CHAPTER 4.--COMPUTERIZED MINE MONITORING[1]

4.1 Introduction

Monitoring systems can have numerous uses in the mine. They can aid in the efficient management of the mine by providing environmental trend data, production and maintenance control, and communications. In some cases, they can provide justification to petition the Mine Safety and Health Administration (MSHA) for a variance of one of the mandatory safety standards. They may also increase the gross revenues of the mine by increasing the amount of coal produced or increase profits by reducing the cost of producing that coal.

No single system will satisfy the requirement of all mines. Some may require simple hard-wired status-reporting systems; others, multipurpose computer-based systems that collect, analyze, and store data and perhaps control some mine functions. Even though systems vary in complexity, they are all composed of three functional components. The first component is *sensors* that measure the environmental or production parameters and produce an electrical signal that is fed into the telemetry. The second is *telemetry* devices that receive the signal from the sensors and transmit it in either analog or digital format to the third component, *analysis and display equipment*. This equipment receives the transmitted signal and either stores it for later analysis or displays it. The analysis-display equipment ranges from simple strip chart recorders with preset alarms to computers, cathode-ray tubes (CRT's), and line printers that can also provide production reports.

4.2 Uses of a Mine Monitoring System

A list of potential uses for mine monitoring systems, including both production-related functions and those related to health and safety, was used to develop a questionnaire. It was presented to representatives of the mining community to determine their current monitoring priorities.

The responses indicated that the industry's priorities fall into the following two categories:

First priority--

- Production and haulage
- Maintenance

Second priority--

- Ventilation
- Communication
- Fire monitoring
- Personnel

The survey shows that production-oriented systems were the most appealing to the questionnaire respondents. Since even small improvements in production efficiency and maintenance can have a large financial impact, the desirability of monitoring systems that focus on these areas is understandable.

The results are summarized in table 4-1. The function that scored 100 was viewed as the most beneficial monitoring function.

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[1]From Guidelines for Environmental Monitoring in Underground Coal Mines. Phase I Report. BuMines OFR 180-82, 1982, 177 pp.; NTIS PB 83-147777.

TABLE 4-1. - Survey results, weighted rank score

1.	Output by section	100
2.	Belt monitoring and control	99
3.	Scheduled routine maintenance	99
4.	Equipment repair history	97
5.	Spare parts inventory	95
6.	Assist in diagnosis of failure	94
7.	Power: Fault location	73
8.	Face equipment operating time	68
9.	Personnel: Shift organization	66
10.	Ground fault detection	63
11.	Trailing cable failure	62
12.	Power center monitoring	62
13.	Monitor car haulage system	59
14.	Personnel: Locate skills; assist in locating people with needed or critical skills	58
15.	Ventilation: Eliminate inspections; eliminate or reduce frequency of some periodic inspections	50
16.	Communications: Reliability	49
17.	Communications: Intelligibility	45
18.	Paging	45
19.	Plan new ventilation; help in planning ventilation, including new ventilation shafts	45
20.	Inspection scheduling; alert foremen or others to scheduled or predictable inspection or repair	43
21.	Fire: Beltways; a system to detect and warn of incipient fires in the beltway due to hot rollers or other problems	42
22.	Beltway for intake air; the use of improved fire detectors and monitoring system so as to qualify for a variance and enable use of the beltway for intake air	41
23.	Communication: Station-to-station	40
24.	Emergency signaling; direct people during any emergency by signaling	40
25.	Detect leaky stoppings; ventilation monitor to detect open doors, blockages in air course, and leaky stoppings	37
26.	Personnel: Emergency; assist in locating and aiding people during an emergency	30
27.	Fire: Haulage; detect incipient fires in trolleyways	29
28.	Ventilation: Control regulators; monitor ventilation, and adjust regulators to improve flow distribution	25
29.	Roof fall prediction; automatically plot falls and/or microseismic activity to predict roof fall	20
30.	Cage; monitor the operation of the cage to predict failures or minimize delays	18
31.	Fire: Gob; monitor gob areas for fire	18
32.	Inventory expendables	10
33.	Rock bursts	10

Responders were also asked to indicate the relative importance of other cost and technological factors that may affect user acceptance. Results, on a 100-point scale, were

1. Reliablity of monitoring equipment in mine environment..... 100

2. Maintenance cost..... 90

3. Initial cost..... 88

4. Skills required to maintain equipment..... 75

5. New technology to mining..... 62

Reliability of the equipment was the most frequently cited "very important" factor.

4.3 Petitions for Modification

Mine monitoring systems can be used to provide a cheaper and safer alternative to satisfying the mandatory safety standards set forth in 30 CFR 75, provided that the alternate method (in this case, the monitoring system) guarantees no less than the same measure of protection afforded by the standard (30 CFR 44). The extent to which the industry currently takes advantage of these usages can be determined by reviewing the Petitions for Modification of Mandatory Safety Standards.[2] Since ventilation regulations appear to be the most likely candidates for modification petitions, petitions were reviewed under subpart D, "Ventilation," in the following sections:

75.305 Weekly examinations for hazardous conditions.

75.306 Weekly ventilation examinations.

75.307 Methane examinations.

75.310 Methane in virgin territory.

75.326 Aircourses and belt haulage entries.

This review identified a number of cases where continuous monitoring was used in a petition for a variance and a number of others that could have used continuous monitoring. Included in the review were petitions that were granted and petitions that were filed, but not acted upon as of the writing of this report. General comments on the petitions follow.

75.305 Weekly Examinations for Hazardous Conditions. - This section requires weekly inspection of at least one entry of each intake and return aircourse, in its entirety, for both methane and for compliance with the mandatory health and safety standards. Typical petitions state that because of poor roof conditions it is not possible to travel the aircourses in their entirety, and offer checkpoint measurements as an alternative. Continuous methane (75.305) measurements could be made with a monitoring system at these checkpoints. Required airflow measurements (75.306) could also be made with the same system.

Only 1 of the 62 petitions that were granted offered continuous monitoring. An additional 20 petitions were filed, but there was no record of any final decisions. One of these petitions did propose to install two methane monitors at specified points.

75.307 Methane Examinations. - This section requires tests for methane at each working place immediately prior to energizing electrically operated equipment.

[2]Sources include the Federal Register, the Bureau of National Affairs, Inc., "Mine Safety and Health Reporter," and the McGraw-Hill 1979 "Guide to Modification of Safety Standards in Coal Mines."

One petition was noted in which methane monitoring devices were installed on permissible electric water pumps in the face area to eliminate the methane examinations by a qualified person required prior to energizing the pumps.

75.310 Methane in Virgin Territory. - This section requires that all electric power be cut off and men withdrawn when air returning from virgin mining areas contains 2% or more methane.

Three petitions for modification were granted under the stipulation that continuous automatic methane monitors were used in the return as an alternative to measurements made by certified mine personnel.

75.326 Aircourses and Belt Haulage Entries. - This section requires that entries used as intake and return aircourses be separated from belt haulage entries.

Fourteen petitions that were granted and ten that were filed but not acted upon were reviewed. Of these, seven petitions were granted on the basis of continuous monitoring systems, and seven of the filed petitions proposed continuous monitoring of carbon monoxide. A review of MSHA tests that demonstrate the "equivalency" of carbon monoxide sensors and the customary point-type heat sensors is presented in reference 15.

In summary, at least 11 continuous monitoring systems have been installed in U.S. underground coal mines for purposes of obtaining a variance from the mandatory health and safety standards. Eight additional petitions for modification mention such systems.

4.4 Technical Factors

The key technical issues are whether the sensors can actually provide the needed input information, the ability of the processing system to interpret correctly the telemetered information, and, finally, overall system reliability.

4.4.1 Sensors

Sensors are the critical element in mine monitoring systems since they provide the input data. If the input data are not correct or are not representative of the required measurement, the entire monitoring process is meaningless, i.e., "garbage in, garbage out." One problem with sensors is that their output represents the response of the sensor to a number of parameters in addition to the one that is to be measured. Typical examples are the response to changes in temperature and the poisoning of environmental sensors by other gases in the mine.

The critical problem relates to the ability of the sensor actually to measure the parameter of interest. In particular, ventilation monitoring systems use point air velocity measurements to represent the total airflow at a cross section in the mine. The total airflow is determined either from an empirically derived factor and the point measurement or from actual calibration of the cross section. The problem is further complicated because the only safe location for the sensor is on the rib or roof in the low-flow boundary layer. It is possible to have large changes in the overall airflow with little or no change in the velocities in the boundary layer and consequently in the sensor output. The reader is referred to reference 13 for guidelines for avoidance of these problems in airflow measurement.

4.4.2 Telemetry

The telemetry system obtains the data from the sensor, converts them to a standard format, sends them to another unit that receives them, checks their authenticity, and then refers them to the analysis-display device. The principal problem in this area is data security, i.e., the error rate for information transmission. The problem is not so much that an error is transmitted but that an error in transmission goes undetected because of the noise on the transmission line. The sensitivity to erroneous data transmission depends upon factors such as the cable used, the local noise field, length of cable run, and data formatting.

Techniques for detecting erroneous data transmissions have been devised principally by computer manufacturers. Notable among these are IBM's synchronous data link control (SDLC) and Digital Equipment Corp.'s digital data communications message protocol (DDCMP).

Bureau research (4-5),[3] indicates that the maximum transmission distance for one undetected random error per year varies between 1.3 and 6.8 miles in an average noise field, and between 0.1 and 0.6 mile in an estimated maximum noise field. Since cable runs are frequently several miles, occasional undetected transmission errors can be expected. For typical monitoring applications with frequent data refresh, this should not be a factor that causes worry; however, in the case of control systems or the least favorable monitoring circumstances, error rates can be unacceptably high, and corrective measures such as more secure transmission systems and improved error detection protocols are necessary.

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

4.4.3 Reliability

The final area of concern is system reliability. The questionnaire identified reliability as the prime concern. The Bureau is currently sponsoring research that provides a methodology for determining the reliability of systems (12, 17, 21). This methodology has been used to evaluate expected failure rates of current mine monitoring systems.

Reliability in monitoring systems takes a number of forms. The first is mechanical reliability of the components. The underground mining environment is notoriously hard on equipment because of water, dust, potential damage due to moving equipment, and rough handling. Therefore, the enclosures for remote stations should be rugged enough to withstand the day-to-day rigors typically encountered in underground service. The enclosures should have tight and durable seals if the internal components are sensitive to moisture or dust. All exterior switches and buttons should also be sealed or be durable enough to withstand constant use in the presence of dirt and moisture. Cables should be durable enough to withstand occasional rough treatment.

The second aspect of reliability is electrical power reliability. Since power outages are all too common in underground mining, some type of backup power or uninterruptable power supply should be provided for this system. Such a power supply is particularly important for monitoring systems that provide essential health and safety information such as main fan operation, fire detection, and methane content. Obtaining these data is important during the common day-to-day, short-term power outages, but it is just as important to have such information during emergency situtions such as roof falls, fires, or explosions. It is also required for system approval.

4.5 Commercially Available Mine Monitoring Equipment

4.5.1 Introduction

The mine monitoring systems discussed in this report are electromechanical systems that remotely sense various environmental and operational parameters and transmit the data to a central location where the data are analyzed and/or displayed. On the basis of this definition, it is reasonable to discuss the system in terms of three basic functions: sensing, data transmission (or telemetry) and data analysis and display. In the case of monitoring and control systems, such as systems that automatically and remotely deenergize face equipment when the methane content at a specified location reaches a predetermined level, the control operation presents a fourth function.

Sensing can be divided into two general categories: environmental and operational or production sensing. The first category of sensors is designed to measure various aspects of a mine's environment to assist in maintaining a safe environment for underground personnel. The parameters that are ordinarily of concern are gas (i.e., carbon monoxide, methane, oxygen, etc.) content, air velocity, air temperature, differential pressure, and humidity. Typically, the data are used to detect and locate potentially hazardous conditions (i.e., fires, gas bursts, etc.) so that the appropriate measures can be taken. Production sensors are used to monitor the operating status of various pieces of underground equipment to detect production bottlenecks, equipment malfunctions, maintenance requirements, etc. Examples of production parameters that are typically of interest are belt output, face equipment operation, belt slippage, blockages, and bearing temperatures or vibration.

Telemetry is the process of transmitting the data output of the sensors to the control center that is usually located aboveground. The output of the sensors can be either a simple status indication, sometimes called a binary, contact closure, or status output (such as high-low, open-closed) or it can be a continuously variable function of time (such as air velocity, methane concentration, etc.). While the continuously variable data can provide significantly more information than the simple status data, how much more depends on the accuracy of the measurement.

As a practical matter, it is generally not feasible to run a separate conductor or conductor pair to each sensor. Therefore, telemetry systems typically incorporate several remote stations or "outstations," each of which accepts and encodes the output of a number of sensors and transmits the encoded data along a common cable to the control center. The two most common encoding techniques are (1) frequency domain multiplexing and (2) time domain multiplexing. Frequency domain multiplexing has the advantage that data from all monitoring points are received at all times, although the number of monitoring points is limited by the overall bandwidth of the system. Time multiplexing can be expanded, at least in principle, to accommodate as many monitoring points as desired. However, each point is sampled only intermittently (i.e., the receiver obtains data from only one monitoring point at a time) since the system interrogates the monitoring points sequentially. The cycle time, or time between successive samplings of the same point, is the time the system requires to interrogate all of the monitoring points.

Time multiplexed systems, the more common of the two, often transmit data in the digital format. That is, a series of high-low state indications is transmitted to indicate the status of the monitor point. A common technique to accomplish this transmission is to use frequency shift key (FSK) encoding. This encoding

process uses two different frequencies (for example, 3,000 and 2,000 Hz) to represent the high and low states, rather than high and low level signals of the same frequency. The FSK encoded data are less affected by noise on the transmission line than data transmitted in simple high-low digital format. In addition, current signal detection techniques make it very easy to detect single frequency signals in the presence of noise.

The third basic function of a monitoring system is the analysis and display of the measured data. These operations are normally accomplished in an aboveground control center. Most of the systems have the ability to trigger audiovisual alarms if a sensor detects that its predetermined threshold (such as 1% methane in a return airway) has been exceeded. Most of the systems can also provide hard copy documentation of the alarms and display the actual values detected by the sensors, either on meters or CRT's. The computer-based systems have the added capability of data storage for trend analysis, record keeping, and reporting.

In the following discussion on commercially available equipment, a distinction is made between the system suppliers and the sensor suppliers. The distinction is made since in many cases the system supplier expects the mine to select not only the parameters to be monitored but also the sensors to be used. The system supplier then configures a monitoring system using both in-house hardware and hardware from outside suppliers to provide the mine with the desired information. Ordinarily, the data telemetry-analysis and display equipment is the supplier's own brand, while the sensors are obtained from outside companies. In most cases, the supplier will assume "full system responsibility." That is, it will not only provide the telemetry-analysis and display equipment, but will also ensure proper interfaces for any sensors selected by the mine, provide software to process the data, and assist the mine during installation, testing, and operator training. The costs for these services, however, may sometimes be broken out separately from the hardware costs. For mines that prefer to use in-house personnel for these tasks, systems suppliers that restrict themselves to providing the hardware alone may be worthwhile.

4.5.2 Telemetry-Analysis and Display Systems

Table 4-2 summarizes the major mine monitoring systems currently available in the United States. Three of the systems, Davis, Hawker Siddeley, and Transmitton, were originally based on the MINOS system developed by the National Coal Board in Great Britain. Systems offered for sale in the United States may, however, differ from the original MINOS system. Most of the systems have the capacity for accepting input from a wide variety of environmental and production sensors. An indication of the extensive use of monitoring systems abroad can be obtained by comparing the U.S.-foreign installations for the two British systems. While these systems are used extensively abroad, they are just beginning to be accepted in the United States.

As discussed previously, most of the systems use an FSK format for data transmission. The exceptions are Conspec, Mundix, and Transmitton, which use a direct binary transmission.

While the range in the number of monitoring points and cable length is substantial, most systems should provide sufficient capacity for typical usage.

In terms of system costs, one manufacturer uses a "rule-of-thumb" of $50,000 for the central station and $20,000 per mine section.

The final category of table 4-2 indicates which suppliers usually assume overall system responsibility.

TABLE 4-2. - Mine monitoring systems currently available in the United States

	Aquatrol	Conspec	Davis	Giangarlo	Hawker Siddeley	Kidde
Current installations:						
Coal mining.....	1	4	1	14	>100	4
Metal-nonmetal mining...	1	12	0	0	NA	0
Other industries.....	3,000	Several	0	8	NA	100
Specifications:						
Data transmission.....	FSK	DB	FSK	FSK	NA	FSK
Maximum number of monitoring points.	NA	768	[1]5,080	[2]6,400	[1]6,944	1,024
Cable (number of conductors).	2	4+S	2+S 4+S	2+S	7+S	1+S Coax.
Maximum cable length. miles..	[1]1	[1]0.8	20	20	8	10
Power requirements, V:						
Ac.....	110	110	110	110	110	110
Dc.....	NAp	12	NAp	12	NAp	NAp
Cost, thousand dollars:						
Central station.....	40-75	25	100	15-23	NA	75-100
Outstation.....	5-10	0.25	25	[3]3-7	NA	3-4
Overall system responsibility.	Yes	Yes	Yes	Yes	Yes	Yes

	MSA	Mundix	Outokompu	R.F.L.	Sangamo Weston	Transmitton
Current installations:						
Coal mining.....	1	0	0	1	0	200
Metal-nonmetal mining...	0	1	1	0	1	0
Other industries.....	0	1	>100	100	>100	0
Specifications:						
Data transmission.....	FSK	DB	FSK	FSK	FSK	DB
Maximum number of monitoring points.	72,000	[2]4,096	Unlimited	[4]128	8,192	7,392
Cable (number of conductors).	2+S	4+S (HF)	2+S	2+S	2+S 4+S	4+S
Maximum cable length. miles..	8	128	>6	>10	[1]2	10
Power requirements, V:						
Ac.....	110	110	110	NAp	110	110
Dc.....	12	24	24	12	12	NAp
Cost, thousand dollars:						
Central station.....	25	80	5-100	1.3-1.5	15-100	50-60
Outstation.....	1	3	3.3	0.7	5-15	4-8
Overall system responsibility.	Not normally.	Yes	Yes	Not normally.	Not normally.	Yes

DB Direct binary.
FSK Frequency shift key.
[1]Extendable.
[2]Digital inputs.
NA Not available.
NAP Not applicable.
[3]Includes CO monitor.
[4]# per station.
S Shield.

4.5.2a Systems Suppliers

The system is typically purchased from a vendor who will supply the telemetry-analysis and display equipment. Since this vendor will usually ask the mine operator to specify the sensors used in the system, sensor operating principles and available sensors are discussed separately.

All of the systems suppliers, with the exception of R.F.L., provide computer-based systems with printers, CRT's, software packages and auxiliary power in case of main mine power failure. The listing is of necessity incomplete, it does not represent endorsement by the Bureau of Mines, nor is responsibility assumed for any errors that may have occurred in system performance descriptions. Much of the material was abstracted from telephone conversations with and brochures received from the designer-manufacturers.

Aquatrol Corp.
2258 Terminal Road
St. Paul, MN 55113
(612) 636-3950

Aquatrol Corp. markets an Intel 8085-based monitoring and control system that is sold primarily to water treatment facilities. It has full system capability including color CRT, printer, and 262,000 random-access memory (RAM) floppy disk storage. The system will accommodate up to 98 outstations on the master trunk, with up to 18 data channels per outstation. Each channel can be analog, resolved to 12 bits, or the 12-bit digital word can be treated as individual binary level inputs.

Similarly, each outstation can output up to 6 analog channels or 12 binary drive levels for each analog channel less than 6.

The cable is two-conductor voice grade, operable to 5,000 ft or, with an extender, further. Power is 110-volt ac or 12-volt dc for both the central or the remotes.

Telemetry is at 300 baud using RS232C format.

A training program about a week long is offered at their plant. They will assume system responsibility and quote a maintenance contract if desired.

Conspec Controls, Inc.
901 Fuhrmann Blvd.
Buffalo, NY 14203
(716) 854-4769

The Conspec Senturion Series 200 monitoring system consists of a central processor that has a CRT display and keyboard, two printers, one or more "data concentrators," which are interface devices, and a capability for up to 768 sensing (monitoring and/or control) points on any of four trunks, each capable of carrying 128 locations. At the sensing location, the electronics necessary to interface a sensor onto the trunk (including entering its address) are housed on a 4- by 6-inch accessor card, which in many cases is incorporated into the sensor package.

Transmission is over four-conductor cable; two for power and two for signal. The power required is up to 30 volts dc, and the maximum end-to-end length is 4,000 ft. If greater distances are required, a trunk extender can be used; powered by 110 volts ac, it permits operation to 40,000 ft. A 600-baud (bit per second) FSK telephone modem is also available.

Data transmission is in a noise-resistant binary format. There are no remote stations, other than the accessor at each measurement location. Either binary or analog data can be transmitted.

Display is in a 20-character alphanumeric format (20 letters or numbers) so that interpretation is simplified. A complete software package is offered that has the capability to alarm on thresholds and set high-low points. Set points can be entered from the keyboard. There is central reset of remote points, a programed restart or load-shedding feature,

time of day or week programing, and sequencing initiated by alarm or keyboard entry.

Alarm states are printed and displayed separately. Routine information such as end of shift reports may also be generated.

Standard accessors available include interfaces for thermistors, pressure, RTD, power, current (4-20 mA, 0-5 volts, 0-1 mA), potentiometer, alarm states, two- or three-state load control, and electrical demand.

John Davis and Sons (Derby) Ltd.
Alfeton Road
Derby DE2 4AB
England

Service Machine Co., Inc.
Box 8177
6072 Ohio River Road
Huntington, WV 25702
Attn: Mr. J. H. Nash

Davis of Derby offers a data transmission system consisting of a surface master station with two video displays, a control keyboard, and a communications switchboard. Associated with this central station are up to 127 outstations, each capable of monitoring up to 40 transducers. Interconnection is by either two- or four-conductor shielded cable. Telemetry is accomplished digitally with FSK coding.

Outstations can be wired to accommodate prestart warning, belt slip, and other transducers, including temperature and pressure.

Virtually all Davis of Derby underground equipment is housed in flameproof housings, and most circuitry is designed to be intrinsically safe. Certification and design are to international standards, such as Cenelec Standard 50 020 and IS1902 Class I. Circuitry is low-power CMOS. Standby battery power is available with automatic changeover.

A variety of system configurations is available. Outstations have been designed primarily for haulage, machinery monitoring, and communication. For example, the type 25200 equipment accepts eight thermal probes and two other transducers, such as pressure and flow. Thresholds are set locally with a potentiometer. Such a unit would be appropriate as a compressor, fan, or pump monitor. There are local and remote stop modes.

Similarly, the FMS1 type 25000 accommodates six transducer inputs, and has six relay outputs for indication and/or control. It can perform level detection, temperature detection, and time delay functions. Applications listed include haulage, bunker, pump, and refrigeration plant monitoring. It is powered with 110-volt main power.

Other communication, conveyor control, and signaling devices are also offered.

Giangarlo Scientific Company, Inc.
2500 Baldwick Road
Pittsburgh, PA 15205
(412) 922-8850

The Giangarlo system consists of a central processor with associated outstations. The outstations are microcomputer controlled and are capable of accepting up to five input boards. Each board may consist of either 8 analog inputs, 16 digital inputs, or 8 relay inputs, and each board has light-emitting diode (LED) status lamps for troubleshooting. There is battery backup power. Telemetry requires a three-conductor shielded cable with data packaged in an ASCI II serial FSK digital format, run at 300 to 1,200 baud. Remote stations can alarm on their own, with visual and audible alarms.

At the central computer, software is available that will use redundancy checks of data to identify faulty transmission. It can display data, set remote alarm thresholds, and perform control

functions. Central computer alarms are independent of remote alarm status.

There is provision for interface from the central computer to a teletype, CRT display, disk memory, or another computer.

Input parameters that might be measured and transmitted to the central station include carbon monoxide, carbon dioxide, methane, temperature, air velocity, radon, belt slippage, belt speed, weight, pressure, power, etc.

Hawker Siddeley Dynamics
Engineering Ltd.
Manor Road
Hatfield, Hertfordshire AL10 9LP
England
Hatfield (07072) 68234

United Technologies Bacharach
301 Alpha Drive
Pittsburgh, PA 15238
Attn: Mr. David M. Nelson
(412) 784-2137

Hawker Siddeley is one of the qualified manufacturers of the MINOS system. It offers systems for environmental monitoring, conveyor and bunker control and monitoring, and mine cage monitoring. The "Dynalink" system for conveyor control and monitoring consists of a surface control center with provision for local control and monitoring or for remote control from the remote station. Outstations are connected to the central station with six-conductor cable at distances up to several miles. Sixteen outstations can be carried on one cable, and seven cables can be accommodated

The control station has a dual visual display. Monitored data, or change of state, or even mimic diagram graphics can be displayed. The central computer is a DEC PDP 11/34 or CAI ALPHA LS1-2/20G. Microprocessors used are Intel 8080 and 8085. There is dual control with automatic switchover for reliability.

Each outstation can accommodate 32 input channels, expandable in increments of eight. Power is 110 volt, 50 Hz, or any standard mine supply.

The bunker-conveyor monitoring and control system can automate haulage from the vicinity of the face to the surface, including bunker monitoring and metering.

Their mine cage monitor maintains the cage within speed and distance limits, comparing cage performance to a desired operation profile every 0.1 sec and making the appropriate corrections.

The environmental monitor can accept either analog or digital inputs from sensors such as anemometers, methanometers, pressure sensors, and bearing temperature probes.

Kidde Automated Systems
(Formerly S.R. Smith Co., Inc.)
7256 County Line Road
Deerfield, IL 60015
(312) 272-8012

The S.R. Smith System uses a remote "data collection panel" architecture. Each remote station is capable of receiving up to 16 contact closure inputs. The remote stations also contain relays that are capable of control functions such as starting-stopping belts. A new system has a capability for the transmission of analog levels.

The central computer facility uses Digital Equipment Corp. display and analysis equipment. A CRT displays information from any of 1,024 monitor points, connected to any of 64 remote stations per channel. Telecommunication is over a two-wire pair, or coaxial line, or 3002 Telco for each channel.

A complete interactive software package is available that displays alarms in a prioritized list. Data are also printed on a high-speed printer, as an aid to failure diagnosis and as a permanent record. Up to 700 characters of description and instruction are possible per alarm point.

Intended applications include belt monitoring (slip, alignment, power, chute plugging, etc.), power center monitoring (breaker position, voltage in range, open ground, etc.), environmental monitoring (methane within limits, air velocity within limits, etc.), fire monitoring, and fan monitoring (operating, temperature in range, etc.). The system can be used with a card reader to control and monitor people underground or in a controlled area.

Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA 15235
(412) 273-5000

Catalyst Research Corp.
3706 Crandall Lane
Owing Mills, MD 21117
(301) 356-2400

Catalyst Research Corp. has designed and tested a computer based supervisory control and data acquisition system (SCADA) which is also available from MSA. The system can accommodate up to 38 field data stations. Each data station is capable of receiving eight analog inputs, plus any one of the following: 16 digital inputs or 4 digital outputs.

Remote stations can be up to 18 miles from the central station. Cabling is by two-conductor No. 19 gage twisted pair. The central station is computer based. It uses a Digital Equipment Corp. LSI11 microprocessor with 64,000 bytes of memory. Data transfer from remotes to the central station uses RS232 at up to 2,400 baud.

Interactive, user friendly software is available. Alarm states are indicated audibly and automatically printed. Hourly and daily summaries can be generated.

Mundix Control Systems, Inc.
5495 Marion St.
Denver, CO 80216
(303) 296-1790

Mundix offers a supervisory control and data acquisition system that can accommodate up to 128 outstations. Each outstation can be configured with four electronic interface cards (extensible to 16). Each card can accommodate any one of the following: four analog inputs (12-bit resolution), eight digital inputs, eight digital outputs, or four analog outputs.

The total system capacity is 4,096 digital inputs or 1024 analog. Telemetry to the central station is accomplished using a 500-kHz digital phase modulation technique (Manchester coding). As a result, the system uses two-conductor shielded cable. The maximum transmission distance is stated to be 128 miles.

The central station is computer-based, and BASIC language programable. There are printers and color or black and white CRT monitors available. Power to the central station is 110-volt ac, while remotes can be powered with either 110-volt ac, 24-volt dc, or 120-volt dc.

Outokumpu Engineering
4680 Packinghouse Road
Denver, CO 80216
(303) 371-0540

There are hundreds of Outokumpu monitoring systems installed in Europe, primarily in power control applications. It is a computer based system (DEC) with an interactive English control software. The system has a capability for up to 30,000,000 bytes of storage on a Winchester disk and printer, CRT options.

The remote outstations are typically configured to accept 4 analog inputs, 16 digital inputs, and 16 digital control outputs. There are two types of outstations, the miniremote described above, and larger, higher capacity units. Outstations can be interconnected in any series parallel configuration. Analog data is resolved to a 12-bit precision.

Telemetry is accomplished using a serial RS232 FSK format at 300 baud (50-600). Outstations can be up to 6 miles distant. Two-conductor twisted pair cable is required.

Power to the central and remote stations is 110-volt ac, 220-volt ac, or 24-volt dc.

R.F.L. Industries, Inc.
Boonton, NJ 07005
(201) 334-3100

R.F.L. Industries manufactures telemetry equipment consisting of building blocks that can be combined to satisfy progressively more demanding system requirements. The simplest system consists of frequency-multiplexed transmitter-receiver pairs that operate with center frequencies between 300 Hz and 30 kHz in spacings of 100 and 120 Hz or more. These devices are available in two configurations: an AM system, in which the carrier is keyed on or off with a 12-volt dc input status, or a system with a switch closure. A more secure frequency-shifted version uses the same audio band center frequencies, but frequency-shift codes the data in any of four codes including a two-frequency code (mark-space) and a three-frequency code (mark-center-space). Both systems are powered by 12-volt dc. If standard CCITT channel spacing is used, there are 46 carrier channels between 300 Hz and 10 kHz, with more at higher frequencies.

If there is a need to transmit analog data, the model 64B series converts input voltages in the 0.4- to 2-volt range, or input current 4 to 20 mA, 10 to 50 mA, etc., into a square wave output, frequency coded in the 5- to 25-Hz range. After voltage- or current-to-frequency conversion, these low-frequency codes are transmitted by using the frequency shift transmitter-receiver described.

If large numbers of status-control signals are to be telemetered, the model 66A encoder-decoder will accommodate 16 input channels. These data are then time-division-multiplexed (TDM) with a redundant transmission (normal and polarity-inverted, doublescan format) to ensure reliable transmission. There are two parity check bits, so that parity errors up to the third order can be detected. Once again the data are telemetered with one of the frequency-shift, frequency-multiplexed transmitter-receiver pairs. The scan time with the normal 60-baud system is 1.1 sec with doublescan and 0.6 sec with single scan. Input data can be binary level or switch closure inputs. Power is 12 volts dc.

Analog channels can also be accommodated on the TDM system. Analog inputs are channeled, one at a time, to an A-D converter. The analog quantity is digitized and this parallel digital signal, together with a corresponding digital address, is fed to a 66A encoder. Transmission is now similar to that in the foregoing paragraph. At the receiving station, the message is decoded, and the digital output is channeled to the corresponding D-A converter to produce an analog output.

Sangamo Weston, Inc.
Industrial Products
P.O. Box 3041
Sarasota, FL 33578
(813) 371-0811

Sangamo Weston manufactures three different monitoring and control systems. Their RECON I has a capability for up to 127 remote stations, each with 12 analog inputs, resolved to 12-bit precision, and 12 output levels. Channels can be extended fourfold as an option. Operation is either manual or by computer control. Cycle time is 0.5 sec per channel.

The RECON II has eight channels per remote and can accommodate eight analog channels each, resolved to eight-bit precision (0.4%). It is controlled by an Intel 8080. The output is a printer terminal. Cycle time is 0.5 sec per channel.

The RECON III is a computer-controlled system that uses a Digital Equipment Corp. PDP-11/24 programed in RSX11M. Peripherals include a color CRT and printer. It is capable of 256 remote stations. Reporting is by exception (report when exceed limits). Each remote is capable of 16 analog inputs and has 16 output control relays (KU series 20A relays). Resolution of input signal is 12 bits (0.024%). The system has a data base and graphics edition and a capability to download to remotes over the data line. Remotes can scan subremotes.

A microprocessor-based system, MIC-RECON, is under development and will be released soon.

Transmitton Ltd.
Smisby Road
Ashby-De-la-Zouch
England LE6 5UG
0530-415941

Reliability Technology
150 Plum Industrial Court
Pittsburgh, PA 15239
(412) 325-3121

Transmitton Ltd. is also qualified to manufacture the British MINOS system. The Transmitton control consol consists of one or two color video displays, a keyboard, two switch panels, and a communications center. The Transmitton system, represented in the United States by Reliability Technology, is designed to monitor and control the operation of conveyors, pumps, electrical switches, shaft elevators, ventilation fans, and bunkers, as well as environmental parameters such as methane, carbon monoxide, air velocity, air pressure, temperature, and smoke.

The system consists of a central control station and up to 168 outstations. Data are transmitted in a digital format, but not frequency coded; i.e., high-low states are transmitted. A four-conductor cable is used.

Conveyor monitoring includes belt speed, misalignment, belt weight, torn belt, motor voltage current and temperature, vibration, and alarm states. Sonic and visual alarms are available locally and can be controlled locally or remotely. Belt start sequencing can be done automatically, so that belts can be shut down to conserve power.

Pump monitoring might include diagnostics, such as electrical current drain, pressure, flow, etc. Energy shedding can be accomplished. Power center monitoring can be used to reset breakers remotely or to locate a problem. Software for summary analysis is included.

The Transmitton systems have been installed in hundreds of deep coal mining operations, internationally.

4.5.2b Summary

A summary of the monitoring systems offered by suppliers currently marketing in the United States is given in table 4-3.

TABLE 4-3. - Mine monitoring system summary

	Aquatrol	Conspec	Davis	Giangarlo	Hawker Siddeley	Kidde
Trunks.....	1	4	1	1	7	2
Outstations per trunk..	98	128	127	512	16	64
Total input channels per outstation.	18	1 analog or 16 digital in; 1 digital out.	40	5 boards	32	24
Inputs per outstation:						
Analog.....	<18	1 (16 bit)	8	[1]8	NA	8
Digital.....	[2]18 analog	16 (1 bit)	32	[1]16	NA	16
Outputs per outstation:						
Analog.....	<6	NAp	NAp	NAp	NA	NAp
Digital.....	[2]6 analog	1 (1 bit)	4	[1]16	NA	8
Transmission distance..	[3]1 mi	[4]4,000 ft	20 mi	20 mi	8 mi	10 mi
Cost, thousand dollars:						
Central station.....	40-75	25	100	15-23	NA	75-100
Outstation.....	5-10	0.25	25	[5]3-7	NA	3-4
	MSA	Mundix	Outokompu	R.F.L.	Sangamo Weston	Transmitton
Trunks.....	3	1	Unlimited	1	32	6
Outstations per trunk..	38	128	32	1	8	28
Total input channels per outstation.....	[6]24	[7]16 boards	20	8 boards	32	28
Inputs per outstation:						
Analog.....	8	[1]4	4	[1]16	16	16
Digital.....	16	[1]8	16	[1]16	16	28 analog
Outputs per outstation:						
Analog.....	NAp	[1]4	NAp	NAp	16	2
Digital.....	4	[1]8	16	[1]16	8	28
Transmission distance..	8 mi	128 mi	>6 mi	>10 mi	[3]2 mi	10 mi
Cost, thousand dollars:						
Central station.....	25	80	5-100	1.3-1.5	15-100	50-60
Outstation.....	1	3	3.3	0.7	5-15	4-8

NA Not available. NAp Not applicable.
[1]Per board. [4]Typical, 40,000 ft maximum. [7]4,096 digital and 1,024 analog, maximum.
[2]Times 12. [5]Includes CO monitor.
[3]Extendable. [6]575 maximum data points.

4.5.3 Sensors

While mine monitoring systems can include both environmental and production sensors, this report focuses on environmental sensors. Of particular interest in environmental monitoring are air velocity, methane and carbon monoxide concentration, and respirable dust.

Air velocity can be measured by using either vane anemometers or acoustic vortex-shedding anemometers. Vane anemometers are basically mechanical devices in which the airflow causes the vanes or impellers to rotate at a speed proportional to the airflow. Although they are most commonly used underground as direct reading, portable instruments, they can also be adapted to a mine monitoring system. However, despite the advantage of mechanical simplicity, they are susceptible to dirt and moisture concentration. Vortex-shedding anemometers, on the other hand, have no moving parts and use acoustic signals to measure turbulence caused by the airflow. Both anemometers have the disadvantage that they are fixed

point measurements normally made in the boundary layer near the roof or rib and therefore do not necessarily represent a true measure of the average airflow.

Methane and carbon monoxide concentration can be measured by either heat of combustion (i.e., catalytic combustion) or infrared absorption techniques. For carbon monoxide, electrochemical analysis is also commonly used. The heat-of-combustion sensor is based on the principle that catalytic oxidation (i.e., burning) of a combustible gas such as methane will result in a temperature rise in the sensor in proportion to the gas concentrations. This technique is widely used in the methane monitors required for face equipment in this country. The infrared sensors are based on the fact that different gases have different infrared energy absorption characteristics. These sensors have been in use in South African and German mines for a number of years. Electrochemical analyzers measure the carbon monoxide concentration by chemical reaction with electrodes that are immersed in an electrolyte. These sensors have been used recently as part of an early warning belt fire detection system (that in some cases allowed the use of the beltway for intake air).

Remote monitoring of respirable dust presents a number of technical difficulties. Of the various measurement techniques currently in use, the beta-attenuation and optical devices appear to be the most suitable for integration into mine monitoring systems. The former uses beta radiation to detect dust concentration, i.e., the amount of beta absorption due to the dust deposited on a sample plate is proportional to the dust concentration. The optical sensors are based on the principle that the dust concentration is proportional to the amount of light reflected by the dust-laden air sample.

The following sections describe the sensing or measurement techniques for the four parameters of interest that are most applicable to underground mine monitoring. That is, only sensors that are suitable for remote, fixed point operation underground and that provide an electrical output that can be interfaced with standard telemetry equipment will be discussed.

4.5.3a Air Velocity Sensors

There are two basic types of air velocity sensors that are applicable to underground mining: rotating vane anemometers and acoustic vortex-shedding anemometers.

The rotating vane anemometers are mechanical devices with vanes or impellers that are rotated or turned by the air flowing through the anemometer. The better instruments use ball bearings that reduce the turning friction of the main shaft on which the vanes are mounted to improve the accuracy at low air velocities. Portable (typically hand held) vane anemometers have been a standard air velocity measuring instrument in underground mines for a number of years. The Davis vane anemometer is probably the most common example of these direct reading instruments. Recently there has been some interest in adopting these instruments to remote monitoring systems; for example, American Mine Chemical Co. is currently distributing the British Abbriko anemometer that provides an electrical pulse count output proportional to the air velocity. However, while the device does have certain advantages because of simplicity of operation, its susceptibility to excessive dirt and moisture represents a significant disadvantage. The National Coal Board, experimenting with such anemometers (such as its BA.1 and BA.2), found that increasing the vane diameter increased the torque on the center shaft and thereby reduced the potential of the shaft seizing because of dirt accumulation (9).

The second category of anemometers, acoustic vortex-shedding, measure air velocity by sensing the frequency at which vortices are shed from a rod placed in the airstream. The vortices, or eddies in the airstream, are sensed by the effect they have on an acoustic (actually

ultrasonic) pulse transmitted through them. A typical configuration would consist of a relatively compact package containing transmitting and receiving transducers mounted on opposite sides of a small rod and the electronics required to transmit the data to the appropriate outstation or control panel. Since vortex shedding anemometers have no moving parts, they are particularly well suited for underground mines. However, while they are less susceptible to contamination than the vane anemometers, they are also typically more expensive than the mechanical anemometers.

It should be pointed out that both types of anemometers are fixed point units and as such have the disadvantage of being able to measure the airflow at only one point in the airway. This restriction is usually compounded by mounting the unit close to the roof or rib of the airway, i.e., in the boundary layer where changes in the average airflow cannot always be accurately sensed. Although there are empirical methods of compensating for this measurement deficiency, they do not always provide the most satisfactory solution.

The two major suppliers of acoustic anemometry equipment in this country are J-Tec Associates and Mine Safety Appliance (MSA). The J-Tec model VA-216B is approximately 12 by 7 by 4 inches in size and can measure air velocity in two ranges; 50 to 3,000 fpm and 150 to 10,000 fpm (±2% of full scale). The unit operates on a 12 to 21 volts dc at a maximum of 35 mA. While the standard output is 0 to 5 volts dc, the unit can also provide 1 to 5 mA or 4 to 20 mA as an option. Calibration, performed at the sensor, is typically recommended at 6-week intervals. The price of the unit runs between $1,000 and $1,500, including output electronics.

The MSA sonic anemometer can measure air velocities up to 25,000 fpm. The sensor requires 110 volts ac power (30 w) and produces either 0-1 mA or 4-20 mA outputs. The list price of the unit is between $500 and $600.

4.5.3b Methane Sensors

There are two primary techniques of detecting and measuring methane concentration that are suitable for use in mine monitoring systems: heat of combustion and infrared absorption. Of the two, the heat of combustion, or catalytic combustion, sensors are the most common in this country. These sensors detect the presence and concentration of methane by measuring the temperature rise of a catalytic element that oxidizes (i.e., burns) the methane at very low temperatures without a flame. The temperature rise in the catalyst is proportional to the methane content of the air surrounding the sensor.

There is some difference in the technique by which the sensors expose the catalyst to the gas mixture to be measured. Some devices rely on diffusion of the gas mixture through a porous metal flame arrestor screen. These are often referred to as "diffusion-head" type sensors. Others use mechanical pumps to drain air samples across the catalyst. A third method, referred to as "sniff and sneeze," alternately draws the sample in and then exhales prior to the next sample. While the diffusion devices have a slower response time they are simpler and do not rely on mechanical pumps that may be affected by dust and moisture. Diffusion-type methane sensors are typically used in the monitoring and automatic deenergizing devices required on face equipment in U.S. coal mines. Although catalytic combustion sensors are relatively rugged and simple in operation, they do have (at least in principle) a disadvantage in terms of specificity. That is, the catalyst temperature will rise in the presence of any combustion gas, not just methane. However, this disadvantage is not always a major problem and can be reduced somewhat by operating at a specified temperature or selecting a catalyst that favors a methane-oriented chemical reaction. A second, and possibly more important, disadvantage is that catalytic sensors are not generally suitable for measuring methane concentrations above 5%.

The second methane sensing technique is based on the absorption, by different gases, of different amounts of infrared radiation. In a typical configuration, infrared energy is passed through a sample cell that has windows that do not absorb in the infrared band. Either the sensor is equipped with a reference cell or the sensor is calibrated by purging the sample cell with nitrogen prior to making any measurements.

An infrared detector, located on the opposite side of the cell, produces an electrical signal proportional to the difference between the reference and the sample. This signal is, in turn, proportional to the methane concentration. Infrared sensors can be used to measure methane concentrations in the entire range between 0% and 100%. While these devices are relatively sensitive and specific, they are typically more complex and expensive than the catalytic sensors.

Table 4-4 summarizes the methane sensors currently available in this country. Although only one infrared sensor is mentioned, it should be noted that several infrared sensors have been developed in other countries, among them the South African SPANAIR and the German UNOR.

TABLE 4-4. - Methane sensors

Company	Model	Measuring principle	Range, %	Electrical output	Power requirements	Cost[1]
Appalachian Electronics.	102A	NA.....	0-99	Digital	110 V ac	$1,800
Bacharach.....	CD800	Catalyst.	0- 5	0-100 mV	110 V ac	1,100
CEA.....	RI550A	Infrared.	0- 2 0- 5	0-10 mV	110 V ac	2,200
CSE.....	140	Catalyst.	0- 5	0-100 mV	110 V ac 270 V dc	2,200
Dynamation.....	1210EX	...do....	0-50	0-1 mA	110 V ac 12 V dc	NA
ERDCO.....	250	...do....	0- 5	0-50 mV 0-100 mV	110 V ac 24 V dc	1,200- 3,000
GasTech.....	1620	...do....	0- 5	0-100 mV	110 V ac 12 V dc	1,100
General Monitors...	480	...do....	0- 5	4-20 mA	110 V ac 24 V dc	1,200
J-Tec.....	VM101B	...do....	0- 5	0-5 V dc	12-21 V dc	500- 1,000
MSA.....	3	...do....	0- 2	0-1 V dc 4-20 mA	110 V ac	500
NMS.....	1810-0073	...do....	0- 5	4-20 mA	12 V dc	300
Scott Aviation.....	40008561 40008015	...do....	0- 5	4-20 mA	24 V dc	400
Texas Analytical...	1930B	...do....	0- 5	0-1 mA 4-20 mA	110 V ac 12-24 V dc	1,400

NA Not available. [1]Rounded to nearest $100.

4.5.3c Carbon Monoxide Sensors

There are three techniques of carbon monoxide sensing that may be considered suitable for use in mine monitoring systems: electrochemical reaction, catalytic-combustion, and infrared absorption.

Electrochemical sensors contain a sensing electrode, a counter electrode, and sometimes a reference electrode in an electrolyte (such as sulfuric acid solution for the Energetic Sciences Ecolyzer 2000). The air to be sampled either is allowed to diffuse into the sensor or is drawn in by a mechanical pump. The carbon monoxide in the air reacts with the electrodes, generating an electric signal proportional to the carbon monoxide concentration in the air sample. General Electric Co. has developed, in conjunction with the Bureau of Mines, a fuel cell carbon monoxide sensor that uses a solid polymer electrolyte. This design, of course, has the advantage of not having a liquid electrolyte that can spill.

The catalytic combustion technique is quite similar to that discussed earlier for methane sensing. That is, the air sample is oxidized in the presence of a catalyst, with the resulting temperature rise in the catalyst being proportional to the gas concentration. As mentioned earlier, the basic technique is nonspecific, and carbon-monoxide-specific catalysts and appropriate filament temperatures are required to reduce the interference of other combustible gases.

The infrared technique is also similar to that described for methane detection. The sensor is made selective for carbon monoxide by modifying the receiver transducer to detect changes in the infrared wavelengths that are absorbed by carbon monoxide molecules. For a nondispersive system, the absorption filters must be changed, and for the dispersive systems, the refraction grating may have to be changed.

Table 4-5 lists several representative carbon monoxide sensor suppliers. While no infrared carbon monoxide sensors are listed, at least one is manufactured in South Africa. It is called the SPANAIR, and it can also be modified for use as a methane detector.

TABLE 4-5. - Carbon monoxide sensors

Company	Model	Measuring principle	Range, ppm	Electrical output	Power requirements	Cost
Dynamation.....	CO-2300	Catalyst.....	0- 300	0-1 mA	117 V ac	$950
	CO-300	...do.....	0- 300	0-1 mA	110 V ac 12 V dc	925
Energetic Sciencies	4125	Electrochemical	0- 50	0-1 V dc	110 V ac 14-28 V dc	1,700
General Electric...	15ECS6	Fuel cell.....	0-1,000	0-20 mA	7-38 V dc	NA
MSA.....	571	Electrochemical	0- 100 0- 500	0-1 V dc	115 V ac 19-60 V dc	1,830
Neutronics.....	910	...do.....	0-4,000	4-20 mA	110 V ac	1,200

NA Not available.

4.5.3d Dust Sensors

Although there are many types of techniques to measure dust concentrations in mine air, a number of technical difficulties limit the availability of dust sensors that would be suitable for use in automatic, remote, mine monitoring systems. For example, while the Bendix-type personal dust sampler has been used successfully for a number of years, it is not amenable to remote monitoring because the filters must be manually removed, weighed, and replaced. Three measurement techniques that might be adopted to remote monitoring are described below; they are optical sensing, piezoelectric sensing, and beta attenuation.

In optical sensors, a beam of light (from either an incandescent or laser source) is directed into a chamber that contains a sample of the dust-laden air. The intensity or brightness of the light that is scattered by the dust cloud in the chamber is governed by the surface area of the dust particles. The intensity of the reflected light is typically determined by comparison with a portion of the direct light. While the device is normally manual in operation (the direct light is passed through a variable filter that is adjusted until the intensity of the direct light equals the reflected light), at least one company manufactures an optical dust monitor with an electrical output. The Japanese-made Horiba monitor provides an output of 0 to 20 mA, but since it requires 110 volts ac (10 W), MSHA approval is necessary if it is going to be used in a return airway. Another unit, GCA model RAM-1 dust monitor, measures concentrations in the range of 1 to 200 mg/m^3, has a 0- to 10-volt dc output and runs on 110 volts ac. The cost of this unit is approximately $6,000.

The main disadvantage of this technique is that a direct comparison between dust concentrations by this technique and other methods is possible only when the particle size distribution of the dust in the air sample is the same as that used for instrument calibration.

The second method is piezoelectric sensing. In this type of dust sensor, particles are drawn through an orifice and deposited on the face of a quartz crystal. This crystal is part of an oscillator whose resonant frequency changes linearly with small changes in crystal thickness (or mass). As particulate mass collects on the crystal face, the frequency decreases. Therefore, the rate of frequency change is proportional to the airborne mass concentration.

The third technique is beta attenuation. In beta attenuation instruments, the aerosol is drawn through an orifice, and particles impact on a suitable surface. The impact surface is positioned between a beta radiation source and a counter. The amount of beta absorption recorded by the counter is proportional to the dust concentration. The major example of this technique is the GCA high-concentration dust monitor that GCA developed in conjunction with the Bureau of Mines.

The major advantage of the GCA dust monitor over the light-scattering monitors is that (within certain limits) the GCA unit measures the mass concentration independent of the type of dust and particle size distribution.

4.6 Existing Mine Monitoring Systems

Monitoring systems have been installed in a limited number of U.S. coal and metal and nonmetal mines. In addition, numerous systems are installed in foreign countries. In this section, several installations are described; the reasons for their development and comments that are relevant to the central issue of monitoring and/or control in underground coal mining are given. In cases where the data have been published and are available, the name of the mine is listed. In cases where data were obtained from mine personnel and are not generally available, only a letter designation for the mine is provided.

4.6.1 U.S. Undergound Coal Mines

Mine A

Coal producer A operates a coal mine in support of its steelmaking operations. A very extensive monitoring and data acquisition system was installed in 1978. The system has production, management, maintenance, and safety components.

In 1978, production was lagging and morale was poor. A human relations audit indicated that section foremen and others felt isolated and left to fend for themselves. Communications were poor. Support to section foremen was perceived as slow and often ineffectual.

The system that was installed focused on improved communication and backup support. It monitors production, provides maintenance support from a data base system, supports underground management with improved reporting and communication, and enhances safety with tracking and followup of unsafe conditions.

At present, phone reports are required from each section foreman every 2 hours (soon to become every hour when a leaky coaxial radio link system becomes operational). The status reports are received by an operator who codes the status, including mechanical problems and repair effort underway, onto a data base reporting system. These reports include

Conditions on section.

When loading of coal started.

Mechanical delays.

Nature of delay.

Start-stop time.

Mechanical problems are keyed to machine and location. Information is coded by a communications coordinator, then telemetered over phone lines to a central office computer. Since a communications coordinator is the only one to enter the data, it is coded in a uniform fashion.

In turn, section foremen are able to interrogate the system at any of the three underground communication centers (one at base of portal, and one each at East and West mains).

Spare parts inventory software was generated from an existing program used in the mill activity. A detailed, pictorial blowup with parts number callout is available near each section. As a result, the inventory status, location, and ordering (reorder from vendor, if necessary) can be accomplished quickly underground. Similarly, management can track problems by interrogating the system.

Because the bihourly reports are relatively complete, formal end-of-shift reports are no longer necessary, and ongoing foremen have a current status sheet on which to base their plans.

This mine installed the cable for the system, purchased modems to enable communication of the data over phone lines, and then leased the remainder of the system, including dedicated phone lines to the computer facility, line printers, CRT displays, etc.

Software was developed in-house, although some of it already existed, since it was in use in the associated steel mill. Software development times were estimated to be

Production system....	14 man-months.
General underground..	18 man-months.
Maintenance.....	Existed.
Safety.....	12 man-months.

Surprisingly, one of the most troublesome links in the system has been the leased commercial phone lines (2,400 baud) used to telemeter data to the central computer facility. There have been instances of outages for days.

Mine B

Coal producer B has a monitoring system that uses equipment built by Larse Corp. of Palo Alto, CA. It is a hard-wired, time-domain multiplexed system (channels interrogated sequentially in time), designed originally for building, process control, or energy monitoring. The producer uses the system for belt monitoring and for carbon monoxide and temperature monitoring on the slope (the mine has a propane preheat system).

The history of the system is that in 1975, local management personnel had decided to upgrade the telephone system to a dial-phone system. Their chief electrical engineer urged simultaneous installation of a monitoring capability, perhaps integrated with the new phone system. He obtained mine managers' approval, and invested approximately one-third of his time during the next 3 years selecting, purchasing, installing, and testing the system. He was assisted underground with cable stringing and other installation tasks about one-sixth of the time.

The Larse system that was purchased is capable of transmitting only binary data. The sequence time is 3 sec per station. Transmission is over a spare twisted pair of conductors in the mine phone cable. An independent electronics and manufacturing firm developed and fabricted solid-state interface circuitry designed to convert voltages on control switch terminals to logic levels compatible with the Larse system. The converter was optically coupled so that belt sequencer circuitry is uncoupled from the monitor, and the converter has no moving parts, enhancing reliability. A printer is used to generate hard copy of alarm or status change. A light panel is also used to display status.

Mine personnel are evaluting the desirability of installing a J-Tec velocity and methane system. Their most likely application would be a continuous monitor of worked out panels, eliminating the need for a 4-hour inspection mandated by the State.

Extensions of this system might include ventilation control. In that case, a variable-speed synchronous motor drive on their fan might be used to reduce energy demand when the full output is not needed. At present, 1,600 hp is drawn for ventilation. Original plans called for some airflow and methane monitoring, but this step was deferred as "too expensive with little payback."

The monitoring system is maintained by one man, who also maintains the telephone system (which requires much more time than maintaining the monitoring system).

Mine C

Operator C has several mines that have very gassy seams and heavy overburden with difficult roof control problems. As a result, personnel at this mine have received a variance from MSHA allowing the use of beltways as an inlet aircourse.

They have 5 years of experience with carbon monoxide monitors, using Energetic Sciences sensors. The current Energetic Sciences monitors that are purchased have two level alarms and a built-in battery pack for uninterruptable power supply.

The telemetry system is an S.R. Smith system that transmits digital information only and necessitates a dual threshold modification to the Ecolyzer. False alarms are generated with the Ecolyzer as the result of power intermittencies, a prime factor in the insistence on an uninterruptible battery supply. To enhance reliability, redundant PDP-11/4 computers have been installed to analyze and display data. Maintenance by DEC has sometimes been slow, although the system has been completely down only once in the last 2 years, thanks primarily to redundant equipment.

Plans include staffing up to one full-time engineer per mine for the monitoring system. Although the system initially gave frequency "nuisance" alarms, those problems have largely been solved, with the occasional exception of false alarms associated with the monthly calibration procedure. They also conduct a weekly inspection. Where alarms are displayed at the surface, the appropriate site is notified by telephone.

Future plans include monitoring of methane and airflow in returns. They have a methane drainage research project for which they have currently purchased methane and airflow monitors. During a 6-week period in the winter of 1981, they lost 10 shifts of longwall production as a result of gas outs, shutdowns that are sometimes mine wide and are the motivation for their ventilation monitoring and control plans.

Adjustment and deployment of the monitoring system hardware, including sensors, is a nuisance factor. There have also been incidents of either willful or careless destruction of equipment, particularly sensors.

They also monitor bearing temperature and water gage on their main ventilation fans, using a FSK audio band telemetry scheme.

The software for the S.R. Smith system was written by a software specialist. The costs for software were viewed as substantial.

Mine D

Coal producer D has made a very substantial commitment to its mine-wide monitoring, data acquisition, and control. Its mines are deep, with typically more than 2,000-foot overburden, are very gassy, and have difficult roof control problems. As a result, the producer has received permission to use the belt passageway for inlet air, provided that carbon monoxide is monitored. Currently two mines are equipped with belt fire monitoring equipment and two more are being outfitted. The two that are presently on-line have been operating for about 6 months. The system consists of Ecolyzer carbon monoxide sensors, with up to 40 monitors per mine, a Giangarlo transmission system, and Niagra Scientific computational and display equipment. There is no maintenance contract. The software was provided by Giangarlo. The system scans stations at a rate of about 1 per second. The cabling for the system is military surplus wire that is four-conductor twisted No. 19 wire with steel armor, which mine personnel purchased inexpensively. It has been found that the digital (frequency shift) signals can be transmitted up to about 3 miles with virtually no problems. The alarm algorithm at present is simply a level exceedance alarm. There have been four cable failures in the last 6 months, two failed open and two failed shorted, owing to accidents with large boulders on the belt. In the case of cables failing open, the system continued to operate up to the cable break, and in the case of cabling failing shorted, the entire system was faulted until repaired.

It is estimated that maintenance of the system requires about two man-shifts per week, including daily, weekly, and monthly inspections. The daily inspection is a physical inspection by the fire boss, the weekly inspection involves electrical tests, and the monthly inspection involves span calibration. The maintenance effort was estimated to be approximately one-half inspections and calibrations and one-half repair functions.

Ac power tends to be unreliable and intermittent. As a result, a gel-cell power has been installed for each sensor with a 48-hour capacity and continuous trickle charge. In the event of inadvertent disconnect and resultant battery discharge, the Ecolyzer indicates a false alarm.

All four systems were expected to be operating by 1982. Following completion of this carbon monoxide fire monitoring system, the system will be extended to monitor belt operation. In the No. 3 mine, there are 25 belts, each typically 4,000 feet long. The intent of the belt monitoring is to display remotely information about which belts are down and possibly, diagnostics as to failure mode.

Because the seam being mined is extremely gassy, the required amount of air is very high. This demand, combined with the extreme depth, results in very high water gage and very high ventilation costs. As a result, variable pitch ventilation fans have been installed, and methane and airflow will be monitored in the returns and the fan pitch modified accordingly to reduce ventilation costs. When a 2,000-hp fan was increased to a larger 7,000-hp variable-pitch fan, the power costs increased $1,900 per day at that mine. Plans also exist to monitor the temperature and vibration of fan bearings.

In addition, the producer is also automating its billing, inventory control, and maintenance functions, such as maintenance history, equipment inventory, lubrication histories, preventive maintenance, etc., as well as automating some mapping and plotter routines. These computational facilities will use their own computers and programs and *not* piggyback on the fire monitoring system.

Other monitoring plans include production tonnage monitoring, by section and shift, as well as power center monitoring, particularly on longwall sections.

Mine E

Mine monitoring at operation E has the following three distinct functions:

Trapped miner location-roof fall monitoring.

Ventilation monitoring at 11 stations.

Fan monitoring.

Trapped Miner-Roof Fall Detection

The trapped miner system was originally installed several years ago as a Bureau-funded research project. Six commercial, 40-Hz resonance, moving coil geophones are implanted about 2,000 feet apart in 50-ft-deep holes backfilled with sand. Their seismic output is fed to a Texas Instruments 980A computer that computes the epicenter of any event observed by three or more geophones. The software package includes graphics that plot the trapped miner-roof fall location with a triangle if three geophones received the signal, a square if four were activated, and an asterisk if five or more sensed the disturbance. The coordinates and computed confidence margin (error) are printed. Triangulation in the southern mine sections where the equipment is located is to within 50 to 100 feet. A disturbance count is also recorded. The trapped miner equipment is all located on the surface.

Ventilation Monitoring

Mine personnel at operation E were interested in upgrading mine technology and therefore were receptive to a Bureau of Mines request for a cooperative development. An electrical engineer from research was assigned to design and supervise the fabrication and installation of a ventilation monitoring (methane, carbon monoxide, air velocity, temperature) system and to assist in the development of a trapped miner location system. The telemetry system he designed is an audio frequency, FSK serial transmission system. It has a capacity for 16 stations and a capability for up to eight analog inputs at each station (0-5 volts dc). Data are telemetered in an audio band. The system is powered with a converter that uses power from the trolley wire,

converting -345 volts dc trolley power to 13 volts dc. At each station this 13-volt power is again converted to ±15 and ±5 for logic and control circuits. Methane is detected by mounting a Bacharach cell directly on top of the explosion-proof container that houses the electronics. Access to the box is via multi-pin Amphenol environmental connectors.

Carbon monoxide is detected with an Ecolyzer 4000 device, from which the 110-volt converter has been removed. Air velocity is measured with a J-Tec anemometer, mounted on a 3-ft-long pole near the center of the passageway. Flow calibration is accomplished with a Davis anemometer.

The processing display package prints hourly summaries of the low reading, high reading, and hourly average at each station.

Manual cross-checks of the system by the fire boss on his round are used to verify system accuracy and reliability. Each station is interrogated electronically every 5 min. The system has a capacity for 16 stations and a maximum cycle rate of 2.5 seconds per station.

Telemetry cables (unshielded twisted pairs) are strung adjacent to the trolley wires. The operation is gradually relocating these cables, since the most frequent failure mode for the system is a loss of telemetry because of a cable cut by a derailed trolley pantograph. Because of line losses, the sensors must be within 500 feet of the power supply and telemetry system.

Data are processed at the surface (thresholding, time averaging, high and low peak) and stored on a Phillips cassette. The cassettes can be processed with a print routine to generate hard copy.

A problem encountered during development of the wire power-to-12-volt dc converter was that there are massive transients on the trolley wire that the converter could not handle. The solution was to use a high wattage voltage divider with a zener limit, then dc-to-dc convert the voltage-divided, filtered dc.

The operation has asked for extension of the ventilation monitoring system to the north to cover the other half of the mine. However, the research staff is now committed to other projects.

All maintenance and operation is performed in-house. Spare boards are stocked for the TI 980 and the computer is maintained by swapping out defective boards. Normal maintenance and record keeping takes about 45 min per day. The system costs a little over $100,000. Individual stations cost $2,000 to $2,500. The biggest maintenance cost, by far, is line repair.

Fan Monitoring

The primary ventilation fans are continuously monitored. Local system dc power and fan head, in inches of water, are reported hourly with a low, average, and high reading. Alarm status is, of course, immediately printed.

Mine F

Operator F has three mines that share a power distribution system and that have very substantial monitoring instrumentation. Mine personnel have also begun development of a data base acquisition system. The system consists of several layers, developed sequentially.

The initial installation was a surface system for fans and circuit breakers. Later, haulage monitoring and underground fire detection were added. A large data base supervisory control system is now being installed that will be used to upgrade the fan monitoring to include vibration and temperature

monitoring so as to (1) anticipate failure, (2) detect smoldering fires by using carbon monoxide monitors, (3) control utility costs by power shedding when desirable, (4) extend haulage monitoring and control, and/or (5) acquire and store maintenance data on machines for preventive maintenance and failure analysis.

Quotations for this system are being solicited from mine monitoring system vendors and particularly from process control and energy management equipment vendors. A brief summary of the equipment to date follows.

Surface System

The surface system monitors ventilation fans and the status of circuit breakers. At present, there are 13 fans in the complex and 28 monitoring substations. The system was developed in-house in 1973 and uses a hard-wired FSK technique, with a 40-channel capacity.

Underground Haulage and Fire Detection

At present there are about six sections of instrumented haulage. A CRT display at the dispatcher indicates the number of available empty cars at each station, an estimated time of depletion of cars (a function of whether the mine is cutting), the number of loaded cars, a count of loaded cars for the shift, and whether the belt is running.

Heat sensor fire detection outputs are also displayed. Data acquisition is accomplished with a Westinghouse neumalogic system. A deluge system is controlled by the output.

Power Monitoring

The three mines have a monthly utility bill of several hundred thousand dollars. As a result, attention is being given to power center control and load shedding. At present, overall power drain data are provided to dispatchers, so that they can shed "unnecessary" or lower priority loads; however, shedding rarely happens because of production pressures and the overwhelming complexity of the problem. Effective control requires mine-wide information, analysis, and synthesis of the data.

The operation buys power from the local utility at 69 kV, then distributes and transforms the power for the operations. Power billing is in proportion to the highest 30-min average, using sequential time windows (not a floating window).

Methane Monitoring

Methane is continuously monitored in one abandoned area.

Mine G

Operator G has a Motorola Intract 2000, UHF high-band transmitter-receiver system that is used at three mines. Personnel at this mine monitor ventilation fan operation, sensing water gage, and measuring bearing temperature and vibration. In each instance, the alarm level exceedance is the only data transmitted. In the case of circuit breakers, they have the capability to reset, trip, and monitor each of these.

Each mine typically has several fans and perhaps 20 circuit breakers physically distributed over the countryside, perhaps up to 4 or 5 miles distant from the portal. Electrical power is either 7,200 volts ac three-phase or 300-volt dc trolley power. In the case of circuit breakers, the system is used primarily for control and for resetting after interruptions. They reset as a test, and, if there is a second interruption, they dispatch a man to the site. Since fan

monitoring is required by law, the system saves personnel assignment to monitor the remote fans.

At the central station, located in the maintenance shop, data are displayed on a console with eight status lights, designating the presence or absence of threshold exceedance of any one of eight sensed variables at a site. There is also a hard-copy printout on a TI printer of twice-a-day status, plus alarms. One-third spares are maintained, and Motorola gives a 3-to-8-week turnaround time for repairs. The system has been on-line for 15 months, with many initial problems that have evidently been worked out.

Two fully qualified technicians with FCC licenses are on the staff and a third is being sought. Testing and qualification certification is contracted out.

Monitoring of this sort dates to 1969 when it began with a FEMCO hardware system. In 1975, an intermediate radio system was added and, later, the Intract 2000.

The parent research organization has also experimented with the feasibility of monitoring cars, as well as production activity, on each section, to improve the efficiency of the dispatch of cars to operating sections. This was a test of instrumentation and technique, using one section. They measured

1. Is the section operating?

    a. Continuous miner off.

    b. Continuous miner tramming.

    c. Continuous miner cutting.

2. At the section, how many--

    a. Cars at ramp.

    b. Empty cars waiting.

    c. Full cars.

    d. Empty--full conversions.

3. How many cars available at the dump site?

The goal was to reduce the "no empty" delays at the section.

The dispatcher has voice communication with the locomotive engineer and the loading supervisor at each section. Development of the design began with the following constraints:

1. Commercial sensors to be used, perhaps repackaged.

2. Existing phone lines to be used (Gaitronics) [but not same wires, i.e., use phone-quality wiring. Cable is figure 8, wire-supported, with 40 conductors in pairs.].

The sensors tested were

1. Infrared photocell (car count).

2. In-track magnetic proximity (count).

3. Sonic level (full-empty).

4. Current sensor at load center.

    a. Off

    b. Tramming

    c. Cutting

5. Traffic switch positions.

All data were telemetered to the dispatcher. There are local displays for debugging purposes. Intel microprocessors were used in remote stations.

A test of the sensing system was conducted by stationing an observer to note visually car passage, operating

time, empty-full status, and switch position. The test results were

	Visual	Automatic	Error
Direction.....	582	599	3%
Empty-full.....	230	233	1%
Operating time.....min..	820	813	
Switch position	49	49	0

It was concluded that sensing reliability was good and quite adequate.

The most difficult problems were (1) the deployment-redeployment of sensors, and (2) cost-complexity of the system.

It was concluded that this type of rail haulage monitoring is technically feasible; however, the economic viability is probabilistic. There is economic payback only if all sections are instrumented, since intersection coordination is the goal. The operator opted for a computer simulation at this point to evaluate the economics, using a modified version of the Penn State RailSim program. The results indicated substantial incremental improvement in productivity, but since the operation is market limited, the economics for such a system were not quite attractive; i.e., it cannot easily sell more coal per year and cannot capitalize on the potential to run less days per year because of large capital costs and institutional factors.

A simpler less costly system might be viable. For example, a system that reported

1. Whether the section is operating (power center).

2. What the car count is at the dump site.

3. Other data manually input by the dispatcher.

Since use of longwall sections is expected soon, problems with haulage coordination will be intensified. "Intangibles" (safety, morale, health, labor resistance, sabotage, etc.) are hard to evaluate.

A "smart sensor" standalone is being considered that--

1. Obtains power off rail line.

2. Senses a parameter, converts data to a secure format.

3. Transmits wireless.

Passive (unpowered) sensors are used wherever possible, and sensors are minimized (more manual input).

Power Monitoring

Billing of power used by energy-intensive industrial users is based on a base rate plus a peak load factor. Mine G's local utility expects to go to a peak factor based on the highest 5-min average, perhaps highest floating 5-min average. Although the potential savings are *very* substantial, an automatic power management system is clearly required to react within 5-min windows.

A very ambitious computerized maintenance management program has also been begun. There seems to be a likelihood that haulage and ventilation monitoring and/or control will eventually be attempted.

Mine H, Federal No. 2

Sensors for carbon monoxide and methane were placed so as to compare methane concentrations entering and leaving each section. Differential pressures were also measured to highlight ventilation problems owing to partial blockages, etc. Temperature, humidity, and air velocity were also measured at dozens of sensor stations. Computer control was performed at West Virginia University. These early tests served to prove that the task of underground monitoring was technologically feasible (2).

More recently, a similar system has been used to test the concept of ventilation control (1). Ventilation parameters, including methane, carbon monoxide, temperature, humidity, airflow, and differential pressure, were measured. Ventilation regulators (louver door design) were operated electronically, and the resultant ventilation redistribution was monitored.

Mine I

Drainage of methane in advance of mining is an effective way of minimizing methane content at the working face. Since most coal mining countries have enacted safety regulations that require that face equipment be shut down if the methane content in the air reaches a predetermined level, methane drainage has production as well as safety benefits. Because methane liberation increases with rate of coal production, methane drainage is more desirable in highly mechanized longwall operations where production rates are relatively high. As a result, methane drainage is used extensively in Europe where longwall mining has become very common. In 1975, approximately 7.5 billion cubic feet of methane was drained in Polish mines, and over 21 billion cubic feet were drained from mines in the Federal Republic of Germany (7). Recently, methane drainage has also become more important as the production rates in U.S. mines have increased.

Because of the inherent design that roof falls, bottom heaving, etc., may rupture the methane drainage piping, the Bureau of Mines has specified that drainage systems be equipped with a "fail-safe" monitoring and control system (22). Basically, the system should be able to shut off the flow of methane into the drainage pipe in the event of unsafe conditions such as a power failure or break in the drainage piping.

One such system has been successfully employed in the Bethlehem Mines, Marianna No. 58, located in Marianna, Pa. This system consists of MSA methane sensors located at 500-foot intervals in the airway containing the methane drainage pipe. The output from these intrinsically safe sensors is transmitted to a control panel located in a nearby fresh air entry. Also located in the fresh air entry is a small (1.05-cfm) air compressor that supplies air through PVC tubing strapped to the drainage pipe, to the pneumatically actuated shutoff valves located at each borehole. The valves are spring loaded and held open by the air from the compressor.

The system can also incorporate a "receiving" station (located above ground) that contains meters that indicate the methane content measured by the sensors and recorders that provide a continuous log of the sensor output.

In the event of a power failure, the compressor would cease to function, the air pressure in the PVC tubing (normally 55 psig) would drop, and the valves would close. If the methane content in the airway containing the drainage pipe exceeds 1% (due to a leak in the pipe), the PVC tubing is vented by solenoids located on the control panel and the valves again shut down the methane flow. In addition, if a roof fall ruptures the drainage pipe, it will also rupture the other PVC tubing that is strapped to the top of the pipe, automatically dropping the pressure and closing the valves. Finally, if a sensor fails to operate or a cable is severed, the solenoids will vent the PVC tubing and again close the borehole valves.

References 10 and 18 discuss this system in more detail.

A summary of the monitoring systems reviewed is presented in table 4-6.

TABLE 4-6. - Summary of monitoring systems surveyed in U.S. underground coal mines

	A	B	C
Function	Production, maintenance, communication.	Belt monitoring	Belt fire monitor, equipment status.
Parameters monitored	Input from section foremen.	Belt operation, belt sequencing, motor temperature and power, CO.	CO, fan temperature and pressure, degasification pumps, fire suppression operation.
Size:			
Remote stations	6	40	15 to 20.
Input per station	NA	10	16 maximum.
Telemetry:			
Cables	2-conductor	2- and 4-conductor	2-conductor and multiconductor, shielded.
Format	Voice and digital	Digital	Digital.
Data display	Line printer, CRT's above and below ground.	Line printer, light panel.	Line printer, CRT.
Alarm	No	Yes	2-level.
Year installed	1978	1978	1978.
Comments	Production reports, manpower planning.	Planned expansion--air velocity, CH_4 monitoring.	Allowed 75.326 variance.
	D	E	F
Function	Belt fire monitor	Environmental, fan operation, roof falls.	Fan operation, haulage, fire, environmental.
Parameters monitored	CO	CO, CH_4, air velocity, fan power and pressure, seismic activity, battery voltage.	Fan operation, haulage, heat-CO, CH_4.
Size:			
Remote stations	13	11	26.
Input per station	1	4	16 maximum.
Telemetry:			
Cables	4-conductor, shielded	5-conductor	2- and 4-conductor, shielded.
Format	Digital	Digital	Digital.
Data display	Line printer	Line printer, plotter, CRT, light panel.	Line printer, CRT, light panel.
Alarm	At station and aboveground	Yes	Yes.
Year installed	1981	1974	1978.
Comments	Allowed 75.326 variance, planned expansion--belt monitor, ventilation monitor.	Result of cooperative agreement with Bureau of Mines.	Planned expansion--fan temperature, vibration, maintenance data.
	G	H	I
Function	Fan operation	Environmental monitoring	Methane drainage.
Parameters monitored	Fan operation, temperature, pressure, vibration.	CH_4, CO, temperature, relative humidity, airflow, differential pressure.	CH_4.
Size:			
Remote stations	10	12	>4.
Input per station	8	10 to 20	1.
Telemetry:			
Cables	Radio link	2-conductor	4-conductor.
Format	FM	Digital	Analog.
Data display	Line printer, light panel.	Mine maps, CRT, teletype	Strip chart, meter.
Alarm	Yes	2-level	2-level.
Year installed	1979	1972	1977.
Comments	Had prototype haulage monitor, planned expansion--maintenance data.	WVU experiment, Bureau of Mines sponsored.	Controls drainage valves, result of Bureau of Mines Research.

NA Not available.

NOTE.--Alphabetic designators are those used for mine designations in text.

4.6.2 U.S. Underground Metal-Nonmetal Mines

Mine J

Although mine J is not a coal mine, its physical layout and mining technique are very coal-like. It is a very extensive, single-level, room and pillar mine that extracts about 5 million tons per year, working about 7 feet of a 9-foot seam that is 1,200 feet deep. The mine is classified gassy because of the presence of oil shale above and below the seam. However, it is allowed use of the beltway for fresh air, since metal-nonmetal mines are governed by 30 CFR, Part 57, which is less restrictive than the sections governing coal.

Up to 10 continuous miner sections and a longwall are operated. Underground equipment is electric, with a combination of rail and belt haulage.

A very satisfactory 50-station haulage monitoring system has been installed, and an additional system is on order. There is about 20 miles of belt conveyors.

The system, which was built by Aquatrol Corp., monitors belt functions such as belt slip, plug up, sequencing, alignment, etc.

Mine K

Operator K operates a multilevel copper mine, and has an ambitious load-shedding program underway. The haulage is electric-powered track and belt. Face operation is with diesel-powered trackless vehicles. Sump pumps run up to 5,000 hp. The utility bill is based on a 15-min peak load factor, which is hoped to be reduced greatly by load shedding. The hardware and telemetry will be purchased from Harris Co. Enlargement to a mine-wide supervisory control and data acquisition system, including airflow, perhaps production monitoring data, etc., is anticipated. An example with rapid payback is automatic measurement of air quality following a large explosive shot. At present, a rescue team is dispatched to certify the work areas. The result is a 3- or 4-hour mine-wide shutdown, which is, of course, expensive.

4.6.3 Foreign Mines

Canada

As in many countries, mine monitoring in Canada has become more important in recent years. The Canadian Mining Research Laboratories (CANMET) has been working on carbon monoxide and methane monitoring in western Canada since 1976. One such monitoring system, which uses an electrochemical carbon monoxide analyzer, was installed in a Kaiser Resources mine to detect mine heating. Air samples were drawn through 1/2-inch OD polyethelene tubing from distances up to 7,000 feet (8). In 1978, this system detected a significant rise in the carbon monoxide levels in one return, indicating the potential onset of heating. This early indication of heating was credited with allowing the mine to alleviate the situation without interrupting the mining schedule.

CANMET began working on methane monitoring in the coal mines in western Canada in 1977. This work centered around the use of remote methane analyzers, again by drawing air samples through polyethelene tubing. In one mine with a history of sudden gas bursts, the system successfully documented the sudden methane liberations (8).

More recently, the Cape Breton Development Corp. has installed a computer-based mine monitoring system in its coal mine in Nova Scotia (6). The system, which monitors methane concentrations, air velocities, air pressures, fan vibration, machine temperatures, and methane pump pressure, was supplied by Transmitton Ltd.

Poland

As is true for much of Europe, the Polish coal mining regulations consider continuous methane monitoring in the return airways with automatic deenergizing as an adequate alternative to individual monitoring on each piece of face equipment (as is done in the United States). Furthermore, the methane threshold values permitted by the regulations are also increased in mines where continuous monitoring and automatic deenergizing are used (16). As discussed earlier, such regulations tend to encourage the use of remote mine monitoring systems.

The Polish Research and Development Center for Mining Mechanization, Electrotechnics and Automation Systems (EMAG) has been working on ventilation monitoring and control systems for Polish coal mines for a number of years. The methane monitoring systems currently consist of remote sensors, telemetering equipment, and a miniprocessor, located in a central station that receives and analyzes the data. The system has the capability of automatically switching off electric power if the methane concentrations exceed the specified level. The system also maintains permanent records of warnings and alarms and provides summary reports on methane liberation cycles, etc.

For fire monitoring, EMAG has also developed a carbon monoxide monitoring system based on a catalytic sensor and an ionization fume sensor. The system has been tested, experimentally, in Polish coal mines.

EMAG has also worked on developing automatically controlled air regulators for coal mines. The regulator, which has pneumatically or hydraulically actuated vanes, is intended to become part of an overall mine monitoring and control system.

Sweden

Since most of the mining in Sweden is metal mining in nongassy mines, interest in methane monitoring and control is not great. The Swedish mines do use diesels, however, and an effort is underway to monitor carbon monoxide, nitrogen dioxide, etc. In addition, some work has been done on the development of automatic air regulation. Because methane liberation is not a problem in Swedish mines, mine air regulation, which would be based on the number of diesels operating and on their location, is currently being studied (19).

U.S.S.R.

Automatic monitoring and control of mine ventilation systems has been studied in the U.S.S.R. for a number of years. This work has resulted in the development of an automatic ventilation monitoring and control system called ATMOS. This computer-based system is reportedly (14) able to monitor ventilation parameters (such as methane concentration, airflow, etc.), calculate the required airflows, and provide the system operator with information on the appropriate fan and regulator settings. Ventilation corrections are made on a weekly basis.

The system has been operationally tested in two mines, and the Ministry of Coal Mining is currently in the process of commercial development of the ATMOS system.

United Kingdom

The development and use of remote mine monitoring systems is probably more advanced in the United Kingdom than in any other country, apparently for two reasons.

The first is that British mining regulations tend to encourage the use of such systems. For example, in contrast with U.S. regulations requiring that methane monitoring devices be installed on each piece of face equipment that can deenergize the equipment once the established methane threshold is exceeded, British regulations permit monitoring of the return airways for methane if the data are transmitted to a central control

station that can remotely deenergize the affected equipment.

The second, and probably the more important reason, is that the British coal industry is nationalized and is supported by a centralized research organization (the National Coal Board's Mining Research and Development Establishment--MRDE). This arrangement has greatly facilitated the development, testing, and implementation of mine monitoring systems in the United Kingdom.

In the 1970's, the MRDE focused its attention on developing a universal monitoring and control system that could be used throughout the coal mining industry. The system, called MINOS (for Mine Operating System), is based on a common core of equipment that consists of a control console, central computer(s), and peripherals. The application software is also the result of MRDE development. The monitoring systems are supplied to the mine by several independent companies that are free to market a variety of transducers, data transmission equipment, and accessories. The concept of a universal computer-based operating system has permitted the MRDE to achieve certain economies in the development of the system and tends to reduce interface problems.

The applications of the MINOS monitoring/control systems can be divided into the following six basic categories:

1. Ventilation monitoring.
2. Coal face monitoring.
3. Coal clearance monitoring.
4. Coal conveying monitoring.
5. Fired plant monitoring.
6. Preparation plant monitoring.

Ventilation monitoring in the United Kingdom is currently being accomplished via tube bundle air sampling as well as telemetering of data from electromechanical transducers. In the former, air samples are drawn through tubes and analyzed by using a gas analyzer located in a surface lab facility. In the latter, the output of the transducers is fed to outstations that encode and transmit the data to the surface via a communications cable. In either case, the environmental data (methane, oxygen, carbon monoxide levels, airflow, differential pressure, etc.) are analyzed, stored, and displayed on video monitors located on the central control panel. The displays and hard-copy reports can consist of warnings, alarms, actual values, or graphs of long-term trends (9). As of 1980, there were approximately two such systems either in operation or scheduled for installation (3).

Development of a system for monitoring face equipment performance began in 1977. One version of the system, called FIDO (Face Information Digested On-Line) was installed and tested in four collieries by 1980. The National Coal Board plans to install the system in an additional 24 collieries that have approximately 100 active coal faces (20). Although the system originally monitored only face equipment operations, the NCB plans to expand the system to provide data on such parameters as roof height, pick force, and equipment orientation, and eventually to permit automatic control of such equipment as longwall shearers.

Monitoring and control of underground coal conveying systems is relatively advanced in the United Kingdom, with the first system in operation in 1972. The systems provide stop-start logic sequencing in addition to sensing of such parameters as bearing temperatures, blocked chutes, motor operation, etc. As of 1980, there were approximately 30 such systems in operation in the United Kingdom (20).

Monitoring and control of coal preparation plant operations (such as conveying, reagent mixing, etc.) is a relatively new application for the MINOS system. The system began development testing in the Lea Hall colliery in 1978.

A decision on expanding the use of the system will depend on the results of this inplant demonstration.

It should be pointed out that mine monitoring systems based on the MINOS concept are currently being manufactured in the United States.

Germany

In recent years, remote monitoring of methane and carbon monoxide has received increased attention in German coal mines. One reason is that the German Federal Regulations on mine health and safety make such systems desirable and, in some cases, necessary. For example, the German regulations permit higher methane threshold values if constant monitoring is carried out by permanently installed recording instruments that can telemeter the data to a remote control center that can automatically deenergize the electrical face equipment (16). Another example is the German requirement for automatic recording of carbon monoxide levels along all belt entries.

It has been estimated that as many as 1,400 methane and 1,200 carbon monoxide measuring devices were in use in the Ruhr district in 1978. Most of these provided remote transmission of the measurement data to a central control station. In addition to the methane and carbon monoxide sensors, some 500 fixed-point air velocity sensors were also estimated to be operating in Ruhr district mines as of 1978.

In addition, investigations have been conducted in Germany into the use of minicomputers as well as microcomputers to receive and process the data from the remote sensors. The primary purposes are (1) the reduction of false alarms through trend identification and signature matching and (2) the manipulation, presentation, and storage of large amounts of monitoring data.

South Africa

Remote automatic detection of underground mine fires is a major concern for South African mining companies. This is particularly true for the deep level gold mines because of the large amount of timber required for roof support in these mines. Instances of spontaneous combustion in South African coal mines have also been reported in recent years. For example, between 1968 and 1973 more than 23 mine fires occurred in one South African mining district. Approximately 65% of these were attributed to spontaneous combustion (11).

Two basic approaches have been used in remote monitoring for underground mine fires. In coal mines, an infrared gas analyzer drawing air samples through polyethelene tubes has been used to sense carbon monoxide levels (11), and a combination of infrared gas analyzers and ionization chamber detectors has been used in the underground gold mines (23). In the latter case, the electrical signals from the transducers were telemetered to a control room located above ground. In the control room, data (carbon monoxide level for the gas analyzer and ionization level for the combustion and particle detector) are recorded in analog form on continuous logs. In addition, the system has the capacity to initiate alarms if specified levels are exceeded.

Although some difficulties were encountered with the ancillary equipment (such as recorders) in the tube system and dirt and condensation in the telemetry system, both have proven effective in detecting mine fires.

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