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ELECTRICAL, MECHANICAL, AND HYDRAULIC SYSTEM IMPROVEMENT STUDY FOR ROOF BOLTER OPERATIONS

Final Technical Report
Contractor—Woodward Associates, Inc.

November 1980

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(formerly U. S. B.M. JO177084)

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ELECTRICAL, MECHANICAL, AND HYDRAULIC SYSTEM IMPROVEMENT STUDY FOR ROOF BOLTER OPERATIONS

Volume I —
Technical Information and Conclusions

FINAL TECHNICAL REPORT
AS OF
NOVEMBER 30, 1980

This report represents work on a program that was originated by the Interior Department's Bureau of Mines and was transferred to the Department of Energy on October 1, 1977.

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U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Energy Technology
Division of Solid Fuels Mining and Preparation

FOREWORD

This report was prepared by Woodward Associates, Inc., San Diego, California, under U.S.D.O.E. Contract Number DE-AC01-77ET12221 (formerly U.S.B.M. Contract Number J0177084). It was administered under the technical direction of the Pittsburgh Mining Technology Center with Mr. L. Robert Allen as Technical Project Officer.

Woodward Associates, Inc. wishes to acknowledge the cooperation and free commentary supplied by all the mine operators, rebuild shops, and manufacturers visited and contacted. The unpublished information supplied provided a fundamental data base.

This report is a summary of the work completed during the period August 27, 1979 to November 30, 1980.

ABSTRACT

Roof bolters as a generic machine type used in continuous coal miner sections were investigated to determine the effect of machine failures and downtime on productivity, pinpoint the causes of machine failures and downtime, and develop the possible design and operational changes required to reduce machine failures and downtime and increase section productivity. In the course of this program it was determined that the roof bolter is not the major contributor to section downtime. This fact develops from the section work cycle in which the roof bolter can normally complete the required roof control work well ahead of the continuous miner. In addition, the roof bolter is a less costly and more maneuverable machine than the continuous miner which allows a mine to provide a standby machine quickly to reduce the section downtime caused by an individual machine.

In developing the information on roof bolter failures and by interviewing machine manufacturers and rebuilders, this report does identify problem areas in drill head, dust suppression system, and undercarriage design that create maintenance and section downtime problems. Specific recommendations are made to improve the present machines and components. This report represents only one element (roof bolters) of a mining system. The other machines in the system (continuous miners and face haulage equipment) are covered in companion reports.

CONTENTS

CONTENTS (CONT)

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TABLES

EXECUTIVE SUMMARY

The effect of roof bolter failures on section downtime was found to be much less than continuous miners or face haulage equipment. On the average, 11 minutes of section downtime are attributed to the roof bolter based on data reporting 4,894 individual failures during 31,429 shifts of operation. The average downtime for roof bolters was 75 minutes per failure. The roof bolter normally completes its required work cycle faster than the continuous miner affording some slack time for minor repairs and maintenance. Even so, based on an estimated 2 tons of lost production per minute of section downtime, the average section downtime of 11 minutes caused by the roof bolter could mean that up to 22 tons of coal per shift are not mined (lost production).

To accomplish identification of specific roof bolter components contributing to the reported section downtime, the data base from 15 mines was encoded for computer sorting and analysis. The reported failures showed the following distribution:

- 42% of the failures were caused by mechanical related problems.
- 31% of the failures were caused by hydraulic related problems.
- 22% of the failures were caused by electrical related problems.

Listed below are the ranked components causing the majority of roof bolter failures and corresponding section downtime:

- Mechanical
  - Dust Suppression System
  - Drill Head
  - Drive Train (Chains)
  - Tires

- Hydraulic
  - Hoses and Fittings
  - Actuating Cylinders (Jacks)
  - Motors and Pumps (Hydraulic Oil Contamination)
- Electrical
  - Trailing Cable
  - Electrical Controls (Contactors, Relays, Switches, etc.)
  - Motors

In the course of interviewing responsible mine and manufacturer or rebuild personnel, and developing the roof bolter failure data base, information was developed that indicates the primary tool for reducing section delays caused by machine failure is an adequate and enforced maintenance program. The mining operations showing better than average roof bolter failure records were also the operations having a planned and controlled maintenance program which recorded all failures and repairs and used the information to identify critical components and their operational life. In identifying these critical components and their failure mode, it may be possible to improve the roof bolter design or operation. Design improvements are not enough in that the proper operation of the roof bolter is critical for prevention of catastrophic failure. In this way then the overall plan required for reducing section downtime caused by roof bolters will require some design improvements (many of which have already been made in new models), better training for operators and maintenance personnel, and compilation of failure and repair records to track the roof bolter performance and identify problem areas.

1. INTRODUCTION

Continuous mining systems continue to replace conventional mining techniques because of increased production capability and potentially safer operating conditions. The development of continuous mining systems exhibiting greatly improved reliability is a key element in the overall effort to improve U.S. coal production. Roof bolters are an integral part of the continuous mining system.

Since 1969, total underground coal production in this country has been steadily decreasing on a per man-shift basis even as the theoretical production capacity of the machinery employed has been increasing. A report prepared by the Bendix Corporation (1)* under U.S. Bureau of Mines (USBM) Contract No. SO144087 indicates that the availability for production (total time available minus section downtime) of continuous mining machines is only 73%. A more recent report** prepared by J. J. Davis Associates under USBM Contract No. JO357096 indicated that the continuous miners studied under that specific contract were in actual production only 23.5% of the shift. The mines contacted by Woodward Associates, Inc. (WAI) during the course of this contract indicated section production times averaging approximately 100 minutes per shift or about 21% of the available time. Part of this section downtime is caused by roof bolters.

To significantly increase coal production, the actual production times must be increased from this 20+% level of productive use. The roof bolter is one of the key elements in the extraction cycle. Improvement in this cycle requires improvement in the availability of the roof bolter to maintain section production. When the roof bolter suffers a breakdown, production from the entire section may be lost until the machine is repaired or replaced. Mine productivity data shows that the typical mine loses up to two tons of coal for each minute of section downtime. Thus it is very important to reduce this downtime.

The purpose of this contract was to identify those mechanical, electrical, and hydraulic problems exhibited by roof bolters which, when properly assessed and solved through subsequent research and development contracts, could result in the development of roof bolters exhibiting a high degree of reliability.

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*Underlined numbers in parentheses refer to items in Section 6 — References.
**To be published.

Past experience with mining equipment has shown that a specific failure may be due to several causative factors. Woodward Associates, Inc. felt that the failure areas could be identified by visits to the mines. In addition, it was felt that rebuild and mine equipment repair shops would be another source of information and could contribute to the analysis of the problem areas. Finally, plant visits to the manufacturers were scheduled to ascertain if these problem areas had indeed been noted and what, if anything, was being done.

Woodward Associates, Inc. was aware that this effort addressed a field populated by large numbers of machines of varying ages, different design concepts, varied maintenance histories, and nonstandard components through initial specification and/or subsequent modification. Efforts were made to define the failure modes by gathering large amounts of data using section delay reports. Analysis of the problem areas defined by section delay reports with input from the three data sources has resulted in the elimination of much of the nonpertinent information from the data and in an accumulation of a history of the problem areas. Problems inherent to specific machines are treated as specific problems. Geographical and operating environments were considered.

1.1 MINE VISITS

Woodward Associates, Inc. used the USBM Coal Mine Equipment Use Data Bank (2) to select mines having a varied inventory of mining machines for data gathering visits. The selection also looked for mines that had machines of varying ages and where, if possible, utilized machines of more than one manufacturer in the operation. Twenty mines were visited in the performance of this contract – 13 Eastern, 4 Midwestern, and 3 Western. Of these mines visited, only 15 made a practice of reporting roof bolter failures in their section reports.

1.2 EQUIPMENT REBUILD SHOP VISITS

Many mine operations will consistently rebuild older roof bolters at a cost that very nearly approaches the purchase cost of a new (and possibly updated) machine. The reasons for this are developed later in this report.

The machine rebuilders visited were very competent. The roof bolter, and associated underground equipment, is complex as well as massive and rugged. Modifications to the design and to the structures require broad technical and engineering skills if the modifications are to be productive in the mine environment. Two types of rebuild shops were visited – captive shops owned by mining companies and independents. The captive rebuild shops must satisfy the demands of mine production people if their services are to be required on a continuing basis. The independent rebuilders have grown by establishing a reputation for expertise and reliability, and are extremely proud of their reputations and their accomplishments. They have acquired a working relationship with the machine manufacturers who offer them engineering guidance and a limited degree of support in the form of shop drawings. The rebuilders reciprocate by informing the manufacturers of "fixes" they have found to be productive. WAI visited two independent rebuilders in the East, two mine-operated rebuild shops in the Midwest, and two Western independent rebuilders.

1.3 MANUFACTURER VISITS

Woodward Associates, Inc. visited three manufacturers of roof bolters during this contract. The manufacturers were quite willing to talk about common problems faced in the operation of roof bolters and discuss the evolution and development of roof bolters. They were, of course, reserved about discussing specific problems that they have, or are presently encountering. The manufacturers extract as much feedback as possible from the mines upon the introduction of a new machine or model. They are well aware that any new machine introduced into the mines is going to experience problems and that in-house testing of prototypes is not going to identify all of the problems. The manufacturers are quite conservative in their engineering approaches, and are aware that unique introductions of technology may cause unique maintenance problems that could offset any technological gain.

All the manufacturers visited are aware that problems still exist both in the design and operation of roof bolters. They have ongoing development programs to resolve these problems. It is interesting to note, though, that solutions to major problems are usually found in a new model machine rather than being supplied as a retrofit or an update kit for existing models.

1.4 SECTION DELAY REPORT ANALYSIS

Using actual mine section delay reports as a raw data base, the failure analysis of roof bolters is based on the resulting data set of close to 5,000 individual roof bolter failures. The data set compares 15 mines using 96 roof bolters. A computer program used to sort the data classified failures by code and downtimes. The analysis of the data in Section 4 of this report results in a statistically significant sample to factually pinpoint maintenance problems in roof bolters. The failure analysis results substantiate most of the problems subjectively addressed by mine maintenance personnel. In other machine failure areas (drill head failures in particular), the statistical data did not reveal as great a maintenance problem as voiced by machine manufacturers or maintenance personnel. One possible answer to this is that this survey looked at section delays occurring during a production shift and their causes. Major machine components wear gradually and real problems can often be fixed during a third or maintenance shift and therefore would not cause section production downtime. This data acquisition problem will be discussed in more detail in Section 4.

2. MACHINE CHARACTERISTICS AND COMPONENTS

The present-day roof bolter has evolved from equipment developed in the 1940s and 1950s. The earlier approach to consolidating the roof, centered mainly on providing timber cribbing and the localized use of roof supports for permanent and concreted roof. Initial roof bolting was often done using hand operated air drills. The first roof drills were shop-built in the coal fields using adaptations of hard rock jumbos to drill and set the roof bolts. As roof bolting came into vogue, new machines were custom built for the bolting of roofs in coal mines. The present-day roof bolter looks very similar to the earlier models. Improvements have been made primarily in the material used in the construction of the roof bolter and in the layout and drill alignment mechanisms.

2.1 THE ROOF BOLTER

For the purposes of this report a roof bolter is defined as a unitized machine which drills holes in either the roof or rib of coal mines and subsequently sets the roof bolt by utilizing a friction bolt and torquing the bolt to a predetermined setting or by using a resin grouted bolt. All of the roof bolters in this report were self-propelled, wheel mounted machines. There were no rail mounted or crawler tracked machines. In the report, about half of the machines were single boom and the other half twin boom. Figure 1 shows the operation in a mine of a single boom roof bolter with temporary roof support in place above the operator.

2.1.1 Single Boom Machines

Most, or all of the first roof bolters built were single boom machines as are also a large proportion of the machines presently in operation in this country's coal mines. The general layout of an arm type, single boom roof bolter is shown in Figure 2. On this machine the drill boom moves up and down on a cammed arm so that the drill head traverses rectilinearly rather than in an arc. This keeps the drill steel from being pushed sideways in the hole during drilling. The drill head provides only rotary motion to the drill head; in-line thrust is provided through the drill arm or boom. This requires that the roof bolter exert an appreciable end thrust which is then counterbalanced by a stabilizer jack. The stabilizer also serves to keep the machine from tipping over during drilling operations; in the figure it is seen as the lower arm. The four tires are not steerable and steering is accomplished by skidding the tires similarly to a crawler tractor-type operation. In hard rock formations or where faster drill penetration is desired, a rotary percussion drill

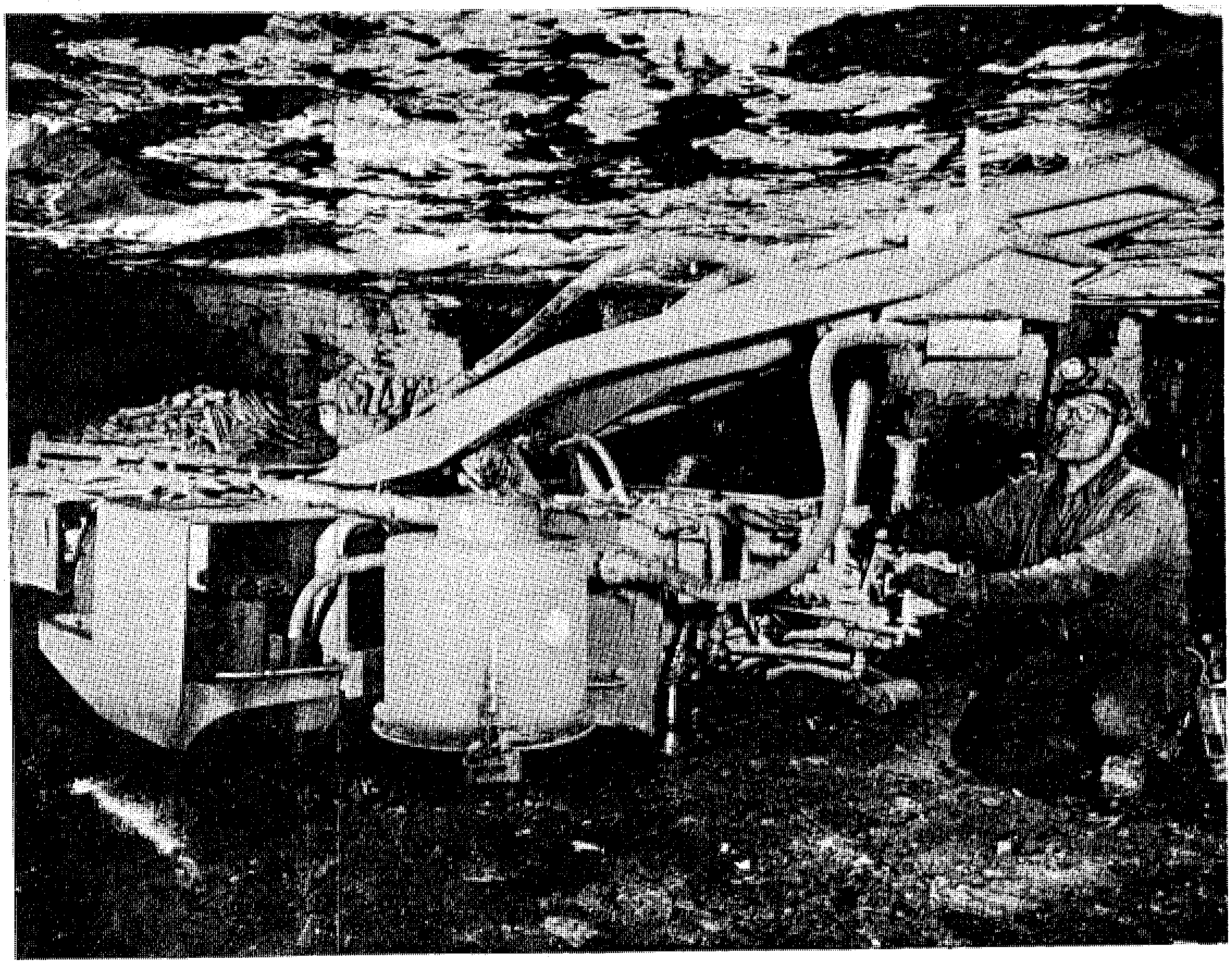


FIGURE 1. Single Boom Roof Bolter in Operation

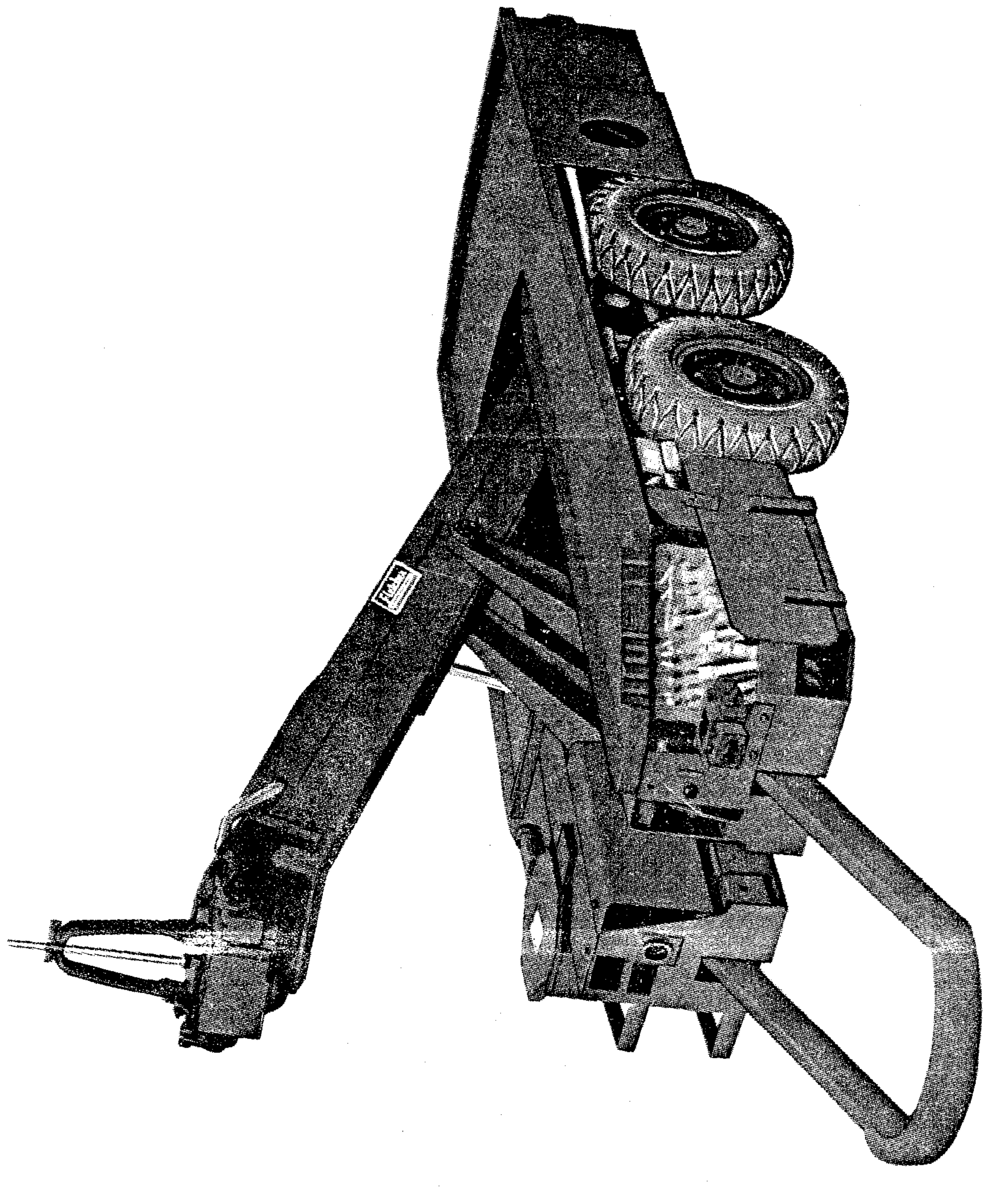


FIGURE 2. Small Single Boom Bolter

head is available (usually as an option). The head utilizes counter-rotating weights which superimpose a vibratory action to the rotating drill. This rotary/vibration action proves very effective for the harder roof stratas. Figure 3 shows another single boom machine featuring a slide assembly which eliminates the long arm with the pivoting mechanism of the machine shown in Figure 2. An additional advantage of the sliding drill head machines is that it can be pivoted within an arc about a horizontal axis for drilling and bolting sideways into the rib where necessary.

2.1.2 Multiple Boom Machines

Of the multiple boom machines, almost all are two-boom. Figure 4 shows a dual boom bolter at work. This bolter uses the slide construction design for moving the drill head up and down. It is also pivoted to permit sideway operation. The dual boom machines are typically larger and utilize the pivoting booms so that with one placement, the machine can bolt across an entire section. An additional advantage of the dual boom machine is that present mine law requires all workers to have at least one other person present; with the dual booms both men are active in bolting operations and therefore productive. Figure 5 shows the sales layout for a dual boom roof bolter. This machine is large; it has room to mount a cable reel on one corner and an operator's canopy on the other corner. The machine still steers using a skid-steer operation. Other dual boom machines have steerable rear wheels as exemplified in Figure 6. Except for the capability of two simultaneous drilling operations, the dual boom machines operate the same as single boom machines.

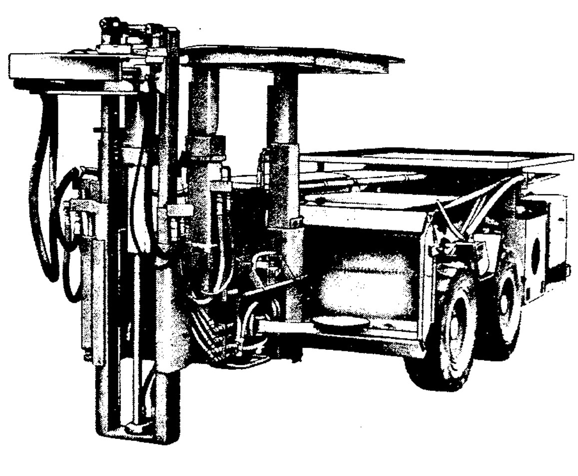


FIGURE 3. Single Boom Using
Slide Mounted Drill Head

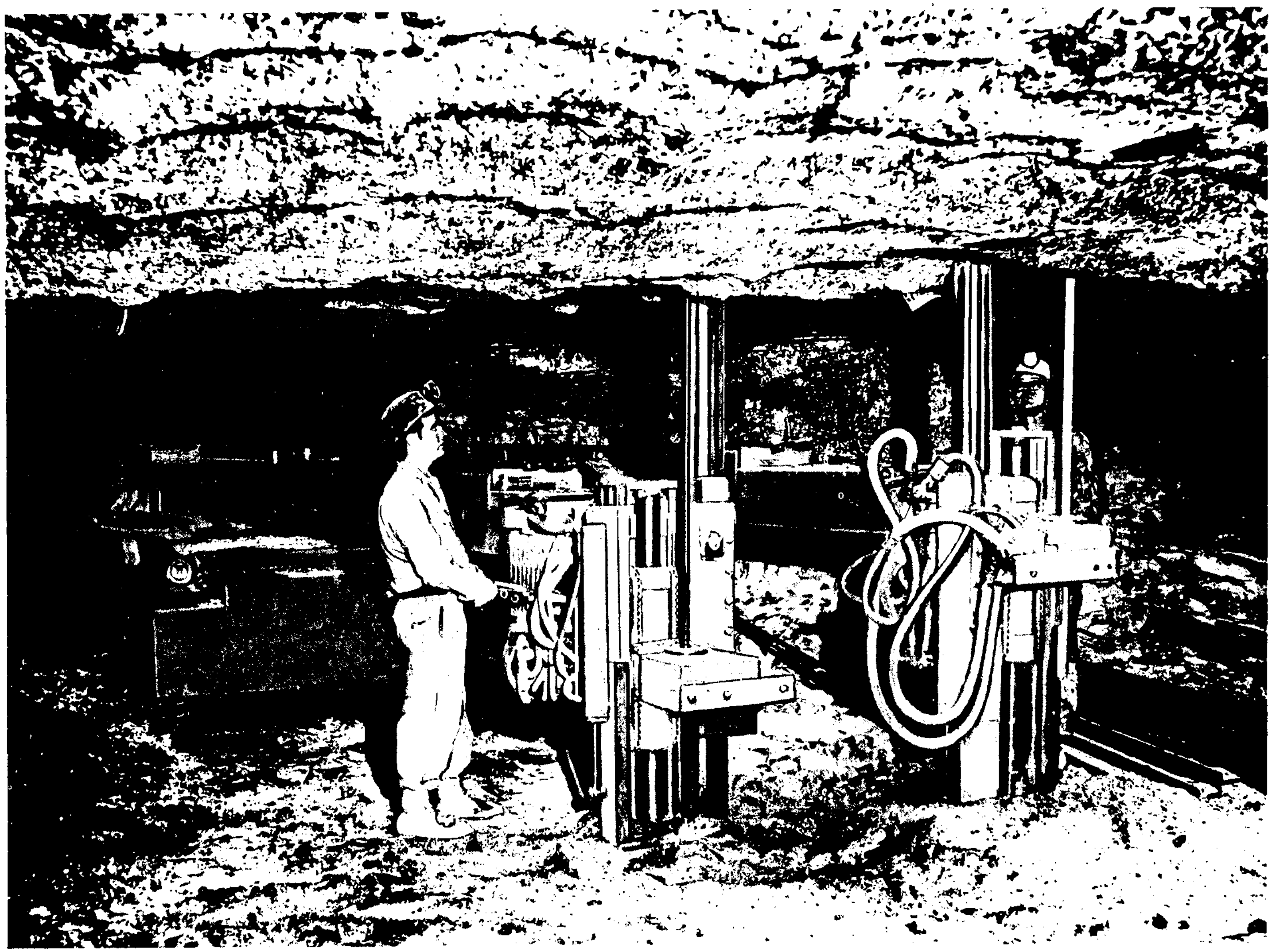


FIGURE 4. Dual Boom Bolter at Work

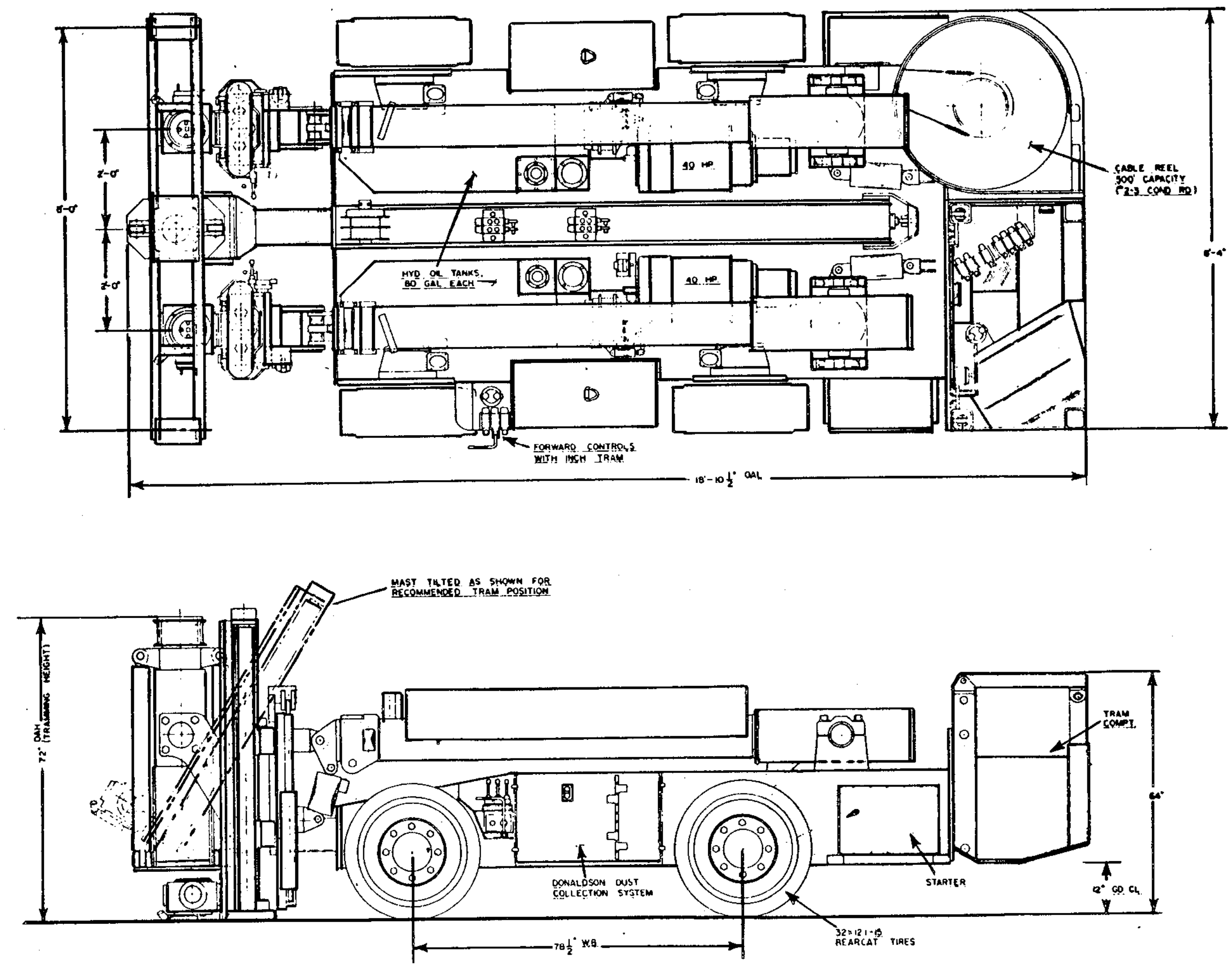


FIGURE 5. Large Dual Boom Roof Bolter

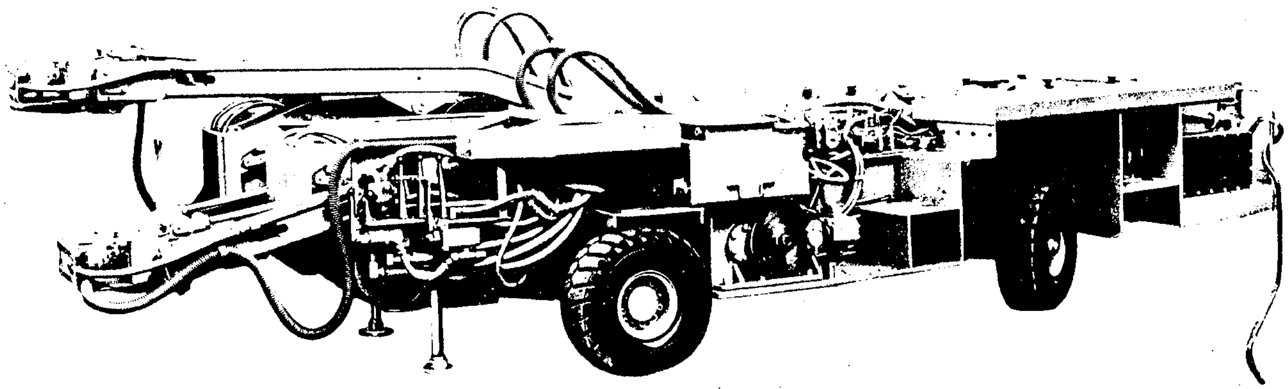


FIGURE 6. Dual Boom Roof Bolter With Steerable Rear Wheels

2.1.3 Roof Fall Protection

Roof bolting is one of the most hazardous occupations in underground coal mining. The very nature of the job requires the bolter operator to proceed out under unbolted roof in order to set the bolts. Accordingly, a recent trend in roof bolter design has incorporated a temporary roof support feature into the machine. This was shown earlier in Figure 1 where a hydraulically extendable reinforced plate could be pushed up against the roof before the bolting operation started. Particularly for the larger dual boom machines, the temporary roof support can be extended and set in place with the operator remaining under bolted areas. The integral temporary roof support built into the roof bolter has been a marked improvement in the safety of roof bolting operations.

2.1.4 Dust Collection Systems

The drilling operation generates dust, much of which may contain significant amounts of silica. Accordingly, all roof bolting machines are required to have some type of dust suppression system. The vast majority of the systems utilize a vacuum/pneumatic conveyance system starting at the point of drilling. Fresh air is drawn into the drilled hole alongside the hollow-core drill steel and into the ported drill bit. The dust-laden air is drawn back through the hollow-core drill steel and conveying lines to the blower and filter box where the chips and dust are removed by paper or cloth filters. The system necessitates frequent clean-out of the filter bag dust collection box.

2.2 OPERATING CHARACTERISTICS OF ROOF BOLTERS

As shown in Figure 7 even the small roof bolter has numerous controls. Many of these link together so that the operator can move the roof bolter from either the drill control position or from the operator's compartment during tramming. In the machine pictured, the operator sits in the compartment while tramming into the area requiring bolting. First he would position the bolter for the first bolt. After setting the temporary roof support, he would move to the drill control station where he would lower the drill head arm and insert the starter steel. The starter steel is a short length of drill-pipe fitted with a bit on the end and, as the name implies, is used to start the hole. Its shortness keeps the drill steel from wandering thereby precluding having to hand-guide it. Subsequently, longer lengths of drill steel are added as shown in Figure 8. This procedure is repeated using increasing lengths of drill steel until the required depth of hole is reached. Low seam coal drilling of deep holes

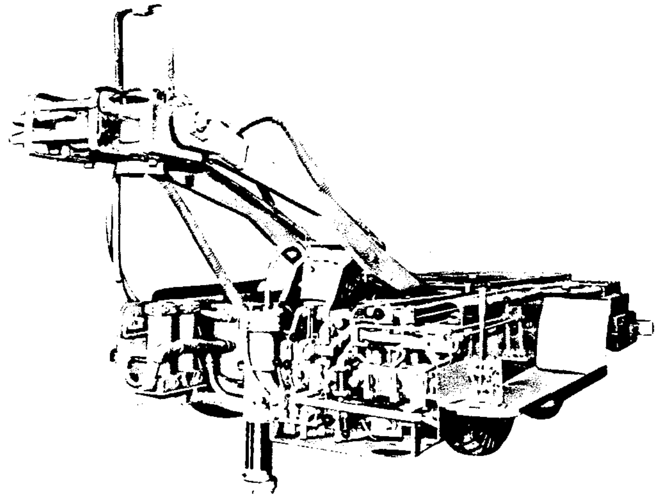


FIGURE 7. Single Boom Roof Bolter
With Dual Linkage on Tram Controls

may require that each hole be drilled through the progressive use of five or six shorter lengths of drill steel. Once the hole has been drilled to the correct depth, the roof bolt is inserted into the hole and the drill head is used to either torque up a friction roof bolt or to rotate the resin grouted roof bolt. Figure 9 shows a friction roof bolt being inserted into the hole along with the bearing plate and the drill head; the drill head will then be used to torque the bolt to a preset torque limit. The torque level is set by limiting hydraulic pressure with a relief valve in the circuit which drives the drill head. As discussed earlier, most of the coal mine roof bolters operate in an overhead mode only. Some mines operating at very deep levels or having roof problems require bolting the ribs and occasionally even the floor to reduce the chance of bumps. For these operations special roof bolters are required in which the mast can be rotated for any side, roof, or floor bolting. Ground bolting can sometimes be accomplished by reversing the drill head itself; special tools are available to facilitate the drill head reversal.

2.3 U.S. ROOF BOLTER POPULATION

The estimated U.S. population of roof bolters is derived using the data base from Woodward Associates, Inc.'s Program Final Report entitled "Coal Mine Equipment Population Characterization and Protective Structures Status" prepared under U.S. Contract No. JO366016 (2). The estimated total population of U.S. roof bolters in use in 1977 was 4,511. Of these, approximately 3,700 were single boom machines and 700+ were dual boom machines. In the present survey we had 96 roof bolters; that number represents approximately 2.1% of the total roof bolter population.

FIGURE 8. Drill Rod Insertion Sequence

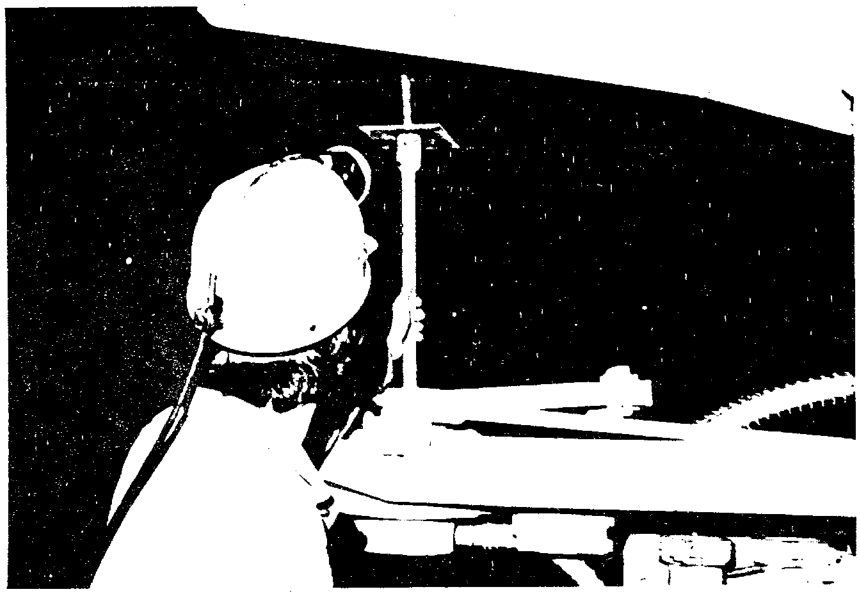


FIGURE 9. Roof Bolt Insertion

3. ROOF BOLTER FAILURE ANALYSIS

As discussed earlier the primary emphasis of the present study is the analysis of section delay reports using a computer-aided sort of 4,809 individual failures of 96 roof bolters in 15 mines. The majority of the section delay reports were for 1978 and 1979. The earliest failures were for 1976. In conducting the section delay analysis, 13 categories were devised which effectively represented the electrical, mechanical, and hydraulic systems of the roof bolter; the maintenance activities are also listed. These major failure categories were further subdivided for additional component identification. Machine failures were identified as much as possible according to the categories and subcategories developed. In Section 7 is a glossary of terms used in encoding the data; rather than being in alphabetical order, the glossary follows the same pattern as was established for the failure categories, therefore also the same as the computer program. Volume II of this report consists of two appendices – A and B. Appendix A is comprised of copies of the reports generated through the computer. In turn, Appendix B is a user's manual describing the data sort computer programs. Table I lists the 14 separate categories and the subcategories under each. For each report the machine identification codes are listed along with the total number of failures recorded and the total downtime. In addition, the time period spanned by the failure data is noted along with the machine-shifts of operation (the number of shifts that the machines worked). This is done to normalize the data and allow comparison between machine types and mines. In addition to the above, the average downtime per failure is recorded along with both failures and downtime per machine-shift of operation.

Under each failure category and subheading the number of roof bolter failures caused by the indicated component or operation are listed along with the percentage of the total failures in the sort. Following across the page is the downtime recorded and the percentage of the total downtime. For statistical purposes the range of downtime in minutes is reported along with the average downtime in minutes and the standard deviation about this average.

The major problem encountered in encoding the failures for each mine was the differences found in various mine section reporting practices. For most mines, the section report was a record of each shift's activity and the problems encountered. Often, the report was used to transmit maintenance requirements to the mechanics and to shift relief section foremen.

TABLE I. Failure Categories

POWER SUPPLY SYSTEM
- Trailing Cable
- Cable Reel Assembly
- Wiring
- Reel Drive Motor
- Reel Control Valve
- Spooling Guide
- Fuses/Circuit Breakers
- Hydraulic Pump Motor
- Other/General

ELECTRIC CONTROL SYSTEM
- Panel
- Breaker
- Meter
- Switches
- Logic
- Contactors
- Solid-State Components
- Other/General

INTERLOCKS
- Methane Detector
- Ground Fault Detector
- Water Flow
- Panic Bar
- Other/General

HYDRAULICS
- Jacks/Cylinders
- Pumps
- Valves
- Hoses
- Fittings
- Oil Filter
- Oil Level
- Seals
- Oil Contamination
- Other/General

TRAM SYSTEM
- Drive Motor
- Clutch
- Clutch Disc
- Torque Converter
- Transmission
- Drive Shafts/Chains
- Final Drives
- Axles
- Tram Control
- Other/General

UNDERCARRIAGE
- Tires
- Equalizer Axle
- Wheel
- Other/General

STEERING SYSTEM
- Operator Controls
- Steering Box
- Cross Shaft
- Levers
- Drag Link
- Cylinders
- Dual Control Linkage
- Other/General

BRAKE SYSTEM
- Brake Lines
- Calipers/Drum
- Cylinders
- Lining
- Controls
- Parking Brake
- Other/General

DRILL SYSTEM
- Drill/Drill Head
- Drill Steel
- Stuck Steel
- Drill Supports
- Drill Controls
- Dual Control Linkage
- Drive Motor
- Other/General

DUST SUPPRESSION SYSTEM
- Spray Nozzles
- Filters
- Hoses
- Fittings
- Valves
- Water Pump
- Air Blower
- Drive Motor/System
- Other/General

LIGHTING SYSTEM
- Lights
- Wiring
- Switches
- Other/General

LUBRICATION
- Fittings
- Hoses
- Oil Level
- Lube Pump
- Other/General

SERVICE DURING PRODUCTION SHIFT
- Service

MISCELLANEOUS
- Stuck
- Frame Failure
- Canopy Repair
- Fire Suppression System
- Sideboards
- Other/General

The quality of information also varied. Table II lists by code number the 15 mines that participated in the present study. For each mine, the operating characteristics are given along with a description of the section records used in encoding data. The major differences centered on how roof bolter downtime was recorded. For a few mines, the delay reports were not complete and often did not record the downtime occurring. For these mines we encoded the failure but did not record downtime. The computer program enters the failure but the downtime is neither entered nor calculated into the average downtime, range of downtime, or standard deviation.

In one of the mines, the downtime recorded was machine repair time. For this mine the downtime recorded was greater than actual section delay time. In addition, for this mine, not all of the failures were recorded. Only failures requiring a maintenance crew were recorded. Consequently, the number of failures are less but the downtime per failure is greater. Thus, for evaluating or comparing individual mine reports, Table II must be reviewed to identify mitigating circumstances such as type of data recorded, quality of data, mining conditions, etc. In like fashion, any comparison of individual machines must also be made with consideration of the mine reporting system. Thus, while the statistical analysis of 4,809 roof bolter failures provides factual insight into the causes and magnitudes of roof bolter maintenance problems, the inconsistencies between mine section reporting preclude exact comparison of individual mines.

The last caution which must be made regarding comparative analyses refers to the difference between section delays and routine maintenance. In particular, the majority of the section delay information covers failures which cause the bolter to stop bolting and consequently delay production. Many maintenance items which reduce the performance of the machine but do not stop it are not reported. For example, hydraulic pumps often fail progressively; pressure and flow rate may go down while noise and heat build up. The pump will very likely be replaced during a maintenance shift. In that case, though production may very well have been reduced due to the impaired performance of the pump, an outright production downtime did not occur, therefore no delay would have been recorded. Only catastrophic failures stopping the bolters were recorded. For this reason, we believe that many of the maintenance activities for major items such as motors, pump, undercarriage and drive trains, end up being underestimated in the section delay reports.

TABLE II. Mine Characteristics

Mine Code No.	Region	Annual Production, tons (year)	No. of Bolters in Survey	Seam Thickness, in.	Type of Records Maintained	Total Failures Encoded	Total Downtime, min.	Machine Shifts of Operation	Calendar Period of Data Encoded
101	Eastern	380,000 (1978)	8	55	Section delays, most failures, some downtime	57	1,025	1,064	1-78 to 12-79
102	"	1,000,000 (1978)	7	60	Section delays, all failures, section downtime	509	35,417	3,154	11-78 to 11-79
103	Midwestern	1,500,000 (1978)	20	78	"	1,510	94,317	4,606	3-78 to 12-78
104	Eastern	200,000 (1978)	6	60	"	22	2,140	418	5-78 to 7-78
105	"	620,000 (1978)	10	58	"	404	37,989	1,543	7-78 to 1-79
108	"	740,000 (1978)	11	40	"	1,029	82,045	6,802	6-77 to 12-78
109	"	500,000 (1978)	3	38	"	137	17,600	1,054	3-78 to 12-78
110	"	480,000 (1978)	6	32	"	215	20,470	1,754	3-78 to 12-78
111	"	322,000 (1979)	5	96	"	191	16,380	1,481	1-78 to 2-79
112	"	139,543 (1979)	2	40-60	"	27	1,005	1,129	1-79 to 12-79
113	"	232,794 (1979)	3	48	"	89	4,296	1,219	12-78 to 12-79
114	"	465,720 (1979)	5	42	"	378	27,550	2,477	1-79 to 12-79
115	"	298,546 (1979)	4	40	"	297	21,786	1,955	1-79 to 12-79
319	Western	680,000 (1978)	1	120	Major failures only, repair time	6	160	722	3-78 to 9-79
337	"	915,000 (1977)	5	96+	Section delays, all failures, section downtime	23	1,380	2,051	1-79 to 12-79

3.1 SUMMARY FAILURE ANALYSIS OF ROOF BOLTER DOWNTIME

Having defined the major failure modes for roof bolters a computer program was used to sort the data and sum individual failure categories. In Figure 10, each major failure category is shown with a bar representing the percent of both the total failures and downtime for each category. The shaded bars represent minutes of section downtime and the plain bars failure count. At 31% and 27% the largest percentage failure count and downtime are attributed to hydraulics. This compares with the next categories – dust suppression and power supply system – both with a failure count and downtime of approximately 15%. In terms of failure count, the next category is drill system at 9%. In descending order of downtime, the failure types of some significance are: tram system, service during production, miscellaneous, and electric control system. A word about service during production; this is not actually a machine or component failure, but is indicated when servicing the bolter caused a production delay. Only a few mines recorded delay time in this fashion but its percentage of downtime for those mines is very high and it is carried through to be reflected in the overall total. In each category, the <u>other</u> listing indicates that the failure could not be identified due to illegible entries on the section delay report or it could not be catalogued under any of the failure categories of this study.

To look at the distribution of section delays, the various failures were summed into electrical, mechanical, and hydraulic categories; Table III lists the percentage failures and downtime for each of the general categories. Almost half of the failures and downtime were caused by mechanical related problems. As discussed later, most of these are chain system related.

To show the relationship of the failure and downtime parameters versus production and section working time, we have developed tables and figures as follows.

Table IV lists the various failure categories showing the mean downtime, mean time between delays, mean production between delays, and mean downtime per ton for section delay data using Keystone mine production data. This information is also displayed as histograms for each mine in Figures 11 through 14.

> Note: In each of the histograms, an average of the information is presented. This average has been computed from the aggregate base data and

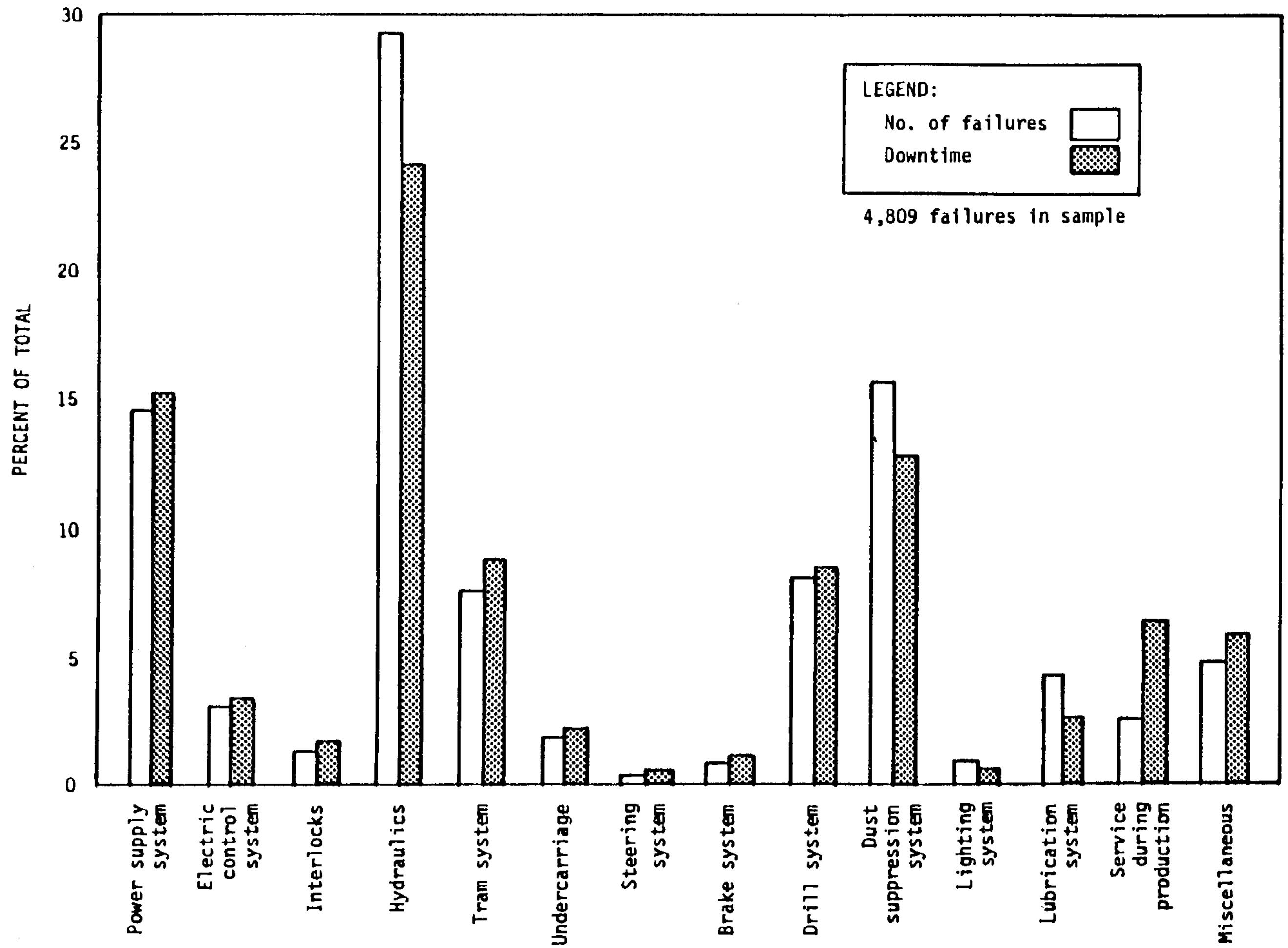


FIGURE 10. Histogram of Major Failure Categories Using Section Delay Records

TABLE III. Major Failure Category Summary of Section Production Delays

Category	Percentage of Total Failures	Percentage of Total Downtime
Electrical	22%	23%
Mechanical	42%	40%
Hydraulic	31%	27%

not as the average of the individual mine averages. This provides a valid average figure since it is based on total failures and total downtime rather than possibly distorted mine average figures (explained in some detail in the following paragraph). Whereas the two averages could be approximately the same, they can also be quite different as can be seen in Figure 14 and more so in Figure 12 where the bar height representing average could not possibly be that of the other bar representations.

In Figure 11 the mean downtime per shift in minutes is shown for each of the 15 mines surveyed. Some explanation must be made of this graph. The major problem, as discussed before, was obtaining consistent statistical data. In particular, for mine 319 the downtime reported was actually the repair time for the machines and not the section delay time. Thus, for mine 319 the downtime appears abnormally high. On the other hand, mine 103 has very good records and reported more occurrences than many of the other mines. Mine 101 records were relatively poor compared to the others and if a true accounting had taken place, their downtime would probably be higher per shift worked than that of mine 103. When looking at mines with comparable section delay reports, differences in section delays do indicate differences in maintenance practices and mining operations. For instance, mine 337 has less downtime per shift than the average. Figure 12 is a histogram of the mean downtime between delays in hours. Again, remember that mine 319 reports maintenance repair time and then, not all section delays (e.g., broken hoses or other items repaired by the workers at the operating section). Further, mine 101 with limited section records shows a high mean time between delays when in actuality it

TABLE IV. Roof Bolter Section Delay Analysis

Failure Category	Total Delays	Total Downtime, min.	Mean Downtime, min.	Mean Time Between Delays, hr.	Mean Downtime Per Shift, min.	Mean Production Between Delays, tons	Mean Downtime Per Ton, min.
Power Supply System	712	53,776	76	309	1.71	11,736	0.006
Electric Control System	156	13,655	89	1,410	0.43	53,840	0.002
Interlocks	93	8,477	94	2,366	0.27	90,312	0.001
Hydraulics	1,410	88,103	64	156	2.80	5,967	0.010
Drive System Tram System	375	33,738	92	587	1.07	22,397	0.004
Undercarriage	112	9,970	90	1,964	0.32	74,991	0.001
Steering System	25	2,350	94	8,800	0.07	335,960	0.000
Brake System	68	6,040	92	3,235	0.19	123,516	0.001
Drill System	434	33,748	79	507	1.07	19,353	0.004
Dust Suppression System	762	47,103	62	289	1.50	11,022	0.006
Lighting System	72	3,180	52	3,056	0.10	116,653	0.000
Lubrication	241	10,410	43	913	0.33	34,851	0.001
Service	122	22,655	186	1,803	0.72	68,844	0.003
Miscellaneous	227	20,379	92	969	0.65	37,000	0.002
Total	4,894	363,560	75	45	11.00	1,716	0.043

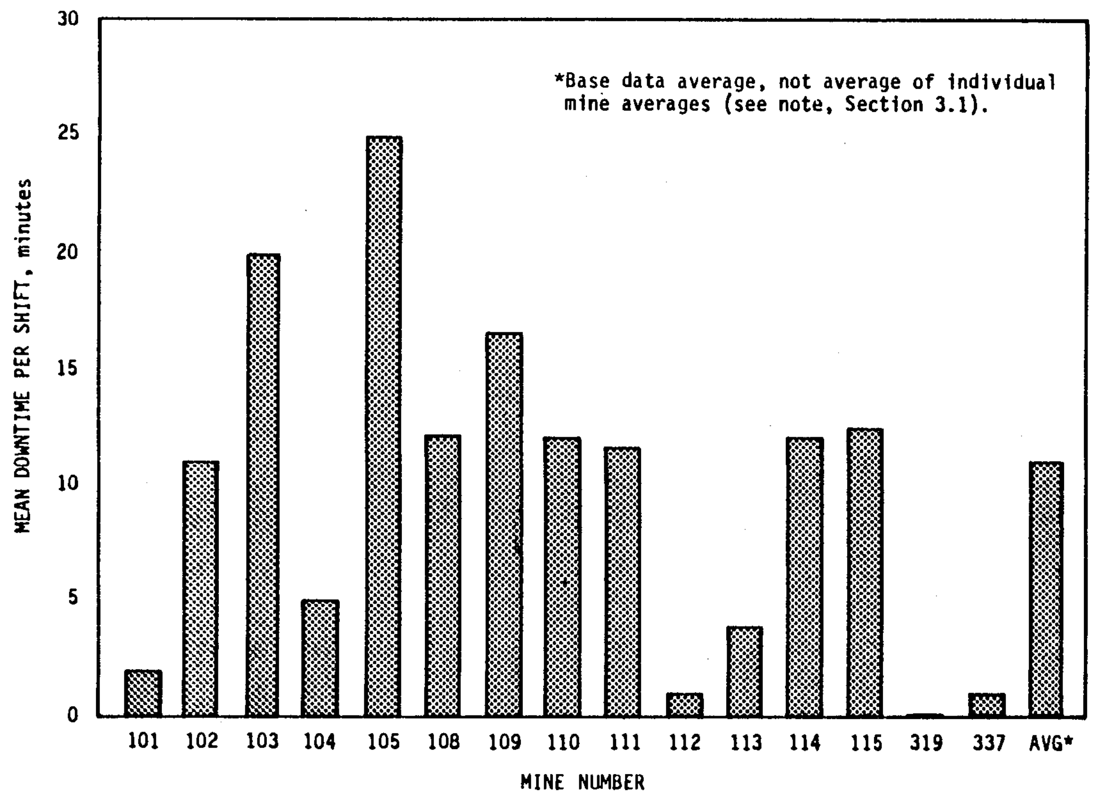


FIGURE 11. Histogram of Mean Downtime Per Shift by Mine

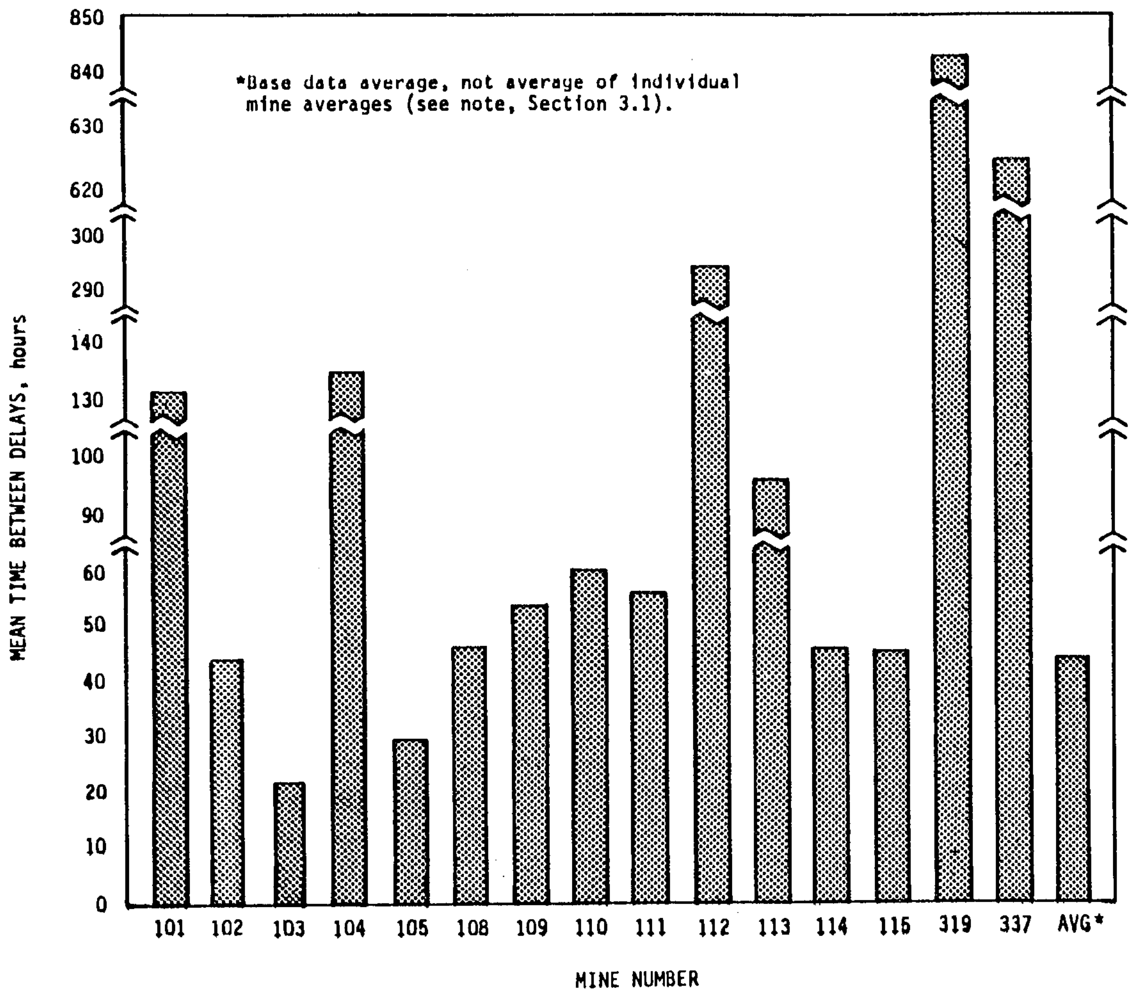


FIGURE 12. Histogram of Mean Time Between Delays by Mine

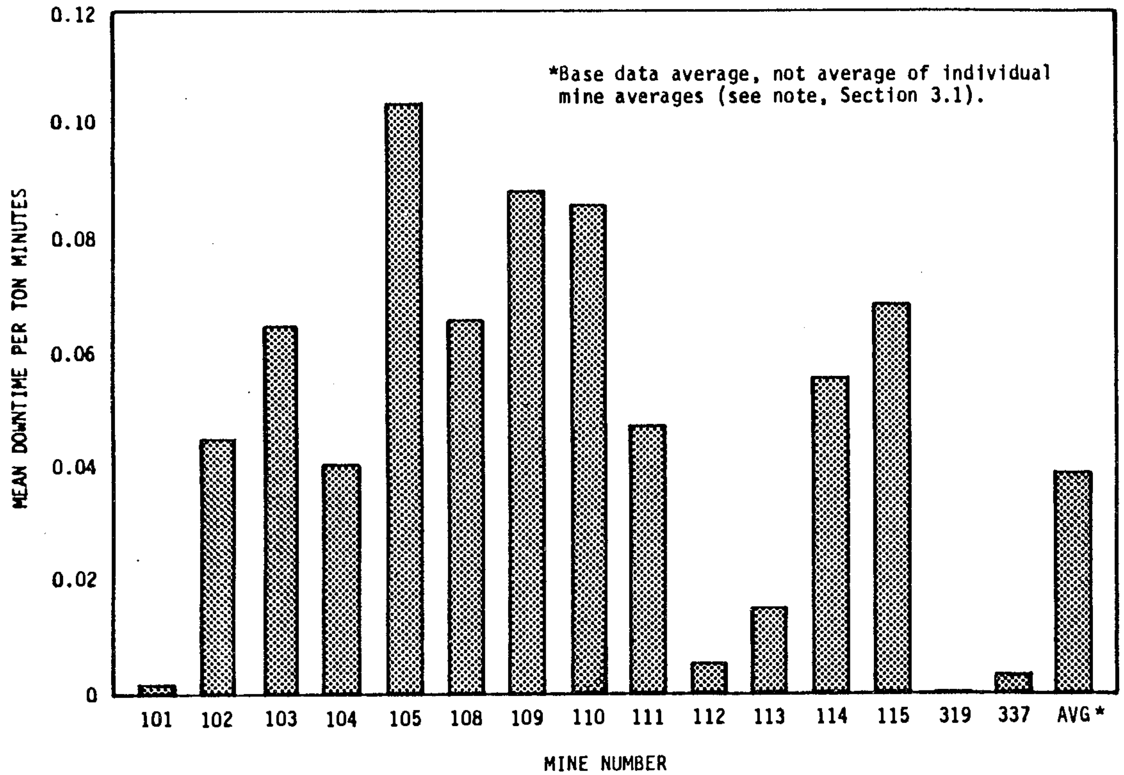


FIGURE 13. Histogram of Mean Downtime Per Ton by Mine

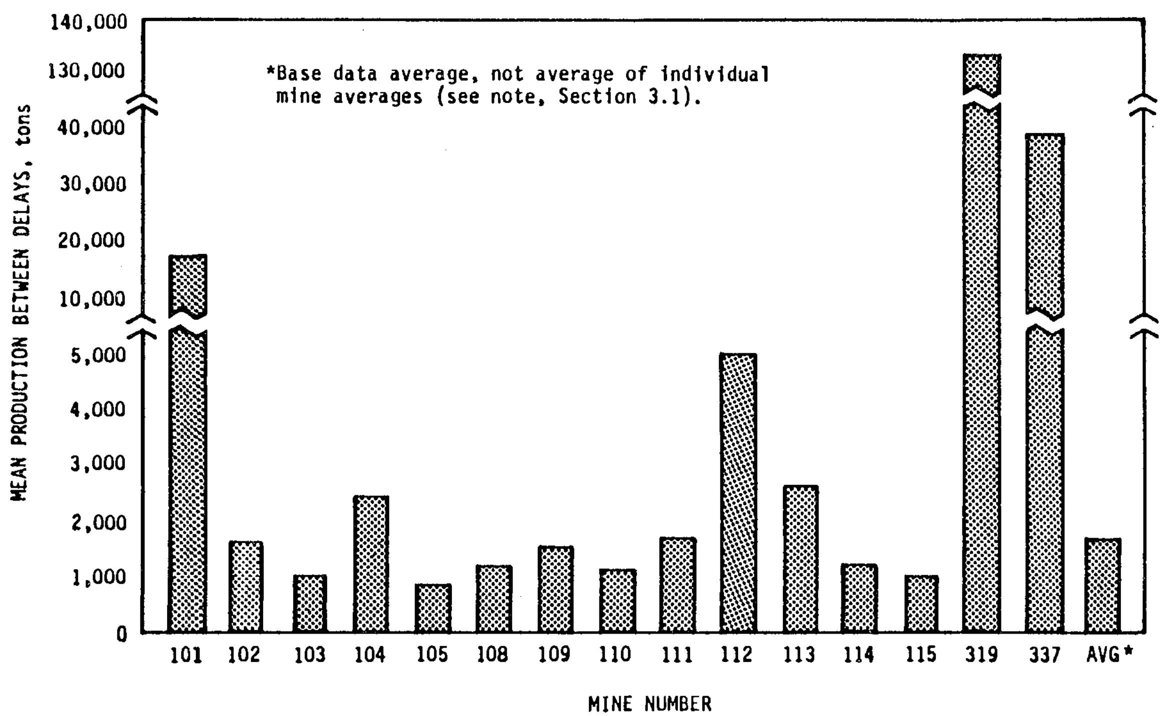


FIGURE 14. Histogram of Mean Production Between Delays by Mine

is probably much less than that. Figure 13 is a histogram of the mean downtime per ton of coal produced using Keystone reported coal production. Again mines 101 and 319 are abnormal entries in that they do not report all their downtime. The average downtime caused by a roof bolter failure was less than 0.05 of a minute per ton of coal produced. Figure 14 shows the mean production between delays in tons. Here we see there are three mines for which the mean production between delays goes clear off the graph. One of these, mine 319, only reported major repairs. Likewise the high number of mine 101 is due to incomplete reporting. As noted before, all of the coal production information recorded on the previous graphs was taken from the Keystone manual.

To check the effect of downtime on production, the actual section downtime and production for each month for a particular mine were summed to see if there was any tracking of production with downtime. Figure 15 displays the results for the mine over a one-year period. With the permission of the mine involved, this information was taken directly from section delay reports. The shaded area at the bottom is a histogram for three of the face machines (continuous miners, shuttle cars, and roof bolters). The symbols within the shaded area show the average downtime per shift for each of the individual machines – triangles represent the continuous miners; squares, shuttle cars; and diamonds, roof bolters. The upper part of the graph shows the total section delay time. Considering the magnitude of "average," it can be seen that over one-half of the total downtime per shift was caused by the face equipment, with the continuous miner the primary source of downtime. This fact can be expected since the continuous miner is the most complex of the three machines and failure of the miner immediately stops production, that is, if a continuous miner is down then the section is also down. If a shuttle car goes down, coal can still be loaded using the other shuttle car (unless it breaks down behind the miner). The roof bolter is the most flexible since it usually can complete the bolting faster than the miner can cut coal. Consequently, repairs can be made without interrupting production. Therefore, many of the roof bolter failures do not show up since they are repaired without causing section delay. In similar fashion many of the failures that occurred in shuttle cars were not reported since they did not cause section delay time. An interesting trend in the data reported in Figure 15 is that when the total downtime per month dropped during the fourth, fifth and sixth months production increased indicating an inverse trend of downtime influencing production even when the total downtime is on the order of 60-90 minutes. This influence of downtime on production is more evident on a day-to-day basis. This is

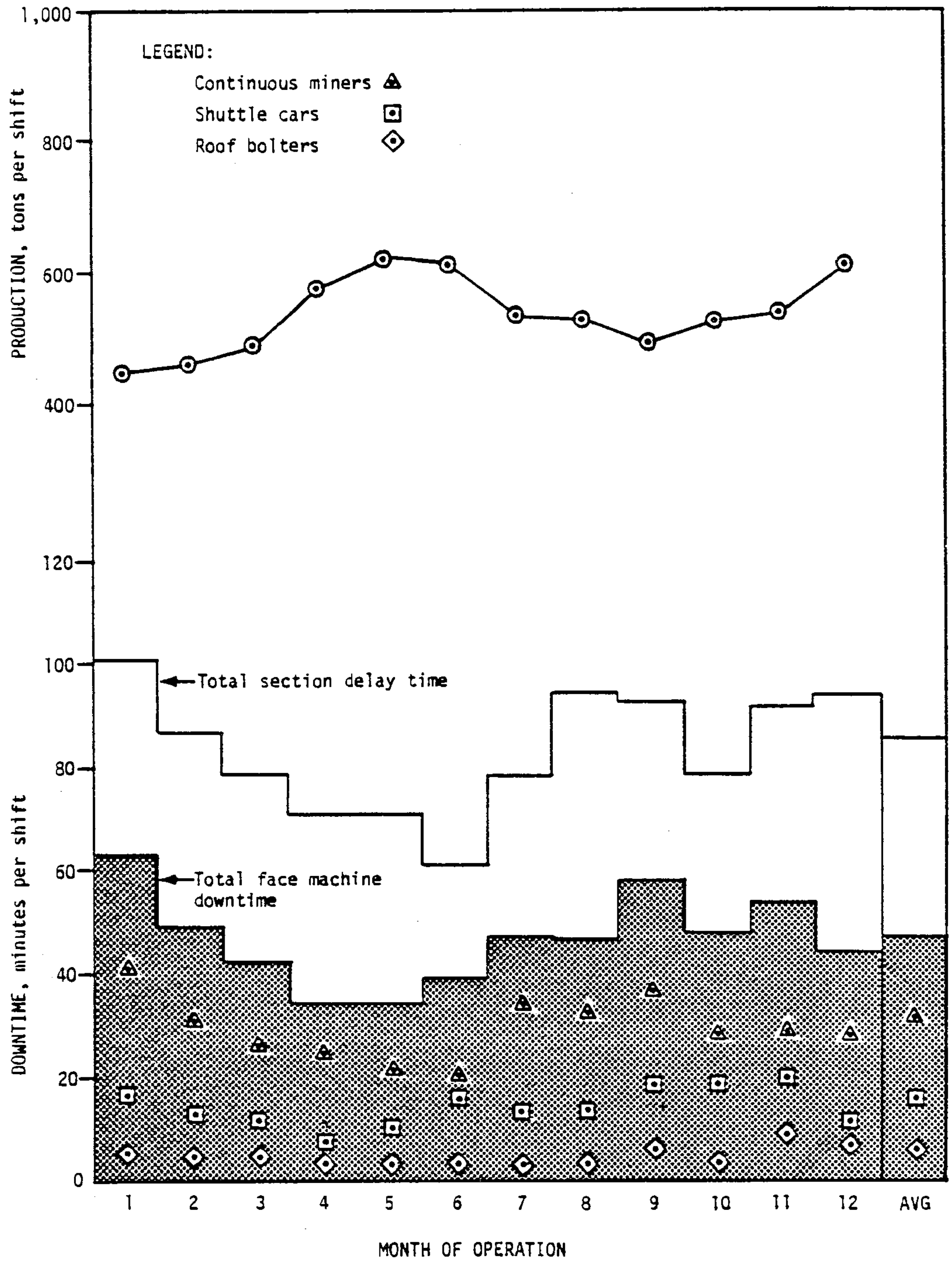


FIGURE 15. Section Production and Downtime by Month for One Mine

shown in Figure 16 which plots the production per shift versus downtime per shift on a day-by-day basis. With data from over 200 days of production in one section, the influence of downtime is quite dramatic showing that the intercept for zero production is 420 minutes of section downtime. This time (7 hours) corresponds to the usual face operating time. Zero downtime production is on the order of 800 tons of raw coal per shift. In summary, Figure 16 shows a distinct relationship between downtime and production. This is intuitively obvious but it was not known beforehand whether other influences such as haul distance, power box location, roof and mine floor conditions, and work crew attitudes and competence might be greater on production than machine downtime.

In reviewing the previous section we find that certain components of the roof bolter account substantially for the overall downtime caused by the bolter. In the next section we will discuss in some detail the various roof bolter failures identified and their causes.

3.2 COMPONENT FAILURE ANALYSIS

As discussed earlier, the data analysis has shown that mechanical failures are very significant in terms of overall downtime, comprising about 40% of the total roof bolter failures. In this section we will look at each subcategory to determine which major components are causing the most downtime. Table V consists of seven pages with direct computer printouts of roof bolter failures by category based on the section delay reported failures. In this table each category is broken down into subcategories, showing their failure count and minutes of downtime plus percentages, range of downtime, average, and standard deviation. Further, each category is normalized by dividing the total failures or downtime by the total machine shifts of operation. In looking at the data for the electrical system three distinct problems are pointed out: trailing cable failures, electrical control system (contactors, relays, etc.), and subcomponents such as motors and seals.

In the mechanical area the primary problem was related to the dust suppression system followed by the drill head and, in turn, the drive train. For the hydraulic system there were two failure areas of equal severity – jacks/cylinders and hoses/fittings. The next ranked significant hydraulic problems involved pumps and then valves. It is noteworthy that from the computer processing of the data as well as from conversations with mine operators, rebuilders, and manufacturers, it was brought out that hydraulic system contamination was the underlying cause of many of the hydraulic component failures. This was particularly evident in damage to pump internal parts as viewed at roof bolter rebuild shops, and returned parts to the manufacturer.

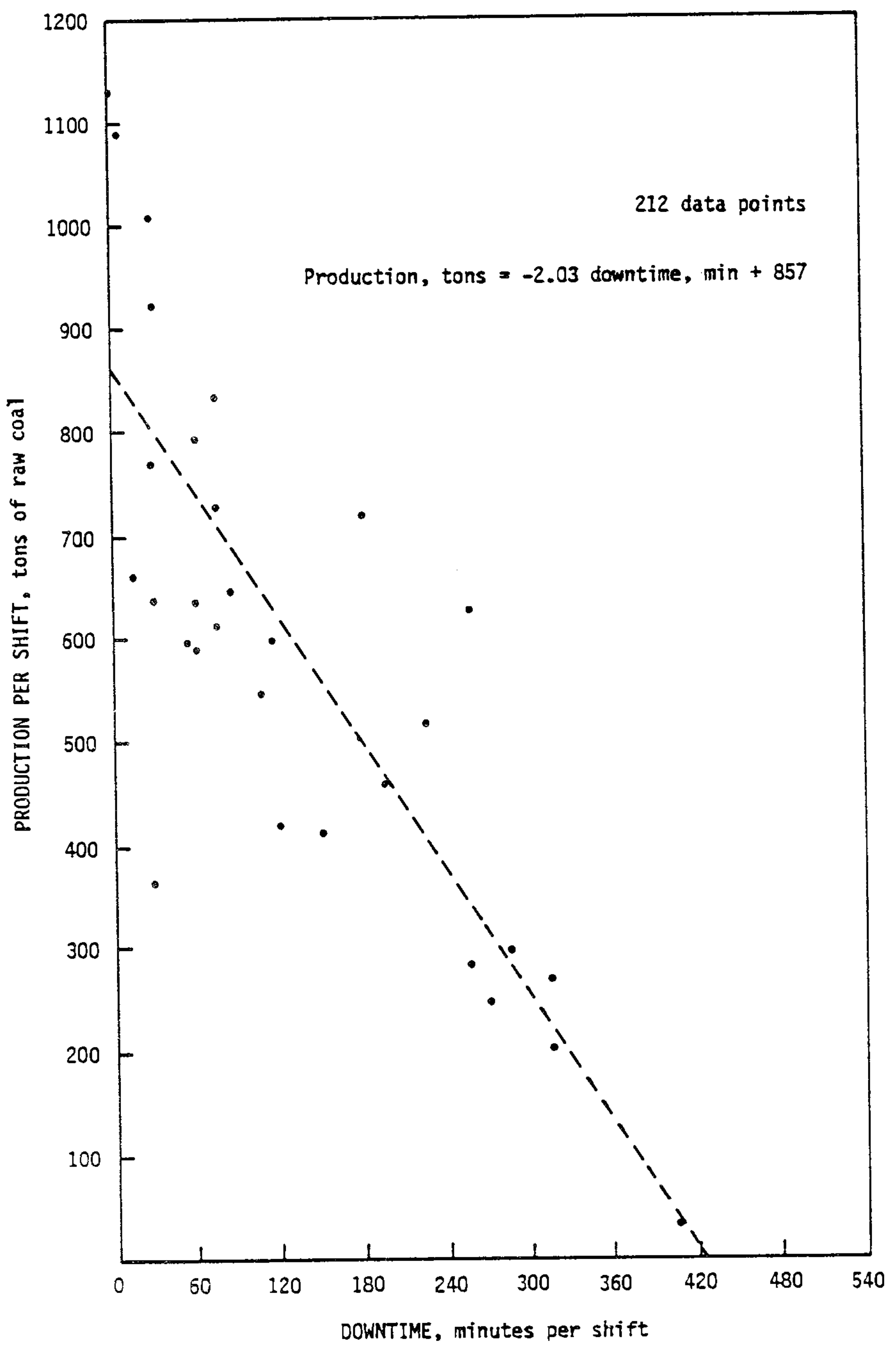


FIGURE 16. Section Production Versus Downtime on a Per Shift Basis

TABLE V. Failures and Downtime for Roof Bolter Repair Time Failure Data

NUMBER OF MINES IN THIS REPORT 15

MINE CODE ID NUMBERS 101, 102, 103, 104, 105, 108, 109, 110, 111, 112, 113, 114, 115, 319, 337,

NUMBER OF MACHINES IN THIS REPORT 96

MACHINE CODE ID NUMBERS 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314,
315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332,
333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350,
351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 364, 365, 366, 367, 368, 369,
370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 700, 701, 702, 703, 704, 705, 706, 707,
708, 709, 710, 711, 712, 713, 714, 715, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735,
737, 742, 744, 745, 746, 747, 748,

TOTAL NUMBER OF FAILURES IN THIS SURVEY 4809

TOTAL MACHINE DOWNTIME RECORDED IN THIS SURVEY 353584 MINUTES

TIME PERIOD OF DATA RECORDED FROM 6-77 TO 12-79

NUMBER OF MACHINE-SHIFTS OF OPERATION 31429

AVERAGE DOWNTIME PER FAILURE 75 MINUTES

FAILURES PER MACHINE-SHIFTS OF OPERATION .153

DOWNTIME PER MACHINE-SHIFTS OF OPERATION 11 MINUTES

TABLE V. Failures and Downtime for Roof Bolter Repair Time Failure Data (Cont)

FAILURE DESCRIPTION	NUMBER OF FAILURES	PERCENT OF TOTAL FAILURES	TOTAL DOWNTIME MINUTES	PERCENT OF TOTAL DOWNTIME	RANGE OF DOWNTIME MIN	RANGE OF DOWNTIME MAX	AVERAGE DOWNTIME	STANDARD DEVIATION
FAILURE CATEGORY: POWER SUPPLY SYSTEM								
TRAILING CABLE	596	12.4	39703	11.2	10	525	68	69
CABLE REEL ASSY	34	.7	2791	.8	10	480	82	96
WIRING	15	.3	1520	.4	15	405	109	109
REEL DRIVE MOTOR	1	.0	480	.1	480	480	480	0
REEL CONTROL VALVE								
SPOOLING GUIDE	5	.1	855	.2	30	270	171	107
FUSES/CKT BREAKERS	8	.2	600	.2	25	210	75	60
HYDRAULIC PUMP MOTOR	33	.7	5897	1.7	15	600	179	164
OTHER/GENERAL	20	.4	1930	.5	20	195	97	60
CATEGORY SUB-TOTAL	712	14.8	53776	15.2	10	600	76	84
* NORMALIZED SUB-TOTAL	.023		1.71					
FAILURE CATEGORY: ELECTRIC CONTROL SYSTEM								
PANEL	12	.2	1555	.4	25	525	130	135
BREAKER	9	.2	445	.1	30	180	64	65
METER								
SWITCHES	50	1.0	3960	1.1	10	420	79	95
LOGIC								
CONTACTORS	12	.2	810	.2	15	210	68	61
SOLID STATE COMPONENTS								
BATTERY	2	.0	120	.0	30	90	60	42
OTHER/GENERAL	71	1.5	6765	1.9	15	405	95	88
CATEGORY SUB-TOTAL	156	3.2	13655	3.9	10	525	89	92
* NORMALIZED SUB-TOTAL	.005		.43					
FAILURE CATEGORY: INTERLOCKS								
METHANE DETECTOR								
GROUND FAULT	51	1.1	5322	1.5	20	510	106	104
WATER FLOW	2	.0	150	.0	30	120	75	64
PANIC BAR	40	.8	3005	.8	15	420	79	90
OTHER/GENERAL								
CATEGORY SUB-TOTAL	93	1.9	8477	2.4	15	510	94	98
* NORMALIZED SUB-TOTAL	.003		.27					

* NORMALIZED BY MACHINE SHIFTS OF OPERATION

TABLE V. Failures and Downtime for Roof Bolter Repair Time Failure Data (Cont)

FAILURE DESCRIPTION	NUMBER OF FAILURES	PERCENT OF TOTAL FAILURES	TOTAL DOWNTIME MINUTES	PERCENT OF TOTAL DOWNTIME	RANGE OF DOWNTIME MIN	RANGE OF DOWNTIME MAX	AVERAGE DOWNTIME	STANDARD DEVIATION
FAILURE CATEGORY: HYDRAULICS								
JACKS/CYLINDERS	249	5.2	25520	7.2	10	610	104	98
PUMPS	74	1.5	10720	3.0	20	645	145	126
VALVES	86	1.8	6707	1.9	15	330	81	70
HOSES	547	11.4	25011	7.1	5	330	46	43
FITTINGS	291	6.1	10260	2.9	5	480	36	43
OIL FILTER	10	.2	685	.2	10	180	69	62
OIL LEVEL	39	.8	1730	.5	5	260	49	49
SEALS	32	.7	1550	.4	15	100	52	28
OIL CONTAMINATION								
OTHER/GENERAL	82	1.7	5920	1.7	10	390	73	79
CATEGORY SUB-TOTAL	1410	29.3	88103	24.9	5	645	64	73
* NORMALIZED SUB-TOTAL	.045		2.80					
FAILURE CATEGORY: TRAM SYSTEM								
DRIVE MOTOR	23	.5	2453	.7	20	380	117	112
CLUTCH	2	.0	300	.1	120	180	150	42
CLUTCH DISC	5	.1	305	.1	45	105	61	26
TORQUE CONVERTER	7	.1	1280	.4	10	480	183	178
TRANSMISSION	20	.4	3350	.9	30	330	168	110
DRIVE SHAFTS/CHAINS	292	6.1	22345	6.3	15	480	78	65
FINAL DRIVES	1	.0	330	.1	330	330	330	0
AXLES	3	.1	810	.2	120	480	270	187
TRAM CONTROL	3	.1	240	.1	60	120	80	35
OTHER/GENERAL	19	.4	2325	.7	30	480	122	124
CATEGORY SUB-TOTAL	375	7.8	33738	9.5	10	480	92	85
* NORMALIZED SUB-TOTAL	.012		1.07					
FAILURE CATEGORY: UNDERCARRIAGE								
CRAWLER TRACKS								
TRACK PADS (GROUSERS)								
TENSION ADJUSTMENT								
TIRES	66	1.4	4305	1.2	10	300	66	60
EQUALIZER AXLE	5	.1	965	.3	25	480	193	178
WHEEL	41	.9	4700	1.3	20	480	115	86
OTHER/GENERAL								
CATEGORY SUB-TOTAL	112	2.3	9970	2.8	10	480	90	84
* NORMALIZED SUB-TOTAL	.004		.32					

* NORMALIZED BY MACHINE SHIFTS OF OPERATION

TABLE V. Failures and Downtime for Roof Bolter Repair Time Failure Data (Cont)

FAILURE DESCRIPTION	NUMBER OF FAILURES	PERCENT OF TOTAL FAILURES	TOTAL DOWNTIME MINUTES	PERCENT OF TOTAL DOWNTIME	RANGE OF DOWNTIME MIN	RANGE OF DOWNTIME MAX	AVERAGE DOWNTIME	STANDARD DEVIATION
FAILURE CATEGORY: STEERING SYSTEM								
OPERATOR CONTROLS	5	.1	770	.2	20	300	154	114
STEERING BOX								
CROSS SHAFT								
LEVERS	11	.2	880	.2	15	265	80	76
DRAG LINK	7	.1	585	.2	30	240	84	73
CYLINDERS	1	.0	20	.0	20	20	20	0
DUAL CONTROL LINKAGE								
OTHER/GENERAL	1	.0	95	.0	95	95	95	0
CATEGORY SUB-TOTAL	25	.5	2350	.7	15	300	94	84
* NORMALIZED SUB-TOTAL	.001		.07					
FAILURE CATEGORY: BRAKE SYSTEM								
BRAKE LININGS	3	.1	460	.1	10	360	153	183
CALIPERS/DRUM	3	.1	255	.1	50	145	85	52
CYLINDERS	1	.0	180	.1	180	180	180	0
LINING	2	.0	225	.1	45	180	113	95
CONTROLS	3	.1	60	.0	20	20	20	0
PARKING BRAKE	1	.0	30	.0	30	30	30	0
OTHER/GENERAL	55	1.1	4830	1.4	15	420	91	109
CATEGORY SUB-TOTAL	68	1.4	6040	1.7	10	420	92	107
* NORMALIZED SUB-TOTAL	.002		.19					
FAILURE CATEGORY: DRILL SYSTEM								
DRILL/DRILL HEAD	300	6.2	20993	5.9	5	420	72	65
DRILL STEEL	9	.2	420	.1	15	140	53	45
STUCK STEEL								
DRILL SUPPORTS	41	.9	4615	1.3	20	405	115	117
DRILL CONTROLS	8	.2	1315	.4	10	430	164	157
DUAL CONTROL LINKAGE	2	.0	120	.0	60	60	60	0
DRIVE MOTOR	66	1.4	5440	1.5	10	420	82	65
OTHER/GENERAL	8	.2	845	.2	15	380	106	122
CATEGORY SUB-TOTAL	434	9.0	33748	9.5	5	480	79	77
* NORMALIZED SUB-TOTAL	.014		1.07					

* NORMALIZED BY MACHINE SHIFTS OF OPERATION

TABLE V. Failures and Downtime for Roof Bolter Repair Time Failure Data (Cont)

FAILURE DESCRIPTION	NUMBER OF FAILURES	PERCENT OF TOTAL FAILURES	TOTAL DOWNTIME MINUTES	PERCENT OF TOTAL DOWNTIME	RANGE OF DOWNTIME MIN	MAX	AVERAGE DOWNTIME	STANDARD DEVIATION
FAILURE CATEGORY: DUST SUPPRESSION SYSTEM								
SPRAY NOZZLES	2	.0	70	.0	10	60	35	35
FILTERS	123	2.6	6975	2.0	10	300	58	48
HOSES	327	6.8	15570	4.4	10	420	48	46
FITTINGS	32	.7	1185	.3	10	155	37	37
VALVES	4	.1	255	.1	35	90	64	28
WATER PUMP	7	.1	1065	.3	30	270	152	94
AIR BLOWER	32	.7	4570	1.3	20	480	143	139
DRIVE MOTOR/SYSTEM	34	.7	4195	1.2	15	490	127	106
OTHER/GENERAL	201	4.2	13218	3.7	15	480	66	77
CATEGORY SUB-TOTAL	762	15.8	47103	13.3	10	490	62	70
* NORMALIZED SUB-TOTAL	.024		1.50					
FAILURE CATEGORY: LIGHTING SYSTEM								
LIGHTS	57	1.2	2330	.7	10	270	50	50
WIRING	1	.0	20	.0	20	20	20	0
SWITCHES	2	.0	10	.0	10	10	10	0
OTHER/GENERAL	12	.2	820	.2	20	180	68	53
CATEGORY SUB-TOTAL	72	1.5	3180	.9	10	270	52	51
* NORMALIZED SUB-TOTAL	.002		.10					
FAILURE CATEGORY: LUBRICATION								
FITTINGS	14	.3	535	.2	10	95	38	24
HOSES	25	.5	1230	.3	15	240	49	46
OIL LEVEL	22	.5	1230	.3	10	480	56	99
LUBE PUMP								
OTHER/GENERAL	180	3.7	7415	2.1	10	270	41	34
CATEGORY SUB-TOTAL	241	5.0	10410	2.9	10	480	43	44
* NORMALIZED SUB-TOTAL	.008		.33					

* NORMALIZED BY MACHINE SHIFTS OF OPERATION

TABLE V. Failures and Downtime for Roof Bolter Repair Time Failure Data (Cont)

FAILURE DESCRIPTION	NUMBER OF FAILURES	PERCENT OF TOTAL FAILURES	TOTAL DOWNTIME MINUTES	PERCENT OF TOTAL DOWNTIME	RANGE OF DOWNTIME MIN	RANGE OF DOWNTIME MAX	AVERAGE DOWNTIME	STANDARD DEVIATION
FAILURE CATEGORY: SERVICE DURING PRODUCTION SHIFT								
SERVICE OTHER/GENERAL	122	2.5	22655	6.4	15	710	186	120
CATEGORY SUB-TOTAL	122	2.5	22655	6.4	15	710	186	120
* NORMALIZED SUB-TOTAL	.004		.72					
FAILURE CATEGORY: MISCELLANEOUS								
STUCK	6	.1	175	.0	10	60	29	17
FRAME FAILURE	25	.5	2365	.7	30	315	95	64
CANOPY REPAIR	29	.6	2800	.8	15	480	100	101
FIRE SUPRESSION SYSTEM	2	.0	75	.0	75	75	75	0
SIDEBOARDS	3	.1	30	.0	15	15	15	15
OTHER/GENERAL	162	3.4	14934	4.2	10	480	93	96
CATEGORY SUB-TOTAL	227	4.7	20379	5.8	10	480	92	93
* NORMALIZED SUB-TOTAL	.007		.65					
PRODUCTION DOWNTIME (NOT MACHINE RELATED)								
MOVING OF EQUIPMENT	9		910					
MINE POWER	106		7344					
BELT CONVEYOR	648		20739					
ACCIDENT	1		120					
UNSAFE ROOF	33		1590					
WAITING FOR PROD. PARTS	659		41660					
LACK OF PERSONNEL	4		325					
DISABLED EQUIPMENT	68		2970					
INSPECTION	22		1600					
OTHER/GENERAL	260		6565					
CATEGORY SUB-TOTAL	1810		83823					

* NORMALIZED BY MACHINE SHIFTS OF OPERATION

TABLE .V. Failures and Downtime for Roof Bolter Repair Time Failure Data (Cont)

FAILURE DESCRIPTION	NUMBER OF FAILURES	PERCENT OF TOTAL FAILURES	TOTAL DOWNTIME MINUTES	PERCENT OF TOTAL DOWNTIME	RANGE OF DOWNTIME MIN	MAX	AVERAGE DOWNTIME	STANDARD DEVIATION
ERRORS IN DATA ENTRY								
ERROR 1	18		1320					
ERROR 2	2		95					
ERROR 3	2		50					
ERROR 4								
ERROR 5	7		755					
ERROR 6	4		325					
ERROR 7	2		75					
ERROR 8	3		298					
ERROR 9	1		20					
OTHER/GENERAL	5		325					
CATEGORY SUB-TOTAL	44		3263					

* NORMALIZED BY MACHINE SHIFTS OF OPERATION

As a recapitulation of the roof bolter problems, Table VI lists the major categories and the ranked component failures responsible for section downtime.

TABLE VI. Ranking of Components Responsible for Section Production Delays

Electrical

1. Trailing cable
2. Electrical controls, i.e., contactors, relays, switches, etc.
3. Motors

Mechanical

1. Dust suppression system
2. Drill head
3. Drive train (chains)
4. Tires

Hydraulic

1. Hoses and fittings, and jacks and cylinders
2. Motors and pumps (hydraulic fluid contamination)

3.2.1 Electrical Systems

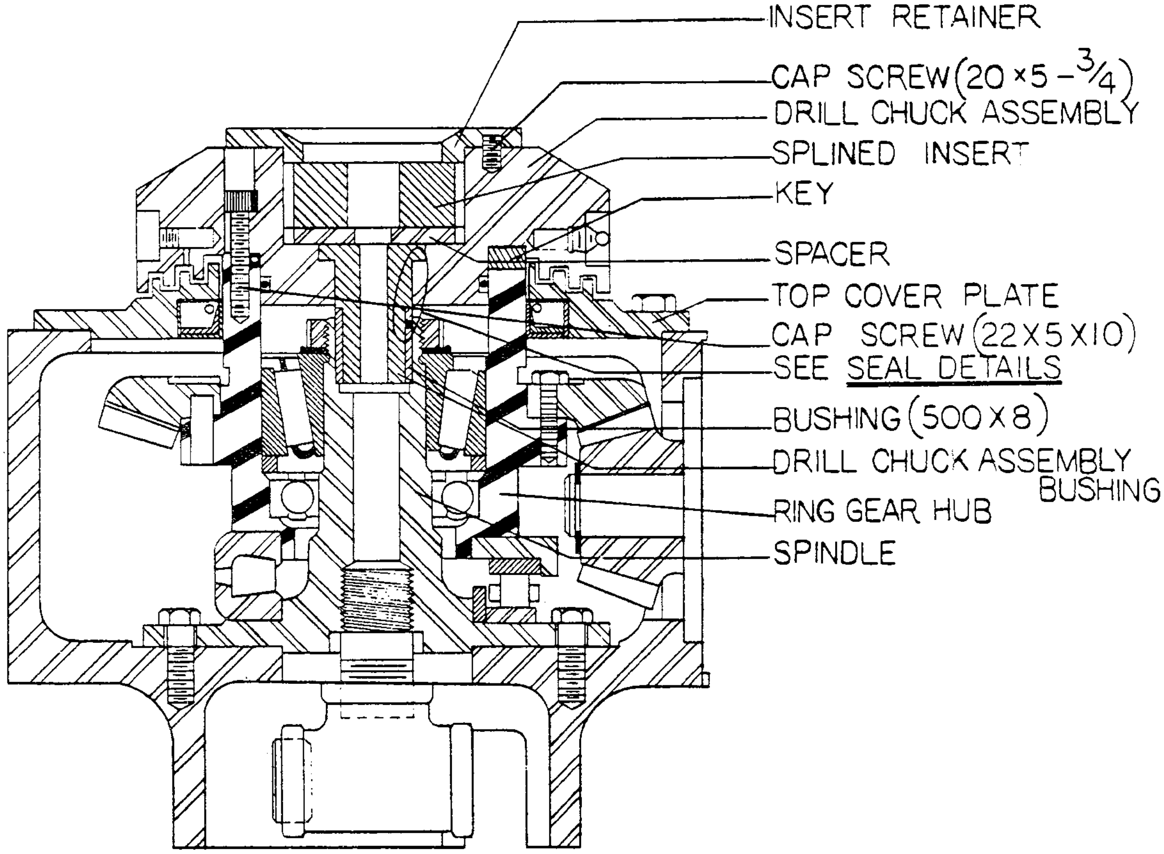
As discussed earlier, the primary area of concern in the electrical system is related to the trailing cable. In our discussion with mine personnel, the primary reason for trailing cable failure is mechanical damage where the bolter itself ran over the trailing cable, or the trailing cable was pulled or crushed against the rib. Thus, in some way the trailing cable was pinched, bent, twisted, or torn. In an attempt to reduce trailing cable damage, cable reels such as used on shuttle cars are used on roof bolters where possible. The control of trailing cable failures, as will be discussed in Section 4, hinges on providing a lighter and easier to handle cable with outer covers which are tougher, more durable, and brightly colored for better visibility.

The second most prominent problem in the electrical system was the control system, in particular motor starters and relay contacts. Since the motor starters or contactors or relays are normally encased within a permissible enclosure and difficult to get at, repair or dressing of contacts requires a considerable amount of time. The heavy currents associated with the lower voltage machines (480 volts) obviously contribute to this problem. In many of the mines utilizing higher voltage machines (995 volts), contactor and relay arcing problems have been reduced considerably.

The third most severe electrical problem involves motors and related components, such as switches and external controls which are subject to mechanical failure and operational abuse. One problem in particular resulted from seal failure, allowing coal dust to enter the motor or switch causing rapid wear of the internal parts. In addition, overloading of motors by jogging results in burnouts and contact arcing. This problem of jogging is related to operator fine control requirements, especially during framing and positioning for bolting.

3.2.2 Mechanical Failures

Of the roof bolter mechanical subsystems, the primary problem was associated with the dust suppression system. In this system most of the problems centered about the hoses used to transport the dust from the drill to the filter and the filter bags themselves. Filter bag change-out is normally done during catch-up time periods when the bolter is not operating. Often the bag will clog with either water, a heavy dust load, or by not having been changed out during the preceding shift. It then would have to be changed during production causing a delay. The second problem centered around the drill head and mast where most of the failures involved the drill head itself. In a visit with a manufacturer, mention was made that the drill head was a problem area. Later in the present study the statistical data did indeed show a higher incidence of drill head breakdowns for that manufacturer's product. Discussion with mine mechanics and manufacturing people indicated that the shaft seal was the major problem with the drill head. Figure 17 shows a conventional rotary head and seal details. This is a newer style drill head. It can be noted in the drill head drawing that the rotating chuck assembly has a labyrinth seal around the outside minimizing the dirt or particles that reach the seal proper (see seal detail drawing) which is comprised of three quad rings and two oil seals to back them up. The other problem in the drill head and mast assembly, esepcially on the arm type drills with the cam mechanisms used to maintain rectilinear vertical-plane motion, was bending of the alignment rods on the arm. We found some roof bolters in mines with bent alignment rods. While this does not necessarily cause outright downtime, the misalignment does increase the side loading on the drill head and problems with the drill steel. The third most prevalent



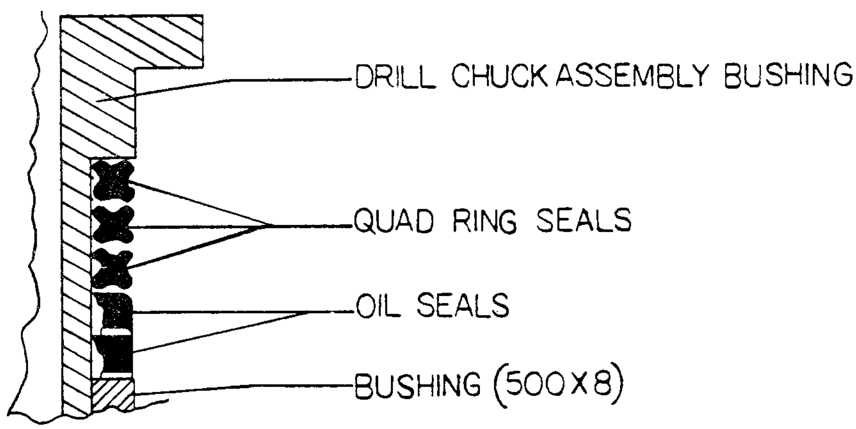


FIGURE 17. Drill Head and Seal Details

mechanical problem with roof bolters was the chains used to drive each of the side wheels from a central hydraulic motor and gearbox. Older models of roof bolters did not have any provision for taking up the slack in chain drive trains which resulted in considerable snapping and shock of the chain (which must have also been transmitted to other drive components). Most newer roof bolters that use skid-steer chain drives have a take-up sprocket with which slack, and therefore the consequent shock, is reduced.

3.2.3 Hydraulic Failures

The section delay problem often at the top of the list of hydraulic system failures is mechanical damage of hoses and fittings. This is often caused by coal and/or rock, crushing or tearing the hose or fitting during operation of the machine. Inspection of present face haulage machines show that there are a number of locations where the hydraulic hoses are looped in confined areas causing fraying and abrasion of the hose during machine operations. A concern expressed by maintenance people is the lack of standard hose lengths or sizes. Many different sizes of hydraulic hoses must be brought underground as spares for on-site repairs. During a hose replacement the mine section mechanic often makes the replacement hose "long enough" to ensure that connections can be made. This results in excess hose looped into confined spaces subject to the physical damage described above. In other instances large pieces of coal and/or rock may crush against the hoses during actuation of hydraulic cylinders or conveyors. The inspection of individual model machines also discloses that the routing of hydraulic hoses sometimes seemed to be random, obliging mine mechanics to guess at replacement length and routing.

The next problem involved actuation cylinders or jacks. The failure here is often leakage of the seals around the piston rod caused by the particulate ingression with every stroke of the rod. Another cylinder problem is bending of piston rods during actuation where a piece of coal or rock lodges in the mechanism causing the barrel to be held rigid while the piston rod is bent. The seal problem was alluded to earlier during the discussion of electrical problems. Based on experience in coal preparation plant operations it appears that coal dust is not the same as ordinary test dust used in standard hydraulic component testing. This is evident to most coal preparation plant operators who have noted that materials which work in sand and gravel and many other mineral industries will not work in coal. In particular, the ultrahigh molecular plastics and other resilient materials which will last for years in other applications often last but a few days in coal slurry applications. This shows that coal dust has different wear characteristics than ordinary dust. During the performance of this program the work being performed on hydraulic system testing by Oklahoma State was observed. The problem of coal dust wear characteristics was discussed and it will be one of our recommendations that the wear properties of coal dust versus standard test dust be reviewed using the standard hydraulic tests. For the problem of mechanical damage to jack cylinders, a solution may be to redesign the cylinder mounting to reduce the cylinder scissors points (i.e., inside elbow joints). In Section 4, each of these problems will be discussed for possible improvement of the roof bolter based on information obtained from machine operators, rebuilders, and manufacturers.

The third most prevalent problem was not pinpointed by computer data analysis but was identified through consideration of mine mechanics' experiences and the findings of the survey. In looking at the root cause of many of the component failures, the problem was caused by hydraulic fluid contamination. The underground coal mine environment obviously does not lend itself to the proper maintenance of hydraulic systems. Adding to the problem of having coal dust surrounding all of the hydraulic elements and covering the hydraulic tank is the poor accessibility of system filters. Sometimes machines are operated with the filter totally bypassing providing no contaminant protection to the hydraulic system. This problem is evidenced in terms of the large volume of hydraulic pumps and motors that are replaced. Inspecting the parts showed them to be grossly chewed-up by contaminants in the system.

4. COMPONENT IMPROVEMENT AND REDESIGN

In this section, Woodward Associates, Inc. discusses the roof bolter problem areas, and what the mine operator, machine rebuilder, and manufacturer might do to compensate for or solve these problems. To facilitate description, these problems have been segregated into electrical, mechanical, and hydraulic categories and each is discussed in order of decreasing contribution to machine section downtime. Table VII lists the major problem areas identified in Section 3. Some of these problems are more prevalent in the older machines and can be expected to continue until they are replaced or updated. As problems are identified, steps toward their solution may possibly be taken. Some of the problems have been resolved on the newer models, however, the lack of good records obscures the real problems. Much roof bolter downtime could be eliminated if mine management had realistic records of what is actually causing the downtime. This data could be utilized to develop effective preventive maintenance programs and procedures. The reporting procedures need not be complex and useful analysis can be easily performed. Every mine should do so to protect their investment in machines and production. Data handling recommendations will be discussed at the end of this section.

TABLE VII. Major Component Failures

- Electrical
  - Trailing cable
  - Contactors
  - Motors
- Mechanical
  - Dust suppression system
  - Drill system
  - Drive train (chains)
  - Undercarriage (tires)
- Hydraulic
  - Hoses and fittings
  - Actuation cylinders
  - Oil contamination

4.1 ELECTRICAL MAINTENANCE PROBLEMS

The primary input to the roof bolters is often 480 volts, 3-phase, but DC input is definitely an alternate (which, incidentally, simplifies the trailing cable considerably requiring only the two power conductors). The 480-volt input is used directly for motors driving mechanical systems or motors driving pumps in hydraulic systems. In other applications it is rectified and used in DC drive systems.

Each stage of the electrical system poses unique problems, several of them which are affected by the operating voltage level. For this reason, a somewhat amplified discussion of "higher voltages" is presented below, in the trailing cable section.

4.1.1 Trailing Cables

Trailing cable problems account for most of the roof bolter downtime that can be attributed to electrical problems. Over 95% of the trailing cable problems can be attributed to mechanical damage that occurs either from the operation of the machine itself or another machine working in the section, e.g., a shuttle car. Another frequent problem is mechanical overstress of the cable, particularly where the cable is pulled loose at its termination which happens to be its weakest point.

Trailing cables, which may deliver up to 100 kW of power to the roof bolter, are sized to ensure low cable losses, heating and voltage drop. Heat buildup is a real, potential problem in large, dirt encrusted, multi-conductor, extended duty-cycle cables. The mechanical aspects to which the cable is subjected can be appreciated when one considers that each time the machine trams in one direction, cable is paid-out, then the other direction, and the cable has to be retrieved. The operator (or his helper) must be aware of the cable even when his prime attention must be focused on the roof bolting requirements. Cable splicing is another area of concern. A three-conductor cable splice can require as much as 2 hours to complete. However, several mines visited reported little trailing cable damage. These mines, incidentally, had high average daily production and indicated that trailing cable damage was a management problem rather than a technical problem. The physical aspects associated with cables can be seen throughout the foregoing, therefore anything that may lessen the "manhandling" (by man <u>or</u> machine) of the cable should be investigated.

One such area involves the cable size itself. A smaller cable would have several advantages. For several reasons but including cable considerations, an approach that is being used more and more with continuous miners (because the gains are greater due to its very large horsepower requirements) but also, to a smaller extent, with the other face machines, involves increasing the operating voltage. A higher voltage can lead not only to a smaller cable but can significantly improve conditions for most of the on-board equipment. Yet, where a continuous miner is operated at a higher voltage (950 volts) the other machines in the section are usually left to operate at a lower 480 volts. (The voltages stated are nominal values; 480 volts could just as well mean 550 volts and 950 be 995 volts.)

Conceptually, the advantages of higher voltage are stated as follows (E. M. Warner of Joy Manufacturing has prepared several papers comprehensively setting forth advantages of 950 volt operation):

a. Better voltage regulation at the motor. At 950 volts, motor stalling just about becomes a thing of the past.

b. As voltage increases, amperage decreases and conductor size decreases correspondingly, leading to a smaller, lighter, less expensive, more flexible, and more manageable trailing cable.

c. With less current, control gear (starters, contactors) can be smaller and the life of contacts will be extended.

d. With less current, a given trailing cable can operate over longer distances (as compared to operation at a lower voltage). As a consequence, transformer and distribution stations need not be moved as frequently and a labor saving is realized.

e. A smaller cable is more easily spliced.

f. A higher voltage creates more awareness of the cable so that it is treated with more "respect." This reduces mechanical cable damage.

The advantages for higher voltages delineated above are indeed real but, at least in the case of the trailing cables, these advantages cannot be accepted at face value. Conductor size can be reduced as current decreases but overall cable diameter is not reduced proportionately since the insulation has to be increased for the higher voltage. Because there is a trade-off of copper for insulation, weight and cost are less but, in the usual application, reductions of weight and cost are tempered by the requirement for the addition of shielding – overall for 660 to 1,000 volts, individually about each conductor for voltages higher than 1,000. Again because of shielding, along with the added insulation, flexibility is not what the first impression of "half the conductor size" might convey.

The above discussion may explain why the use of 950 volts has not spread as much as its technical advantages would lead one to expect. Further, one mine reported more electrical shocks (yet not actual accidents) at the higher voltage. Another reason for the limited use is likely the problem of integrating this voltage with existing mine electrical installations and machinery.

What can be derived from the foregoing is that there are advantages to higher voltage but not without some qualifications. Nor is it that the higher the better as can be seen from the following discussion which seems to break down to a case of 950 volts versus 2,300/4,160 volts:

a. Regulations allow operation with up to 4,160 volts at the face. But motor controls (starters or contactors) can be on-vehicle mounted only for up to 1,000 volts; beyond that level the control equipment must be back to the first outby crosscut.

b. Even if on-vehicle mounting of 2,300/4,160-volt starters were allowed, their size would preclude their use since they are of a radically different design and considerably larger than their lower voltage counterparts, whereas 950-volt magnetic starters are of a similar design to the 460-volt units and can handle a higher horsepower.

c. A 950-volt motor can be wound into the same frame as a 460-volt motor, using the same type of insulation. For 2,300 and 4,160 volts, major accommodations must be made requiring a larger frame for a given horsepower.

d. Solid-state motor controllers are readily available, rated at 460 and even 950 volts; not so for the higher voltages.

e. A minor point but still a factor, trailing cables for use at voltages to 1,000 volts require an overall shield but beyond 1,000 volts, individual conductor shielding must be used – thereby the cable proves less flexible and more expensive.

To conclude, there are very tangible benefits to be had with higher voltage, but at the present development of applied industrial technology, 1,000 volts stands out as the limiting voltage level for face operated equipment. This limitation will likely exist (for practical reasons) for some number of years. But even 950 volts is approximately twice the voltage of most present face equipment and there is much to be gained from increasing the operating voltage to 950 volts. When a new roof bolter is being considered and most certainly for a new mine, a study should be made seeking to incorporate 950 volts as the operating voltage.

As the demand for the higher voltage (i.e., 950 or 995 volts) developed, equipment manufacturers would respond by optimizing designs at the voltage, and much would be gained. For the trailing cable, at present, manufacturers commonly produce cables rated at 600, 2,000, and 5,000 volts. Any equipment operating at a voltage between 600 and 1,000 volts must use 2,000-volt rated cable. Optimizing at 1,000 volts would lead to shielding and insulation advantages. The cable would be smaller, more flexible, and cost less.

The splicing of cables is a very tedious and time-consuming procedure particularly for the shielded, three-conductor cable. Several manufacturers have developed splice kits for the mining market. These kits use crimps and shrink tubing which greatly reduce the amount of time needed to complete a high quality splice. It must be noted that some "in-mine" splices are considered temporary repairs by the Mine Safety and Health Administration (MSHA) and that cables so repaired must be removed from service within 24 hours to effect an approved permanent repair if such a permanent repair can be made. The probability of a failure of a splice is greater than in the cable proper. The most common splices employ compression sleeves or sleeves with compression bolts. Both of these splice mechanisms induce stress concentrations and work hardening in the conductors. Thermite-welded, staggered brazed, or soldered splices fail through two predominant types of fracture forces – fatigue and tensile overloads. The fractures occur in the copper wire rather than in the welded or brazed joint as a result of the formation of regions of recrystallization and grain growth prompted by the high temperature involved in the metallurgical bonding processes. The development of a low melting point zinc-based solder system developed by a U.S. Bureau of Mines Research Center has shown to have both tensile and fatigue strengths superior to those of tin-lead solders. Results of tensile and flexibility tests for the solder joints show an improvement in joint flexibility of approximately 64% for these soldered splices over brazed ones.

Another possible solution to cable failures during section operations would be to detect possible cable failures before they occur. Incipient failure analysis of cables has been investigated by West Virginia University who reported the development of several portable instruments that would detect when the insulation in cables and motors has reached the danger point. Infrared detectors can find hot spots in cables or indicate if a motor is generating excessive heat. Another technique under development in the aerospace industry involves the use of an oscilloscope display to show the frequency components of a current pulse supplied to either a cable or motor. As the insulation in the motor or cable begins to break down, the oscilloscope pattern of display shows more and more individual components being reflected back from the deteriorating insulation. A third technique for anticipating cable failure is to measure the phase difference between voltage and current in an unloaded cable. With the cable disconnected, the phase difference is nearer 90° for a good insulation condition. If the phase difference approaches 0°, the indication is that the insulation has broken down.

Although not directly a trailing cable failure problem, the connectors used on existing cables and equipment are of the threaded variety presenting problems of joint simplicity that such connectors are supposed to provide. The threads can become damaged or clogged with dirt and thereby make a connection very difficult. Several new connectors have come out on the market, e.g., those for adapting to threaded connector, and other original equipment connectors wherein only 5-30° of rotation are required to make a positive engagement.

4.1.2 Contactors and Electrical Control Elements

The electromechanical contactor is still the most used device for motor control in coal mining equipment presently in service. This type of device has the inherent disadvantages of requiring frequent contact point maintenance; requires the use of heavy duty solenoids operating at high temperatures; and is required to operate over a wide range of line voltage. Electromechanical contactors also exhibit vibration characteristics wherein, with each engagement and disengagement, electromechanical shocks are produced which can affect voltage converters and other similar equipment.

Alternative power controls are now available. Solid-state devices such as thyristors and opto-electronics have been combined to provide the end user with a solid-state "contactor" with no moving parts. Also, the solid-state contactor switches power at the zero point of the AC cycle which eliminates radio frequency interference and the generation of transient voltages. Disadvantages of the solid-state "contactor" are its susceptibility to noise transients already existing on the AC line; high initial cost; and the requirement for dissipating heat. These disadvantages have discouraged the use of solid-state contactors in coal mining equipment. The susceptibility to failures caused by power system transients has in the past tended to negate the promise of longer operating life. Present state-of-the-art transient limiting and transient protection systems now economically eliminate these types of failures. The solid-state "contactor" continually dissipates more power in its circuit than does the electromechanical contactor. As a result, heat-sinking techniques must be used to conduct heat away from the device.

The introduction of solid-state systems should be supported with diagnostic aids built into the circuitry. Efforts must be made to package these devices in such a way that the mine maintenance personnel can rapidly acquire the skills to service the new components. It should be noted that maintainability is a prime requisite and that diagnostic equipment is not commonly found within the mine. The development of simple training aids for mine maintenance personnel would prove immediately beneficial. Much present-day contactor maintenance is trial and error, and in many instances this maintenance is simply repetitive (such as dressing pitted contact points, which also involves the time-consuming effort of opening the permissible box). It should be a prerequisite that new training aids and guides be supplied with solid-state contactors as they are introduced on the new equipment.

The development of solid-state control retrofit kits should be investigated which would be used in rebuilding operations replacing particularly troublesome electromechanical contactors or relays.

At present, most mine operators recognize the fact that training and maintenance techniques must be upgraded for the modularized, newer, and more complex machines. Both mines and manufacturers are developing (or have developed) troubleshooting charts that, when followed, allow the maintenance man (or even machine operator) to diagnose the problem. The troubleshooting charts also fix the level of responsibility. The machine operator knows the level to which he is expected to troubleshoot before calling the mechanic. The mechanic knows at which point to call the electrician. This helps to reduce the damage caused by unskilled repair efforts. In addition, test points and terminations are being labeled in more precise ways, providing aids to diagnosis. Manufacturers are now using both color codes and numbering systems. Maintenance manuals continually improve and the clarity of the troubleshooting charts shows steady improvement. The mine operators are sponsoring formal technical training programs. These programs stress the importance of diagnosis and the fact that most machine problems can be isolated by careful examination of the symptoms. The logic of machine operation is being stressed. The proper use of test equipment is being taught both at this technical school level and in the ongoing operation of the mine. Technical skills are being upgraded, but not as rapidly as is required.

To improve the present situation, fault lights or similar indicators should be located on solid-state modules. A fault or problem within the module should provide a clear indication that the module is defective. Modules also should be designed for plug-in installation utilizing vibration-proof clamping sockets (screwed, twist-lock, spring-loaded, etc.) to reduce the possibility of erroneous hookup and also to reduce the damage done when terminals are repeatedly removed and made-up. These types of sockets are now commonly found on military and aerospace hardware. In addition, special test equipment should be developed to test the modules at the mine. This test equipment should be supplied as part of the original machine or equipment package. This would reduce the possibility of unknowingly replacing a defective module with another defective module.

Early attempts to use solid-state equipment in very harsh electrical and mechanical environments proved to be unreliable largely because of an underestimation by the designers of the severity of the environment. Present technology has taken into account the typical failure modes encountered by solid-state circuitry. Transient protection is now standard in commercial equipment, and new logic concepts have been developed wherein high noise immunity is a standard option for solid-state control logic. The use of solid-state power control devices instead of the equivalent electromechanical devices can decrease the physical space required for control equipment, and increase the space available for operator compartments, mechanical equipment, or reduce the overall size of the machine.

In summary, for the resolution of machine contactor and control problems, solid-state components are making inroads into the power handling circuitry that used to be the domain of electromechanical relays and mercury arc rectifiers.

4.1.3 Electrical Components

A major electrical component problem of roof bolters is electric motors which operate in a harsh environment and are subject to adverse cyclic loading. Motors suffer burnout, delamination, turn-to-turn insulation failures, bearing failures, water-induced problems, and outright mechanical problems. A general problem has been internal water condensation resulting from temperature cycling. Also, field windings have failed due to repeated on/off cycling or jogging (forward, off, reverse, etc.) or lack of thermal protection. In addition, certain downtime occurrences have been attributed to excessive ground current. Part of the problem has been traced to water condensation caused by temperature cycling of the motors. This results in excessive leakage currents which can trigger the ground fault interrupter. Very little vapor is required to initiate a short duration transient current in the ground circuit to cause a ground current trip. Present technology has the capability of developing circuitry that will discriminate between a false ground current and a dangerous ground current. Nuisance type trips would be reduced while providing maximum protection to the operator. Production need not be compromised to ensure safety. In addition, shaft seals used on electric motors need to be improved to reduce water and coal dust ingression into the bearing cage.

The original equipment manufacturer not only has difficulty specifying what the motor must do but also has difficulty developing an adequate acceptance test which truly relates to operating conditions. As a minimum, all motors are specified with class F type insulation. Further, many motors are protected with thermistors implanted in the motor windings; these sensors trigger outside level sensing circuitry for overload protection.

The problem of defining service factors and an acceptable test for motors could be reduced if the motor manufacturers and the equipment manufacturers worked closely to develop comprehensive specifications for the electric motors. These must be coupled with the development of realistic and indicative acceptance testing procedures. Table VIII lists some pertinent criteria.

TABLE VIII. Pertinent Electric Motor Specification and Acceptance Test Criteria

1. Sequencing (number and rate).
2. The number of anticipated plug reversals in a specified time.
3. Maximum space available and a description of the surroundings relative to heat dissipation capability.
4. Lowest voltage from the utility line to be expected and an estimation of severity of transient voltages (amplitude and duration).
5. A description of the real severity of service such as dust, water, ambient temperature and loading.
6. A description of anticipated stall requirements (number of stalls in a specified time).
7. The anticipated number of start-forward-reverse cycles per unit time.
8. Anticipated momentum loading on the motor.
9. A description of the acceptance test sequences, number of units to be tested per batch, and a description of the severity that they must undergo in order to cull the marginal units.
10. Items 1 through 9 must be specified in addition to the standard electrical and mechanical requirements.

Maintenance of electrical components is complicated by restricted accessibility in a number of roof bolter installations. The machines are quite compact and space is at a premium. However, in many cases it appears that the installation of components was made without due consideration to servicing. In the simplest of terms, lack of accessibility results in the expenditure of more time in repair operations. Also, lack of accessibility many times prevents timely servicing resulting in costly future production downtime. Manufacturers and rebuild shops are giving increasing consideration to those components requiring frequent access or that pose difficult handling problems. On all machines now being manufactured, increasing consideration is being given to the provision for line-of-sight access to all fittings and mounting bolts. Thus, the problems described above are being addressed by manufacturers, rebuild shops, and mine maintenance personnel. Unfortunately, many of the accessibility problems are unique and defy a standard solution other than the application of a concerted design effort.

4.2 MECHANICAL MAINTENANCE PROBLEMS

Mechanical problems account for about 40% of roof bolter section downtime.

In addition to the problem of restricted access, maintenance is difficult to perform because of the weight and size of the machines combined with the limited clearances, poor illumination, and dirty working environment. Worn parts, loose hardware, cracked welds, etc., are difficult to detect before they cause a catastrophic failure of the machine with resulting downtime. Preventive maintenance programs are based on a history of past failures. While many of the problems that originally contributed to machine downtime have been partially or completely solved, new causes of downtime continue to appear. In the following sections, we will address the mechanical problems identified in Section 3.

4.2.1 Dust Suppression System

This system is similar to a rugged, oversized vacuum cleaner.

As discussed in Section 3, the dust suppression system is the largest single source of mechanical failures of the roof bolters. Largely involved are the hoses used to conduct the rock dust and chips from the drill head back to the filter. The hoses are more or less of a "common" variety, made usually of urethane or like plastic with wear resistant properties;

but beyond the material aspects of the hoses, some of the problems can be traced to operator abuse during the operation of the machine. This type of problem, of course, can be remedied through training to improve the operator's attitude towards the machine. Other efforts can be addressed, e.g., to the selection of a hose type more specifically suited to the application. Guards and guides, too, can be added for the hose and its routing on the machine can be made with an express purpose of protecting from tearing or crushing. Better hoses are available from manufacturers but criteria are needed for their selection since a difference between sales claims and actual field performance can exist; this may come about from a failure of definition or appreciation of the service conditions to which a roof bolter is subjected. To this end, it would behoove the mining industry to have hose test standards not only for mechanical strength and resistance to crushing but also flammability and toxicity of the hose which are crucial aspects of plastic materials that may end up on machines that are to operate in a confined, underground coal mine environment.

Along with hoses, a companion problem of the dust suppression system is the filter bags. Improvements would be directed to more easily serviced and longer lasting filter assemblies. Space availability constrains the roof bolter as much as other underground coal mining machines. Pre-cleaners or cyclones occupy considerable space on the machines; however, considerable work has been done in this area. In particular, the Donaldson Company, who has developed small, swirl chamber pre-cleaners for off-highway air filter applications. These pre-cleaners should, and are indeed being installed in the roof bolter systems. One Eastern rebuilder "routinely," in rebuilding a roof bolter, finds or makes room for installing one of these pre-filters.

On the topic of rebuilds, it is well to review at this time some of the reasons why a mine will rebuild a roof bolter at a cost which is not much less than that of a new machine. A full rebuild entails a very complete disassembly and remanufacturing of the machine. The rebuilder referred to above adds not only the filter pre-cleaner but any other feature desired by the mine to make the machine more serviceable to their particular needs and within the standard rebuild package the following is done:

- The main frame is thoroughly reinforced; double pass welds are used rather than single pass as originally manufactured. (The lower the machine for working thinner seams, the less box-frame construction or reinforcing members that will be found in the original design.) Extra reinforcing metal is used, particularly around the wheel units. A bar is installed between the wheel units to prevent flexing of the frame sides.

- The boom support structure is reinforced.
- On some machines, an extra stability jack is added.
- A modified drill head is installed.
- In wheel units, a pilot pinion bearing (all wheel units experience this problem) is replaced with a brass bearing which does a "fantastic" job in supporting the pinion gear.
- A second panic bar and hydraulic valve are added for instant hydraulic pressure dump. The original factory system cuts electric power but inertial overrun of a pump-motor can extend an accident action to more serious consequences.
- New covers, etc., are added. (The old ones are usually pretty well battered or rusted, or both.)

4.2.2 Drill Head and Supports

Seal failures were often mentioned as the cause of drill head bearing or gear failures. The drill head area represents a particularly hostile environment. Dust generated by the drilling operation drops onto the drill head and support mast. The fine dust settles on and under the moving components completely encapsulating them. Contamination of this type is the prime contributor to damage of the drill head including its drive mechanisms. Hydraulic drive motors placed under the drill head often experience contamination damage.

In discussions with roof bolter manufacturers and rebuilders, it is apparent that much work has been done to improve the drill head seal. As shown previously in Figure 17, the newer drill heads use a combination of labyrinth and "O" or quad ring seals. One manufacturer visited had just implemented a seal design change to reduce the drill head failures that were occurring. The new design used the labyrinth seal concept under the rotating head to reduce the ingression of dirt and coal dust to the rubber seal area. This change had markedly reduced their customer complaints of drill head failure.

Sealing is another area that can benefit from the interjection of some of the practices demonstrated in other industries. Installing improved sealing systems requires coordinated changes in both the stationary and rotating portions of the interface. The changes pose a major problem in retrofitting machines already in service. Seal manufacturers are continually making improvements for their customers. Unfortunately, the roof bolter does not present a very large volume market. Seals of any kind are a volume sensitive item and the seal manufacturer must direct his development, sales, and engineering efforts toward the volume customer. The available sales literature and engineering data sheets are not an adequate substitute for the advice of a competent sealing specialist.

Any improvement in physical sealing must be accompanied by personnel training in correct installation of the sealing device and demonstrating that correct service of the seal will reduce other machine maintenance. Protective covers and boots need to be replaced after machine repair.

4.2.3 Drive Train

Drive train and tram system failures account for about 8% of the total section downtime attributable to roof bolters. It is the drive chains used in a skid-steer drive application that are most often at fault. As discussed before, most manufacturers at one time did not provide tension adjustments for the drive chain. In service the chains were subjected to considerable snapping and shocks; breakage was a frequent result. Chain breaks present a two-fold situation – not only is the roof bolter disabled on the spot, but its repair is seriously hampered by the equipment that is built about the drive system (the operator compartment frame, tires, and components in the immediate chain area). A major improvement in the drive train design proved to be the addition of the take-up idler for the drive chain. This take-up idler reduces the chain slack and thereby the shock loading. One manufacturer offers a drive chain tension idler retrofit package available to the mines and rebuilders. Thus even though the drive chain is shown to be a problem of some consequence, a means for significant improvements is available in the retrofit package. Also, improved high strength chains are available which increase the service load factor for roller chain applications.

4.2.4 Tires

In the present study, a flat tire on a roof bolter proved to be an infrequent failure but when it happened to be the tire adjacent to the operator's compartment on some roof bolters it caused an inordinate amount of downtime, necessitating the removal of the operator seat and controls for access to the tire. This difficulty is recognized by the manufacturers and a design modification is being worked on. Other designs found in bolters have swing-away assemblies providing quick access to the tires. A good solution to the flat tire problem for the bolters with limited accessibility is to fit them with foam-filled tires; their initial higher price will be paid off by eliminating one flat and much more than paid off if production downtime is averted.

4.3 HYDRAULIC SYSTEM

The roof bolter hydraulic system is faced with adverse operating conditions and maintenance problems. All bolters use hydraulics to actuate/position stabilizer jacks, booms, and to drive the drill head and tram motors. Resolving or reducing the hydraulic problems translates into a similar reduction of section downtime. To illustrate general solutions, some successful surface mining and construction hydraulic practices concerning hydraulic system design are discussed below:

- System Filtration – Several practices are recommended to ensure that the filtration system will be as effective as possible at protecting the hydraulic system components:
  - Filters should be placed between major components to preclude chain reaction failures.
  - Filter elements should not be installed in the hydraulic fluid reservoir not only because of the high risk of introducing contamination during filter

element replacement but also the difficulty of replacement.

- Where possible, system filters should be grouped together in one location, close to other service points on the machine, with the bypass indicators visible to the operator without requiring the removal of access panels or opening doors.

- The different filters on the machine should be sized to give an equal and acceptably long service life to allow same-time replacement and at convenient intervals.

- <u>Hydraulic Oil</u> – Hydraulic fluid should be selected with a viscosity towards the higher end of the manufacturers' recommendation since low temperature extremes are normally not a problem underground.

  The oil should be replaced if it has the milky appearance of a large amount of water content. Oil test kits are available. The oil should be tested at prescribed intervals.

- <u>Cooling</u> – A heat exchanger will extend oil and component life.

- <u>Relief Valves</u> – Factory pre-set cartridge type relief valves should be used rather than field adjustable ones which are subject to being incorrectly set.

In the following sections, we discuss individual hydraulic problems as identified during the failure analysis of the face haulage machines.

4.3.1 Hoses and Fittings

The design of the hydraulic system plumbing is often the last of the "details" to be completed before a machine is released for production. This concept of low priority for the plumbing layout on the machine will inevitably lead to a disproportionate amount of downtime for the machine.

The layout of the hydraulic plumbing must be considered when the machine structure and major components are located during the early design stages. Thought must be given to line sizes and to the total number of lines required at any given location on the machine. Space allowances need to be made for:

- Adequate wrench clearance on all fittings.
- Access to joints in continuous runs of hose or tubing to ease disassembly, of both complex shapes and frequently damaged areas.
- Groups of lines to be run together for convenient access.
- Access to properly located clamps used to restrain hydraulic tubing.

Several design measures can be taken to increase the reliability of the hydraulic plumbing on the machine and to standardize replacement parts:

- Steel tubing rather than hose should be used wherever flexibility is not required. The more reliable JIC 37° flare fitting should be used with the tubing.
- Where flexibility is required, hoses, of course, are to be used but they should be of some minimized number of different "standard" lengths. This not only simplifies stocking of spares but also promotes faster repairs and with the right length hose.
- Only two or three different hose diameters should be used for all applications on the machine.
- All hose should be rated to operate at the machine's highest pressure to preclude the accidental use of a low pressure hose in a high pressure application.

- All hose should have straight JIC 37° flare female swivel fittings on both ends for uniformity.

- Pipe threads should not be used because of the higher risk of leakage.

- Hydraulic ports in components should all be SAE O-ring type.

- Hoses that fail by rubbing should preferably be relocated to eliminate the interference. Coils of spring wire or urethane that wrap around the hose are available to minimize chafing if the hose cannot be relocated.

- Hoses should bend in one plane only and with a minimum radius at least as large as the manufacturer recommends.

4.3.2 Hydraulic Actuation Cylinders

Hydraulic cylinders or "jacks" are used on virtually every roof bolter in a variety of applications. In all cases they are required to position the drill head and mast, stabilizer foot, and temporary road support.

Cylinder failures were blamed for approximately 7% of the total roof bolter caused section downtime based on the section delay records. Typical cylinder failures were attributed to:

- Pressure seal failure because of heat, abrasion, and poor design.

- Rod wiper seal failure which allows abrasives to, in turn, fail the pressure seal, score the cylinder rod and barrel, and cause contaminant wear in all hydraulic system components.

- Worn and broken pins in the connecting clevises.

- Rod wiper and pressure seal failure because of surface damage to the cylinder rod.

- Bent piston rods caused by wedging of coal or rock against the cylinder barrel.

Some design improvements which may be made by the manufacturer of hydraulic cylinders to decrease machine downtime are:

- Select an optimum rod wiper seal based on the standard SAE "Rod Wiper Seal Ingression Test." The effect of coal dust on rod wiper seals should be specifically investigated.
- Shield cylinder rods by careful design location to minimize exposure to abrasives and wedging of cylinder barrels.
- Install internal pressure relief valves to relieve excessive cylinder pressures to protect rod and piston pressure seals, and cylinder barrels.
- Design adequately sized connecting pins and bushing inserts made of an abrasion-resistant heat-treated steel to improve clevis joint life.

The equipment user and rebuild shop can reduce downtime caused by cylinder failures by:

- Periodically rebuilding hydraulic cylinders before rod wiper and pressure seals fail.
- Replace cylinder clevis pins and bushings periodically.
- Leave protective shields or closures for cylinders in place after repair.

4.3.3 Hydraulic System Contamination Control

Emphasis will be placed on possible contamination control procedures that could be applied to roof bolters because a number of hydraulic system failures can be directly or indirectly attributed to contamination. An approach to solving contamination problems will be outlined analyzing the hydraulic system in total, as well as the performance of individual components. The hydraulic system must be examined finding the most contaminant sensitive components and selecting filtration that will allow a reasonable service life by maintaining a sufficiently low contaminant level.

The contaminant level of the hydraulic system can be controlled by minimizing the amount of external contaminant allowed to enter the system. Both manufacturers and users of roof bolters can contribute to controlling external contaminant ingression.

The manufacturer can reduce contaminant ingression by component design and selection, and their placement on the machine:

- Cylinder Rod Wiper Seals – The performance of rod wiper seals can be evaluated to give a quantitative and qualitative comparison of different manufacturers' seals using a standard test (SAE, "Cylinder Rod Wiper Seal Ingression Test"). This test puts the cylinder in a known contaminant environment and measures the rate of contaminant ingression. The known rate of ingression provides the information required to estimate how much contaminant will be added to the hydraulic system through the rod wipers during mine operations.

  The equipment designer also can reduce the amount of contaminant exposure to the cylinder rod by shielding it through design location.

- Sealed Hydraulic Reservoir – Designing the reservoir to operate under a positive pressure eliminates the contaminant introduced when the fluid level changes in a conventional vented reservoir. The fluid level changes in operation because of cylinder rod volume differential, thermal expansion, or fluid loss. A vacuum relief and a pressure relief must be included on a sealed reservoir in order to maintain at least atmospheric pressure and to protect the tank structure from overpressurization. A positive pressure is maintained in the reservoir during operation because the reservoir air temperature increases with an attendant increase in pressure. The positive pressure during normal machine operation also improves hydraulic pump reliability by effectively supercharging the pump inlet. This sealed reservoir system has been used by surface construction equipment manufacturers with success. The reservoir must be sized large enough to prevent overpressuring during cylinder rod retraction.

The contaminant sensitivity of the hydraulic system can be reduced by component selection based on standard sensitivity tests:

- Hydraulic Pumps – A standard Pump Contamination Sensitivity Test has been developed at the Oklahoma State University Fluid Power Research Center for positive displacement pumps. The test will allow both a qualitative and a quantitative evaluation of the different hydraulic pumps available. The pumps are assigned an Ω rating which is an indication of the filtration efficiency required to give a fixed service life. The pump is usually the most contaminant-sensitive part of the system.

- Hydraulic Valves and Other Components – Standard tests are available to evaluate the effects of contaminant wear on control and relief valves along with silting tests to evaluate any valve jamming problems because of contamination buildup.

When the contaminant sensitivity of the components to be used has been established, and the external contaminant ingression can be measured or estimated based on seal efficiency, the system filtration can be selected according to a desired wear life specified by the roof bolter manufacturer. A "Multipass Filter Test" has also been developed to rate the contaminant removal efficiency of filters for different particle sizes (usually the 10 micron size is specified). A β rating is established that relates the ratio of the number of particles upstream of the filter to the number downstream.

A filter with a minimum β rating must be selected according to the Ω rating of the hydraulic pump and the amount of external contaminant ingression expected to enter the system per unit time.

The cost, mechanical reliability, and contaminant sensitivity must be considered when selecting components to make up a hydraulic system. A more sensitive component may be chosen because of other reasons such as cost or mechanical durability, but it must be protected by more efficient and generally more expensive filtration (both in first cost and maintenance costs).

The peak contaminant levels of the hydraulic system must be controlled since a short duration exposure to a high contaminant level is more damaging than a proportionately longer exposure to a lower level. Anytime the system is opened to the outside environment such as during component replacement, new contamination is allowed into the system.

When the system is exposed to external contaminants to any extent, the hydraulic oil should be free-circulated at low pressure to clean up the system before returning the machine to service. Motors or other actuators should be bypassed and the oil circulated through each loop for at least an hour to allow the filtration system time to remove the fresh contaminant without the extra burden of ingression caused by normal operation. The amount of damage caused by contaminants in the system is directly proportional to the operating pressure, so the components will not be hurt as badly if the system is free-circulated at low pressure.

The manufacturer can reduce the problem of built-in or repair-induced contamination by:

- Using more reliable components such as steel tubing rather than hydraulic hose.
- Designing the machine layout for easy access to major components so that other portions of the system do not have to be disturbed to gain access.
- Placing filters between major components to minimize chain reaction failures.
- Using an on-board filter for all oil being added to the reservoir.
- Avoiding pipe threads and using only positive seal connections for plumbing to avoid the need for reservoir replenishment.

The problem of repair-induced contamination can be helped by the equipment user by:

- Promoting a general attitude of cleanliness when working on hydraulics regardless of the location.
- Providing a clean repair facility in the mine.
- Maintaining an adequate stock of major components to allow removal and replacement of complete assemblies at the face.
- Proper training of personnel to locate failed components with minimum disturbance to the system.
- Free circulation of the system for cleanup before returning the machine to production.
- Pre-cleaning all components used for repairs and protecting them before installation.

4.4 IMPROVING MAINTENANCE PRACTICES

Maintenance practices, of course, directly affect equipment availability for production. Since coal mining is very much an interwoven operation, a breakdown of one piece of equipment can stop production of a section. In many mines, the pressures of production relegate maintenance to an "only if you have to" status. Careful analysis of records show that such an approach is a losing proposition, both in production and equipment costs. So many factors enter into a mining operation that it is difficult to make a "black and white" comparison of one maintenance practice versus another but based on the results of this present study of continuous mining equipment, certain statements can be made about maintenance operations.

Mines that enforced proper maintenance and machine operation experienced less production downtime than mines that allowed equipment breakdowns to dictate their activities. The former is a strong advocate of preventive maintenance, keeps a close tab on operations, and uses section maintenance records very actively. The latter, with a comparable size crew, strains to keep up with repairs and uses maintenance records limitedly, usually only as a means of providing continuity from one shift to the next (yesterday's report has no further value).

It is interesting that all mines visited keep section reports with maintenance activity information but, from that point, a wide disparity exists in the use made of the reports. Further, the fact that two mines belong to the same company does not mean that they have similar operations and record keeping. For some mines, the section reports are an invaluable guide for running the maintenance operation; the reports can serve the following purposes:

a. The basis for "working" reports, i.e., reports with specific purposes such as to pinpoint the more frequent breakdowns or the breakdowns costing the most downtime.

b. A means of monitoring performance of both men and machines.

c. Spare parts with ready access by section people can be kept closely in tune with actual needs.

d. Principal component change-out periods can be established.

e. Cost accounting.

f. An aid for determining when a machine is due a complete machine overhaul.

g. Provide a solid basis for scheduling and defining the scope of preventive maintenance.

A few mines used computer processing of their maintenance data. The computer allows the mine to optimize a maintenance operation. One Eastern mine introduced an excellent computerized maintenance system where each machine in the mine is very closely monitored, and different levels of required preventive maintenance are periodically printed out by the computer. A summary of unscheduled maintenance is printed out once a month. It goes to the general mine foreman and the general maintenance foreman. This summary identifies the equipment, problem, date, total tons, cause, repair time, and lost production time. Failures by component, or category, or machine, can readily be retrieved.

One company relies on computers to centralize maintenance records of its numerous mines. It is likely that in the near future the operation will be expanded to increase its utility. At present the system provides the following information on a monthly basis:

a. Downtime of each face machine as a percentage of production shift time per section, per mine, per division, and per company.

b. Categorizes percentage downtime as to electrical, hydraulic, or mechanical problems.

Two mines had excellent maintenance operations and use their records very actively; both processed them manually, i.e., computers were not used. One of the two had a particularly well-organized maintenance operation. It is described in the following paragraphs.

It is an Eastern mine with ten continuous miners in operation. It operates three production shifts per day, five days a week, and conducts preventive maintenance (of all equipment) in each section on a rotating schedule. The total time devoted to scheduled maintenance, in proportion to production time, is considerably less than the more common two-production/one-maintenance shifts a day. Yet the production shift breakdown count is among the lowest of all the mines in the study. Last year it was the top producing mine in the company in terms of tons per shift. The individuals interviewed at the mine were quick to point out that the maintenance operation was only part of general mine policies. Management provides strong support to the maintenance operation, recognizing it as integral to mine operations and not merely accepting it as a "necessary evil."

A possible key to the effectiveness of the maintenance operation lies in the control of, and cooperation from, the people in the department. The general maintenance supervisor receives strong upper management support and is held accountable for the operation of the department. In similar fashion he supports and also expects accountability from the people in his department. He provides the tools, equipment, spares, and training to his people and expects results.

For this mine the section maintenance people are concerned only with maintenance. Their foremost responsibility is to the maintenance foreman, not the section foreman, and it is their end-of-shift reports that form the nucleus of the maintenance data program. Maintenance has the prerogative to interrupt production if it is felt that a breakdown can be forestalled.

To facilitate scheduling, mine sections are designated "red" or "blue" on a rotating five-week schedule. Starting the cycle as "blue," all machines in the section get one 8-hour preventive maintenance shift per week for five weeks while operating for three shifts per day. After this "blue" period the section is then designated "red." While "red" the section receives a 24-hour maintenance period once a week while continuing to operate for three shifts per day. At the end of the five-week "red" period, a very thorough preventive maintenance program requiring 40-hours is conducted. This 40-hour maintenance is started on a Friday afternoon and completed Monday morning, minimizing production time interruption. The section then starts a new "blue" cycle. Note that the machines get the 40-hour maintenance very ten weeks. If a breakdown occurs that may interrupt production substantially, a preventive maintenance shift may be declared at that time. If so, the section will then defer another preventive maintenance shift until a normal cycle period has elapsed; the only adjustment made is to accommodate the 40-hour shift to span a weekend.

Preventive maintenance is done against an extensive checklist covering all of the major components and subsystems. Each subsystem is broken down to individual items or services.

As to their data management, the section shift-maintenance reports are first consolidated into a daily report form by a clerk. (Should a shift report not be turned in, as can happen during an unusual work situation, an explanation is required from the responsible individual on his next shift.) Working from the consolidated reports, an industrial engineer prepares various reports tailored for different purposes. Through these reports, maintenance activities are closely monitored and planned.

An individual going into maintenance is placed in an 18-month trainee program where on-the-job training is interspersed with 40-hour classes on hydraulics, mechanics, and electricity/electronics plus three weeks of welding and two to three weeks on permissibility laws. While "on-the-job," he is rotated to work along with different experience maintenance people. After the 18-month period is completed, maintenance people still attend refresher or specialized classes which exceed regulatory requirements.

An emphasis on training is sustained all the time. If reports show an individual is lacking in some area, he is scheduled into a special training class. If an individual simply appears to require a "talking to," the maintenance foreman reviews the situation with the individual. If a section experiences persistent machine problems through the different shifts, all three maintenance individuals assigned to cover the shifts are scheduled together into a training class. In this way, differences that exist amongst the three are resolved into one common practice by a training specialist.

To conclude our observations of maintenance practices in different mines, there is a fault that can creep into the two-production/one-maintenance shift per day operation. It is the inclination, spurred by the desire to keep production going, to leave all maintenance, short of that which will stop the machine, for the maintenance shift to take care of. This practice can lead to costly consequences. The machine may end up operating at impaired efficiency for the greater part of a production shift while aggravating the basic problem and often setting the stage for other problems. Consider, for example, one or more drill steels that have been bent and not replaced during a shift. This will have a direct bearing on the speed of drilling the hole and at the same time increase vibration from the head, on back through the machine and possibly to the operator himself. This may explain tomorrow's failure of a drill head.

4.5 OPERATIONS/MAINTENANCE – DATA ACQUISITION AND HANDLING

As discussed before, most coal mines keep fairly detailed production records. The quality and accuracy of records pertaining to machine operation vary greatly throughout the industry. Records range from virtual nonexistence to computer data banks. This fact was noted throughout the course of this study.

Most data required to monitor mine operations originates in the section. But the quality of the data is highly dependent on the section foreman and his immediate supervisor. Production data is subject to verification and is reasonably accurate. Data pertaining to machine maintenance, failures incurred, and machine downtime are subject to individual judgments and lapses of memory in many instances. This is partly due to mine history and partly to the fact that the section foreman and maintenance man may not fully realize the value of maintenance data. Descriptions of problems and failures, in many instances, do not provide sufficient data for the implementation of an effective preventive maintenance program.

During our interviews with mine personnel, it was evident that they recognized that the use of more costly and sophisticated mining equipment had to be accompanied by better reporting systems. Fortunately, production data is a necessity for proper accounting. It is imperative that management know the production history of each piece of major equipment and what its contribution is in terms of cost per ton of coal mined. Most mines have added or modified existing forms to generate maintenance and downtime data. Several of the larger coal companies have generated new, concise forms to gather more accurate data in such form that it may be effectively analyzed. Most mines depend on the data provided on the shift report filled out by the section foreman at the completion of each individual shift. Many of the mines use additional forms that are filled out by maintenance personnel immediately after completion of tasks. Unfortunately, most of the personnel responsible for filling out the forms do not do so in sufficient detail or accuracy.

The maintenance data that is gathered is useful. Even in its simplest form, it is routinely used by the maintenance superintendent to establish and verify the preventive maintenance program. Change-out schedules for such items as undercarriage components, drill heads, hydraulic pumps and motors, and electrical components, etc., are usually established from this data. These change-outs may be effected after a certain number of tons are mined or after failures occur within a specified frequency. Three of the larger coal mines we visited encode data from the shift reports, maintenance reports, and parts purchase records. This data is subject to computer analysis and is used to establish change-out periods, to schedule machine rebuilding, to predict parts usage, to establish spare parts levels, and to determine very accurately the cost that may be attributed to each consumable part per ton of coal mined. Most mines, however, are not equipped to perform such analysis. Data is not presented in such a way as to establish trends, pinpoint recurring problems, and accurately define problem areas. Purchase records for parts are often used in an attempt to define problems. However, in many instances a repeat repair is required to complete a faulty repair. This does not appear elsewhere in the data and what is really a maintenance problem appears to be a failure history attributed to poor reliability. A classic example, often quoted by mine maintenance superintendents, of this is found with hydraulic pumps, wherein pumps are repeatedly replaced when the real problem is with a relief valve that has been previously reset at too high a pressure level. To improve productivity, the industry must know the real maintenance problems and cost of repairs in terms of downtime, maintenance personnel, and spare parts. The encoding of section data as performed in this report represents a start. Clearly, standard reporting formats to be used by the individual mines would increase the accuracy and reliability of the data analysis. As with other industries, the individual mines could submit the encoded section data to an industry association such as the American Mining Congress for composite processing.

4.6 STANDARDIZATION OF COMPONENTS AND SYSTEMS

Before discussing the topic of standardization, it must be noted that mining machine manufacturers are subject to the regulation of the marketplace. They must produce a machine that meets the requirements of the purchaser. They are also subject to the laws of the land; they cannot set prices, act in concert to establish what product will be available, or in any other way limit competition. There is little, if any, formal interchange of technical information directly between competing manufacturers. Most interchange is through the customer or through rebuilding facilities. Unfortunately, this lack of technical interchange limits concerted efforts to solve common problems.

Also, mining machines are a relatively low-volume item. Machines are often modified to satisfy customer requests and specifications. Thus, the marketplace — the coal mine — becomes the proving ground. Machines are continually improved as feedback is received from the field. Thus, even machines with consecutive serial numbers may be different. This contributes to the spare parts problem and is one of the contributing factors toward inefficient and incomplete repair procedures.

The manufacturers do make use of as many standard components as they can since, in their relatively low-volume situation, it is less costly to buy components than to manufacture them. Thus, at the component level there really is some degree of standardization though many components are identified with the manufacturer's part number or designation. Interchangeability with parts from other machinery or from other sources may thus not be apparent to mine personnel.

There are numerous independent parts suppliers (Pirate Parts Houses) that cater to the mining industry. Some of the mines feel that some of the parts supplied by these independent sources are superior to those originally supplied and many such parts are supplied or specified in rebuilding operations. The salesmen and field personnel from these independent parts houses are helpful in the interchange of technical information in the mining community.

Except for the above noted items, very little has been done to effect standardization except within the confines of compliance with local and state codes and MSHA regulations. As mentioned before, standard components, when found, are usually the result of procurement from a sole source supplier or are components or parts manufactured to JIC, SAE, NFPA, NEMA, FPA, etc., standards.

One example of the mining industry attempting to effect some degree of standardization and generate effective industry-wide specifications for specialized mining equipment is through the Society of Automotive Engineers. In this case all engineering activities are performed by a volunteer work force who contribute their expertise in concert with their colleagues. The present efforts related to underground mining machines are being directed through Subcommittee 29 – Specialized Mining Machinery of the Off-Road Technical Committee of the Society of Automotive Engineers, Inc. The major manufacturers of specialized mining equipment are represented on this subcommittee along with strong representation from the Department of Energy, Bureau of Mines, MSHA, component manufacturers, mine operators, and engineering organizations. There are currently 12 working groups actively involved in developing standards as follows:

- Maintenance performance standards.
- Drill steel performance specifications.
- Human factors.
- Performance standards for hydraulic fluids.
- Hydraulic components.
- Fire suppression.
- Rebuild standards and rebuild test standards.
- Brake standards for underground machines.
- Categories of machines.
- Ingress/egress for surface mining machines.
- Machine maintenance information standards.
- Underground diesel powered machines.

Each of the working group members is typically a senior member of his company and provides this counterbalanced quality technical input. The technical interchange is at a decision-making level. The products of the working groups are readily usable to the engineering departments of manufacturers and enjoys wide acceptance by the mining industry since their representatives are instrumental in the generation of the voluntary standards.

5. CONCLUSIONS/RECOMMENDATIONS

5.1 CONCLUSIONS

Reliability and ways of increasing reliability of roof bolters is a complex problem. The bolter manufactured today is a well developed and time proven machine. Each generation of machine has incorporated technical improvements. To be competitive, the manufacturer must offer machines capable of improved drilling and bolting performance at a competitive price. The machine manufacturers are well aware that much of this increased performance is dependent on machine reliability. The manufacturer can:

- Design for high reliability.
- Use the most reliable components and materials.
- Institute a stringent quality control program to ensure that the machines shipped meet the design specifications.

However, the manufacturer cannot:

- Control or dictate the manner in which the machine is operated.
- Control the mine maintenance program.
- Control the price structure in the mining machine market.

There are technical problems affecting machine reliability that must be addressed and are readily solvable using today's technology. These have been discussed in broad detail in this report. However, during the course of this program, Woodward Associates, Inc. has noted that machine reliability is greatly affected by:

- Operator attitude.
- The maintenance program that is in effect at the mine.
- The level of training imparted to the maintenance people.
- The mine service facilities.

- Availability of correct spare parts.

- The level of cooperation between production and maintenance.

- Section supervision.

- Mine operating conditions.

It should be noted that many of these technical problems are more related to the human element than to machine design. Unfortunately, much downtime is caused by this human element rather than the actual wearing out of machines. Although technological advances must be pursued, it must be understood that these can only increase the possibility that the availability of the machine will improve. To ensure increased production, these technical advances must be coupled to:

- Greatly improved operator training.

- Greatly improved maintenance training.

- Understanding by mine management that the "quick fix" or neglected maintenance reduces overall production.

- An improved worker attitude towards the machinery.

Solutions to these problems related to the human elements will take longer than technical programs, therefore technical programs should be addressed towards:

- Simplifying and foolproofing machine operation.

- Simplifying and standardizing machine maintenance.

5.2 RECOMMENDATIONS

The following paragraphs are recommended approaches by which the Department of Energy could enhance the performance of roof bolting machines:

- Sponsor programs wherein technology is transferred into the fabrication of improved components for roof bolters such as:

    - Seals, both mechanical and hydraulic identifying the ingression and wear properties of coal dust relative to "calibrated standard dust."

- Solid state activated controls.
- Machine component and system diagnostics and improved interlocks.
- Hydraulic System contaminant control and detection.
- Trailing cables, cable handling systems, and connectors.

- Then sponsor subsequent demonstrations of these improved components on roof bolters under controlled conditions.

- Sponsor the development of training programs and training materials for use by the mines in training new roof bolter operators and improving the skills of present operators.

- Sponsor the development of training programs and training materials to be used by the mines in the development of more efficient maintenance programs and more efficient maintenance efforts. These programs would include short courses in the latest troubleshooting techniques, use of troubleshooting charts, use of test equipment and test procedures, basic hydraulic principles, principles of hydraulic repair, etc.

- Sponsor the development of computer-aided maintenance and section record keeping. These records would provide both mine management and maintenance personnel with continually updated information on the performance of specific machines, repair times and cost, component failures for development of preventive maintenance schedules, spare parts usage and inventory schedule, and the overall mine maintenance requirements. If the record keeping is maintained in many mines, an association such as the American Mining Conference could compile aggregate data for industry comparisons and manufacturers' use in determining the true field performance of their machine.

- Sponsor the development of performance standards for mining machines, components, equipment, and materials working through SAE Subcommittee 29 or other industry organizations. The development of machine and component standards sets industry goals and tends to eliminate machine weaknesses. Working through associations ensures that all parties concerned have equal input into the generation of meaningful, progressive standards and goals.

The sponsorship of such programs will enhance the technology and also improve contributions from the human element.

6. REFERENCES

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7. GLOSSARY

In this section we define the terms used in this report to clarify the failures reported and how classified.

AVAILABILITY OF A PRODUCTION MACHINE

$$= \frac{\text{Total machine time available - downtime}}{\text{Total machine time available}}$$

$$= \frac{\text{Operational time}}{\text{Operational time + downtime}}$$

Example: Downtime = 48 minutes
Operational time = 130 minutes

$$\text{Availability} = \frac{130}{130 + 48} = 0.73$$

Total machine time available = 130 + 48 = 178 minutes.

DELAY TIME — For a production entity. The time interval when production of the entity is interrupted for any reason due to causes inside and outside the entity.

Example: Section delay time = Sum of the idle, above-ground, service, maneuver, place change, and cleanup time + total machine downtimes + sum of all other delays such as roof falls, accidents, etc.

DOWNTIME — For any production entity. The time interval, during a production shift, when production is impossible without first performing some repair or maintenance work. Downtime includes preparation, fault detection, actual repair and checkout. It does not include idle time when the entity could not be producing anyway due to causes originating outside the entity.

Examples:

(1) Continuous miner downtime is shift time devoted to continuous miner repair.

(2) Section downtime is the total of all shift time devoted to repair of machines on the section and which would otherwise be devoted to production.

FAILURE OR CATASTROPHIC FAILURE – An event which renders a machine incapable of being operated without first performing some repair or maintenance. A failure is the cause of downtime.

Example: Cutterhead drive motor fails.

IDLE TIME – Time when a production entity is not engaged in its assigned production activity and for no cause within the entity itself.

Example: Section idle time due to no power on the section.

MANEUVER TIME – Continuous miner. Time spent in moving miner into position for the next cut.

MAN-SHIFT – This is a productivity term used for defining the labor required to mine and transport coal. As used in national mine productivity reports, this consists of all productive workers at a mine (deleting office and surface preparation or central shop workers). For a continuous mining operation, this would consist of all section and maintenance workers underground (normally about 10 to 20 workers per section).

NORMAL FACE OPERATING TIME – Eight hours minus lunch minus mantrip time in and out. Taken as 7 hours for the purposes of this report.

OPERATIONAL TIME – The interval during which a production entity is in actual operation and performing its intended function under the operating conditions encountered.

PARTIAL FAILURE – An event which impairs the operation of a machine but does not stop it.

Example: Cutterhead drive motor cannot develop full torque but coal can still be mined at a reduced rate.

PRODUCTION ENTITY – Any machine, mining section, mine, factory, etc., which performs an assigned production function.

REPAIR TIME – Time required to get a machine back in service afte a failure. Includes production shift time and maintenance or repair shift time. Does not include waiting for parts to be delivered from suppliers.

SECTION — A production entity normally consisting of one continuous miner, two shuttle cars, and one roof bolter with attendant auxiliary equipment (rock duster, utility scoop, ventilation fan, etc.) as required to mine an area and transport the coal to a loadout station.

SECTION DELAY REPORTS — Record of failue experience on the section for each shift. In most cases identifies the failed machine and indicates the resulting section downtime. (Machine downtime may not be reported if it does not cause section downtime.) Some mines record machine repair time instead of section downtime.

SERVICE TIME — Section machines. Time spent in performing service work (if it delays production).

SHIFT — An 8-hour period of continuous attendance by a crew of workers (normally a day or first, evening or second, and midnight or third (graveyard)).

POWER SUPPLY SYSTEM

Trailing Cable – Electric umbilical cable used to transmit power to mobile equipment. Cable is severed, crushed, or the cable ends are pulled loose. The cable will not transmit electricity safely. Electrical failure.

Cable Reel Assembly – On-board cable storage system which may, like on shuttle cars, pay-out and take-up cable automatically. Reel will not transmit electricity from trailing cable to mining device. Will not wind or pay out cable. Mechanical failure.

Wiring – Conductors used to carry electrical current on the machine. Broken or damaged wires (not able to conduct electricity). Electrical failure.

Reel Drive Motor – Power source for cable reel; seized or jammed, will not drive reel assembly. Electrical or hydraulic failure depending on type of motor.

Reel Control Valve – Valve with which cable pay-out tension and take-up force is set; stuck, jammed, broken valve, does not control operations of reel drive motor. Hydraulic failure.

Spooling Guide – Will not guide trailing cable onto reel, drum-guide is bent, broken or out of adjustment. Mechanical failure.

Fuses/Circuit Breakers – Electrical current overload-sensitive devices which interrupt power to protect wiring in the primary power supply system. Fuses blow, will not carry circuit load; breakers trip, overload. Electrical failure.

Hydraulic Pump Motor – Electric motor used to power hydraulic pumps. Will not supply power, will not rotate, jammed, broken. Hydraulic failure.

Battery, Energy Source for Scoops – Down due to charge loss, low on electrolyte, damaged connectors or case. Electrical failure.

Other/General – None of the above or not identified adequately in mine section report. Electrical failure.

ELECTRIC CONTROL SYSTEM

Panel – Control station containing switches, valves, and gauges. Destroyed, crushed, shorted out, burned up. Electrical failure.

Breaker – Electrical current overload devices which interrupt power to subsystems or motors. Circuit breaker trips, kicks out, overloads. Electrical failure.

Meter – Devices for recording hours of operation, voltage or electrical current. Shorted out, open circuit. Electrical failure.

Switches – Devices for completing or interrupting an electrical circuit. Broken, doesn't operate, burned up. Electrical failure.

Logic – Electrical circuits which sense subsystem conditions and respond with appropriate control signals. Control system down, not performing logical function. Electrical failure.

Contactors – Electrical power switching components usually magnetically actuated. Contacts broken, bent or burned, magnet coil out, won't transmit power to motor. Electrical failure.

Solid-State Components – Electronic devices that can control current or signals without requiring filaments or mechanical moving parts. Overheated, shorted out, broken. Electrical failure.

Other/General – None of the above or not identified adequately in mine section report. Electrical failure.

INTERLOCKS

Methane Detector – A device for detecting the presence of methane and subsequently shut down the machinery. Downtime due to inoperative detector, detector causing shutdown without gas present or at inappropriate percentage of methane. Electrical failure.

Ground Fault Detector – A device for detecting a faulty ground circuit between an electrical power source and a machine. Down: out of calibration or ground circuit failure. Electrical failure.

Water Flow – Not an interlock. Simply failure of water supply to machine. Mechanical failure.

Panic Bar – An operator actuated emergency shutdown device. Interrupts power to the machine. Down due to inoperative or malfunctioning shutdown switch, bent strike bar or linkage adjustment out. Electrical failure.

Other/General – None of the above or not identified adequately in mine section report. Electrical failure.

HYDRAULICS

Jacks/Cylinders – A hydraulic powered ram or lifting device. Down due to leaks, material failures, bent components. Hydraulic failure.

Pumps – Devices used to impart liquid flow. Down due to leaks, mechanical failures, or seizing. Hydraulic failure.

Valves – Devices that control the flow of hydraulic fluid through a system. Down due to being plugged, leaking, seizing, mechanical failure. Hydraulic failure.

Hoses - Supply lines for hydraulic fluid. Down due to cuts, leaks, or ruptures. Hydraulic failure.

Fittings – Mechanical connecting means between hoses and components. Down due to plugging, stripped threads, broken or missing fittings. Hydraulic failure.

Oil Filter – A device for separating solids or suspended particles from hydraulic fluid. Down due to being plugged, leaky or broken assembly. Hydraulic failure.

Oil Level– The amount of oil in the reservoir. Down due to insufficient oil in reservoir. Hydraulic failure.

Seals – Devices which prevent the passage of fluid from one chamber to another. Down due to being leaky, cracked, torn, or missing. Hydraulic failure.

Oil Contamination – Foreign material in oil. Down due to dirty oil, foreign debris in oil or oil reservoir. Hydraulic failure.

Other/General – None of the above or not identified adequately in mine section report. Hydraulic failure.

TRAM SYSTEM

Drive Motor — Hydraulic or electric motor that powers the tram drive system. Downtime due to cracks, leaks, physical damage, wear, or electrical motor failure. Hydraulic or electrical failure depending on type of motor.

Clutch — A mechanical coupling between a power source and drive system. Downtime due to slipping, wear, or physical damage. Mechanical failure.

Clutch Disk — A friction disk assembly in the clutch. Down due to slipping, worn or broken disk. Mechanical failure.

Torque Converter — A fluid coupling in the drive train. Down due to slipping, seized, or broken. Mechanical failure.

Transmission — The mechanical system for transferring power at selected speeds. Down due to damaged gears, housing, shafts, etc. Mechanical failure.

Drive Shafts/Chains — Transfers power from source to driven components. Down due to being bent, or broken. Mechanical failure.

Final Drive — The final gearbox that transmits power to the crawler track drive sprokcet or wheel. Down due to being jammed, broken, or stipped. Mechanical failure.

Axles — Load support shafts. Down due to being bent, broken, or damaged. Mechanical failure.

Tram Controls — Mechanical linkages systems through which the amount of power supplied to the tram drive system is controlled. Down due to being broken, damaged, bent or loose. Mechanical failure.

Other/General — None of the above or not identified adequately in mine section report. Mechanical failure.

UNDERCARRIAGE

Tires — Fitted to wheels to provide traction/protection/first line of shock absorption; may be pneumatic or foam filled. Down if flat, blown-out, torn, or loose. Mechanical failure.

Equalizer Axle – A horizontally pivoted suspension assembly for an end pair of wheels which enables four-wheel contact of the machine over uneven roadbeds. Down if assembly members are bent, broken, or loose. Mechanical failure.

Wheels – Supporting rim and hub for mounting tires. Down if bent, broken, or loose. Mechanical failure.

Other/General – None of the above or not identified adequately in mine section report. Mechanical failure.

STEERING SYSTEM

Operator Controls – Mechanical linkages to control the direction and power applied to the tram and drive system. Down due to being broken, damaged, bent, loose, or missing. Mechanical failure.

Steering Box – A gearbox through which operator controlled rotational motion is converted to lever/link actuation to exert steering control. Down due to being broken, damaged, or jammed. Mechanical failure.

Cross Shafts – Rods that transmit steering control from one side of the machine to the other. Down due to being broken, bent, damaged, or missing. Mechanical failure.

Levers – The means through which steering control is made; often associated with crawler track drives. Down due to being damaged, broken, or missing. Mechanical failure.

Drag Link – The link member between the steering box and the linkages attached to the wheel assembly. Down due to being damaged, broken, or missing. Mechanical failure.

Cylinders – Hydraulic or pneumatic rams that are an integral part of the steering system reducing the effort needed to steer. Down due to leaky, broken, damaged cylinder. Hydraulic failure.

Dual Control Linkage – An on-board "remote" control system connected to the operator console controls. Down due to damage, breakage, loose, or missing controls to remote point. Mechanical failure.

Other/General – None of the above or not identified adequately in mine section report. Mechanical failure.

BRAKE SYSTEM

Brake Lines - Tubular lines through which fluid pressure is transmitted to actuate brakes. Down due to being pinched, cracked, or broken. Mechanical failure.

Calipers - Actuating mechanism that brings brake pads to bear against the rotor of disk brakes. Down due to being jammed, broken, or leaking. Mechanical failure.

Cylinders - Fluid cylinder assembly used to convert a mechanical force ("foot" brake) to a fluid pressure, then a second cylinder returns the fluid pressure to a mechanical force to actuate brake calipers or shoes. Down: broken, jammed, leaking. Mechanical failure.

Lining - Frictional material that is brought to bear against a rotating surface to reduce or stop motion. Down due to being worn, missing, or slippery. Mechanical failure.

Controls - Subsystem through which brake actuation forces are controlled. Down due to being blocked, jammed, broken, worn, or missing. Mechanical failure.

Parking Brake - Brake used to hold a machine in place during nonmoving periods. Down due to worn or broken lining, or damaged and missing controls. Mechanical failure.

Other/General - None of the above or not identified adequately in mine section report. Mechanical failure.

DRILL SYSTEM

Drill/Drill Head - Drill "chuck" and drive gearbox system for boring roof support holes. Down due to being jammed, broken, damaged drill. Mechanical failure.

Drill Steel - Cylindrical steel shaft with hollow center with means for holding drill bit on its end and used to extend depth of hole being bored. Down due to bent, broken, or stripped steel. Mechanical failure.

Stuck Steel - Drill steel is jammed, wedged in drill hole, or can't be removed easily. Mechanical failure.

Drill Supports - Structural members extending out from roof bolter frame and on whose end is installed the drill drive and head assembly. Down due to being out of adjustment, bent, broken, missing or damaged parts. Mechanical failure.

Drill Controls – The devices (valves) through which drill speed/torque and travel is made. Down due to leaks, jamming, or broken. Hydraulic failure.

Dual Control Linkage – The linkages that tie-in operator cab controls with drill station controls. Down due to being bent or broken. Mechanical failure.

Drive Motor – The hydraulic motor that drives the drill head. Down: leaking, lubrication failure, jammed, or broken. Hydraulic failure.

Other/General – None of the above or not identified adequately in mine section report. Mechanical failure.

DUST SUPPRESSION SYSTEM

Spray Nozzles – Water atomizers which create a mist at work point to trap and settle dust. Down due to nozzles being plugged, broken, or missing. Mechanical failure.

Filters – The devices for separating dust and particulate from system aspirated air. Down due to clogged, dirty filter elements, filter leaking or broken. Mechanical failure.

Hoses – Lines for conducting water or air. Down due to cuts, leaks, or burst hoses. Mechanical failure.

Fittings – Mechanical connections between hose lines and pumps, nozzles, reservoirs, etc. Down due to being plugged, stripped, broken or missing. Mechanical failure.

Valves – Control devices for liquid or gas supply. Down due to seizing, broken housing, or plugging. Mechanical failure.

Water Pump – Mechanical devices which induce water flow through lines. Down due to leaks, broken components, or seizing. Mechanical failure.

Air Blower – Develops vacuum to aspirate dust-laden air from drilling area to filters. Down due to plugged, broken line, mechanical failure of fan. Mechanical failure.

Drive Motor System – Power source system for air blower, generally electric. Down due to burned out motor or electric system failure. Electrical or hydraulic failure.

Other/General – None of the above or not identified adequately in mine section report. Mechanical failure.

LIGHTING SYSTEM

Lights – The on-board illumination system. Down due to broken fixtures, or burned out lamps. Electrical failure.

Wiring – The intersystem electrical conductors. Down due to cuts, shorts, or open segments. Electrical failure.

Switches – The devices for completing or interrupting an electrical circuit. Down due to physical damage, worn contacts, or burned. Electrical failure.

Other/General – None of the above or not identified adquately in mine section report. Electrical failure.

LUBRICATION

Fittings – The hose or tube connection devices; includes the devices through which lubricant is introduced to the machine. Down due to plugging, stripped threads, broken or missing fittings. Mechanical failure.

Hoses – On-board lubricant transport lines. Down due to cuts, leaks, or ruptures. Mechanical failure.

Oil Level – The amount of lubricating oil or grease in the lube reservoir. Down due to insufficient lubricant in reservoir or gearbox. Mechanical failure.

Lube Pump – The pump used for introducing lubricant to the machine reservoir. Down due to being leaky, broken, or seized. Mechanical failure.

Other/General – None of the above or not identified adequately in mine section report. Mechanical failure.

SERVICING DURING A PRODUCTION SHIFT

Service – Preventive maintenance activities (e.g., drive train adjustments, bolt tightening, debris clean-off, etc.) for which production was interrupted. Not used in calculation of major failure categories.

MISCELLANEOUS

Stuck – Machine is not able to move. It is jammed, wedged, or immobilized. Not used in calculation of major failure categories.

Frame Failure – Main structural frame is cracked or broken. Mechanical failure.

Canopy Damage – The safety structure over the operator's compartment is bent, crushed, broken, or has fallen off. Mechanical failure.

Fire Suppression System – A chemical (water infrequently) dispensing system for snuffing-out an on-board fire. Down due to malfunctioning or direct damage to the system, low fire-suppressant level. Mechanical failure.

Sideboards – Panels added to the sides of a conveyor to increase its capacity. Downtime due to being bent, broken, or missing. Mechanical failure.

Other/General – None of the above or not identified adequately in mine section report. Not used in calculation of major failure categories.

PRODUCTION DOWNTIME (NOT MACHINE-FAILURE RELATED)

Not used in calculation of major failure categories or overall production downtime analysis.

Tram – Moving equipment from one job site to another.

Mine Power – General mine power failure.

Belt Conveyor – Conveyor system for transporting the mined material from the job site when the conveyor shuts down, production stops.

Accident – Unplanned event which causes damage to equipment or personal injury.

Unsafe Roof – Roof conditions where loose material may fall and cause an accident or where a complete roof failure is likely.

Waiting on Production Parts – Lost time due to the unavailability of necessary machine parts.

Lack of Personnel – Production loss due to the inability to maintain the needed minimum work crew.

Disabled Equipment – Production loss due to disabled equipment blocking or impairing the progress of the needed production equipment.

Inspection – Production loss due to work stoppage for mine or equipment safety or planning inspection.

Other/General – None of the above or not identified adequately in mine section report.

ERRORS

Not used in calculation of major failure categories or overall production downtime analysis.

Errors are listed but not added into the total number of failures or downtime. Listed below are reasons for data error:

- Failure category code not listed for machine being studied.
- Date of failure outside of range specified.
- Mine code number not matched with machine code.
- Alphabetical or other nonnumerical character in data list.
- Data list in wrong order or spacing.

24