

COAL MINE ELECTRICAL ACCIDENT REDUCTION*

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ABSTRACT

Many electrical accidents occur each year in the coal mining industry, ranging in severity from harmless shock to death. These accidents result in a large number of lost workdays, and analysis shows that many of them occur under similar circumstances. These circumstances are investigated and grouped to produce a list of "generic" accidents. Bureau of Mines research contracts are reviewed to determine what effect they may have on the frequency and/or severity of common electrical accidents. Many of the ideas drawn from the contracts relate to the introduction of new safety equipment and electrical trouble-shooting and repair procedures. These measures are categorized and estimates are made of their potential effectiveness in reducing accidents. This analysis, in conjunction with the amount of money spent by the Bureau on the research it supported, is used to generate a cost-vs-benefit table for the Bureau. Areas are identified that are being somewhat neglected, and to which more thought should be given to making safety-related changes in equipment or procedures.

INTRODUCTION

Over the five years from 1975 through 1979, approximately 500 electrical accidents per year have been reported to MSHA by the coal mining industry, resulting in more than 42,000 lost workdays and 48 deaths [1]. These alarming accident statistics have been the major stimulus for much of the research contracted by the Bureau of Mines. However, the Bureau needs to direct its research efforts in areas where it expects the most benefit from the money and effort it extends. This is necessary, now more than ever, because of the cutbacks in the Bureau's research funds and because equal amounts of research money spent in different areas will not produce the same impact on accidents.

ACCIDENT DATA COLLECTION AND FORMULATION

Electrical accident data was obtained from the MSHA forms 7000-1 which were submitted to MSHA by mine operators. Form 7000-1 contains such information as: Mine ID Number; Location of Accident; Nature of Injury; Part of Body Injured; Description of Accident; and other

*This paper is based on studies performed under USBM Contract J0100096 to West Virginia University

such pertinent information. In fact, the form requires almost every necessary detail to do a wide assortment of statistical analyses. The completeness and legibility rules for filling it out are not enforced, however. Many of the accidents had to be listed in the unknown categories of our analyses because there was no way to retrieve the needed information from the form because of missing, incomplete, illegible, or illiterate responses. For example, the description of the conditions contributing to a fatal accident reported on one form was "Employee moaned and fell dead." If MSHA, or any other body, is to obtain any useful information about accident causes from these forms more effort must be put into ensuring that they are properly filled out.

It was necessary to use the classification system developed by MSHA through their Health and Safety Analysis Center (HSAC) to retrieve the appropriate accidents in order to avoid the task of searching the entire accident file. The HSAC classification categorizes accidents as "electrical" if the proximal cause of injury or potential injury was a shock, electrical current, electrical arc, smoke and debris from an electrical arc, or a reflex reaction to these factors. Excluded from this list are mine fires and explosions initiated by electricity. Because these accidents are not classified as electrical, the benefits of research on permissibility and intrinsic safety could not be evaluated.

A total of approximately 1350 electrical accidents was obtained from records for the years 1975, 1978, and 1979. The pertinent information for each accident was encoded onto a form designed especially for our purposes. The form is shown in Figure 1. The form contains most of the information listed on MSHA Form 7000-1 plus an additional assignment of any existing hazard or negligent behavior that directly contributed to the accident. The hazards and negligences were clearly defined as shown in Table 1. Once the forms were completed for each accident, the information was punched on cards and fed into the WVU computer to form our data base.

An assortment of statistical analyses was carried out on the data once it was stored in the computer. Using mine production statistics from the MSHA Coal Mine Reference files, accident-prone mines were identified based on the number of accidents and lost work-days per number of employees, man-hours worked, and production in tons. Also the accidents were listed in percentages based upon a particular item such as; job title, injured activity, injury type, degree of injury, and so on. These analyses were made for each year individually and cumulatively. Space does not permit the inclusion of all these results, but the cumulative classification by hazard and negligent type is shown in Tables 2 and 3. The remaining analyses may be found in our contract final report [1].

RESEARCH CATEGORIES

In the effort to assess the impact which Bureau of Mines sponsored research has had on electrical accidents, it was first necessary to determine the nature and quantity of research which they have sponsored.

Table 1. Key to Code Used on WVU Accident Form

HAZARDS - Mining has some level of risk associated with it that is implicitly assumed to "normal". Particular jobs, such as electrician also have inherent risks which are assumed to be normal. We define a HAZARD as an abnormal risk not usually assumed to be inherent in the job.

H1 - Energized ground or frame - A potential appearing on any normally noncurrent carrying part of electrical equipment or structure.

H2 - Energized power conductor thought to be safe by reason of being disconnected.

H3 - Improperly insulated or guarded power conductor so that personal contact occurs under conditions where it was assumed to be prevented.

H4 - Abnormal arcs or sparks generated by a short circuit, fault, defective switch, or other defect in the power system. Also include short circuits which cause excessive heating without arcs or sparks. Not including flashes which are a result of operator error.

H5 - Defective tool or protective gear, not including defective circuit breakers or other power system protective devices.

H6 - Putting power to an electric circuit which is loaded or shorted when it was assumed to be open-circuited.

H7 - None - no hazard other than normally accepted in the situation.

H8 - Unknown or other electrical hazard not classifiable above.

H9 - Lightning

NEGLIGENCE - Persons performing jobs have a certain error level which is considered "normal" for the situation. The "normal" acceptable error level depends on the level of training of the individual. We define a NEGLIGENCE as an error which is abnormal for a person with a particular title or level of training. A NEGLIGENCE for an electrician may not be an abnormal error for a laborer.*

N1 - Not attempting to remove power to circuit under repair.

N2 - Not tagging, locking out, grounding, or otherwise ensuring that circuit cannot become energized or equipment started while under inspection or repair.

N3 - Failure to test for voltage on conductor.

N4 - Incorrect tool or equipment or improper use of acceptable equipment.

N5 - Failure to maintain clearance with boom, truck bed, pipe (non-electrical tool) while working in the vicinity of energized conductors with normal clearances.

N6 - Failure to maintain clearance with body or hand tool (not working on involved circuit).

N7 - Not wearing or using protective gear.

N8 - Abusing equipment.

N9 - Improper operation or maintenance of electrical devices or equipment.

NA - No errors other than those usually considered to be normal.

NB - Unknown or other negligence or error not classifiable above.

*To be uncertified to perform the work attempted is a special category of negligence.

Table 2. Accident Classification by Hazard Type
for 1975, 1978, 1979

Number of Accidents	%		Hazard
583	46.05	H7	None
290	22.91	H4	Abnormal Arcs/Sparks
129	10.19	H8	Unknown or Not Classifiable
115	9.08	H3	Improper Insulation
54	4.27	H2	Energized Power Conductor Thought to be Safe
50	3.95	H1	Energized Ground/Frame
31	2.45	H6	Loaded Electrical Circuit Assumed Open
9	0.71	H9	Lightning
4	0.32	H5	Defective Tool or Protective Gear
1	0.08	H3,H5	

Table 3. Accident Classification by Negligence Type
for 1975, 1978, 1979

Number of Accidents	%		Negligence
349	27.567	NA	No Errors
215	16.983	N1	Not Removing Power to Circuit Under Repair
171	13.507	N9	Improper Operation
163	12.875	NB	Unknown
93	7.346	N5	Failure to Maintain Clearance with Boom, Truck-bed, etc.
92	7.267	N4	Incorrect Tool
82	6.477	N7	Not Wearing Protective Gear
76	6.003	N6	Failure to Maintain Clearance with Body or Hand Tool
16	1.264	N2	Not Ensuring That the Circuit Cannot Become Energized
5	0.395	N8	Abusing Equipment
4	0.316	N3	Failure to Test for Voltage on Conductor
2	0.16	N6,N7	
1	0.08	N1,N4	
1	0.08	N1,N6	
1	0.08	N1,N7	
1	0.08	N4,N7	

The Minerals Research Contract Review (MRCR), which lists all active and completed contracts granted by the Bureau of Mines from July 1, 1969 through December 31, 1980, was used to generate a list of contracts which seemed to be electrically oriented. Also a computer printout was obtained from the Denver Research Center which lists all of the Bureau's contracts and memorandum of agreements involving studies of electrical technology beginning after December, 1974. No in-house or privately funded research was incorporated in the list.

Once the list of possible electrical contracts was complete, abstracts were obtained for each one to determine its orientation and content. These abstracts came from three different sources: 1) the report documentation page as copied from the report itself at the USBM library in Pittsburgh, 2) the abstract as it appears in the Open File Report listing of the U. S. Bureau of Mines List of Publications and Articles, or 3) telephone conversations with the contract's Technical Project Officer (TPO). All abstracts were reviewed to determine orientation and content, and specific areas and types of research were defined. These areas and types were sorted, evaluated, and combined where possible to form individual categories. Each category was given a title which is descriptive of the nature of the research in it.

Each report or contract abstract was reviewed again to determine which specific research topics each one included and the amount of effort each topic in the abstract contributed to the whole. Once each topic was assigned a fractional effort, an equal fraction of the total research funds on that contract was also assigned to it. Having this, the amount of money spent on each research category was formed by summing all the individual topics from each contract in that category. Twenty-four distinct categories were identified as research which would have a direct effect on electrical accidents. Figure 2 is an example of the information accumulated for each of these categories. A summary of the research included in the category, a listing of the contract numbers which contributed the research, and the cumulative total funding spent on the category is given. The total funding for all twenty-four categories is \$6,311,000.

Another group of categories was defined in addition to the one which directly affects electrical accidents. It is "Electrical Research not Directly Affecting Electrical Accidents" and is broken down into two subdivisions labeled: "Electrical Research with Expected Direct Impact on Electrical Accidents but None Found or No Way to Identify the Affected Accidents" - Total Bureau Funding - \$2,501,000; and "Electrical Research with No Expected Direct Impact on Electrical Accidents but with Expected Impact on Nonelectrical Accidents" - Total Bureau Funding - \$11,486,000. These categories are given with the same information as the previous 24 in the contract final report.

RESEARCH IMPACT

Each category was evaluated as to what type or types of accidents it might impact. This was accomplished by reviewing the type of research done under each category and estimating the final outcome or

results of the work. Particular accidents and accident types were then defined as possibly being impacted by that research. Also a hazard, negligence, injured activity, or combination of the three which would define an occurrence that might be impacted by the research was defined for each category.

Since all of the accidents were encoded in a standard format and stored in the WVU computing facilities, a retrieval method using specific identifiers from the encoded format was chosen. Each specific accident or accident type associated with a category was evaluated to determine what entries or combination of entries in the format could be used as identifiers for that particular accident. A combination or several combinations of these identifiers were developed to describe each particular accident associated with a category, by which the computer searched the cumulative accident data file. A listing was produced of all accidents corresponding to a particular category's identifiers that contained all of the available information about the accidents.

When evaluating the impact that a research category might have on a particular accident, a degree of subjectivity is necessarily introduced. The extent of subjectivity is dependent upon the particular accident and the nature of the research in the category. The accident description is often illegible, insufficient, or worded to hide any violation that might have caused the accident. In these situations, a scenario of the events leading to the accident must be hypothesized in order to evaluate any possible impact. Also, as mentioned before, certain assumptions about the outcome or results of the research must be made in order to have a basis for the impact evaluation.

To avoid making an unfounded decision where there was not sufficient information to develop a sound scenario, a level of "possibly impacted" was included. This level includes all of the accidents where it is unclear just what device or machine was involved in the accident and how it was involved, but there is a reasonable probability that the actual situation was one which would be impacted by the research. Next, there are certain accidents which may appear on the surface to be impacted by a particular research category, but due to the assumptions about the outcome or the underlying cause of the accident are really not affected. To indicate these accidents, a level of "definitely not impacted" is included. Finally, for those accidents involving a device or procedure which would most surely be affected by the research, a level of "definitely impacted" was included.

An impact evaluation was made for each category using the generated list of accidents and research assumptions. Figure 3 is an example of the evaluation made for each category and includes the following information: the types of accidents expected to be impacted; the identifiers for the accidents; the number and type of accidents definitely and possibly impacted, including an example; the type of accident which may be thought to be impacted but isn't (if there is any); and finally any assumptions made about the outcome of the research.

Research Category #15 - Remote Control Trolley Energizing/Deenergizing

Expected Impact - Accidents occurring when off-track equipment is moved under and contacts a live trolley and also those injuries resulting from contact with the trolley when men are working around or near a live trolley wire (i.e. loading and unloading supplies, etc.)

Accident Identifiers

Hazard	Negligence	Injured Activity	Injury Type
		0	
H7	N1	Gx	
H7	N5	Gx	
H7	N6	Gx	
H7	N9	Gx	

<u>Accidents Definitely Impacted</u>	<u>Number</u>	<u>Days Lost</u>	<u>Fatalities</u>
	85	825	0

Type - Injuries resulting from accidental contact of body or object with the trolley wire. (Assuming only one vehicle per track section at a time and all poles are removed from the trolley wire when the vehicle is not moving or preparing to move.) Employee is injured by the arc which occurs when the trolley pole is placed on the wire. (Example: While jacking supply onto the track, jack handle hit trolley wire.)

<u>Accidents Possibly Impacted</u>	<u>Number</u>	<u>Days Lost</u>	<u>Fatalities</u>
	15	172	1

Type - Accidents occurring around or involved with a track vehicle when it is unclear whether the pole should be off the trolley wire or not. (Example: Door on tool car contacted trolley wire, the car moved as he was closing the door.)

Definitely Not Impacted

Type - Accidents involving the arc which occurs when the pole is removed or jumps from the trolley wire. Accidents occurring while pole is on the trolley wire.

Research Assumptions

Application of the research in this category would mean that no trolley section would be energized except when there was specific demand for it to be. Assume a slight delay is introduced before the trolley is energized when the pole is being put on (thus no arc occurs when putting on under load).

Figure 3. Typical Evaluation of Impact of Research on Accidents.

Table 4 gives the numerical results of the evaluation along with the category funding figures. The categories are listed in order of most expensive to least expensive.

AREAS WHERE MORE RESEARCH IS NEEDED

An analysis of the electrical accidents and research areas shows that Bureau research has been carried out with respect to nearly every type of accident. There are several areas in which future research appears to be highly desirable in terms of reducing electrical accidents. Some of them are extremely simple, and are really suggestions for alterations in equipment design. Others would require a great deal of work. It is quite likely that a few are already underway. They are not ranked in order of importance.

A. A sensitive ground fault interrupter, that would work on 480 V 3-phase systems to drastically reduce arcing and sparking when a high-resistance ground fault occurs. Care must be taken to assure that this system is not prone to false trips.

B. A study to determine the costs and benefits (safety and monetary) of such practices as monthly visual inspections of circuit breakers.

C. A simple cable fault locator that could be placed on every mining section.

D. Design of control circuits, breakers, and other pieces of equipment with diagnostic sockets so that they may be tested without taking them apart or entering energized cabinets. An extension of this would be to design self-diagnostic control circuitry.

E. Methods by which workers could be easily warned of the dangers of energized conductors. This might take the form of some sort of visual indication by the insulation that a field was present, indicating lights on breakers and catheads to show that conductors are energized, or small sensors in screwdrivers and cable-skipping knives to warn that a field was present.

F. Design of all sizes of fuses to provide a clear visual indication that they are blown.

G. Design of special tools for electrical work. These would include a goof-proof multimeter and probe arrangement, and insulated or nonconducting screwdrivers and wrenches. They should have special configurations to mate with electrical connectors such that their use would be encouraged.

H. Design of switches and breakers that do not flash or eject material under any condition. An alternative would be to develop solenoid-operated devices which could be operated remotely by low-power control circuits.

I. Design of fuse boxes and breakers so that access is prevented while the power is on. Design of reliable (probably mechanical) interlocks for small boxes, panels, etc.

J. Redesign of molded case circuit breakers to prevent accumulations of dirt on terminals from initiating phase-to-phase faults.

K. Design of control circuits to prevent arcs at trolley poles and nips that result from making and breaking these contacts under load.

L. Redesign of batteries and battery connections. Use of incompatible + and - terminals to prevent crossed connections. Use of recessed battery terminals to prevent accidental contact. Use of a battery cable connector that would provide no exposed energized conductor when attached to a battery. Use of completely insulated battery tops.

M. Control circuitry for battery chargers which will deenergize the charger when no battery is present to be charged.

N. Design breakers and fuses so that inadequate interrupting capacity devices are physically incompatible with the mount or bracket.

O. Addition of insulators on top of jeeps and locomotives to "catch" any trolley wire that falls or sags down into contact with the vehicle.

P. Redesign the trolley wire to provide better inherent protection from accidental contact. Redesign trolley pole so that the energized lead is completely inaccessible to a person handling the pole.

Q. Develop a control circuit to deenergize all portions of a locomotive except the lights and radio whenever the vehicle is not moving.

R. Develop plastic-coated light bulbs that will not explode if defective or abused, such as the coating for camera flash bulbs. Make base design of bulbs for different voltage levels incompatible.

CONCLUSIONS AND RECOMMENDATIONS

The cost/benefit approach for determining the cost-effectiveness of past and future research is certainly applicable as shown by Table 4. This table evinces that this method produces good indicators of the relative benefits and costs of each investigated topic. Additionally, through the process of this investigation there are worthwhile by-products such as identifying needed research areas which may have not been recognized before and observing illegal practices which are consistently causing accidents. These practices were not brought out in this paper because of space limitations. Also, this method is as applicable to an individual mine's specific situation as it is to the industry-wide situation discussed here.

In a further paper to be presented at the IEEE Industry Applications

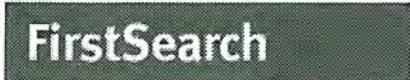
TABLE 4. Possible Safety Benefits and Costs to the Industry of Proposed Electrical Safety Measures

Research Category	Electrical Accidents Definitely Impacted			Electrical Accidents Possibly Impacted			Cost to Industry to Implement
	No.	Lost Days	Fatals	No.	Lost Days	Fatals	
Cable Fault Locators (#1)	15	152	0	15	465	0	Minimal - DG Minimal - S
Cable Splice Material Improvement (#2)	16	131	0	71	673	0	Minimal - DG Minimal - S
Protective Device Reliability and Coordination (#3)	51	567	0	10	107	0	Minimal - DG Minimal - S
DC Circuit Breaker Performance-Withstand Capability (#4)	2	6	0	28	529	0	Minimal - DG Minimal - S
DC Discriminating Circuit Breaker (#5)	11	153	0	20	134	0	High - DG
Proximity Warning Devices (#6)	10	3915	6	1	999	0	Minimal - DG Moderate - S
Intermachine Arcing - Ignition Hazard (#7)	3	18	0	4	24	0	Minimal - DG
Predicting Incipient Failure (#8)	6	44	0	57	653	0	Minimal - DG Minimal - S
Ground Wire Monitoring (#9)	4	16	0	16	139	1	Minimal - DG Minimal - S
Stray Currents - Generation and Effects (#10)	0	0	0	8	47	0	Moderate - DG
Improved Trolley Pole Operation (#11)	24	256	1	16	64	0	Moderate - DG
Low-Voltage Shielding for Shock Eliminator (#12)	45	646	0	6	81	0	Moderate - DG
Cable Mechanical Stress Elimination (#13)	0	0	0	73	1117	0	Minimal - DG
Sensitive Ground Fault Detection (#14)	147	2653	2	114	2071	5	Moderate - DG
Remote Control Trolley Energizing/Deenergizing (#15)	85	825	0	15	172	1	High - DG
Cable Handling Devices (Underground) (#16)	7	26	0	20	378	0	Moderate - DG
Elimination of Shuttle Car Trailing Cables (#17)	37	565	1	111	1806	1	Moderate - DG
DC Ground Fault Interruption (#18)	0	0	0	7	24	0	Moderate - DG
Cable Shield Integrity (#19)	2	37	0	12	98	0	Minimal - DG Minimal - S
Cable Handling Methods and Devices - Surface (#20)	2	37	0	0	0	0	Minimal - S
Battery and Battery-Charger Safety (#21)	42	150	1	0	0	0	Minimal - DG Minimal - S
Reduction of Accidental Contact with the Trolley (#22)	82	701	2	7	29	0	Minimal - DG
Ungrounded Power System Analysis (#23)	9	112	0	30	493	0	High - DG Moderate - S
Cable Handling Methods (Underground) (#24)	52	677	0	38	864	0	Minimal - DG

Society Annual Meeting in San Francisco this fall, this method is used to show the relative costs and benefits of implementing research-related safety changes on an industry-wide basis.

REFERENCES

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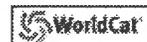
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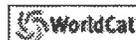
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