RI 9568

REPORT OF INVESTIGATIONS/1995

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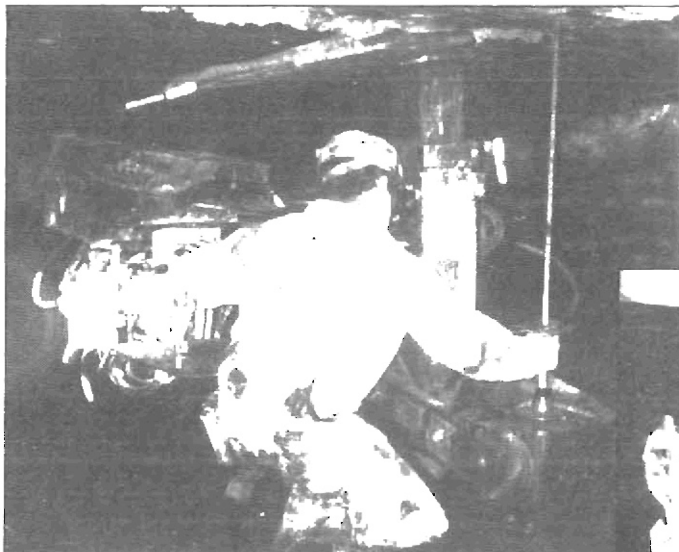
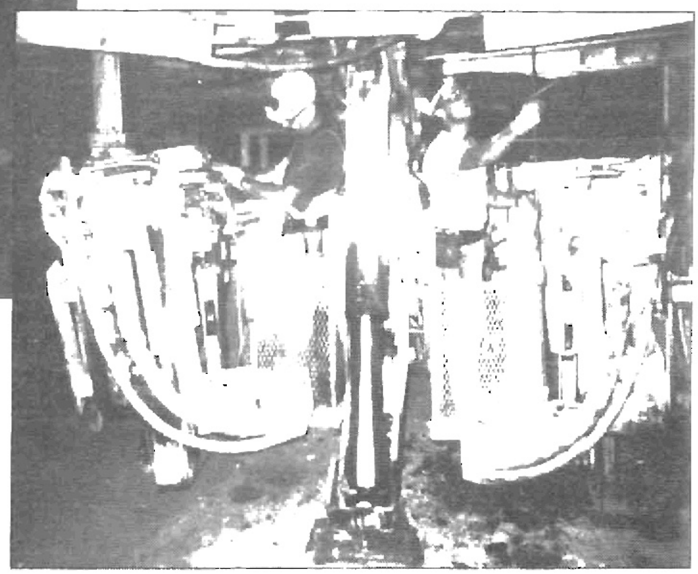
Human Factors Analysis of Roof Bolting Hazards in Underground Coal Mines





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Cover:* *Top, Arm-feed roof bolting machine with the operator working outside the machine next to the coal rib. (Photo: Alan G. Mayton, Pittsburgh Research Center) Bottom, Mast-feed roof bolting machine with operators working inside the machine. (Photo: Kim M. Cornelius, Pittsburgh Research Center) These photographs demonstrate how operators working with the two most common types of roof bolting machines are exposed to moving equipment parts.

Report of Investigations 9568

Human Factors Analysis of Roof Bolting Hazards in Underground Coal Mines

By Fred C. Turin and others

UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES
Rhea Lydia Graham, Director

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PREFACE

On October 26, 1993, U.S. Bureau of Mines (USBM) researchers met with the West Virginia Board of Coal Mine Health and Safety (WV Board) to discuss roof bolting hazards in underground coal mines. The WV Board had completed a nationwide investigation of roof bolting machinery-related accidents from 1983 through March 1993. It identified eight fatalities that involved the victim being caught between the drill boom and the top or automated temporary roof support (ATRS). The fatalities occurred between May 1988 and March 1993.

As a result of this meeting, USBM researchers agreed to study human factors issues related to roof bolting activities and to provide a report of the findings. In July 1994, a report entitled "Human Factors Analysis of the Hazards Associated With Roof Drilling and Bolt Installation Procedures" was presented to the WV Board. The report was a result of the efforts of the following members of the Mining Systems and Human Engineering group of the USBM's Pittsburgh Research Center: Michael Brnich, mining engineer; Kim Cornelius, industrial engineer; Roberta Calhoun, safety and occupational health specialist; Joseph DuCarme, mechanical engineer; Sean Gallagher, research physiologist; Christopher Hamrick, industrial engineer; Alan Mayton, mining engineer; E. William Rossi, industrial engineering technician; Lisa Steiner, industrial engineer; Fred Turin, industrial engineer; and Rich Unger, civil engineer.

This report of investigations contains the essence of the report submitted to the WV Board with minor modifications.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Metric Units

cm	centimeter
cm/s	centimeter per second
N	newton

U.S. Customary Units

in	inch
lbf	pound (force)

Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

HUMAN FACTORS ANALYSIS OF ROOF BOLTING HAZARDS IN UNDERGROUND COAL MINES

By Fred C. Turin[1] and others

ABSTRACT

The U.S. Bureau of Mines conducted a human factors analysis of hazards associated with roof bolting activities in underground coal mines. Emphasis was placed on hazards related to the movement of the drill-head boom or mast of a roof bolting machine. The objective was to identify hazards and recommend solutions. The data-collection effort consisted of analysis of U.S. Mine Safety and Health Administration accident data; visits to underground mines and interviews with experienced roof bolting machine operators; discussions with roof bolting machine manufacturers; interviews with workers injured while performing roof bolting tasks; and reviews of research on roof bolting safety. A set of recommendations to increase the safety of roof bolting operations was developed. In particular, the following list of recommendations was presented in ranking order: (1) use an interlock device to cut off power to controls when an operator is out of position, (2) place fixed barriers at pinch points, (3) provide appropriate control guarding, (4) reduce fast-feed speed, (5) use automatic cutoff switches at pinch points, (6) redesign control bank to conform to accepted ergonomic principles, and (7) use resin insertion tools and resin cartridge retainers.

[1]Industrial engineer, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

At the request of the West Virginia Board of Coal Mine Health and Safety (WV Board), the U.S. Bureau of Mines (USBM) initiated a study of human factors issues related to roof bolting in underground coal mines. The objective of the study was to determine what hazards may be associated with roof bolting activities and make recommendations aimed at improving operator safety. This objective is consistent with the USBM's mission to enhance the health and safety of the Nation's mine workers.

Eight fatalities were identified in a report (*1*)[2] by the WV Board where the victim was crushed between the drill-head boom of a roof bolting machine and the mine roof or automated temporary roof support (ATRS). In each case, the victim activated a raise lever while positioned in a hazardous location. For this reason, the human factors analysis focused on hazards that exist during roof drilling and bolt installation activities. Particular emphasis was placed on hazards associated with movement of the drill-head boom or mast and use of a fast-feed drill-head raise lever.

Analysis work was divided into several tasks that included interviewing bolter operators, observing roof bolting activities, contacting roof bolter manufacturers, analyzing mine accident data, and reviewing past research on roof bolting safety. The project team consisted of USBM researchers with backgrounds in engineering (industrial, mechanical, mining, and civil), physiology, training, and safety.

Two fatalities occurred in early 1994—February 15 and March 5; each involved a victim being crushed between the drill mast and frame of a J. H. Fletcher & Co. HDDR bolting machine. The similar nature of events that led to these fatalities initiated a coordinated investigation by the U.S. Mine Safety and Health Administration (MSHA). During the course of its investigation, MSHA asked the USBM for assistance in developing improved reach aides when rib bolting using a Fletcher HDDR bolter. A third crushing-type fatality involving a different style of roof bolter occurred on March 25, 1994, which prompted MSHA to organize a roof bolting machine committee. Members included representatives from MSHA, the WV Board, and the USBM. Four major roof bolter manufacturers participated as liaisons. This committee studied roof bolting machine safety and generated a report (*2*) that identified safety hazards present on roof bolting machines in use at underground mines and suggests solutions for some of the problems. All relevant data collected as part of the human factors analysis were made available to the roof bolting machine committee.

METHOD

Data collection consisted of analysis of the MSHA accident database, visits to underground coal mines and interviews with experienced roof bolter operators, discussions with manufacturers of roof bolting equipment, interviews with miners who had been injured during roof bolter operations, and reviews of past research on roof bolter safety. After the data were analyzed, recommendations were developed and ranked using a structured decision making technique. The data-collection and recommendation ranking methods are outlined below.

ACCIDENT DATABASE ANALYSES

MSHA accident data files for 1988 through 1991 were examined to capture roof bolter accidents that resulted in injury due to operator exposure to moving or active machinery. The search criteria used are listed in table 1.

The above data were then characterized by mine seam height, age of victim, victim mining experience, and time elapsed since the beginning of the shift. Furthermore, 16 fatality reports for roof bolting-related accidents were examined for the period January 1984 through April 1994. Fatalities examined were limited to those that took place at or near the drilling station during the bolting process or maintenance of the machine.

Table 1.—Criteria used to search MSHA accident database

Accident or injury code	*Search criterion*
Accident injury illness	Machinery or powered haulage.
Mining machine	Rock or roof bolting.
Source of injury	Underground mining machine or drill steel.
Mine worker activity	Roof bolter (drilling, inserting bolt, tramming, and not elsewhere classified); machine maintenance or repair.
Accident type	Struck against stationary object; struck by powered moving object; caught in-under-between running or meshing objects; caught in-under-between a moving and stationary object.
Degree of injury	Injuries of all types (including fatalities).

NOTE.—Codes and search criterion are worded as they appear in the database.

[2]Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this report.

MINE VISITS AND INTERVIEWS

USBM personnel visited three underground coal mines to observe roof bolting activities and to interview underground workers about roof bolter safety. Two of the mines were in western Pennsylvania and one was in southern West Virginia. Miners with roof bolting experience were interviewed at each mine. An interview guide was developed to assess the miners' views about the safety issues associated with roof bolting. A copy of the interview guide is included as an appendix to this report. Issues addressed in the interview guide included demographic information, procedures used, training received, control layout and design of equipment, accident causes, and potential solutions. Table 2 provides the seam height, type of bolting equipment used, and the number of interviews taken for each mine.

MANUFACTURER CONTACTS

Representatives from four major roof bolter manufacturers were contacted to obtain information about their bolting machines. These manufacturers included Fletcher, Eimco Coal Machinery Inc., Fairchild International, and Long-Airdox Co. Two visits were made to Fletcher and the other manufacturers were contacted by phone. The company representatives were asked to describe the models they manufacture and the layout of the controls for each model. Furthermore, they were asked if they were aware of any fatal accidents that occurred because of miners being trapped between the boom and roof or canopy. They also were asked if any design modifications were made to reduce the likelihood of such accidents.

INTERVIEWS WITH INJURED OPERATORS

Three miners who had experienced accidents while roof bolting were interviewed. The miners worked at the same western Pennsylvania coal mine with a 132-cm (52-in) seam height. First, demographic data, such as age, work experience, and job classification, were recorded for each miner. Each miner then related to the interviewer the story of his or her particular accident. Next, followup questions were asked to get the miners' views on causes and possible solutions for roof bolting accidents, mine conditions at the time of the accident, and the training they received.

REVIEW OF PAST RESEARCH

The USBM has funded several research projects that looked at roof bolter design and safety. There have also been reports issued by MSHA and private companies that addressed roof bolter safety. These reports were studied for information relevant to this project. In addition, discussions about roof bolting safety have been held with many mining experts, including officials from MSHA, the United Mine Workers of America, and mine operators.

RANKING OF HAZARD-REDUCTION RECOMMENDATIONS

Since one objective of this project was to recommend solutions to hazards associated with roof bolting, the USBM felt it was necessary to use a structured technique to rank alternative recommendations. The technique chosen was the Analytic Hierarchy Process (AHP) (*3*). AHP is a multicriteria decisionmaking process that was developed at the Wharton School of the University of Pennsylvania by T. L. Saaty. This method was selected because it provides a means for taking into account multiple criteria and objectives when evaluating alternatives. Because ranking alternatives becomes complex when there are multiple objectives, tradeoffs must be made among competing objectives. AHP is a tool that helps to break down complex decisions into manageable parts that can be effectively rated and calculates overall rankings of the alternatives under consideration.

Table 2.—General information on mines visited to observe roof bolting

Mine	Mine location	Seam height, cm (in)	Bolting equipment	Number of interviews
A . . .	Western Pennsylvania . .	213 (84)	Fletcher HDDR, dual-head bolters with walk-through chassis.	4
B . . .	Western Pennsylvania . .	132 (52)	Fletcher Roof Ranger II bolters and Lee Norse TD 2 bolters.	4
C . . .	Southern West Virginia . .	107 (42)	Fletcher DDO-15 bolters and Roof Ranger II bolters.	2

RESULTS

ACCIDENT DATA ANALYSES RESULTS

The total number of accidents identified in the MSHA data files using the search criteria described in table 1 was 613. This included five fatalities. Ninety percent of the victims were *caught in-under-between a moving and stationary object*. Only 1.5% of the accidents occurred during equipment maintenance. The source of injury for 87% of the accidents was the machine, with 13% being the drill steel. The job title for 74% of the victims was roof bolter or roof bolter helper. Over 80% of the accidents occurred in Kentucky, West Virginia, Pennsylvania, and Virginia.

The above data were further characterized by mine seam height, age of victim, victim's mining experience, and time elapsed since the beginning of the shift. Little significant difference could be found between the accident characteristics for the selected roof bolter accidents and accidents for all underground coal mine workers, except for the category *experience at this mine*. Examination of accidents for all underground coal miners showed that the frequency of injury is highest for miners with 2 years or less experience at the mine where the injury occurred. However, there was a subsequent rise in injury frequency that was somewhat normally distributed around 12 years. For the select roof bolting accidents, the frequency of injury was highest for miners with 1 year or less experience. The injury frequency dropped rapidly until it becomes fairly level for miners with 3 or more years of experience at this mine. One possibility for this observable difference, based on interviews with miners, is that roof bolter operators tend to remain roof bolter operators while other workers are more apt to change jobs after they gain seniority at a mine. The most common reasons given for the job stability of roof bolter operators were that (1) roof bolter operators have the highest paid job; (2) many miners do not want to be roof bolter operators; and (3) many experienced roof bolter operators like the independent nature of the work.

Of the 16 fatality reports examined for the period January 1984 through April 1994, 11 fatalities (roof fall, etc.) involved the inadvertent activation (by the operator) of a control. Equipment maintenance was the activity cited for 5 of the 16 fatalities. Four of the five maintenance-related fatalities involved the inadvertent activation of a control.

Of the 16 fatalities, 14 involved movement of the drill-head boom. Of these, nine resulted in the victim being crushed between the boom and the mine roof, three resulted in the victim being crushed between the boom and the canopy, one resulted in the victim being crushed between the boom and the machine frame, and one resulted in the victim being crushed between the boom and the ATRS. Only one of the accidents involved the boom being lowered toward the victim. Two of the sixteen fatalities involved a drill mast head and, in both cases, the victim was crushed between the drill head and the machine frame.

Finally, 12 of 16 fatalities occurred in seam heights of 152 cm or less. For 2 of the 16 fatalities, there is evidence that the operators had to position themselves over the boom and into a hazardous position to see the drill steel or hole.

MINE VISIT AND INTERVIEW RESULTS

Four operators of Fletcher HDDR bolters (mine A), four operators of Fletcher Roof Ranger II bolters (mine B), and two operators of Fletcher DDO bolters (mine C) were interviewed (table 2). Fletcher HDDR models are dual-boom mast-feed machines with walk-through chassis. Operators work from an operator platform inside the HDDR chassis. Fletcher DDO and Roof Ranger II models are dual-boom, arm-feed machines. Operators work outside these arm-feed machines between the drill boom and coal rib. The interviews with Roof Ranger operators were conducted with workers who had experience with both the old Roof Ranger design (straight boom and lever controls) and a new Fletcher design (offset boom and joystick control). The interviews with DDO operators included workers who had experience with and without the two-handed fast-feed design. The following sections summarize the major issues discussed in these interviews.

Accidental Actuation of Controls

Based upon the interviews conducted by the USBM, accidental actuation of controls (i.e., choosing the wrong lever or bumping controls) is a relatively common occurrence among roof bolter operators. Of the operators interviewed, most admitted to accidentally activating controls. Those who had not done so themselves usually knew someone who had. It appeared from these interviews that choosing the wrong lever was more common than activation through bumping. One bolter operator complained that drill steels would fall onto the controls from their storage area on top of the machine before a bracket was added to hold them in place.

Bolters Getting Into Pinch Points

Visibility was mentioned as a reason why bolter operators may get into drill-head boom pinch points. This is a particular problem with the Roof Ranger and DDO machines working in low- to medium-seam heights. Operators said that they can imagine situations where the operator might place his or her head over the boom to see the drill hole. For the operators of HDDR's, the primary reason cited for entering a pinch point was retrieving a stuck drill steel. In addition, operators of both types of roof bolters said that the process of resin insertion may require the operator to get into a pinch point. The two DDO operators said that they are forced to work in an off-balance position closer to the boom when bolting next to the rib if gob is left by the continuous miner.

Use of Fast-Feed Lever

Operators were asked about their use of the fast-feed lever. The responses of the operators were fairly uniform, saying that the use of the fast-feed lever was limited to the process of lowering drill steels and pushing the bolt up into the mine roof. Most operators said that it was not used in any other way; however, one HDDR operator did say that some bolters drilled and bolted with the fast feed during rib-pinning operations. However, the operator added that this usually caused problems because the suction could not keep up with the drilling process.

Operators were asked whether they felt that the fast feed was necessary to do their jobs. Most operators said that they needed the feature because it allowed them to keep up with the mining cycle. Some operators also said that the feature was necessary so that bolts would not be lost because of the fast-setting resin. One operator said that the fast feed was sometimes helpful, but was not absolutely necessary to do the job.

Comparison of Old and New Roof Ranger Boom Designs

Mine B (table 2) had both the old Roof Ranger design (straight boom and lever controls) and the new Roof Ranger design (offset boom and joystick control). The operators were questioned about the benefits and drawbacks of the new design. In general, the operators felt that there was not much difference between the two, once they became familiar with the operation of the joystick. The features that the operators liked most about the new design included the better maneuverability of the drill head, the joystick control that made operation easier (less controls to operate), and the improved workstation design that allowed more space and a better escapeway. Negative reactions associated with the new design were that the fast-feed speed was slower, it took some time to get used to the joystick control, and the controls were too far from the drill head. With regard to the latter, one operator was fairly short and had difficulty reaching the drill head while operating the controls.

In summary, the operators felt that the new design was as safe or safer than the old design. The new design was considered safer in terms of the better workstation design (better controls and more room to work in), and a better head swing design. The main complaint about the new design was that it was a little slower than the old machine.

Comparison of One- and Two-Handed Fast-Feed Designs

Both mines B and C had two-handed fast-feed controls. Nearly all of the miners at these mines felt that the two-handed design was safer than the old single-handed design. Although most operators felt it was safer, they were split on their overall opinion of the two-handed feature. Some did not like it as well as the one-handed design, but others said that they actually preferred the two-handed operation. One operator felt that it slowed bolt installation and took some time getting used to.

MANUFACTURER CONTACT RESULTS

Several visits to Fletcher were conducted. The design engineers at Fletcher provided information on how the fast-feed lever was *intended* to be used and what safety features they were incorporating into new bolter designs (two-handed fast feed, C-rings to replace cotter pins on control linkages, rubber guards on the boom arm to serve as a pinch-point warning, and offset booms to provide more workspace on their Roof Ranger model). They also revealed that they had investigated the possibility of putting an automatic cutoff switch on the boom so that the switch would be activated when it contacted an object. However, they were concerned that such a switch might be disabled, unknown to the operator, who might be relying on it to work. In addition, practical limitations to retrofitting these machines for safety purposes were also discussed. Fletcher acknowledged that it was aware of accidents that involved operators being crushed by the boom of roof bolting machines. However, Fletcher indicated that these accidents were not unique to its machines. Fletcher's engineers agreed to cooperate with any future efforts on the project and to provide engineering drawings for analysis purposes.

Other manufacturers contacted by telephone included Eimco, Fairchild, and Long-Airdox (Simmons Rand). General information concerning the design of their machines and sales literature was obtained from each.

INJURED OPERATOR INTERVIEW SUMMARIES

Three operators of Fletcher Roof Ranger II bolters (mine B) were interviewed. Each had been injured in the past while roof bolting. Summaries of these injuries are detailed below:

1. The bolter operator was installing a 122-cm (48-in) full-grout resin bolt in a 117-cm (46-in) seam height. *He was bending the bolt before he pushed it up in the hole when he felt pain in his lower back.*
2. The operator had just completed drilling the first half of the inside bolt hole (starter) and turned around to get the finisher and pusher steels *when a large piece of rock fell.* The bolter operator was pinned between the boom and the rock. He suffered a dislocated hip, a cracked vertebra, torn knee cartilage, and a cracked pelvis.
3. The bolter operator was installing a 183-cm (72-in) point anchor bolt with a coupler between the bolt sections. He was pushing the bolt up into the hole when the coupler hung up on the lip of the hole, causing the bolt to bow. The operator was holding the bolt so that it would not fall into the mud and reached for the fast-feed lever in an attempt to drop the bolter head to realign the bolt. *The rotation lever linkage was sloppy and caused the lever to overlap the fast-feed lever. When the operator lifted the fast-feed lever, the head dropped, but the reverse rotation was also activated.* Because he was holding the bolt when the reverse rotation was activated, the operator's arm was twisted around the bolt, resulting in a fractured right arm.

Only one of these injuries dealt with the primary focus of this study and hazards associated with movement of the drill-head boom or mast. The cause of accident 3—inadvertent activation of a control—was also the cause of 9 of the 16 roof bolter fatalities studied and was a recurring theme during many of the interviews with roof bolter operators.

REVIEW OF BOLTER-RELATED LITERATURE

The USBM has sponsored several projects since the late 1970's that looked at roof bolter safety. Those with direct relevance to this project included a study on standardized controls for roof bolters,[3] a study on personal protective equipment for underground coal miners,[4] a study of accident risk during the roof bolting cycle,[5] and a study to develop Society of Automotive Engineers guidelines for underground operator compartments (*4*). Other work relevant to the project includes a report by MSHA on injuries associated with roof or rib bolting (*5*), an MSHA-generated job safety analysis on roof bolter operations (*6*), and a privately published manual on how to roof bolt safely using boom-style bolters (*7*). The reference section at the end of this report lists these and other studies.

DEVELOPMENT OF SOLUTIONS

POSSIBLE SOLUTIONS

As a result of the data-collection and analysis efforts, the project team decided that the goal of any intervention should focus on reducing the likelihood of a roof bolter operator being crushed by the boom or mast of a bolting machine. Based on this general criteria and working from a human factors perspective, the team developed a list of possible solutions:

1. Perform a crewstation redesign with a greater emphasis on operator reach and visibility requirements.
2. Use an automatic resin insertion device.
3. Reposition or redesign personal protective equipment so that it is less likely to bump or become tangled in the controls.
4. Reduce the likelihood of the drill steel jamming through better maintenance and drill shaft designs.
5. Redesign the control bank to conform to accepted ergonomic principles.
6. Place fixed barriers at pinch points and other dangerous areas.
7. Reduce the speed of the drill-head boom fast-feed lever.

[3]Helander, M. G., and E. J. Conway. Design and Develop Standardized Controls on Roof Bolting Machines. Phase I Specifications Report. Canyon Research Group, (undated), 87 pp.

[4]Blake, T., M. Sanders, G. Krohn, D. Wick, K. Volkmer, and B. Beith. Experiments on Personal Equipment for Low Seam Coal Miners: IV. Incorporating Coiled Cord Into Cap Lamp Battery Cords. Canyon Research Group, Jan. 1980, 24 pp.

[5]OFR 113-93g. Coal Mine Inquiry Analysis: A Model for Reduction Through Training. Volume III—Accident Risk During Roof Bolting Cycle: Analysis of Problems and Potential Solutions by M. J. Klishis, R. C. Althouse, T. J. Stobbe, R. W. Plummer, R. L. Grayson, L. A. Layne, and G. M. Lies.

8. Provide appropriate control guarding.
9. Use an interlock device to cut off power to controls when the operator is out of position.
10. Use automatic cutoff switches at pinch points and other dangerous areas.
11. Use resin insertion tools and resin cartridge retainers.

After further study, it was determined that solutions 1 through 4 would require extensive effort to design and implement. For this reason, they were classified as extended-term solutions. Short-term solutions were identified as those that could be implemented using existing technologies and would not require significant machine redesign or time to implement. Solutions 5 through 11 were classified as short-term solutions. The short-term solutions were ranked using AHP as outlined in the following section.

CRITERIA FOR RANKING SOLUTIONS

AHP was used to rank the proposed solutions. AHP is a theory of measurement for dealing with quantifiable and/or intangible criteria. It is based on the principle that to make decisions, experience and knowledge of people is at least as valuable as the data they use (*3*). This process requires that criteria or standards by which solutions are to be judged are established. The sections that follow provide information regarding the weight given to various factors in the ranking process. The amount of weight given to the various criteria was obtained through a process of consensus by the project team. Three major categories were considered in rating the proposed solutions: (1) ability of the proposed solution to effectively protect the operator, (2) ability of the solution to be implemented in a timely fashion, and (3) the costs associated with the proposed solution in terms of installation, maintenance, and operating expense. Within each of these categories there were several criteria used to evaluate how well the proposed solutions would achieve these three major goals. Table 3 gives a breakdown of the criteria and the weight given to each in the ranking process.

Protection of Operator

Protection of the operator received highest priority by the project team. In fact, 65% of the total score for each proposed solution was based on the ability of the solution to protect the worker from being crushed by the drill boom or mast. The criterion judged most important in terms of operator protection was the ability of the solution to keep the operator out of boom-mast pinch points. If an operator can be effectively removed from a pinch point, it was reasoned, accidental activation of the controls would not have a catastrophic impact. The ability of the solution to reduce the likelihood of accidental activation of controls was rated as the second most important criterion in terms of protecting the worker. Finally, solutions were evaluated in terms of whether they might reduce or increase the mental or physiological stress (workload), thereby reducing or increasing the likelihood of accidental injury. The latter criterion received least weight.

Table 3.—Categories and criteria used to evaluate proposed solutions

Category	Criterion	Description
Protection (65%)		Ability of solution to protect operator from crushing injuries.
	Pinch points (63%)	Ability of solution to keep operators out of pinch points.
	Accidental activation (22%)	Ability of solution to prevent accidental activation of roof bolter controls.
	Mental or physiological workload (15%)	Likelihood of solution not to increase mental or physiological stress.
Time (21%)		Ability of solution to be implemented in a timely fashion.
	Hardware setup (67%)	Time necessary for development and installation of proposed solution.
	Implementation (33%)	Time required for operator to properly learn to use proposed solution.
Cost (14%)		Cost of solution in terms of installation, maintenance, and operation.
	Installation (20%)	Installation cost of proposed solution.
	Maintenance (20%)	Maintenance cost associated with solution.
	Operational (60%)	Operating cost, training cost, and effect on productivity of proposed solution.

NOTE.—Percentages in parentheses specify relative weights assigned to categories and criterion for the ranking process.

Time

While the project team felt that the protection of the operator was the most important characteristic of a proposed solution, it also considered the time associated with carrying out the solution an important factor. Obviously, worker exposure to hazardous situations can be greatly reduced if the solution can be implemented quickly. Thus, the time necessary for full implementation of the solution was factored into the ranking process. Full implementation time consisted of both the time necessary for hardware development and setup and the time required for the operator to learn to use the proposed solution once it became operational. The time estimates were based on the knowledge and experience of the project team. This factor accounted for 21% of the total score.

Cost

The cost associated with the solutions was also recognized as an important factor to consider in the evaluation process. As shown in table 3, the project team considered the costs associated with installation and maintenance, as well as the operational costs of the alternatives. The cost factor comprised 14% of the total score in ranking the solutions. The costs of the proposed alternative on operating costs (or cycle costs) received the greatest weight in this category (60% of the cost factor), followed by maintenance costs (20%), and installation costs (20%). The cost estimates were based on the knowledge and experience of the project team.

Once the weights of the criteria were developed, the alternative solutions were compared in a pair-wise fashion with respect to only one criterion at a time. For example, two proposed solutions would be compared, considering only how each resolves keeping the operator out of pinch points. The project team decided by what factor one solution out performed the other according to this criterion. Comparisons continued until all combinations of alternatives were exhausted. Next, the alternatives were compared two at a time with respect to inadvertent actuation of the controls, and so on. Calculations were then made to derive overall priorities for each proposed solution. A relative weight was given to each proposed solution based on the calculations, where the weights of all the alternatives summed to unity. The final ranked solutions are listed in table 4.

The next section discusses the ranked short-term solutions proposed by the USBM for reducing the likelihood of a roof bolter operator being crushed by the drill boom or mast of a bolting machine. Any design changes made to a roof bolting machine based on these recommendations need to be evaluated to (1) make sure it is effective and (2) make sure there are no new hazards created.

Table 4.—Solutions ranked using AHP

Rank	Solution	Relative weight
1 ..	Use an interlock device to cut off power to controls when operator is out of position.	0.239
2 ..	Provide fixed barriers at pinch points and other dangerous areas.	0.166
3 ..	Provide better control guarding	0.153
4 ..	Reduce speed of fast feed	0.127
5 ..	Use automatic cutoff switches for pinch points and other dangerous areas.	0.125
6 ..	Redesign control bank to conform to accepted ergonomic principles.	0.112
7 ..	Use resin insertion tools and resin cartridge retainers.	0.077

AHP Analytic hierarchy process.

DISCUSSION OF SOLUTIONS

The seven short-term solutions are discussed in order of rank, followed by a brief discussion of the extended-term solutions. In addition, the USBM feels that it is important to increase the miners' awareness of the hazards of roof bolting through additional task-specific operator training. Such training needs to be given for each phase of the roof bolting cycle. Should any roof bolters be modified based on the recommendations in this report, the operators need to be retrained to do their jobs on the modified equipment.

SOLUTION 1: USE INTERLOCK DEVICE TO CUT OFF POWER TO CONTROLS WHEN OPERATOR IS OUT OF POSITION

To reduce the risk of an operator being crushed, an interlock device should be installed on all roof bolters that would prevent the movement of the boom or drill mast when the operator has left the designated operating area. An interlock device is a common safety feature used to ensure that an event does not occur inadvertently while a certain condition exits. There are two general categories: those that must be activated for motion or action to occur (deadman controls) and those, which upon activation, will stop motion or action (automatic cutoff switches) (discussed in the section "Solution 5: Use Automatic Cutoff Switches at Pinch Points"). One form of deadman control that may effectively prevent an operator from accidentally engaging the fast-feed lever is a two-handed control mechanism. Requiring the use of a two-handed fast feed would also help to keep the operator within the safe work area and away from the drill boom while it is in motion. Careful consideration must go into the design and use of this system to ensure that the two-handed control cannot be overridden casually by the operator (figure 1). To discourage circumvention, other drill functions, such as drill rotation, may have to be disabled while the fast feed is engaged. Also, the operator must be able to complete required tasks effectively while using both hands for the fast feed. (An official from Fletcher has stated that all its new machines will use a two-handed fast feed and that retrofit kits will be available for machines already in use.)

Setting up a general deadman device to control the drill-head motion functions would be another way to ensure that the operator is within a designated safe area when operating a roof bolting machine. Possible devices include a foot pedal, a weight-sensitive platform, or a rail to which the operator must apply light pressure to activate the motion functions of the machine. Again, care must be taken in designing a deadman device to ensure that no new hazards are introduced and to ensure that a bolter operator can effectively perform the job. One item that must be addressed is to ensure that the device will not fatigue the operator because of awkward body position required to keep the deadman switch engaged.

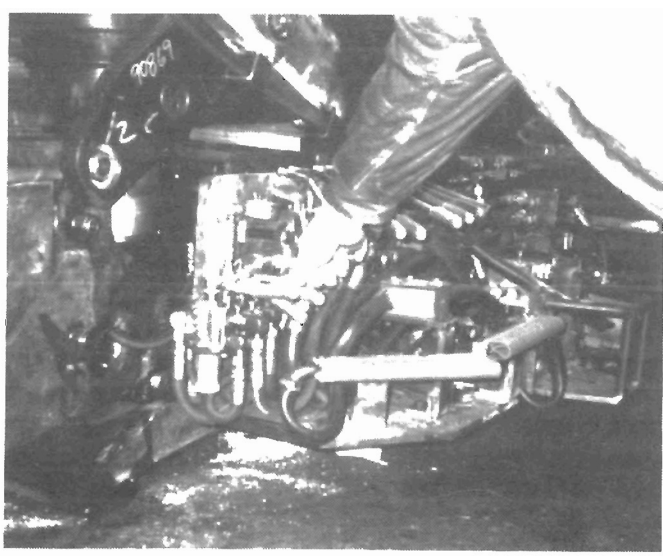
SOLUTION 2: PLACE FIXED BARRIERS AT PINCH POINTS

Roof bolting machines have many moving parts that create pinch points. All pinch points on the machine should be marked with reflective warning labels. Labels need to be cleaned regularly so that they are always visible. One very effective and inexpensive way to protect the operator from being caught in a pinch point is to place a stationary obstruction between the worker and the hazard (figure 2). The design of fixed barriers must be thought out carefully so that the operators do not expose themselves to other hazards while attempting to work around the barrier. Barriers must be difficult for the operator to circumvent, i.e., fasteners for fixed barriers should be of a type not easily removed, and the barriers themselves should be made as rugged as possible. A barrier should not cause the operator to assume awkward postures, and it should not further restrict visibility. Finally, it should not force the operator into another pinch point area to perform bolting tasks.

SOLUTION 3: PROVIDE APPROPRIATE CONTROL GUARDING

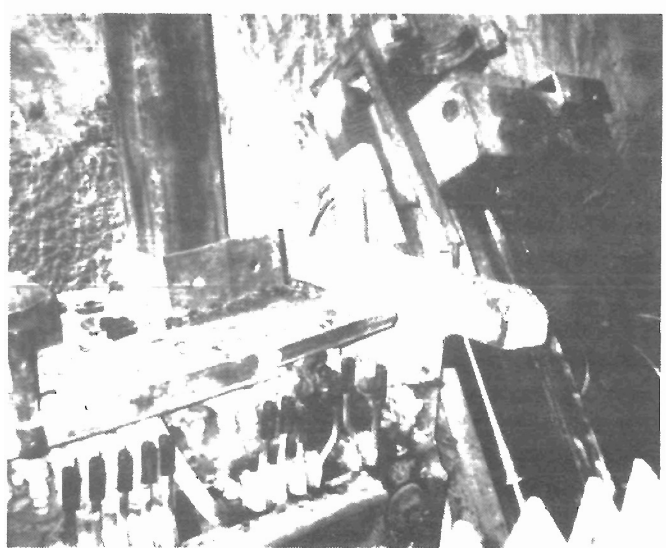
A simple and inexpensive way to help prevent inadvertent activation of a control is to provide appropriate control guarding. A guard is a barrier that prevents any part of the body from inadvertently entering the control area. For

Figure 1



Positioning deadman switch too close to fast-feed lever allows operator to activate both with one hand.

Figure 2



Heavy steel tool tray welded onto HDDR bolter by mine personnel provides fixed barrier to mast pinch point.

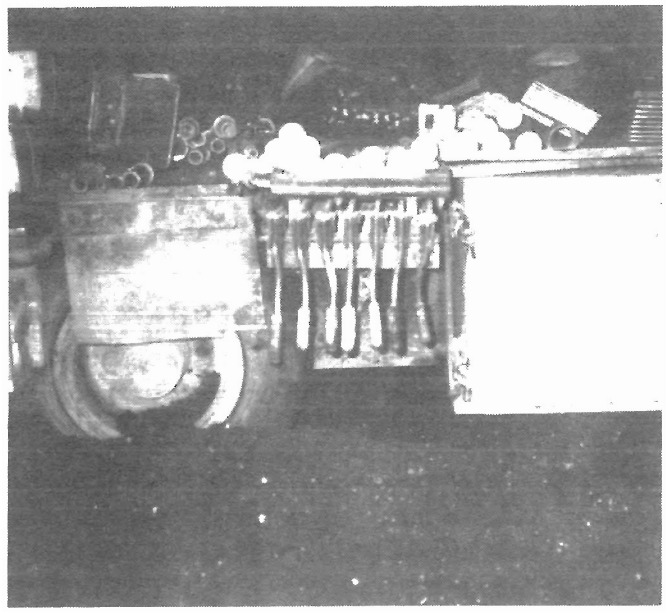
roof bolters, it should also prevent falls of the roof or rib or other objects (tools, drill steels, resin boxes, etc.) from activating a control (figure 3). A well-designed control guard for roof bolters must have certain characteristics. First, it must impose no new restrictions, discomforts, or difficulties for the worker. It must automatically move into or be fixed in place. If adjustable, it must not move out of alignment easily. It should be designed specifically for the machine, the type of operations to be conducted, and the hazards that are present. It should in no way restrict access to emergency shutoffs. Finally, it should be easy to inspect and maintain.

SOLUTION 4: REDUCE FAST-FEED SPEED

Fast feed is a feature that bolter operators use primarily when installing resin bolts to prevent the resin from setting up before the bolt has been completely inserted into the hole. However, many roof bolter operators speed up the bolting process by using it to lower the boom quickly when extracting drill steels and after installing a bolt.

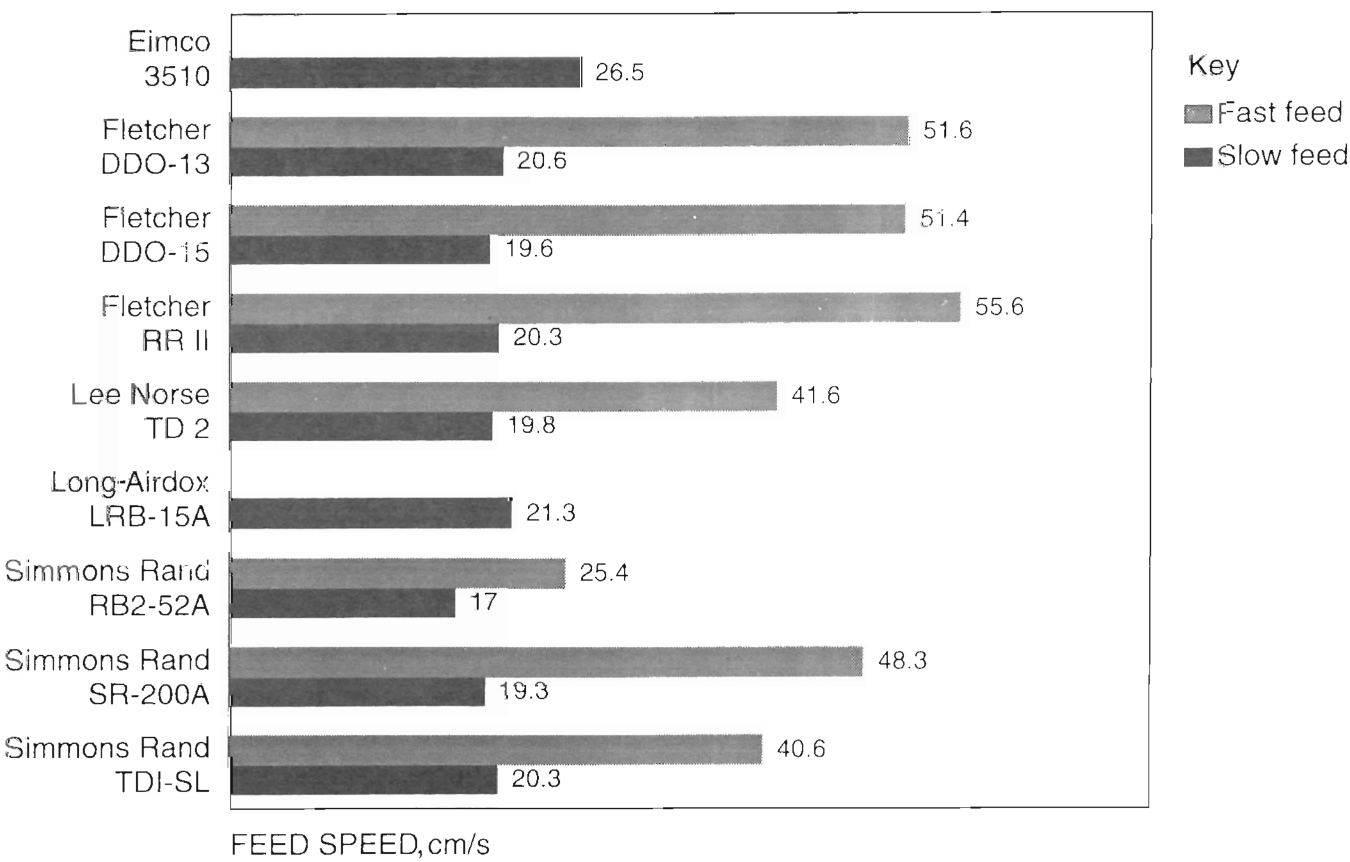
Figure 4 compares the fast- and slow-feed speeds for roof bolting machines from an unpublished informal survey

Figure 3



Unguarded controls are more likely to be activated by roof or rib falls.

Figure 4



Average fast- and slow-feed speeds for roof bolters.

conducted in West Virginia. The chart shows a wide variation in fast-feed speeds, with some roof bolter models having no fast-feed feature. When the necessary time is considered for operators to remove themselves from drill boom or mast pinch points, these fast-feed speeds may be excessive, particularly in low-seam heights where there is less room to maneuver. Unfortunately, it is difficult to determine what is a safe fast-feed speed. It depends on many variables, such as the machine configuration, the operator's workspace, and the ability of the operator to react in an emergency situation.

Until further research can be done to determine "safe" fast-feed speeds, or other measures are taken to ensure that roof bolter operators cannot become pinched by the drill boom or mast of a roof bolting machine, it would be prudent to limit the fast-feed speed on roof bolters. Since the slow-feed speed is limited by factors related to bit life and the hardness of the overhead strata, it may be reasonable to limit the fast-feed speed to some multiple of the slow-feed speed. As an example, table 5 illustrates the effect of limiting the fast-feed speed to two times the slow-feed speed. Another alternative would be for individual miners to do their own time studies to determine the impact of lowering the fast-feed speed and using a slower acting resin.

This solution does nothing to keep the operator out of pinch points created by the drill boom or mast, or to prevent the inadvertent actuation of controls. However, it may increase their chances of escaping a hazard once they become aware of it.

Table 5.—Effects of limiting fast-feed speed on roof bolters to two times slow-feed speed

Roof bolter	Speed, cm/s			Difference, %
	Current fast feed	Current slow feed	New fast-feed limits	
Eimco 3510 . . .	NAp	26.54	NAp	NAp
Fletcher DDO-13	51.56	20.62	41.25	-20.00
Fletcher DDO-15	51.41	19.56	39.12	-23.91
Fletcher RR II . .	55.63	20.29	40.59	-27.03
Lee Norse TD 2	41.55	19.76	39.52	-4.89
Long-Airdox LRB-15A	NAp	21.33	NAp	NAp
Simmons Rand RB2-52A	25.4	17.01	34.04	34.00
Simmons Rand SR-200A	48.26	19.30	38.61	-20.00
Simmons Rand TDI-SL	40.64	20.32	40.64	0.00
Average . . .	17.69	8.08	15.40	-12.94

NAp Not applicable.

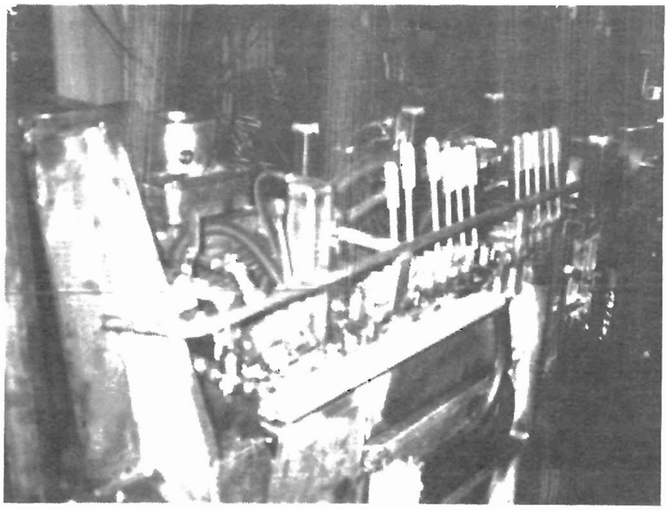
SOLUTION 5: USE AUTOMATIC CUTOFF SWITCHES AT PINCH POINTS

An automatic cutoff switch is another form of the interlock device discussed earlier. In contrast to a deadman control, an automatic cutoff switch will stop motion or action only upon its activation.

Two fatal accidents involving Fletcher HDDR walk-through bolters occurred when the operators placed themselves over the drill mast in an attempt to retrieve a drill steel that had become jammed in the rib. While in this position, the fast-feed lever on the control bank was activated, causing the drill mast to move. The operators were crushed between the advancing drill head and the frame of the machine. Because of these accidents, Fletcher has designed an automatic cutoff switch for the HDDR roof bolter. It consists of a bar extending the entire length of the control bank and through to the pinch point between the drill-head mast and the machine frame. If the operator presses on the bar, it immediately deactivates the hydraulic controls, stopping all motion of the drill head (figure 5).

Installing such an automatic cutoff is a relatively simple task on the HDDR roof bolter because of the straightforward design of its operator station. Unfortunately, other roof bolting machines, such as the Fletcher Roof Ranger II, do not have fixed operator platforms. These machines typically have the drill head mounted on the end of a boom that raises and lowers. With no convenient locations to mount a cutoff switch, the feasibility of applying this solution to these types of machines is more difficult. A significant human factors and mechanical design effort would be necessary to develop mechanical cutoff switches

Figure 5



Hydraulic safety bar installed on Fletcher HDDR roof bolter that acts as control guard and automatic cutoff switch.

for boom-style machines. Some issues that would have to be considered include making the switch fail safe, designing the switch to minimize inadvertent activations (otherwise, the operator may disable it), and ensuring that the switch does not interfere with other controls.

One idea for an automatic cutoff that may warrant further research would be to place infrared sender and receiver proximity switches along the drill boom. These switches would be set up to disable drill boom movement whenever the beam was broken. An infrared switch consists of two parts: a sender unit and a receiver unit. The sender unit sends out a beam of infrared light. The receiver unit "sees" this beam and sends out a signal accordingly. The signal would be used to control the hydraulic oil reaching the boom raise cylinder. If any part of the operator's body would come close to the boom and break the infrared beam (while installing resin, retrieving a stuck drill steel, etc.), the boom would not move even if the controls were activated.

Of course, this equipment would have to be rugged and capable of surviving in the underground environment. Furthermore, all electronics would have to be intrinsically safe and MSHA approved. Thus, setting up this system may best be completed at the manufacturing level rather than retrofitted in the field.

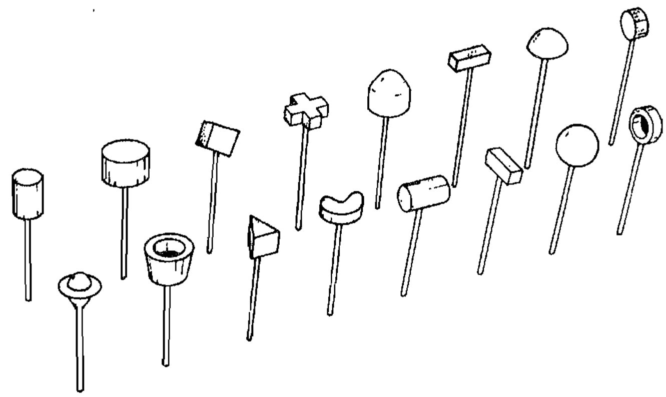
SOLUTION 6: REDESIGN CONTROL BANK TO CONFORM TO ACCEPTED ERGONOMIC PRINCIPLES

There has been a significant amount of research done on the design of controls for mobile equipment (*8-10*), and at least one study was conducted that looked specifically at the design of controls for roof bolters (Helander and Conway).[6] Some general findings from that previous work, as well as the application of human factors principles to mining (*11*) are discussed as follows:

1. Controls should be coded by sequence, location, and shape so that they can easily be distinguished. Figures 6 and 7 depict examples of control shapes. According to Helander and Conway, coding by sequence and location is important because people are good at remembering where items are located in the space around them. One way that sequence and location coding can be accomplished is by arranging controls into functional groups. Controls should also be labeled clearly. Coding according to color is not considered practical in the underground mine environment.

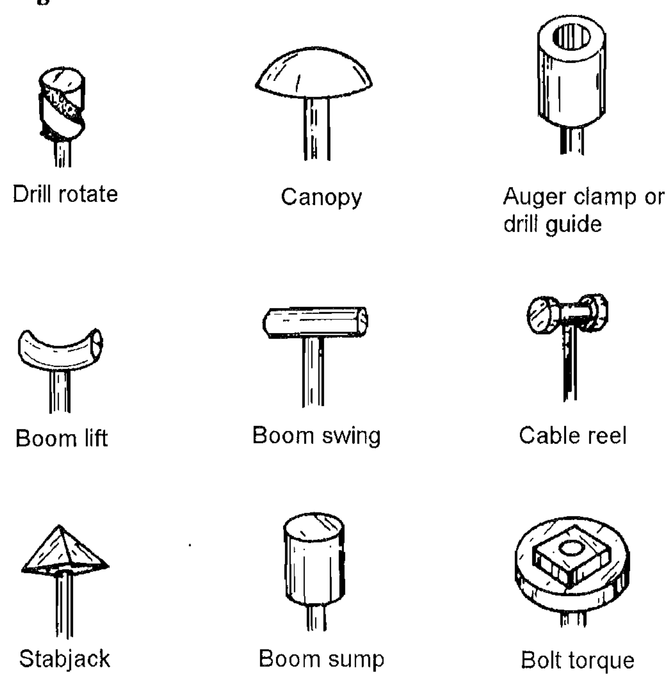
[6]Work cited in footnote 3.

Figure 6



Knob shapes that can be recognized by touch by operators who wear gloves.

Figure 7



Suggested knob shapes for roof bolters that relate to function being controlled.

2. Whether or not it is correct to mirror image controls for dual-boom bolters (figure 8) is being debated. One study reports that either mirror image or place arrangement is acceptable. However, another study suggests that when the operator on the left side operates the controls with the right hand and the operator on the right side uses

the left hand, the mirror-image arrangement decreases the time the operator needs to adjust to a switch in sides.

3. The direction of control movement should be according to control movement stereotypes (table 6).

4. Where practical, the number of controls should be reduced by combining control functions into one control. (Fletcher now offers a joystick control option on its Roof Ranger model that combines drill rotation with drill feed.)

5. Optimum control resistance is approximately 44 to 67 N (10 to 15 lbf) for controls operated with full-arm motion and the hand.

6. For controls operated with the forearm and hand only, the minimum resistance is 22 N (5 lbf), and for hand-operated controls, the minimum resistance is 9 N (2 lbf). In addition to the above, control layouts for the same model of roof bolting machine should be identical on a per-mine basis to avoid problems related to adjusting to different control layouts.

Another important aspect of control design is maintenance and maintainability. Sloppy control linkages have been implicated in many injuries and several fatalities. Control linkages should be inspected before every shift, and loose or broken linkages should be repaired immediately. Controls should be designed to allow easy visual inspection and should use components that can withstand the mine environment.

The reference section at the end of this report contains many references related to control design. If a roof bolting machine's controls are modified based on the recommendations in this report, then it is imperative that the bolter operators be retrained on the modified equipment.

Table 6.—Typical control movement stereotypes

Function	*Direction of movement*
On	Up, right, forward, clockwise, pull.
Off	Down, left, rearward, counterclockwise, push.
Right	Clockwise, right.
Left	Counterclockwise, left.
Raise	Up, back.
Lower	Down, forward.
Retract	Up, rearward, pull.
Extend	Down, forward, push.
Increase	Forward, up, right, clockwise.
Decrease	Rearward, down, left, counterclockwise.

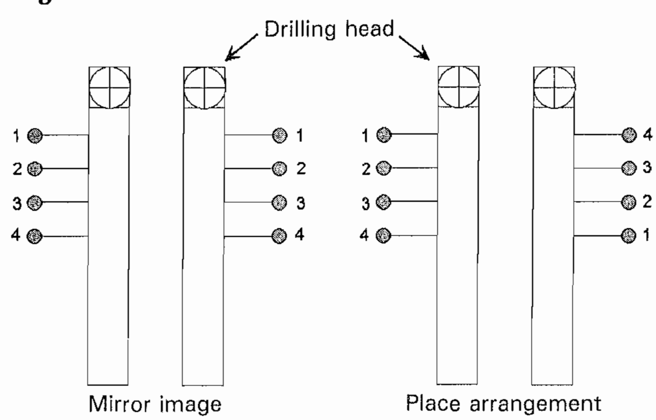
SOLUTION 7: USE RESIN INSERTION TOOLS AND RESIN CARTRIDGE RETAINERS

Operators of both boom- and mast-type roof bolters have indicated difficulty installing resin cartridge(s) into the hole, particularly in higher seams. Consequently, they are compelled to climb out onto the drill mast or boom to reach the hole. There have also been instances of operators riding the boom up to the roof to install resin.

The use of resin insertion tools is one alternative for reducing the tendency of bolter operators to position themselves in hazardous locations or to perform unsafe acts. During this analysis, the USBM learned of two insertion tools. One, a resin and bolt insertion device, was designed by the Birmingham Bolt Co. for use in truss bolting with expansion-shell-type bolts (figure 9). It consists of a variable-length polyvinyl chloride (PVC) pipe with a slot cut through its entire length. The pipe's inside diameter is determined by the diameter of the expansion shell. The slot width is determined by the diameter of the bolt being used. The pipe is snug fit over the expansion shell and holds the resin while it is inserted into the predrilled hole. The bolt then acts as a plunger, forcing the resin into the hole. When the expansion shell enters the hole, the PVC pipe section drops off so that it can be recovered and reused.

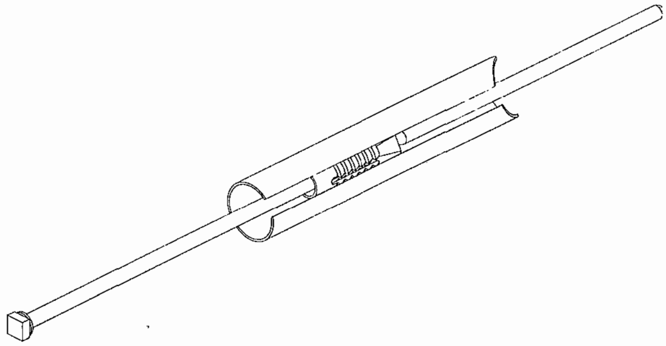
The other insertion tool was designed by Fletcher (figure 10). It consists of a variable-length, 91- to 305-cm

Figure 8



Two dual-boom bolter layouts illustrating mirror image and place arrangement of controls (1 through 4).

Figure 9



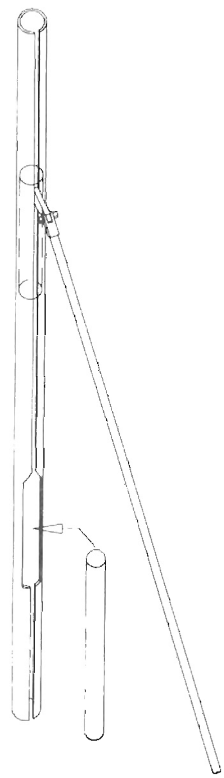
Resin transfer tube designed by Birmingham Bolt.

(36- to 120-in) PVC pipe with a slot cut in it that allows a hinged handle (used as a plunger) to push a tube(s) of resin into a predrilled bolt hole.

Any resin insertion device must be inexpensive so that it will be practical to have available at the section. The device must also be easy to use and provide a definite advantage over having the roof bolter operator to climb out onto the drill mast or boom to reach the hole.

The USBM has learned of two in-hole retaining devices for tubes of resin that are available from resin manufacturers—the "clip" and the "parachute" (figure 11). The clip (made by Celtite Mining Div., Fosroc Inc.) is a 2.3-cm (0.94-in) square piece of plastic, 0.2 cm (0.08 in) thick, with a 2.1-cm (0.83-in) hole in the middle. The (daisy) parachute made by E. I. du Pont de Nemours & Co., Inc., resembles a badminton cock; it is 5.2 cm (2.04 in) long and 2.8 cm (1.10 in) in diameter. Both the clip and the parachute are used almost exclusively in noncoal mining, particularly hard-rock mining in Canada. The parachute is designed specifically for the pneumatic, semiautomatic insertion feature of Secoma U.S. Inc.'s bolting machines. The clips and parachutes come preassembled on the resin cartridges, although the manufacturer will provide them separately if the customer desires. The extra cost of using the clips and parachutes is approximately 15% and 20% to 25% of the cost of the resin, respectively.

Figure 10



Resin insertion assist designed by Fletcher.

EXTENDED-TERM SOLUTIONS

The following unranked solutions would require extensive effort to implement. However, the ideas discussed have great potential to increase the general safety of roof bolting.

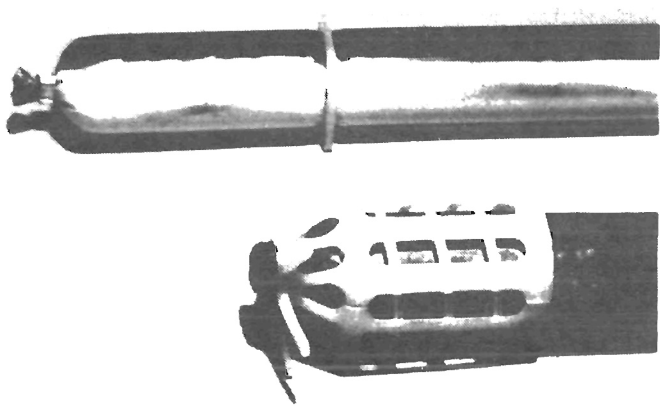
Perform Overall Crewstation Redesign

Based on mine and manufacturer visits, it appears that many of the crewstations for roof bolters have been designed with production considerations foremost. The operators' needs have been met only after the basic layout of the machine has been completed. Thus, the operator has to lean over the control panel to retrieve a drill steel, or position himself or herself over the boom to insert a drill steel.

Our suggested approach to solving this problem is to perform a thorough analysis of roof bolting tasks to better define the needs of operators and to identify how tasks can be completed safely and efficiently. Some factors that need further study (through literature reviews, laboratory experimentation and task analysis) include—

- Visibility and illumination: What does the roof bolter operator need to see (drill head, hole, controls) and in what detail?

Figure 11



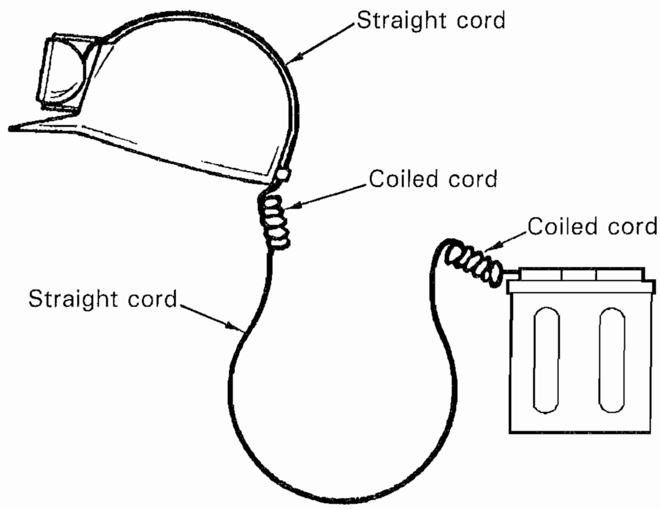
Resin retaining devices: clip (top) and parachute (bottom).

- Noise and communication: Who does the operator need to communicate with while bolting (other bolters), and what information must be transferred?
- Postural analysis: What postures are best for a given seam height and workload (sitting, kneeling, prone)?

• Reach accommodation: What controls need to be handled and at what frequency, what tools need to be handled, and what needs to be reached from the crew-station (mine roof, rib) to perform the task?

Once there is a thorough understanding of the task and the operators' needs, it is possible to begin to design a crewstation and machine that meet those requirements. It is likely that many of the more hazardous operator requirements can be designed out of the system once the engineers have a better understanding of what the machine needs to do. For instance, design engineers have to understand the potential hazards associated with removing a jammed drill steel. They need to consider the force required to remove the steel, the frequency of its occurring, and the tendency for operators to take the easiest path to the steel (over the controls).

Figure 12



USBM coiled cap lamp cord concept.

Reposition-Redesign Personal Protective Equipment

In tight quarters, personal protective equipment is more likely to bump or become tangled in the roof bolter controls, possibly causing an inadvertent activation. One solution is to provide designated areas on the bolter for storing the operator's person wearable self-contained self-rescuer (PWSCSR) so that it need not be carried at all times. This could be expedited by using a carrying harness that simplifies attaching and detaching the PWSCSR to the miner's belt. The storage area would have to be designed to provide quick and easy access to the PWSCSR. Another alternative is to develop a carrying harness that positions the PWSCSR so that it no longer interferes with roof bolter controls.

A possibility for reducing the chances that a control will be activated if it is snagged by the cap lamp cord is to use the coiled cord concept (*4*) developed by the USBM (figure 12). A more extreme idea (that would require further study) would be to improve the lighting systems on bolters (spot and area lighting) so that personal cap lamps are not necessary for bolter operation. Designated areas would be provided on the bolter for storing a cap lamp so that it is not necessary for the operator to carry it at all times. As with the PWSCSR, a carrying harness that simplifies attaching the lamp battery pack to the miners' belt would be a possibility.

Miners today wear a wide range of outer garments, ranging from old street clothes to expensive coveralls, that have not been tailored to the mine environment or mining tasks. Few mine operators regulate the work clothes worn by their miners beyond requiring a snug fit around the ankles. In one of the most hazardous work environments known, a miner may be permitted at the worksite in blue jeans and a T-shirt. Perhaps bolter operators need clothing that minimizes the chance of snagging a control, such as tighter fitting coveralls or jackets.

Also related to personal protective equipment, roof bolter operators working in lower seam heights spend a large percentage of their time on their knees. In high-production sections, such as extended-cut sections, where there is pressure for the bolter operator to keep pace with the continuous miner, roof bolter operators have less opportunity to stretch and rest their legs. There is evidence that one of the most frequently occurring problems for lower seam bolter operators is damage to the knees. There were 64 accidents involving roof bolter operators injuring their knees in 1993. Uncomfortable postures may lead some operators to assume positions that relieve the pain in their legs, but expose them to pinch point hazards.

Because of the need to reach bolts and tools, insert resin, and adjust the position of the machine, it may be impractical to construct a crewstation that allows the operator to sit while bolting in low seams. However, it should be possible to provide bolter operators with knee pads that take advantage of new cushioning materials that are more suited to the bolting task. Also, an adaptation of a device used by carpet layers (a combination knee pad-stool) may work in low-seam mines.

Reduce Likelihood of Drill Steel Jamming

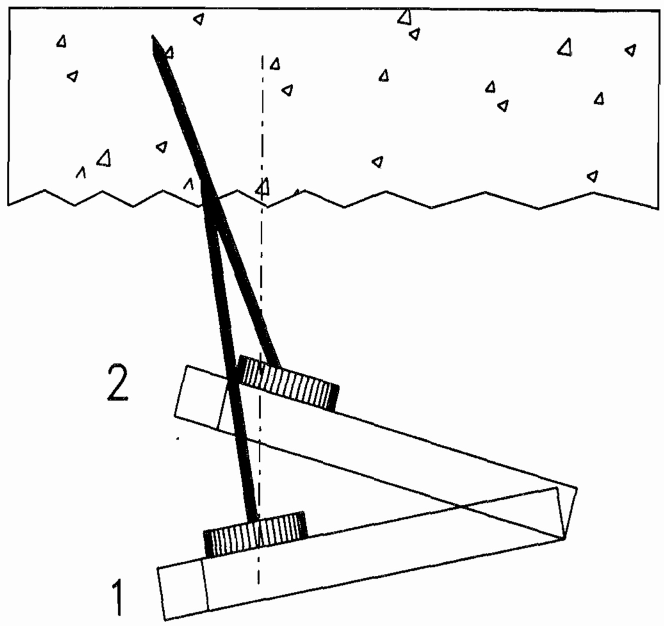
During drilling operations, drill steels can become caught in the hole. There are several reasons why this could happen: (1) The bolter operator may not be drilling a straight hole; (2) the strata could be moving and could bind the drill steel; (3) there could be water that could cause dust clogging; or (4) the dust vacuum could be inadequate. In any event, the bolter operator must retrieve the drill steels, often forcing the operator to get in a position considered unsafe (such as crawling out onto the boom, or reaching or leaning out beyond the protective canopy) to retrieve the steel.

The Helander and Conway study[7] found that initial misalignment of drill steels is a primary reason why they get stuck. Using a deep chuck and drill guide may help improve the initial alignment. Unfortunately, drill guides are in a vulnerable location and are high-maintenance items. Since they are not critical to the drilling cycle, they are often not repaired when damaged. A disadvantage of using deep chucks is that, unless the initial alignment is correct (difficult to do unless the floor is horizontal), the steel will bind in the hole unless the roof bolter boom is repositioned while drilling[8] (figure 13).

One possible solution is to make the drill steel shaft smaller than the bit. This would cause the hole to be slightly larger than the shaft, making it less likely to jam. However, after checking with several ground control experts, it was decided that this solution is limited by current technology. The smallest diameter of drill steel needed to maintain strength is approximately 2.22 cm (7/8 in). For a 2.54-cm (1-in) hole, this is the smallest diameter that can be used for the drill steel.

Better maintenance procedures may reduce the jamming problem. If the dust bins and filters are not cleaned out regularly, there may be a decrease in suction power. The maximum vacuum can be maintained if the dust bins and filters are checked and cleaned regularly as part of the normal preshift inspection. Suction hoses also need to be inspected regularly for cuts and excessive wear. Switching to water-dust-suppression systems may help to eliminate the dust clogging. Unfortunately, water drilling is messy and many roof bolter operators do not like it.

Figure 13



Misalignment increases when boom goes from position 1 to position 2 unless roof bolter is moved forward.

Use Automatic Resin Insertion Devices

Ultimately, the hazards associated with resin insertion are best handled by eliminating the task altogether. Although there are no fully automatic methods of resin insertion available, semiautomatic insertion methods exist. Two are made by Fletcher and Secoma for roof bolters used predominantly in noncoal, hard-rock mining operations. With the Secoma machine, the bolter operator feeds tubes of resin into an injection hose from the operator compartment to the predrilled hole by compressed air. The Fletcher roof bolters, also described as "roof-referenced, double-extending mast machines," are being used by mine operators in the northern West Virginia-Maryland area. These machines insert resin tubes semi-automatically and remotely using a mechanical mechanism. A basic requirement of using these machines, however, is sufficient working height. (The Fletcher machine uses a resin retainer that resembles the plastic cap commonly used to protect the ends of pipe. According to Fletcher, these are relatively inexpensive, e.g., several thousand for under $100. The retainers are assembled by the bolter operator, not by the resin manufacturer.)

Research efforts are under way to develop automated bolting systems, including work by the USBM. This research is in the early stages of development and is not addressed in this report.

[7]Work cited in footnote 3.
[8]Work cited in footnote 5.

RECOMMENDATIONS

Implementation of the following recommendations could significantly reduce roof bolting injuries related to the movement of the drill-head boom or mast of roof bolting machines.

1. Implement as many of the following ranked short-term solutions as possible. (After any modifications are made to roof bolting equipment, operators must be re-trained to do their jobs using the modified equipment.)

   a. Use a deadman interlock device to cut off power to the controls when the operator is out of position.

   b. Place fixed barriers at pinch points and other dangerous areas.

   c. Provide better control guarding.

   d. Reduce the fast-feed speed.

   e. Use automatic cutoff switches for pinch points and other dangerous areas.

   f. Redesign the control bank to conform to accepted ergonomic principles.

   g. Use resin insertion tools and resin cartridge retainers.

2. Increase mine worker awareness of the hazards of roof bolting through additional task-specific operator training.

3. Perform a study to determine the maximum safe speed for equipment appendages (booms, conveyors, stab jacks, etc.) in the underground workplace.

4. Incorporate the following long-term solutions into the design of future generations of roof bolting equipment and, where feasible, examine the possibility of modifying existing equipment.

   a. Perform a crewstation redesign with greater emphasis on operator reach and visibility requirements.

   b. Reposition-redesign personal protective equipment so that it is less likely to bump or become tangled in controls.

   c. Reduce the likelihood of the drill steel getting caught in the hole through better maintenance and drill shaft designs.

   d. Use automatic resin insertion devices.

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APPENDIX

Roof Bolter Operator Interview Form

Interviewer: ______________________________ ID: ______________

Date: ______________________________

We are researchers from the U.S. Bureau of Mines in Pittsburgh, PA. We want to learn more about roof bolting operations. In particular, we want to determine if there are safety problems associated with roof bolting. If there are problems, we want to help develop solutions to them. Since you have first-hand experience we consider you the expert and want to hear what you have to say about your personal experience. Your name will not be associated with any information you provide and your participation is completely voluntary.

1. Demographic Information

a. Age: b. Sex:

c. Total Years Underground Mining Experience:

d. Total Years Mining Experience at This Mine:

e. Job Classification:

f. Total Years Experience in Current Job at **This Mine**: ______________

g. Height: ______________

h. Weight: ______________

i. Right handed: ______________ Left handed: ______________

2. Work Methods and Mining Conditions

a. Please describe your normal job duties.

b. Please tell me, step by step, how you bolt roof. (Note: May want to record during a demo.)

c. Are there any physical conditions in the mine that make bolting difficult (Y/N)?
(Probes: water, soft bottom, roof, rib, methane, ventilation)

d. What are the biggest obstacles you face when operating a roof bolter?
(Probes: reach, visibility, steel handling, resin insertion, position of controls)

e. What could be done to make your job safer? (Probes: equipment, tools, methods)

3. Roof Bolting Training

a. Did you receive on-the-job training (from an experienced person)? (Y/N)

b. Did you receive vocational-technical training? (Y/N)

c. Did you receive written job procedures? (Y/N)

d. Did you receive any other type of training? (Y/N)

e. In your own words, briefly describe the type of training that you received when you learned to operate a roof bolter.

f. How long did it take to learn your job?

g. Did you have any difficulties in learning your job? Please explain.

h. Could your roof bolter training have been better? (Y/N)

If so, how?

4. Control Layout and Design

a. Are any modifications made in bolting machines after they come from the manufacturer? (Y/N)

If yes, what are these modifications? (Probes: guards, safety bars, hydraulics, control position, other devices)

b. Are you satisfied with the controls on the roof bolters that you use? (Y/N)
(Probes: type, layout, location)

If not, why not?

What would you do to make them better?

c. Have you ever heard of anyone accidently activating a control lever? (Y/N)

If yes, what control and how?

d. What do you use the fast-feed raise feature for?

Is it used in any other way at your mine?

e. Do you need the fast-feed feature to do your job? (Y/N)

If yes, why?

f. Do you like the fast-feed feature? Please explain why or why not.

5. Roof Bolting Safety Issues

a. Are you aware of any safety problems with the bolting cycle?
(Probes: pinch points, accidently hitting controls, boom raise speed, etc.) Please describe:

b. What is the most dangerous part of operating a roof bolter? Please explain.

c. How can this danger be corrected (if at all)?

d. What is the most common injury a bolter operator may suffer?

e. Have you had a work-related accident of any type in the last 5 years? (Y/N)

If yes, please describe.

f. There have been at least eight roof bolter operator fatalities since 1988 when they were caught between the boom and either the roof or canopy-ATRS.

How do you think an accident like this could happen?

What do you think can be done to prevent this from happening?

Are there any design solutions to this problem?

Would there be any reason for an operator to position his or her head or upper body between the boom and canopy or roof? Please explain.

g. There have been two recent angle bolting fatalities. In each case, the operator reached across the control bank, accidently activating the fast-feed lever, causing the boom to crush him or her against the machine. Three tasks have been identified, which may expose an operator in this way. They are retrieving drill steels, inserting resin, and piloting a wrench to drill steels.

Have you ever done truss bolting or rib bolting? (Y/N)

If yes, do you have any difficulties performing the tasks described? Please explain.

Can you think of any other reason why an accident like this may occur?

What do you think can be done to prevent this from happening?

Are there any design solutions to this problem? Please explain.

It has been suggested that tools be developed to make these tasks easier and safer. Do you have ideas about what type of tools may be useful, if any?

6. Concluding Remarks

Is there anything else about roof bolting or mine safety that you would like to talk about?

Optional Questions: Comparison of Fletcher Offset Boom Versus Regular Boom

1. Have you used both the new-style Fletcher bolter (offset boom) and the old style?

2. Do you think the new design is better or worse than the old design? Why?

3. What are the best features of the new design?

4. What are the worst things about the new design?

5. What do you think of the two-hand operation for the fast raise lever? Is it safer? Are there any problems with it?

6. Do you think the new design gives you a better area to work in?

7. Does it provide you with a better escapeway?

8. Is there any difference in the speed of bolting between the two bolters?

9. In general, do you feel that the new bolter is safer, less safe, or about the same as the old bolter?

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