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Underground Mine Communications, Control and Monitoring

By Staff, Bureau of Mines

UNITED STATES DEPARTMENT OF THE INTERIOR

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PREFACE

Since 1969, the Bureau of Mines, U.S. Department of Interior, has sponsored numerous programs aimed at improving methods of underground communication. As a result of these research and development programs, a wealth of information has been made available to the mining industry. Unfortunately, some of this material is highly analytical, and most is written in terms best understood by communication specialists. Because of the volume of data (over 100 studies have been performed) and its highly technical nature, most of the information is not readily available for practical application by mine operators. This manual brings together relevant data from all previous reports, studies, and other sources, and presents these data in such a way that they may be applied by the mining industry to improve communications in underground mines.

This report is intended as a guideline and not as a comprehensive documentary of mine equipment. Installation of equipment in a mine should be done only by people thoroughly qualified to do such work. Installations should follow procedures recommended by the equipment manufacturer and should comply with good safety practices. All installations should also comply with applicable codes and regulations.

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CHAPTER 1.--INTRODUCTION

1.1 History of Underground Communications

Although the technology involved in removing material from below the earth's surface has a long history, communication systems in underground workings are relatively new to the industry. Communication equipment did not begin appearing in underground mines until the early 1900's. Figure 1-1 shows a miner using a Western Electric standard telephone set for underground mines in 1913. These early phones were essentially the same as those used aboveground, except that they were enclosed in cast-iron boxes as protection against moisture, acid fumes, and gases.

In the 1950's, the Chesapeake and Potomac Telephone Co. of West Virginia introduced a telephone set for use in explosive atmospheres that was designed around the philosophy of explosion containment. To contain an explosion within the telephone set required a 39-pound casing, which greatly limited portability.

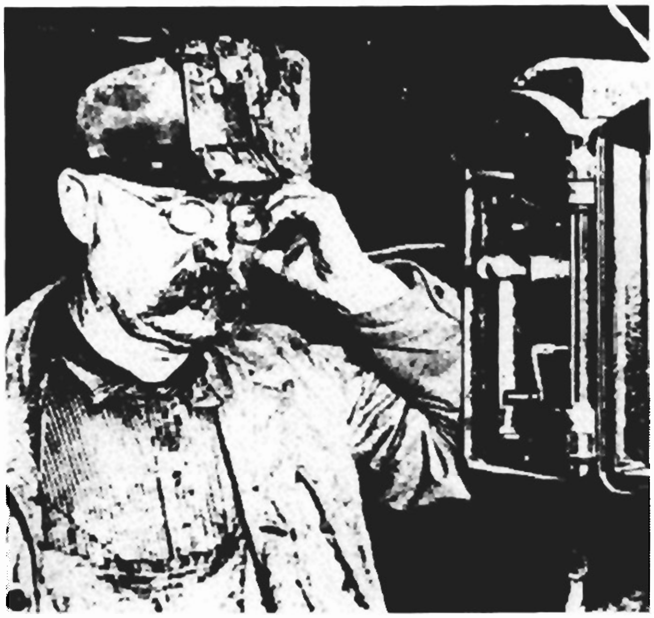

FIGURE 1-1. - Coal miner talking on an underground telephone in 1913.

Both of these telephone sets required "pipe" or conduit, not a very practical item for a 100-square-mile coal mine. A common thread prevalent in the first 40 years of design and development is that the primary effort was placed on the telephone set.

In the early 1970's, as work began on the design of modern communication systems for use in underground mine environments, the following requirements were established:

1. Must meet intrinsic safety standards.--This applies not only to coal mines, but to other explosive environments.

2. Must be compatible with the environment.--The system must withstand dust, moisture, and corrosive conditions.

3. Must be rugged in structure.--The system must withstand maintenance by 10-inch pliers and 4-pound hammers, as well as impact from a falling piece of roof.

4. Must be size-flexible.--Whatever is built must be sized for the small operator as well as the large companies.

5. Must be a total system in design.--The system must be intrinsically safe, including cable, power supply, and station set.

6. Must work with present telephone system.--The system should be compatible with aboveground communications already in place; it should not be the single cause of change in aboveground communications.

7. Value-added pricing.--The system should be reasonably priced so that savings created by its introduction will more than offset the installation cost.

8. Full-service full-support concept.--The service offering the system must provide for maintenance, training (initial and continuing), route design, and transmission engineering.

In recent history, the most common method of underground mine communications consisted of loudspeaking- or paging-type telephones, or alternatively, magneto ringing telephones. In most cases these phones were connected on a common party line with one telephone for each working section and additional phones at other key locations, such as maintenance shops, both underground and on the surface. As mining operations became more mechanized, underground rail haulage systems were developed. Eventually, these were driven by electrically powered locomotives, and trolley carrier current communication systems were developed. While a few mines have begun to use dial-type telephones underground, their use to date has been very limited. It is expected, however, that more and more mines will install dial-and-page telephones and radio-type communication systems in the future. Today's rail transportation systems are typically equipped with carrier current phones to provide communications between vehicles and between vehicles and a central dispatcher.

Early shaft communications consisted of bells or whistle signaling systems. Today these systems have been replaced with radio and carrier current systems that allow two-way voice communication to and from personnel in the cage.

It is recognized that presently available mine communication systems need improvement. Research and development programs are continually being conducted by the Bureau of Mines, the mining industry, and equipment manufacturers to improve communication technology and techniques. The primary objective of all of these programs is to increase the productivity of the mining industry and increase the safety of miners.

1.2 Productivity and Safety

Underground mining operations, like other industrial enterprises, are tied together by communications. Adequate communication within a mine and between the surface and the underground work stations is a vital part of the proper operation of any underground facility. This communication capability is not only an important factor in the concept of safety, but also is an aid to the day-to-day operations and the task of extracting and moving the product to the surface. If a rapid, accurate flow of data is automatically and continuously presented to management, then decisions can be made sooner and more accurately. Some people consider the operation of a mine to be a relatively static operation planned many months, even years, in advance. However, the productive time per shift and productivity trends indicate that a large amount of waste time accumulates due to unpredictable daily events. If management were aware of breakdowns within minutes, attention could be more quickly focused on solving the problems, thereby increasing long-term production.

Safety can certainly be enhanced by accurate fast communication channels. Quicker medical assistance, faster evaluation of the situation underground, and accurate location of problems will be direct benefits. In addition to these obvious advantages, remote monitoring and control of equipment and conditions underground will allow management personnel to prevent accidents and other causes of production losses.

A study of 9,300 injury-causing accidents that occurred in underground bituminous coal mines during 1974 found that the financial cost totaled almost $57 million, or an average of $6,100 per accident. This figure did not include the intangible cost of reduced efficiency in fellow workers resulting from the accident. The study detected a marked tendency of mine crews in or near the area where the accident occurred to slow down their pace of operations for a period of time, especially after a serious accident; consequently, production would drop. Such a drop was in addition to the accident itself, and to the time required to clean up after the accident. About 41%, or an estimated $23.6 million, of the total (current and future) cost of underground coal mine accidents in 1974 was borne by mining companies in the form of compensation payments to accident victims and survivors, lost coal production, and the expense of investigating the accidents. Any devices or techniques, including good communication systems, that will reduce accidents will quickly pay for themselves.

The evolution of mining technology, including underground communications, is inevitable as coal assumes a more significant role in the national energy plan. Another factor that will aid this development is the application of modern remote control and monitoring methods to increase production. Advances in remote monitoring and control of equipment and conditions underground will involve increased use of computers. Mine monitoring systems using a computer have already been installed in some mines. Basically, these systems consist of sensors placed at strategic locations, data relay stations, and a digital computer in the mine office. The computer is programed to process the data, determine when and where abnormal conditions exist, and alert mine personnel.

Six types of sensors in common use detect methane, carbon monoxide, temperature, relative humidity, airflow, or differential air pressure. Systems can include an electronic display of the mine layout, electric typewriters, and video display screens connected to the computer. The computer receives data from the remote stations in the form of electrical signals, which are translated into numerical measurements and checked against a set of standards to see if all factors are within normal limits. If any factors at a remote station exceed normal limits, an alarm may be initiated. At the same time, the electric typewriter connected to the computer types out either a warning or a danger message to specify what is wrong and at which sensor the trouble is being detected.

In the United Kingdom, a commercial mine monitoring and control system, MINOS (Mine Operating System), is being developed. The heart of the system is a digital computer (fig. 1-2) located within the system control center. This computer is programed to obtain various data from remote sensors and monitor the satisfactory operation of the mine, giving audible and visual alarms as well as initiating automatic shutdown of equipment when necessary. Control of the conveyor system including startup, shutdown, and feed rate is also possible. Printouts and daily summaries of specified information are outputted automatically or are available on demand by keyboard commands entered at the system center. Remote control and monitoring of surface facilities and preparation plants as well as underground equipment such as pumps and fans can also be accomplished with the computer-controlled systems.

Any remote monitor and control system is relatively sophisticated, and an

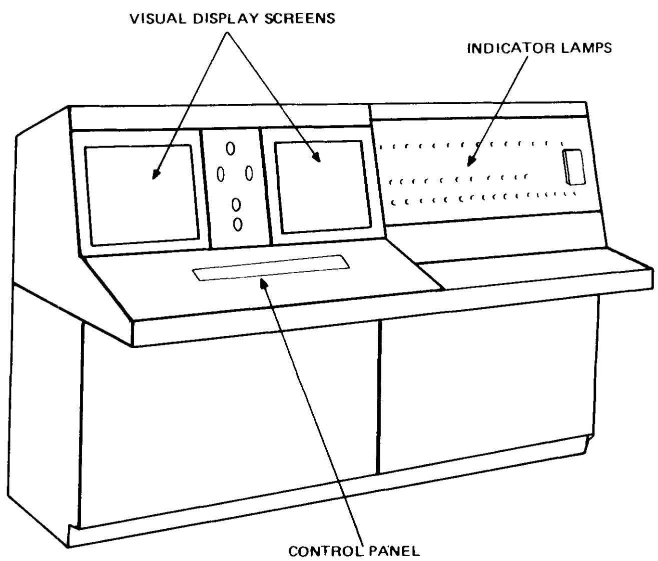

FIGURE 1-2. - MINOS system center.

economic analysis of the tradeoffs involved in the mechanization is required. However, minewide remote monitoring and control, coupled with an effective communication system, is one of the tools that can be used to increase safety and productivity in underground mines.

1.3 Constraints on Equipment

The environmental constraints on equipment expected to operate in any underground mine are severe. Equipment designed for surface operation, even if it would work underground, could not be expected to last for any length of time in the harsh mine environment.

Equipment must be protected from, or immune to, high-moisture atmospheres (0 to 100% humidity levels) and remain operable over wide temperature ranges. Dust can be expected to clog airflow passages, plug relay contacts, and cause switches to stick. Dust accumulation on electronic components can also cause heat buildup and even "short circuits." Some mine atmospheres are highly corrosive, and equipment in these mines must be constructed from materials that are resistant to the corrosion, or else protected from it. The very dry atmosphere in some mines causes gaskets and seals to quickly dry out and start leaking. Static electricity in these mines can also pose a problem for certain types of solid state electrical circuits.

In addition to the environmental constraints, physical considerations must be taken into account. Space is often at a premium in underground mines, especially in low coal seams. Communications, control, and monitoring equipment must be small in size and should be light in weight. Because it must exist in close proximity with heavy mining machinery, communication equipment must also be ruggedly designed and shock protected. Reliability and ease of maintenance are other reasons why most equipment designed for surface operation cannot be utilized in underground mines.

Much of the communication equipment in coal mines today is located in ventilated areas where there is less likelihood of an explosion. However, if a ventilation system is required to control the gas or dust hazard and basic communications must be maintained in the event of a ventilation failure, then this communication equipment must not be capable of generating an ignition spark. Thus, much of today's mine communication equipment carries a "Permissibility" label granted by the Mine Safety and Health Administration. To achieve the permissibility rating without explosion-proof packaging, all sources of sparks must be controlled by limiting voltages, currents, and the amounts of stored energy--such as in batteries, capacitors, and inductors--to safe levels. Such a device is defined as "intrinsically safe."

The amount of spark current in a resistive circuit required to ignite a methane-air mixture varies with the open-circuit voltage. Guidelines to safe operating limits, such as shown in figure 1-3, indicate a hazard at

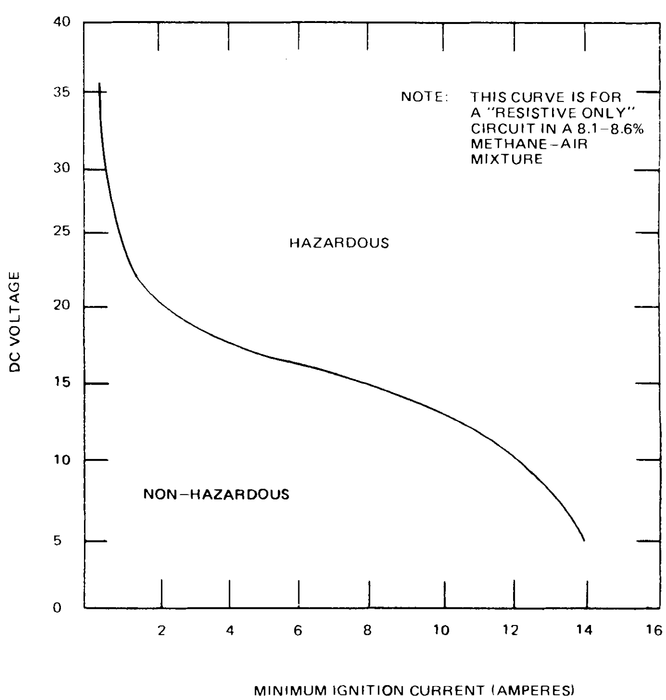

FIGURE 1-3. - Typical ignition hazard curve.

2 amperes in a 20-volt resistive circuit. However, no greater hazard exists with 10 amperes in a 12-volt resistive circuit. When reactive circuits (circuits with inductors or capacitors) or energy storage elements (batteries) are considered, limits on safe circuit design are even tighter. These safety considerations have directed the design of all the "permissible" communication devices on the market today. One of the most recent pager-type phones does not contain any inductive components other than the speaker and handset and uses only a single 12-volt battery.

In gassy mines, only permissible or intrinsically safe communication equipment should be acceptable for use in all locations under all conditions.

The permissible rating requirement rules out use of most systems designed for surface applications. For instance, a permissible rating cannot be given to a standard telephone connected to a telephone switchboard because of high voltages (48 volts dc while on hook and as much as 120 volts ac while ringing) and use of many highly inductive devices in the circuit. While placing the telephone in an explosion-proof housing could be considered as a means of making it "permissible," the cost would be unreasonable.

Other restrictions on communication equipment used underground are specified in the U.S. Code of Federal Regulations (See appendix B of this manual.)

1.4 Communication Requirements

In an ideal communication system an individual should be able to initiate and receive calls regardless of his or her position in the mine. To accomplish this, more than one communication system may be required. Communication requirements are more readily defined by separating the underground personnel in present-day mine operations into four functional groups:

Working section crew

Maintenance crew

Motormen

Inspectors and management personnel

The position of dispatcher is considered separately because he or she generally coordinates the communications as well as the haulage traffic.

In small mines and belt-haulage-type mines the communication center may be the responsibility of the hoist engineer, the supply man, or the maintenance foreman. Because hoist communication requirements are unique, they also can be treated separately.

1.4.1 The Working Section Crew

Under normal operating conditions the section forman communicates by fixed phone to the shift foreman to request supplies and maintenance services and to file periodic productivity reports. Under emergency conditions he must be able to request medical aid for personnel and report hazardous conditions in his area.

The high acoustic noise level created by the mining machinery greatly reduces the effective communications between the foreman and his crew. This noise also interferes with the foreman receiving calls. Often a motorman must deliver a call-in message to the foreman when he is transferring hauling cars in his section. Some belt haulage mines must even resort to turning off the conveyor system, thereby causing all the section foremen to call in. Communication requirements of the section crew can be satisfied by loudspeaking pager phones that can easily be moved to keep them within hearing range, or by some form of radio link (two-way radio, pocket pager, or "beeper").

1.4.2 The Maintenance Crew

Unlike a working section crew, the maintenance crew is spread throughout the mine. The maintenance foreman must be able to receive repair requests and dispatch his crews for both emergency and scheduled repair work. He should also be able to maintain communications with the individual crew members while they are in transit or after they have arrived at the repair site. The dispatcher may provide assistance by routing messages for equipment repair and parts to the foreman from the maintenance crew.

Wireless mobile communication equipment, linking the maintenance foreman and his crew together, would be ideal for the above tasks. However, any portable radio equipment used must be small and lightweight because crew members already have much to carry.

1.4.3 Motormen

The motormen are responsible for coal or ore haulage and the delivery of men and supplies to the working sections. Rights-of-way and the disposition of haulage cars must be known to all motormen to avoid accidents. In mines using tracked-trolley haulage, activities can be coordinated by a trolley wire (carrier) phone system. These are known as "carrier" systems because the communication is "carried" on a wire not intended for communication, in this case the trolley line; the term "carrier," however, refers to the technique, not the wire itself. This single-channel network keeps the dispatcher and all motormen in continuous contact with one another. This phone system also allows the dispatcher to notify all motormen of any mine emergency. The two drawbacks to this system are

1. Dead zones, which are sections of track where the phone is inoperative owing to excess electrical noise or excess attenuation of signal strength.

2. Trolley wire power failures, which cause the phones to go dead. (Newer phones have backup batteries installed in each phone so this may not be a problem.)

In spite of these drawbacks, carrier phone systems usually meet the requirements of the motormen, except for an emergency that severs the trolley wire or otherwise removes power from the wire.

In mines without tracked-trolley haulage systems, a radio link must be established to allow motormen to remain in contact with one another.

1.4.4 Inspectors and Management Personnel

These people are underground primarily to observe mine conditions and personnel. They should be able to stay in continuous contact with the communication center for the following reasons:

To be informed of any emergencies that might arise.

To keep the center informed of their location.

To receive calls from other parts of the mine.

These requirements could be satisfied by an effective, extensive wireless mobile communication system. A vehicle-mounted system may be sufficient in some cases, such as the trolley carrier phones in track haulage mines.

1.4.5 The Dispatcher

The dispatcher's location in some mines has developed into a communication center for all underground operations. He is in direct contact with all motormen via the trolley wire phone system, and directs all vehicle traffic in the mine. In some mines, he also controls the fixed phone circuits via a small switchboard. He locates personnel by the paging phones or by relaying messages through the motormen to the sections. He serves as the human coupler between the different phone systems, and he is in the best position to quickly notify all underground personnel of any emergency condition.

If this evolution continues, the dispatcher's job will expand to the point where he may become overworked. For safety and productivity reasons the voice traffic control and the monitoring function of the dispatcher's job cannot interfere with his prime responsibility of vehicle traffic control. Therefore, it may be desirable to transfer these responsibilities to other personnel or to automatic dialing and alarm equipment. For this reason some mines have established a separate communication system "operator" position. This person has responsibility for voice traffic control, and also for monitoring environmental conditions in the mine. The operating conditions of the haulage and mining equipment could also be monitored from the communication center.

1.4.6 Hoist Communications

A hoist-shaft communication system should satisfy the requirements for communication throughout the full travel of the cage, providing two-way voice communication between the cage and the hoistman. The system should also allow for shaft-inspection communication between the inspector and the "hoistman." For the modern, automated shaft, signals are also required for a slack-rope indication, to permit selection of level, enable interface with interlocks, and jog for exact position at any level or shaft station. Cage equipment must be small and capable of being located so that it cannot be damaged by any of the various uses of the cage such as transporting supplies and machinery into the mine.

Additional microphone-speaker stations should be located on each cage level when multilevel "man trip" cages are used. Until recently, bell signaling was the only form of hoist-shaft communication. A disadvantage of the bell signaling system is that communication with the cage when it is between levels is impossible. This deficiency is especially crucial during shaft inspection or repair, where movement of the cage must be controlled precisely. Today, however, equipment is available that allows two-way voice communication between persons in the hoist cage and the hoistman or other locations at the shaft top or bottom.

Reliable hoist-shaft communication should be considered as a vital part of the overall communication system, especially during or following an accident or disaster situation. Experience has taught that the hoist often becomes a bottleneck during rescue or evacuation operations, and good communication to and from the cage is essential.

1.5 Present Communication Systems

Communication systems currently used in many mines generally consist of two systems, the trolley wire carrier phones and the fixed pager phones. The trolley wire channel must be a party line to keep all motormen informed of one another's location. The pager phone system is often divided into multiparty circuits which are controlled by the dispatcher. For example, one mine studied used eight party line phone circuits terminated at a simple switchboard in the dispatcher's office. A logical partitioning of the pager phone network into a multichannel private line system would be to give each working section a separate line, or at the most two sections per line, and have one common line for all haulageway phones. Individual section phone lines would eliminate peak traffic demand during production reporting time and provide the section foreman with a private line during an emergency situation. Other phone lines could be used for monitoring the environment and equipment. Based on data and survey results to date, it appears that about two to eight phone lines, depending on activity of the mine, would be sufficient to provide efficient service for the working sections and also provide a common private line for the haulageways.

1.6 Summary

The need for effective communication between locations underground and between underground and surface locations has been recognized for some time. Unfortunately, the equipment to totally satisfy these requirements in underground mines has only recently become available. Part of the reason for lack of equipment can be blamed on the uniquely harsh environment present in underground mines.

Despite past deficiencies, equipment is now available to meet most of the requirements for effective underground communication systems. The operational requirement of the ultimate system may be simply stated as follows: Each individual should be able to initiate and receive communications regardless of his location within the mine. In practice, this ultimate requirement will normally be modified. The size and age of a mine, operating conditions, and economic considerations will affect the degree to which a system fully meets this ultimate requirement.

Vehicles operating on rails within a mine should have a communication unit mounted in every powered vehicle (required in some States). Operational safety is increased when there is an intervehicular communication system. Operators can report to each other or to a central dispatcher, thereby reducing the chances of a collision. Carried to the ultimate, the central dispatcher can control the movement of all vehicles at all times.

Often there is a need to call a man who is not near any vehicle or phone. As a minimum, some form of paging capability should be included in the overall mine phone system that can be used to tell a called party to go to the nearest phone and return the call. The ability to communicate with men underground, no matter what their location, is essential to the efficiency of any mine. Safety and productivity are directly related, and both depend upon good communications. In addition to the obvious advantages of reliable and effective communications, there are intangible benefits that may not be recognized:

1. The general attitude of the underground workforce will be improved if they know that they are not "cut off" communicationwise from the surface.

2. Mines with good communication systems should be able to more effectively compete in the labor market. High turnover rates, which are costly owing to training requirements, will be reduced.

3. Mines with effective communication systems and good safety records are usually subjected to inspections less frequently, and since studies have shown that production rates decrease when it is known that inspection personnel are on the property, the effect on production should be good.

Adequate communications within a mine and to the surface is a vital part of the proper operation of an underground facility. This communication capability is not only an important factor in the concept of safety precautions, but also an aid to the day-to-day operations and the task of moving the mined product to the surface. The mining industry exists to bring the product out and to bring it out safely and economically. Adequate communication is one of the tools available to assist in this task.

In a like manner, a judicious choice of remote monitoring and control of parameters in the underground environment and on selected machinery will yield a cost savings in production and augment safety. Many man-hours and dollars can be saved by knowing conditions before they become a problem. Situations that could be disastrous can be predicted and proper solutions implemented before the disaster occurs. Proper environmental and machine monitoring is another key to safer, more productive underground mining.

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