availability. The three-stage crusher circuit is run from a computer screen by one operator.

- A metals mining firm has developed an implemented system of “Critical Performance Indicators,” such as unit costs and availability, labor productivity, and safety. These indicators (which are derived from a series of measures deemed critical by management) are then compared with company goals over time and across units.

- A materials producer is developing a companywide GIS database that incorporates data on each of its mining units, including production, costs, orders, and inventory. By putting real-time process data on every manager’s desk, the company hopes to better manage inventory, improve load management between facilities, track unit progress in meeting goals, and facilitate benchmarking.

Finally, several discussants pointed to the goal of integrating the local data networks of mines and quarries within an organization and with outside vendors and partners. The vision, explained one discussant, is “to effectively make any piece of mining equipment a node on the internet.” Once this occurs, an unlimited range of outside providers can tap into an enterprise’s data network and “layer in” process-optimization solutions for mine planning and management, blast optimization, equipment performance monitoring, equipment dispatch, inventory management, regulatory compliance, training, etc.

Process Integration

The availability of minewide information sharing has provided the capability to begin linking previously separate operations around the mine such as surveying, mining, processing, and reclamation (see Figure 4.1).
As discussed above, surveying can now be integrated with mining through continuous map updating as mining proceeds. After an initial survey, high-precision equipment positioning and material tracking allow topographic and ore-body maps to be automatically updated and distributed throughout the mine with each shovel scoop. This integration can extend through the life of the mine and into the reclamation stage, where high-resolution earthmoving systems can be used to optimize restored topography.

A second aspect is the closer integration of ore production and processing operations. One of the most important technology innovations in mining, one executive said, was the use of GPS to identify material as it is mined and the use of in-process sensors to track the material’s movement in the handing process. Similarly, geomechanical and geochemical information collected immediately in front of the advancing face in underground operations is being used to plan specialized blasting, roof-support, and ore-processing needs.

With such capabilities, mining sequences can be planned and modulated to add flexibility to and optimize plant operations. For example, information from
the mine, such as ore production rate, ore grade, and particle size and hardness, can be monitored and used to adjust ore delivery; crusher power; blending ratios; stacking, leaching, and washing rates; and other processing variables. Conversely, stockpile size, specialized blending requirements, and changing customer specifications can be communicated upstream to the mine face so that operations can be adjusted accordingly. Such capabilities are especially important for operations such as quarries and industrial minerals producers that want to ramp up production to meet strong demand.

Surface imaging and detection technologies are gaining wider application in mining.

- A metals producer is deploying video cameras and image-recognition systems to monitor ore going into primary crushers, at the first transfer points, and at the mill.
- To reduce the potential for contamination of industrial minerals, a producer installed video cameras inside its product storage bunkers to remotely monitor inventory levels and operating equipment.
- Automated measurement of material drawdown at crushers is enabling an aggregates producer to optimize ore flow rates and maximize crusher throughput in a heavy-demand environment.
- A coal company has refined and employed high-resolution surface seismic monitoring to study geologic anomalies between core holes in advance of mining that may affect coal recovery or ground control. When areas of concern are detected, additional core holes are drilled to study the suspected anomaly in greater detail.

The use of advanced information systems to optimize ore grades becomes more important as the number of shovels and excavators in a mine falls, reducing equipment operators’ ability to blend ore grades, as one observer noted. Likewise, as downstream processing and utilization become more sophisticated and rigidly controlled (in response to environmental regulations, for example), optimizing and maintaining quality control of feed stocks become more critical.

**Knowledge Management**

Many discussants noted that although mine operations are generating more data, such information rarely is well utilized. For example, two equipment and service suppliers said that while their firms’ technologies generated large volumes of data, the information is never reviewed except in summary form or in the case of an exceptional event. Echoing the view of several discussants, a manager argued that the challenge is, first, to decide what information is important, and then to decide how to make use of it.
The newest haul trucks provide a large volume of performance data. The information (presented as codes and numbers) may be used by specialists well versed in data analysis, but it is not readily interpreted by on-site mechanics. While these trucks record the number of times an engine exceeds a specified RPM, the time of each incident is not recorded, and thus the operator cannot be identified.

—Mine manager

Accordingly, another critical technology is effective knowledge management: tools and capabilities for distilling complex mine information into an actionable format that a mine engineer or operator in the field can comprehend and act upon in real time. One means to improve data utilization, said an operating company representative, is wireless data-transmission systems to get the information off the equipment and to the proper location to analyze it. On the other hand, it was argued, such data typically require complex and time-consuming interpretation that can overwhelm mine operators. One solution cited is the use of simple graphical interfaces, for example, red and green icons indicating where an operator should go.

“Data is not as interesting as insight.”

—Coal-company executive

Several discussants argued that operating companies were slow to realize the benefits of knowledge management. “What will all this data do for us?” a technology supplier asked rhetorically. Many technology providers argued that mining companies do not have a good understanding of cost centers across their entire operation. This can deter investment decisions, they suggested. One equipment provider argued that it was difficult to convince operating companies that his firm’s technologies could radically reduce their ore-handling costs.

“There is more to be gained with information technology over the short term than automation.”

—Technology supplier

Knowledge management appears to be correlated with company size: The larger a mining organization is, the more resources and know-how it can dedicate to gathering and interpreting operational data and discerning how to utilize the information in the field. With their greater analytic capabilities, one technology provider observed, larger mining companies tend to be more cost
conscious and to more closely evaluate technology investments and operations and maintenance (O&M) costs.

REMOTE CONTROL AND AUTOMATION

Remote control (also referred to as telemining) and automation have been high on the mining R&D agenda for a long time. During our critical-technology discussions, proponents of these capabilities cited numerous anticipated benefits, including

- Higher equipment utilization by avoiding lengthy shift changes and transits (up to three hours in some cases), breaks, and worker fatigue.
- Reduced need for human support systems (most importantly in underground environments).
- Reduced wear and tear on equipment.
- Increased safety resulting from moving the operator away from an active mine face.

Although they are based on the same set of core technologies, remote and autonomous operation are different in some fundamental ways from the process-optimization capabilities discussed above. The primary distinction is that with remote control and automation, computer algorithms are used to control actual equipment operations, rather than operational decisions. Participants noted that this new paradigm amplifies existing technological challenges such as development of robust algorithms and reliable communications, and also introduces a suite of new hurdles, such as operating with different human sensory inputs, increased reliability requirements resulting from the absence of human assistance, and difficulties of integrating remote or autonomous and manual equipment at the same facility or section.

“You can’t automate something that doesn’t work properly and reliably.”

—Coal-company executive

“Before you automate something, you must make it efficient and you must understand the system. . . . The technologies for driving machines have been around for a long time. But to do this with high reliability and integrity 24/7 is very hard.”

—Technology supplier
Another impediment is cost: The unique character of each mine operation requires that remote and autonomous systems be highly customized. “We never build the same thing twice,” observed a coal-company executive. These systems also require advanced technological capabilities, particularly remote ore-characterization and horizon-monitoring sensors, that are not yet commercially available and that few suppliers have the capability to develop and integrate. The systems will require that mines develop and promote talent in disciplines outside of traditional hiring and promotion paths (e.g., computer programming, systems operation, and electronics). Finally, developing fail-safe systems (for example, assuring that radio communications do not interfere with other operations) and ensuring the safety of personnel working in an environment of autonomous machinery were identified by some discussants as remaining technology development challenges. Such challenges ensure that the advent of the “workerless mine” will be beyond a 20-year horizon.

“We’ve had a robotic mail cart in this building for years. Robotic technology is available; it’s just not advanced enough to cope with the complex mine environment.”

—Technology supplier

There was no strong consensus among the discussion participants on the feasibility or benefits of remote and autonomous equipment operation. We heard from many ardent proponents: “The payoff is astronomical,” claimed one advocate. The representative of an operating company with considerable experience in prototype development claimed that the commercial application of remotely controlled equipment was likely to double the productivity of the company’s underground mines—an improvement that will outpace any other technological innovation in the company’s 100-year history (see Figure 4.2). He concluded, “Remote operation can never beat the best human operators, but it can always beat the average.” On the other hand, several participants noted that many of the anticipated benefits of remote and autonomous operations had yet to be convincingly demonstrated; as one caustically observed, “Imagine a doctor operating by remote control.”

The lack of consensus may stem from differing views of the role of mine personnel in a remote or autonomous mining operation. Proponents claim that the technologies will reduce the need for human support systems, such as ventilation, in underground facilities. Yet several speakers observed that personnel will be required to remain nearby to service the equipment. Another discussant noted that laser guidance systems and image-recognition systems will require

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3As a matter of fact, remote-controlled and automated surgical procedures are already being envisioned and performed.
ventilation to reduce dust and smoke. Autonomous haul trucks are likely to have personnel on board, at least initially, overseeing operations, according to another discussant.

**Remote Control**

Use of remote control is standard in only a few applications in the United States, according to the technology-discussion participants.

Line-of-sight wireless remote control is routinely used for guiding LHDs in unsupported stopes in underground metal mines. Several participants noted that remote control enabled the development of large, unsupported stopes and full extraction in mucking out. With remote control, some personnel are able to operate an LHD beyond their line-of-sight, using sound cues. The addition of remote video monitoring provides enhanced “around-the-corner” mucking ability, requiring fewer draw points to be cut per stope. Many underground coal continuous miners utilize untethered remote controls, where the operator stands behind the machine as it cuts. Highwall coal mines also drive entries using remote controls.
Remote-controlled LHDs have allowed a gold producer to recover more ore per stope, even as overall production volumes have fallen. The cost of conversion for each unit ($30,000) was equivalent to the cost of two cone muck piles. When there has been a stope fall, the equipment was dragged from the muck pile, repaired, and returned to work.

—Gold-company executive

Several participants expressed a strong interest in extending remote-control capabilities to cover more mining operations, despite their relatively limited use to date. Three participants pointed to advanced remote-control capabilities being developed on an operational basis in Sweden, where an individual can remotely operate three LHDs, controlling the scooping function while an automated navigational system takes over and controls the tramming and dumping functions.

A mining-company/manufacturer/government partnership in Canada has made considerable progress in the development of a fully remote underground mining system, the progress of which, several study participants noted, they are following closely. The consortium’s goal is to run all development and production operations from the surface at greater efficiency and less cost than could be done with traditional in-situ methods. Thus far, they have developed production drills that are remotely operated in working mines. Long-distance wireless remote control of other operations, such as surveying, development (jumbo) drilling, blast detonation, LHD mucking and tramming, and shotcrete application, has been demonstrated with varying degrees of success but is not yet in commercial use.

One finding of this effort is that the need to provide operators with multiple sensory inputs may not be as important as expected: Remote operators are provided with sound, but they routinely turn down the volume until a visual cue prompts them to listen, according to one observer.

Automation

No fully autonomous mobile equipment was reported to be in use in the United States. The only fully automated task reported to be in relatively widespread use was automatic advance of shields and face conveyors in longwall coal mines.

Automation should be viewed as an evolutionary process, said one executive. Thus, considerable attention has been focused on developing semiautonomous and operator-assisted controls as an intermediate technology. Operator assists (or “smart” technologies) have been developed for a range of applications, and
there was a strong consensus among the participants that their development and diffusion is an important, albeit less noticed, trend. Examples of demonstrated or commercially available operator assists cited by study participants include surface and underground drill-bit positioning; control of drilling speed, pressure, and depth; shovel, wheel loader, and LHD scooping; and continuous-miner guidance. Autopositioning of loaded shovel buckets over truck beds is expected to be available in 2001. According to a truck manufacturer, other tasks that are under consideration for operator assist include truck steering, dumping, collision avoidance, and ramp-climbing.

Operator’s view of a 50-cubic-yard shovel bucket scooping overburden. Heavy excavators are equipped with operator assists to optimize scooping power and reduce wear and tear on the machinery.

Several types of autonomous mining equipment will be available on a commercial basis within the next few years, said several equipment manufacturers (see Table 4.1). Many participants expressed interest in the advent of autonomous haul trucks. Although hauling was generally cited as being one of the most difficult tasks to automate, the large number of trucks in use makes the potential payoff to both mining companies and manufacturers significant. One mining executive noted that labor accounted for 30 percent of haulage costs at his operation and that the company had looked into acquiring driverless technology; however, the control systems were deemed to be inadequate to reliably implement a driverless system at that time.
Table 4.1
Anticipated Availability of Autonomous Mining Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Anticipated Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autopositioning shovel bucket</td>
<td>2001</td>
</tr>
<tr>
<td>Autonomous surface-haul truck</td>
<td>2002–2005</td>
</tr>
<tr>
<td>Autonomous LHD vehicle</td>
<td>2005</td>
</tr>
<tr>
<td>Autonomous surface drill</td>
<td>2003</td>
</tr>
<tr>
<td>Autonomous shovel</td>
<td>2005</td>
</tr>
</tbody>
</table>

Source: RAND discussion participants.

The discussants differed widely in their opinions on where automation was likely to proceed most rapidly; this difference is most likely a function of the diverse nature of mining. Automated drilling and surveying are proceeding more quickly in open cast mines, due to the availability of GPS and wireless communications in the open environment. Semiautomated tramming of haul trucks has been introduced in several underground mines—a development facilitated by the more confined space, uniform lighting, and stable operating environment. In an open pit, by contrast, more precautionary measures must be integrated into vehicle controls, to prevent haul trucks from deviating from their course or driving off a bench. On the other hand, one industry representative contended that the application of driverless trucks might proceed more rapidly in quarries, given their shallower profile and the less-dynamic nature of the working environment.