Given the large expenditures on capital equipment characteristic of mining, technology developers and users alike place a very high priority on improving equipment productivity. Proper maintenance is essential to maximizing both availability and productivity. At the same time, maintenance services are a major cost element of all mine operations. Accordingly, after process optimization, equipment operations, maintenance, and repair technologies were most commonly cited as critical by the participants. The prominence of O&M technologies in mining coincides with earlier RAND assessments of critical technologies across U.S. industry.

Maximizing returns from fixed capital has become increasingly important to the success of coal and metals producers as margins have been squeezed by competition and weak commodity prices. Moreover, as individual unit-ops increase in capacity (and, for example, the number of shovels and trucks in a mine is reduced), outages have correspondingly greater impacts on overall mine production. Similarly, as mine processes are more tightly integrated (as in a longwall), an outage in a single mission-critical component can shut down an entire production line. Optimizing O&M is likely to become even more critical as mining equipment and geological conditions become more complex and the provision of support for skilled maintenance staff in remote locations becomes more difficult.

Maintenance is especially critical for the stone and aggregates industry, as producers strive to keep up with strong demand—a trend that is likely to last well into the present decade. When asked to identify bottlenecks to boosting pro-

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1To illustrate the scale of the issue, one participant estimated that maintenance alone accounted for 25 to 35 percent of a mine’s operating costs.

2See Steven W. Popper et al., op. cit.
ductivity at his firm, a stone and aggregates executive ranked insufficient maintenance as his second most important organizational challenge.

A loaded 240-ton haul truck climbs out of an open-pit mine. Reliability becomes more critical as equipment increases in scale, because an outage affecting a single piece of machinery can have a large impact on the output of a mine or quarry.

To avoid such bottlenecks, several priority O&M solutions currently are being developed and applied in mining:

- Equipment monitoring and diagnostics
- Repair and maintenance scheduling
- Maintenance technologies and practices
- Engineering robust systems

In addition, mining and quarrying enterprises are increasingly outsourcing their maintenance operations (this discussion is reserved for Chapter Six). While most of the participants in the RAND discussions stressed the importance and criticality of O&M, the practices they engage in and their views about solutions varied tremendously.
EQUIPMENT MONITORING AND DIAGNOSTICS

Many technology providers highlighted a variety of recent and emerging technologies for equipment performance monitoring and diagnostics.

Major pieces of equipment are being outfitted with an increasing range of on-board sensors to monitor the state of critical systems—a capability one executive described as “absolutely critical.” Vital-signs monitoring outputs include fluid temperatures, levels, and pressures; engine speed and gear position; brake temperature; bearing rotations and temperature; drivetrain performance; and hours of operation. By 2001, new-generation heavy-truck tires will have sensors that monitor tire pressure and temperature and transmit the data to on-board or roadside receivers. Real-time monitoring is expected to help operators reduce tire wear, improve equipment performance, and avoid catastrophic tire failures. Additional sensors, such as on-board oil analysis and structural-strain gauges, are under consideration or in development.

Remote monitoring of amperage levels on conveyor belts at an underground coal operation has reduced the number of staff required to watch the belts and provides central dispatch with real-time notification when a belt goes down.

—Coal-company executive

Vital-signs data typically are manually downloaded at regular intervals for analysis and are entered into a spreadsheet or analyzed as a shift report. In some cases, monitoring data are transmitted in real time via radio frequency or wire to a remote location, such as the mine’s dispatch center. For example, programmable logic controls provide mine operators with performance and diagnostic data on belts, fans, drive motors, power distribution systems, etc.

Off-board diagnostic techniques include vibration, lubricants, ultrasonic, and thermographic analysis. Many mining operations reported regularly analyzing their engine oil, hydraulic fluids, and other lubricants for signs of wear, contamination, or malfunction. High soot and fuel content, for example, is an indicator of piston blow-by and lower engine output. Fuel or coolant contamination, in turn, indicates lubricant degradation and reduced lubrication capacity. Progressive analysis over time can indicate equipment abuse or the need to modify the lubrication or maintenance regime. Vibration analysis of critical elements (e.g., bearings, bearing races) is assisting the implementation of predictive maintenance regimes, and mission-critical systems increasingly have real-time vibration sensors built in.
A shift report downloaded from an LHD. Such data reports can help mine management monitor the vehicle's output and efficiency, work-shift performance, and malfunctions.
Vibration analysis and lubricants analysis were cited as two important O&M technologies.

- A mine manager reported that monitoring crankcase oil for brass—an indicator of bearing wear—helped his unit avert costly engine rebuilds.
- A major aggregates producer reported that vibration analysis enabled technicians to accurately predict when equipment would go down and was a more reliable gauge of performance than the accumulated knowledge of plant foremen garnered over time.
- The maintenance service group of a heavy-equipment manufacturer reported using ultrasound and vibration analysis to predict consistently and with good accuracy structural-steel failures as far as six to seven months in advance.
- A shovel manufacturer analyzes the vibration of gear assemblies at the factory and supplies its customers with a "birth certificate" that provides users with baseline reference data to monitor trends in the condition of the assembly over time.

REPAIR AND MAINTENANCE SCHEDULING

Maintenance practices vary greatly throughout the industry and do not appear to be correlated with firm size or industry segment. Many mining companies follow manufacturer specifications, while others "run their equipment until it drops," said an industry observer. "Every part we change has gone to destruction," reported an operating-company manager. Many executives noted a shift to predictive maintenance (also referred to as reliability-centered or performance-based maintenance), whereby servicing is conducted according to machinery and equipment performance parameters and the needs of the mine operation, rather than manufacturer guidelines or rules-of-thumb.

Predictive maintenance is supported by enhanced vital-signs monitoring that signals when maintenance or repair interventions should be taken. Such advanced diagnostics can flag a problem much earlier than conventional indicators, such as noise, smells, or power loss can. (As one industry executive observed, a noisy bearing indicates that too much damage already has occurred.) Alternatively, variations in performance over time are compared with historical data or design specifications to help schedule maintenance most efficiently.3

The keys to success with such diagnostics, as one observer noted, include obtaining sufficient trend data over time and developing the confidence of equipment operators and maintenance personnel in the predictive abilities of what at first glance looks like abstract data. According to its advocates, predic-

3Historical data ("working curves") may be developed either from the mine’s own maintenance records or from a variety of sites observed by contract maintenance services.
Predictive, or performance-based, maintenance is being practiced widely in the mining and quarrying industry.

- One large mining firm described its current preventive-maintenance implementation efforts as “scatter-shot,” with the goal being more targeted monitoring and greater fact-based analysis. The goal of the maintenance-improvement process was to move equipment availability rates from the “high 80s to the mid-90s.”

- A large underground mining firm uses performance data to schedule maintenance during planned downtimes, such as at the end of a panel in a longwall operation, when equipment must be dismantled and moved. By carefully scheduling maintenance, operators can better “define the terms of engagement,” thereby creating a better work environment and increasing safety.

- Wheel-bearing temperature indicators being installed on large haul trucks warn of imminent problems, enabling the driver to decide to schedule maintenance or, in serious cases, to stop the vehicle immediately. Such systems can reduce major bearing damage, and hence maintenance costs, by 90 percent.

The maintenance benefits of on-board diagnostics extend beyond scheduling. Equipment health data can be transmitted to a mine-site control center, a regional headquarters, and the manufacturer. This allows maintenance actions to be planned, parts ordered, personnel notified, and production operations modified in accordance with performance parameters.

MAINTENANCE TECHNOLOGIES AND PRACTICES

New-generation 360-ton haul trucks incorporate modular designs to facilitate the change-out of hoses, components, and engines. According to one operating company, this represents “a big breakthrough in serviceability.”

—Technology supplier

Equipment suppliers are making improvements in equipment design to facilitate maintenance—for example, centralizing the locations of maintenance
ports and service elements and making them easily accessible. Key systems, such as planetary gear assemblies and engines, are being bundled as modular “plug-and-play” components that can be easily accessed and quickly replaced. Modular design and subsystem replacement can reduce in-field maintenance time, reduce the need for highly skilled workers and clean environments in the field, and allow more time-consuming and complex repairs to be accomplished under optimal conditions.

Many mining operations are investing in better maintenance areas, greater contamination control, more thorough and efficient record-keeping, and more complete and careful equipment rebuilds. As mining equipment gets larger, components requiring service, such as wheels, drivetrains, and bearings, also increase in size, motivating companies to develop new maintenance capabilities.

A repair technician devised a novel method that uses suction to speed crankcase oil drainage, thereby reducing the time required to a fraction of the standard three to four hours.

—Gold-company manager

Enhanced diagnostics offer the ability to quantify the effect of deferred maintenance and nonstandard equipment operation. Several participants noted that mines often operate equipment outside of the manufacturer’s recommended conditions (e.g., they overload trucks, ignore warning lights, etc.) in order to meet production targets. Discussants noted that it is often difficult to determine the financial costs of such behaviors. The integration of O&M data is allowing managers to quantify the costs of stressing equipment, although the limited availability of high-capacity underground wireless communications systems has generally limited these capabilities to surface environments.

ROBUST SYSTEMS AND MATERIALS

As noted in Chapter Three, equipment at aggregates operations is being placed under particularly demanding conditions to meet market demand. The development of more-robust subsystems is helping to reduce costs by lengthening maintenance cycles and reducing the incidence of critical failures.

Using more-expensive, longer-life parts, such as hardened excavator bucket teeth, entails a significant initial cost premium but returns greater savings over the long term.

—Operating-company manager
One operating-company representative noted that a principal determinant of equipment life is the capacity of lubrication systems. The heat tolerance of lubricants is being increased, reducing cooling requirements of engines and motors. The resulting ability to use lower-viscosity (thinner) lubricants in drive trains increases the transmission of useful energy to the road and rock face, reducing engine wear and tear. At the same time, the soot-holding capacities of motor oils have increased, lengthening the intervals between oil drains by 100 percent and reducing air emissions, said one manager. According to another observer, large oil reservoirs and “superfiltration technologies” such as centrifugal dirt separators can extend maintenance intervals. Oil changes on haul trucks are typically needed after every 500 hours of operation, with the latest super-size trucks able to run for 1,200 hours. The interval should increase to 5,000 hours in the future, this observer said.

Key innovations are the rise of maintenance-free systems such as “filled-for-life units,” currently available in some noncombustion applications, e.g., bearings and gear boxes. Another innovation is automatic replenishing systems, such as oil burners that inject a fraction of crankcase oil into the engine combustion chamber.

The development of robust component systems was cited by one industry executive as an important prerequisite for the successful implementation of remote-controlled and automated equipment, given the expected distant location of support personnel and time lags in responding to equipment malfunctions.