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CONCEPTUAL DESIGN OF AN AUTOMATED LONGWALL MINING SYSTEM

PHASE II-STATE OF THE ART

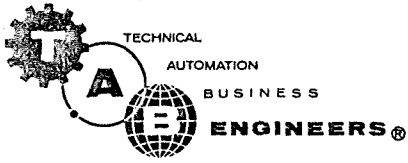
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CONCEPTUAL DESIGN OF AN AUTOMATED
LONGWALL MINING SYSTEM
PHASE II - STATE OF THE ART SURVEY

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October 1, 1974
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KEEP TAB ON YOUR BUSINESS-IT PAYS

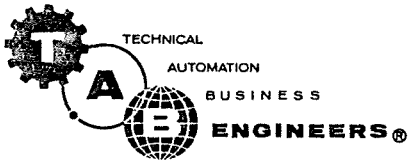
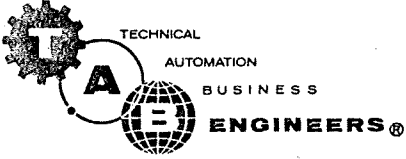


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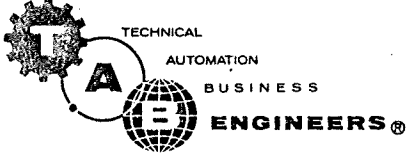
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ABSTRACT

To develop a conceptual design for an automated longwall mining system, one should know what has been done, what is being done today and what is being planned for tomorrow. The bibliography referenced and discussed in this report provides a good source for that knowledge. To scientifically determine where attention should be focused to up-grade a system, the system must be quantized as far as possible. The Mechanization Profile of Appendix A-1 is discussed in this report and has been used to analyze and determine the degree of mechanization currently in use and/or described in the literature for all three major elements of the long-wall system, namely, Winning, Roof Support and Haulage. The charted profiles make it self-evident where attention and design effort is needed to remove human operators from the face of the mine.



1.0 INTRODUCTION

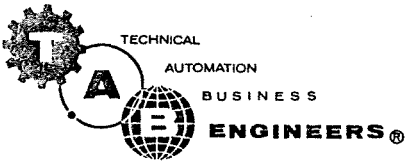
This report covers Phase II of a three-phase study authorized by the U. S. Bureau of Mines to develop a conceptual design for an Automated Longwall Mining System. Phase I relates to a survey of existing operating longwall mines and their equipment.

Phase II is a Survey of the State-of-the-Art of automation and remote control and is the subject of this report.

Phase III is the development of a conceptual design of an automated longwall mining system including all equipment and functions located at the face and in the head and tail entries.

Phase II, the survey of the State-of-the-Art was conducted in four parts.

Part one was a review of the literature pertaining to automation of longwall equipment and of other heavy equipment where it might have application to a longwall installation. A bibliography of this literature is listed in the Appendix of this report. The listing is in reverse chronological order. Where pertinent in the text of the report, certain references are annotated. No translation was made of any foreign articles, but they were scanned

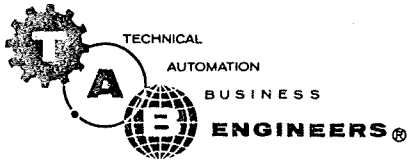


for content and did not contain any information that was not available in English.

Part two included two visits to Longwall Mines and direct observation of typical current methods of operation and control. The observations made, along with the data developed by Phase I, are reflected in the Mechanization Profiles in this report.

The data gathered in parts one and two was analyzed in part three. It was quickly evident that a wide range of procedures are used among the current mines and therefore our analysis is based upon a hypothetical mine and the equipment is discussed in generic terms. Where the report refers to the "Frontier" State-of-the-Art in the discussion it is referring to controls that are described in the literature without regard to their degree of success. It does not refer to what can or might be done. That will be included in Phase III.

Part four is this report and its presentation. Because of limits of space and time the report does not discuss all aspects of the means for controls and automation nor does it do justice to the voluminous literature on the subject. The report has however, faithfully followed the basic intent of the overall study and has covered the total



range of operations and equipment to be controlled and has prepared a sound basis for proceeding with Phase III, the development of a Conceptual Design for increasing productivity and improving safety.

2.0 MECHANIZATION PROFILE

The production of coal involves a number of basic and elemental functions or operations or tasks. The coordinated combination of all elemental functions results in the "producing" of coal.

Each operation can be ranked on a scale from 1 to 17 that reflects the level of mechanization present in the performance of the elemental operation. At the lowest level (1) the operation is completely manual. At the highest level (17) the elemental operation is performed completely automatically, not requiring man's direct intervention.

A system chart can be created by listing every elemental operation in sequence as it normally occurs in the production process, and then plotting the appropriate level of mechanization that occurs at each operation.

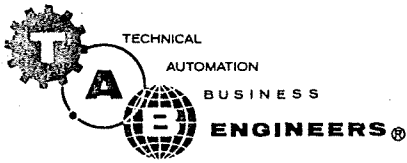
Figure 1, "Mechanization Profile," is a chart where it is convenient to record, for each elemental operation, the level of mechanization used in its execution. The levels are both numbered and described.

The levels in Figure 1 are bracketed in terms of power source, control source and feedback. Mechanically powered work

MECHANIZATION PROFILE

| | | OPERATION, MACHINE OR FUNCTION (STATION) | | | | | | | | | | | | | |
|-------------|----------------------|--|---|-------------------------|-----------|---------------------|---------------------|----|---|---|---|---|------|--|--|
| CLOSED LOOP | CONTROL SOURCE | POWER SOURCE | LEVEL NUMBER | LEVEL OF MECHANIZATION | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | etc. | | |
| | | | | | OPEN LOOP | PERFORMANCE CONTROL | M E C H A N I C A L | 17 | ANTICIPATING REQD.PERFORMANCE AND ADJUSTING | | | | | | |
| | RESPONDS WITH ACTION | 16 | CORRECTING PERFORMANCE WHILE OPERATING | | | | | | | | | | | | |
| | | 15 | CORRECTING PERFORMANCE AFTER OPERATING | | | | | | | | | | | | |
| | | 14 | IDENTIFYING AND SELECTING APPROPRIATE ACTION | | | | | | | | | | | | |
| | | 13 | SEGREGATING OR REJECTING PER MEASUREMENT | | | | | | | | | | | | |
| | RESPONDS WITH SIGNAL | 12 | CHANGE SPEED POSITION, DIRECTION PER MEAS. | | | | | | | | | | | | |
| | | 11 | RECORDING PERFORMANCE | | | | | | | | | | | | |
| | | 10 | SIGNALING THE MEASUREMENT OF VALUE | | | | | | | | | | | | |
| | MECHANICAL CONTROL | 9 | MEASUREMENT OF A CHARACTERISTIC | | | | | | | | | | | | |
| | | 8 | ACTUATION BY INTRODUCT. OF WORK PIECE OR MATL. | | | | | | | | | | | | |
| | | 7 | POWER TOOL REMOTE CONTROL | | | | | | | | | | | | |
| | | 6 | POWER TOOL, PROG.CONTROL (SEQUENCE FUNCTIONING) | | | | | | | | | | | | |
| | | 5 | POWER TOOL, FIXED CYCLE (SINGLE FUNCTION) | | | | | | | | | | | | |
| | MANUAL CONTROL | M A N U A L | 4 | POWER TOOL HAND CONTROL | | | | | | | | | | | |
| | | | 3 | POWERED HAND TOOL | | | | | | | | | | | |
| | | | 2 | HAND TOOL | | | | | | | | | | | |
| | | | 1 | HAND | | | | | | | | | | | |

Fig. 1



first appears at level 3, but complete manual decision-making and control is required up through level 4. At level 5 a single function can be completed mechanically. The first sensing of a process or function characteristic by hardware shows up at level 9. However, manual decision-making is still required up through level 11. At level 12 closed loop control feedback first appears. Sophistication of feedback control continues up through level 17.

Thus, each level of mechanization is described in several ways. For example, an operation at level 5 is seen to be carried out by a Power Tool, Fixed Cycle (Single Function). The power source is shown to be Mechanical. The control source is shown as Mechanical Control. The feedback is indicated as Open Loop.

A considerable amount of information is automatically implied whenever an operation is assigned to a certain level.

Each of the 17 numbered levels of mechanization, as interpreted for various coal mining operations, is briefly described below.

level 1 Hand

Body members are used to perform the required action without tools; for example, picking up coal, or sighting alignment by eye.

level 2 Hand tool.

A nonpowered tool is added to supplement the force, strength, forming action, or manipulative ability of body members; for example, a shovel.

level 3 Powered hand tool

Mechanical power is added to supplement body strength; for example, a jackhammer.

level 4 Power tool, hand control

A framework is added to guide and limit processing action to specific spatial limits. Control of tool application remains in the operator's hands; for example, a roof bolt drill.

level 5 Power tool, fixed cycle, single function

The machine repeats a single action without human attention; for example, a belt conveyor.

level 6 Power tool, program control, multifunction

The machine performs a fixed sequence of actions without human intervention; for example, a batch control chock system.

level 7 Power tool, remote control

The point of control is separated from the point

of application, enabling consolidation or integration of many controls in one station; for example, the headgate control console.

level 8 Power tool, activated by workpiece

The machine is triggered into its cycle by the work, rather than the operator; for example, a panel belt conveyor edge guide.

level 9 Measurement

The machine identifies quantitatively some characteristic of operation; for example, coal hardness or thickness.

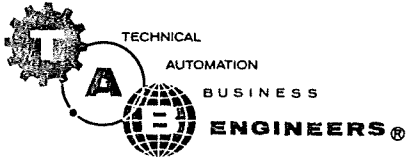
level 10 Signaling selected values of performance

The machine measures and then signals significant performance actions by making a comparison to established standards; for example, coal hardness compared to rock hardness.

level 11 Performance recording

The machine measures and creates permanent records of its action; for example, number of tons of coal being won.

- level 12 Machine action altered through measurement
The measurement of performance is translated into a signal that adjusts some simple machine action such as speed, volume, or direction; for example, a nucleonic probe that adjusts ranging arm.
- level 13 Segregating or rejecting according to measurement
The machine makes physical disposition of work produced according to some measured characteristics. Longwall mining examples for this and higher levels have not been found in this survey.
- level 14 Selection of appropriate action cycle
The machine selects one of several sets of production actions (of the level 6 order) through identification of some environment or product characteristic.
- level 15 Correcting performance after operating
The machine examines its output and adjusts itself to correct it.

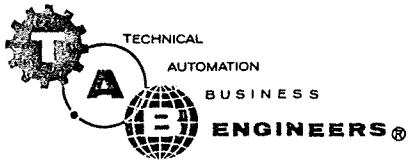


level 16 Correcting performance while operating

The machine measures and adjusts continually during the operation to maintain output within standards.

level 17 Anticipatory performance control

The machine analyzes environmental requirements and adjusts to achieve desired performance prior to operation.



3.0 LONGWALL PROFILE

The longwall profile is an analysis of both current longwall methods and advancing, "frontier" technologies.

Current methods are based on a hypothetical, composite longwall mine. See Figure 2. Operations of particular mines may vary slightly or greatly.

The sequence of activities for each major longwall operation is described in detail, beginning on page 3.2.

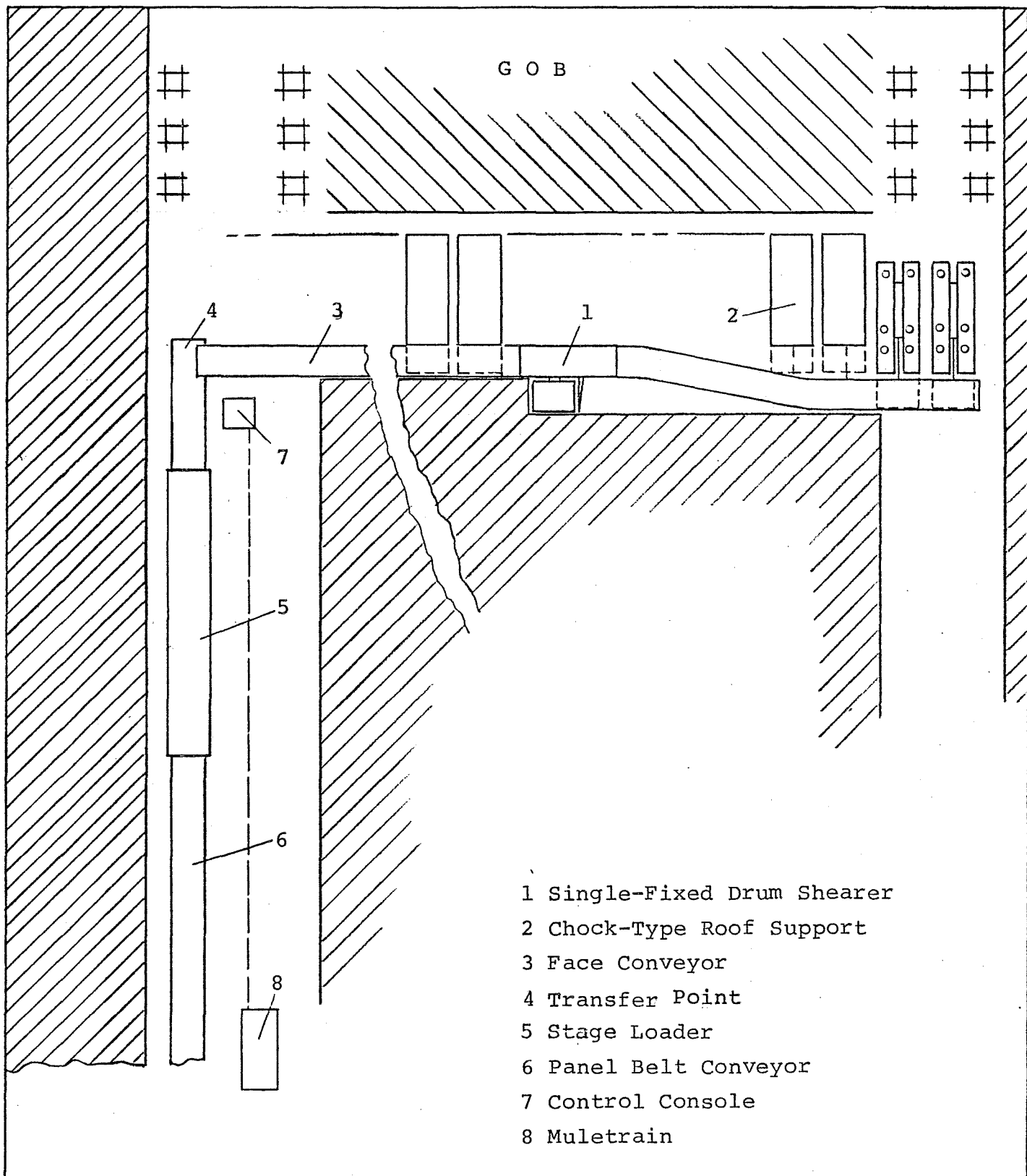
Mechanization levels for current methods are analyzed.

The chart of these levels, page 3.42, forms the mechanization profile of commonly encountered longwall practices.

In addition to current methods, relevant advanced technologies are also described, with corresponding mechanization levels. These levels reveal the current advance of mechanization.

The line between the mechanization levels 6 and 7 delineates the level where an operator is no longer required at the point of operation. To accomplish successful mechanization, the majority of longwall methods must be advanced to level 7 or beyond.

The mechanization profile will form the basis for an orderly program of elevating longwall mechanization levels.



- 1 Single-Fixed Drum Shearer
- 2 Chock-Type Roof Support
- 3 Face Conveyor
- 4 Transfer Point
- 5 Stage Loader
- 6 Panel Belt Conveyor
- 7 Control Console
- 8 Muletrain

Fig. 2

LONGWALL COAL MINING SYSTEM

3.1 Winning

3.1.1 Shearer

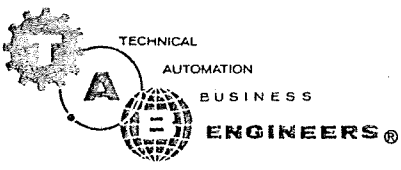
3.1.1.1 Inspection

At the beginning of each travel along the long-wall face, the shearer operator performs a series of manual inspections. He checks the cutter drum for broken or damaged bits. He looks over the shearing machine to check for damaged or loose equipment or controls, the condition of the conveyor rails and shearer running gear, the alignment of the shearer unit with the face, etc.

The operator inspects the condition of the conveyor pans and drag chains. He also visually checks the orientation of the conveyor with the face.

He inspects the condition of the face for conditions that obstruct beginning of the next travel.

The operator corrects any defects he finds, or obtains help. Repairs are made by hand or with hand tools.

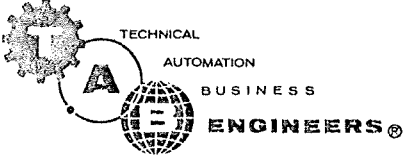


These functions are all performed at level 1 (they become level 2 if hand tools are used for maintenance).

No advances were found in the state of the art of the initial inspection function for longwall mining.

These functions are necessary for successful operation of a shearer. Because of adverse conditions and heavy service, mechanical, electrical, and hydraulic problems will arise. Without inspection the shearer would be subject to frequent breakdowns and unsatisfactory performance.

Detectors, signal devices, and alarm systems are available and can be incorporated into a shearer design to automatically monitor some of the important problem areas, detect defects, stop the shearer at the end of the face, summon a mechanic, and indicate the nature of the problem. For example, a commercially available device could be adapted to monitor hydraulic fluid pressure and temperature. The commercial system, designed for



fork lift trucks, has sensors to measure fluid temperature and pressure. A control unit compares the signals to preset values. If either measurement becomes critical, an alarm is activated to indicate the vehicle should be serviced. If not serviced, the machine is stopped after a predetermined delay.

Such an automated system could not detect all of the problems that a man could theoretically find. On the other hand, the automated system would find faults sooner and would detect faults that a man could not see. The control system would be level 10, measuring and signaling defects as they occur or are about to occur.

A decision would have to be made to either automate the inspection function or to provide a man at one or both ends of the face, who would perform the inspection of the shearer. The economics of these alternatives would be the investment in control equipment versus the savings in labor and reduced maintenance.

It should be noted at this point that an automated shearer will be most effective if it is redesigned to incorporate the automation components. Retrofitting control system is not impossible; however, sacrifices in performance generally are encountered when patchwork is attempted.

3.1.1.2 Startup

After completing the inspection function, and performing any maintenance required, the operator must make the decision that the equipment is ready for the next pass. Having decided to proceed, he begins the startup function. He observes the position of the cowl and determines that it must be moved. He then reverses the cowl. The operator jams a timber between the drum and cowl, turns on the drum and uses drum power to flip the cowl. More recently, a power cylinder has been added to raise the level of this operation to level 5.

Next, the operator visually checks the height of the roof and/or the floor desired in the next pass, estimates the height of the shearer drum(s), and adjusts the drum(s) to the desired location(s).

The operator then inspects the water spray equipment, adjusts the equipment, and turns on the water.

The operator checks and determines that all of the above functions have been satisfactorily performed and then starts the drum motor(s). In the final step of the startup function, he checks for correct conveyor and support alignment, for obstacles in the shearer path, for correct shearer drum operation, for correct alignment of the shearer relative to the face, for conveyor operation, and other items; and starts the shearer travel.

As in the inspection function, all startup activities are performed at low levels of the mechanization profile. Inspection and observation are done manually, level 1. Operating the

various shearer controls is performed at level 4 (hand controlled power tool) or level 5 (hand activated power tool with a fixed cycle).

The general layout of a system to perform the startup function in an automated shearer can be readily envisioned. It would be a level 6 system, automatically performing a sequence of operations. The startup sequence would be activated manually or by the completion of the previous function.

First, a hydraulic cylinder would reverse the cowl. Second, sensors would indicate roof and floor position. (The sensors would be part of the shearer control system used during running along the face). A proportional control device would adjust the drum position(s). Third, the water and drum motor would be activated. These controls would be interlocked to previous functions to prevent activation if the previous function were not completed. Finally, the travel motor would be started. It would also be interlocked: to the completion of previous activities, to switches indicating

correct alignment of shearer, conveyor and supports, and to sensors indicating correct shearer operation.

The startup control section could be integrated with the turnaround system, described later, and the inspection system, above. The three functions occur in sequence and have common elements of inspection and repositioning of shearer components.

The decision must be made whether to design and install the comparatively simple system in an automatic shearer or to retain men at each end of the face.

No advances have been found in the state of the art in this area.

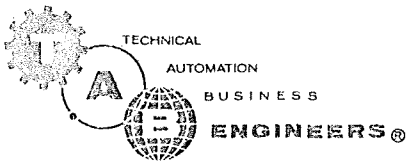
3.1.1.3 Running

The next shearer function is running down the seam face. During the run the operator alternately observes the progress and operation of the shearer and adjusts two controls: shearer speed and drum height. This is the most complex of the longwall functions.

The operator's observations are mainly at level 1, without tools. Occasionally, he may measure roof height with a rule, a level 2 function.

In order to control drum height, the operator makes observations and interprets their possible meaning that might cause him to decide to adjust the drum height:

- drum vibration: breaking through seam,
hitting rocks in seam
- shearer sound: breaking through seam,
hitting rocks
- coal color: cutting too close to roof or floor
- sparks: breaking through seam, hitting rocks
- lump size: breaking through seam
- rock visible in face: avoid rocks
- inclination of seam: change horizon
- height of seam: adapt to change in height
- fault, obstruction in face, roof support interference: stop shearer; obtain assistance if needed; break out fault interference, if



necessary, remove or break up obstruction, manipulate chock controls and remove chunks from canopy to reposition roof support; manipulate shearer controls to cut around and pass obstacle.

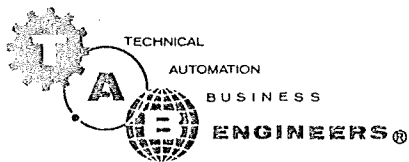
- a number of observations may be made that are not known at this time, that may affect the operator's decision to adjust the drum height(s).

All of the above observations are made at level 1, without benefit of tools.

The operator translates the observations into a decision to adjust the drum(s) and a judgment of how much to adjust them. Adjustments of shearer controls are level 4 (hand controlled power tool).

There are currently four significant approaches to drum height control mechanization:

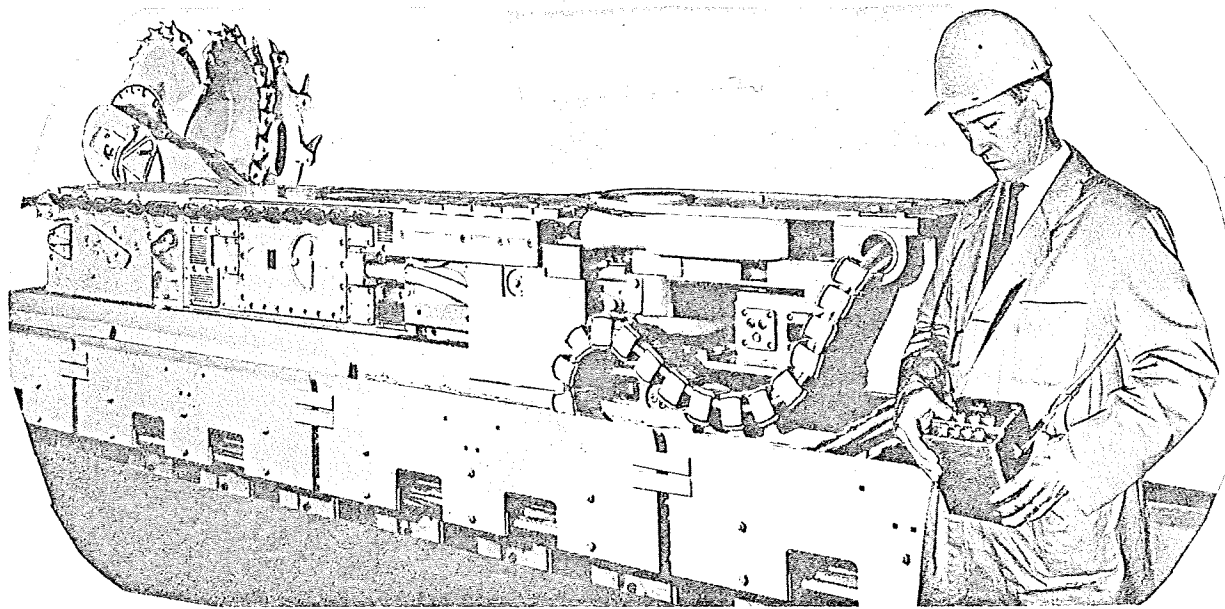
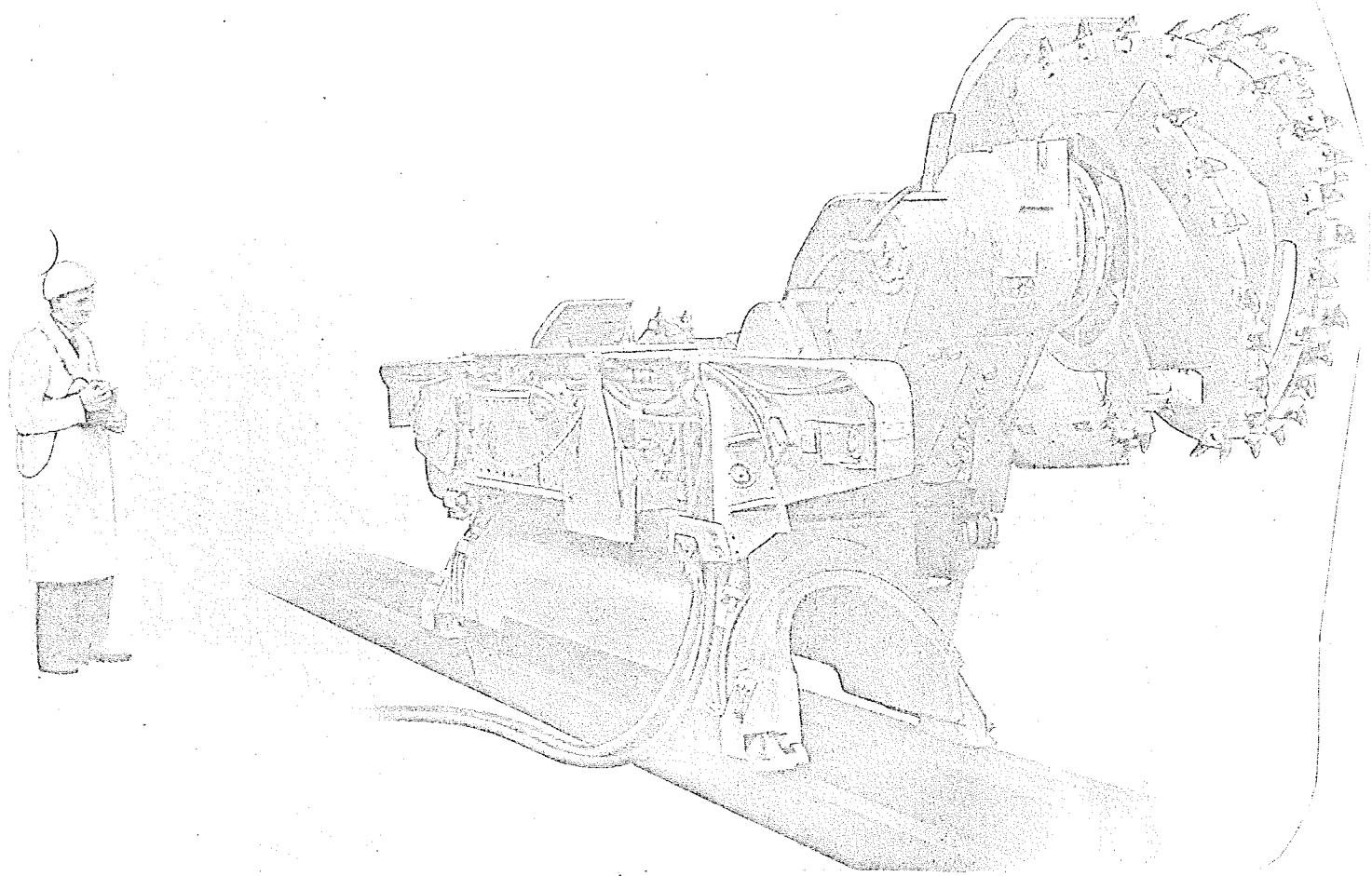
First, remote control systems (level 7) have been installed on a number of shearers. The operator carries a control panel up to 25 feet away from the shearer. He has the ability to adjust drum height (as well as travel speed). Typically, control lines between the control panel and shearer are electric or hydraulic.



A radio transmitter-receiver set is also available with a reported range of up to 50 feet, depending on mine conditions. (Reference 84, 57, 163 Appendix B).

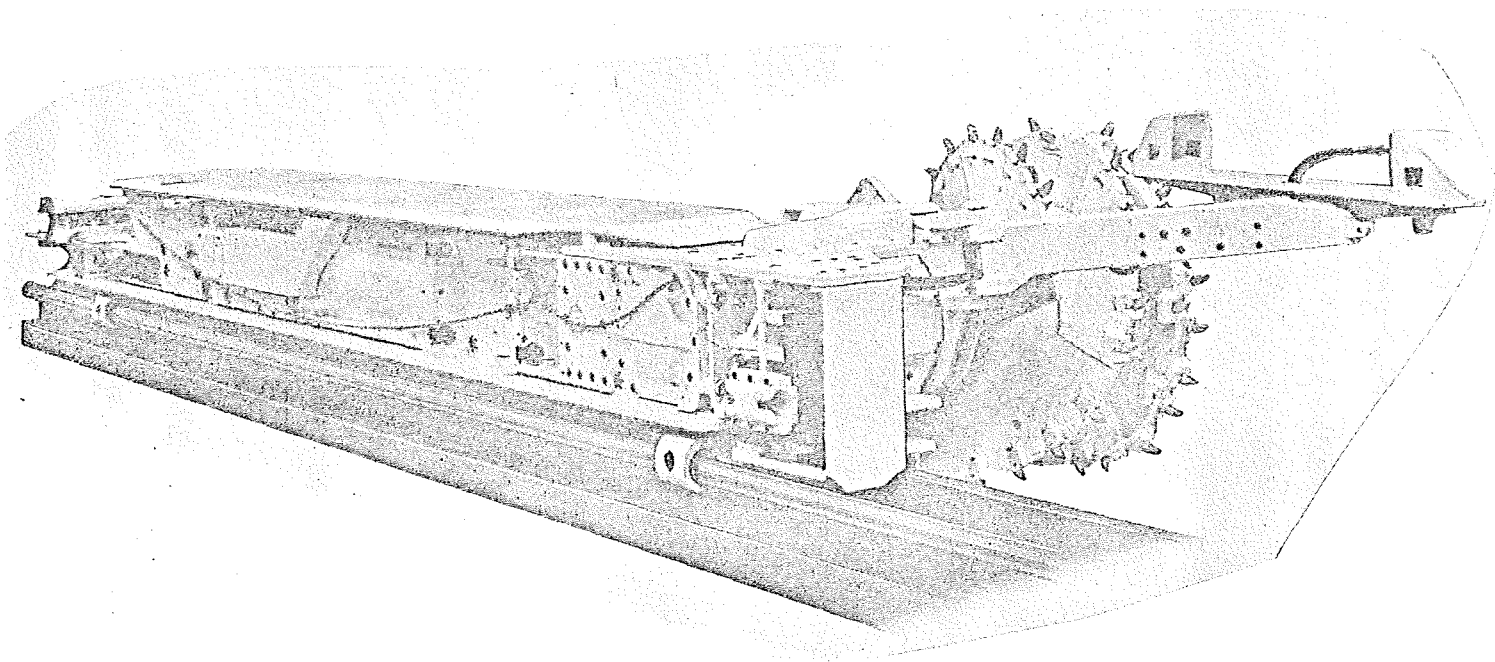
The advantages of this system are that the operator is safer away from the shearer and has a better vantage point for observing the face and equipment. However, he has not been removed from the longwall face.

The second system provides closed loop control of a shearer function for the first time. A nucleonic sensor pressed against the roof measures coal thickness by differential coal/overburden radiation absorption. An electronic controller adjusts drum height to maintain the correct horizon. (References 28, 129, 163 and 170, Appendix B). The system is a level 12 function and eliminates the need for the operator for drum height control. In the installations that have been tested, the operator is still required to control travel speed. See Fig. 4.



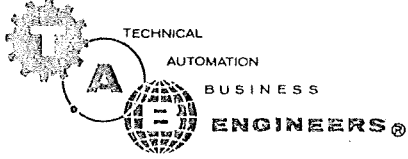
DRUM SHEARER WITH RADIO CONTROL

Fig. 3
3.12



NUCLEONIC AUTOMATIC STEERING SYSTEM

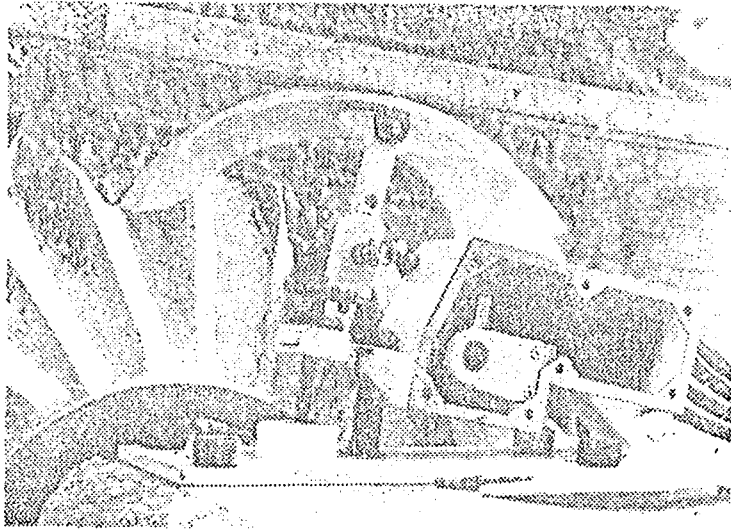
Fig. 4



The third drum height control system uses a tracer to sense the level of the roof from the previous cut. The signal is used to provide an adjustment signal to the operator (level 10), or automatically change the drum height (level 12). This system appears to have limited value because it does not eliminate the need for the operator in the first case, and because it does not truly adapt the horizon to the seam, but merely repeats the past horizon. (Reference 165, Appendix B). See Fig. 5.

The fourth system contains sensors on the drum picks to measure cutting resistance. When the drum breaks through the seam into the harder overburden, the sensitized picks generate a signal that lowers the drum. This level 12 feedback system also has potential for sensing rock inclusions in the seam. (References 165, 30f, Appendix B).

The second major shearer control is travel speed. In present practice, the operator performs a pattern of observation/decision/adjustment similar to that described for drum height

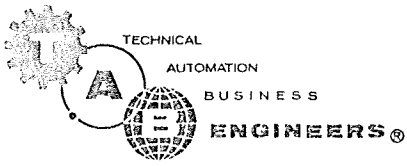


ROOF FOLLOWER STEERING MECHANISM

Fig. 5

control. Observations are again performed at level 1 or 2. The observations and interpretation of meaning are:

- cutter vibration: overloaded cutter, slow travel
- shearer sound: overloaded cutter, slow travel
- coal color: stop for adjustment
- sparks: stop for adjustment
- lump size: stop for adjustment
- rocks visible in seam: slow travel
- inclination of seam: stop for adjustment
- height of seam: stop for adjustment
- faults in face: stop or slow
- obstruction at face: stop to avoid
- conveyor stopped: stop shearer (where shearer motor not interlocked with conveyor movement)
- conveyor overfilled: stop or slow shearer
- support position: stop to avoid hitting support
- other factors may require observations that are not known at this time

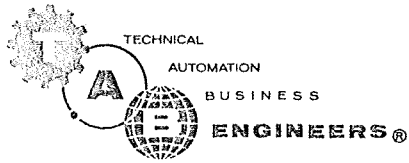


Based on the above observations, the operator decides to change travel speed or stop the shearer, a level 5 function.

On machines equipped with speed control, the operator can also decide to select automatic mode. In automatic, the resistance to shearer travel is sensed, indicating hardness of the face. Travel speed is automatically switched to fast or slow corresponding to "hard" or "soft" faces. This is a level 12 operation (automatic measurement and adaptation). This system could easily be expanded to include an "emergency stop" output.

Reviewing shearer running control, it is apparent that automation can be accomplished by combining the nucleonic probe for drum control with the automatic speed control system. These two systems, or adaptations of them, would perform the basic operator functions. The shearer would become a unified level 12 machine.

It is also apparent that the present operator performs a number of observations that influence

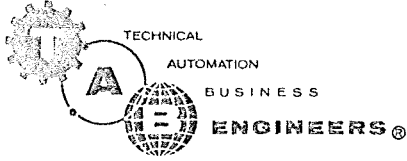


his actions and that are not sensed in the above combined control system. Some of the observations are unknown. The operator himself may not be able to define what he observes.

Further study is required to determine one, which conditions must be measured in an automated system to insure acceptable shearer operation; and two, how the shearer design can be improved to minimize the amount of measurement and corrective action required.

3.1.1.4 Turnaround

As the shearer reaches the end of the face the turnaround sequence begins. The operator observes that the end of the face has been reached. He changes drum positions and moves the shearer back and forth to complete clean-up of coal at the end of the cut and to start the next cut. He waits for the conveyor snake to be completed and stops the shearer at the end of the face. The water spray and drum rotation are stopped. The shearer is then ready to start a new cycle beginning with inspection.



All observations are manual, level 1, and all shearer operations are level 4 or 5.

No state of the art advances are known for shearer turnaround.

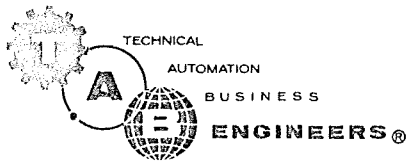
A sequenced, level 6 system can be developed to perform the turnaround function. A limit switch would sense the end of the face and start a programmed sequence that would change the drum height(s), reverse the shearer travel for a predetermined distance, wait for a snake completion signal from the last chock, and return to the end of the face.

3.1.2 Winning, Plow

3.1.2.1 Inspection

A plow operator manually inspects the plow at the end of each travel cycle, normally at the headgate. He looks for dull or broken bits. He performs a visual inspection for damaged, loose, or nonfunctioning equipment, haulage, and controls. He also inspects the condition of conveyor rails and plow guide shoes.

He checks the condition and alignment of the conveyor pans and conveyor chains, flights, and drive. He inspects the face near the headgate area.



Fault or problems are corrected manually, level 1, or with hand tools, level 2, by the plow operator or by a mechanic.

The plow operator observes the correct advance and alignment of the face conveyor and drives, level 1. Corrections are made as necessary, generally by adjusting hydraulic cylinders, level 4. The operator judges that the plow will plane into the coal face correctly. The plow operator checks to see that there are no coal jams or other obstructions, level 1.

Based on his inspection of the face or information from others in the face, the plow operator may reposition the plow bits to adjust the height, depth, or profile of the face, level 2.

Roof support operators also inspect the condition of the face. They communicate to the operator the need to adjust plow bits or the need to stop the plow and have it pass over a portion of the face more than once.

The roof support operators observe that the plow is cutting at the correct level. They may adjust conveyor tilting jacks, level 4, to correct cutting height.

No proven advances in plow inspection or adjustment were discovered. In one manufacturing company, a plow had been tried experimentally which had a spring loaded upper bit assembly for removing top coal. The bits were designed to plane along the roof without cutting into rock. The spring accommodated variations in seam thickness. This plow has apparently not been used extensively for production. As a machine that responds to changes in the work (coal seam) without human intervention it is a level 12 mechanization.

As with the shearer, regular and pertinent inspection and repair of the plow and associated equipment helps maintain coal output by preventing unexpected machinery breakdowns.

Some inspection control devices could be adapted to the plow to check for plow misalignment with conveyor and face caused by damaged parts or other reasons. It would also be possible to detect broken or excessively dull tool bits. These sensors could be incorporated into alarms and controls at the plow operator's controls.

3.1.2.2 Start-up

After making inspections and corrections, the plow operator determines that the plow is ready to start its next pass down the face. He activates the water spray system and starts the travel motor, level 4.

3.1.2.3 Running

Water spray nozzles may be activated along the face by a mechanism of level 8, activated by the work piece. An analog nut is driven by a threaded shaft coupled by the plow drive such that the position of the plow along the face is proportional to, and is represented by, the position of the nut on the shaft. At appropriate points the nut turns water sprays on and off in the face area surrounding the plow.

The operator also controls water spray manually as required, level 2.

The operator observes the plow operation in the vicinity of the headgate. Roof support operators stationed along the face observe the progress of the plow and the condition of the face. They communicate problems and malfunctions in the face to the plow operator, who takes or coordinates corrective action described under 3.1.2.1, Inspection.

The plow operator observes the coal coming from the face conveyor. He or the roof support operators investigate and take corrective action when the coal is interrupted or jammed. Coal presence and pileup detectors can also be used on the headgate end of the face conveyor to detect interruption and jams and activate an alarm.

3.1.2.4 Turnaround

The tailgate operators perform abbreviated versions of 3.1.2.1, Inspection and 3.1.2.2, Start-up functions when the plow reaches the tailgate. The plow is stopped, manually or by a position sensor; alignment of the conveyor and plow is checked and corrected; the plow is inspected for damage; and the return pass is started.

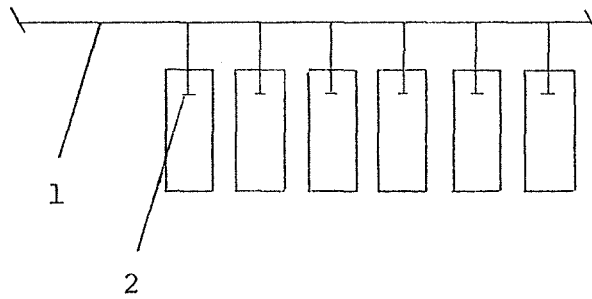
No evidence was found of significant advancement in the automation of plow start-up, running, or turnaround.

3.2 Roof Supports

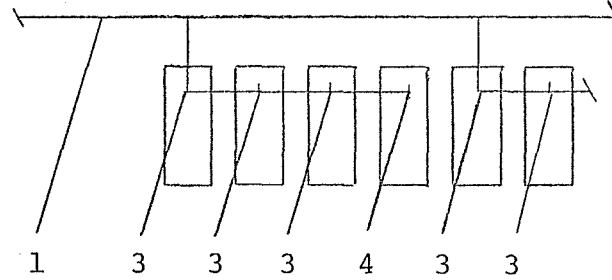
3.2.1 Shearer System

Chock roof supports are used in this typical profile. There are four control methods of advancing the chocks: Manual, Bank/Sequential and Remote Controlled, and Shearer Actuated. See Fig. 6.

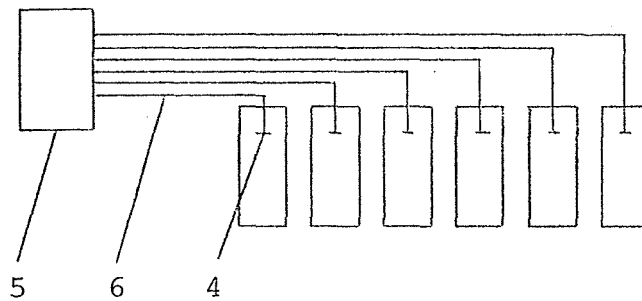
a. Manual



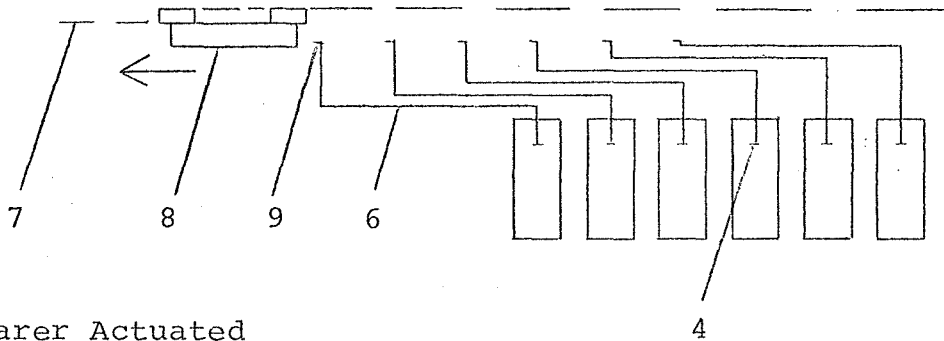
b. Batch/Sequential



c. Remote



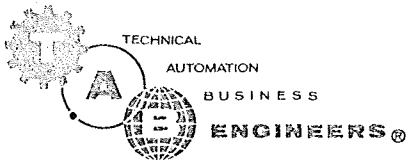
d. Shearer Actuated



CHOCK CONTROL SYSTEMS

- | | |
|--------------------------|------------------|
| 1. Hydraulic line | 6. Control lines |
| 2. Manual valve | 7. Face |
| 3. Sequencing valve | 8. Shearer |
| 4. Remote-operated valve | 9. Sensor |
| 5. Control panel | |

Fig. 6



There are two operating procedures for sequencing conveyor snake and chock advance, the one web back and the conventional (or non-one web back) methods. The primary distinction between the two is that with one web back operation, the chock advances immediately after the shearer makes a cutting pass. Then the chock ram pushes the conveyor against the new face. In this way the newly cut roof is supported by the chock canopy as soon as possible after the shearer passage.

With non-one web back operation, on the other hand, the chock ram first pushes the conveyor forward, after a shearer cutting pass, and then performs its advance. The new roof is not supported by the chock until after conveyor snake is completed.

A "rapid support" variation of the conventional operating method does allow immediate support of the freshly exposed roof section. The front of each chock canopy has an extendible section. The operating procedure is different in that the extendible section is moved forward immediately after the shearer cutting pass, in order to quickly support the roof. The conventional sequence of conveyor snake followed by chock advance is then followed.

Any of the operating methods can be used with the Manual, Bank/Sequential, Remote Controlled or Shearer Actuated Control Systems. The one web back and the standard non-one web back procedures are described under the manual method.

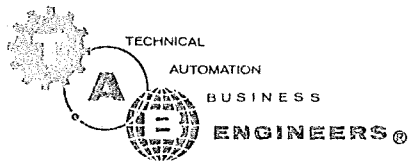
3.2.1.1 Manual

In the manual method, operators crawl along the face, making observations and judgments (level 1) and operating hydraulic valves (level 4 and 5).

3.2.1.1.1 One web back

Starting at chock 1, the operator observes the shearer and judges that it is 5 to 15 feet away. He determines that there are no obstacles in the path of the chock advance. He lowers the canopy by means of a hydraulic valve movement. He advances the chock by means of another valve movement. He raises the canopy and observes completion of the chock advance. If necessary, he adjusts the chock's terminal position to secure the chock advance.

He moves to the next three chocks and repeats the advancing operation.



The conveyor is then snaked forward under the recently advanced chocks. He moves to chock 1 and observes that there are no obstacles to snaking the conveyor.

He actuates the hydraulic ram valve to advance the ram. He observes completion and corrects as necessary.

He moves to chock 2 and releases the ram hydraulic lock. He moves to chock 3 and releases the ram hydraulic lock. He moves to chock 4 and releases the ram hydraulic lock.

He observes the shearer position, determines that there are no obstacles and advances the ram. He observes if advance is satisfactory and adjusts if necessary.

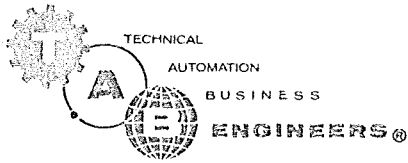
He moves to chock 2 and advances the ram. He moves to chock 3 and advances the ram.

He moves to chock 5 and repeats the chock advance sequence. He continues down the face in unison with the shearer.

The manual method is sometimes altered such that the valves that operate one chock are located on the adjacent chock. The operator is in a safer position because he is not under a moving chock while operating the valves.

3.2.1.1.2 Non-one web back

The operator observes the shearer passage along the face. Beginning at chock 1, he determines that the shearer is 25 to 30 feet away. He moves to chocks 1, 2, 3 and 4 in turn, releasing the ram hydraulic locks. On chock 1 the operator activates the hydraulic valve pressuring the conveyor ram, pushing the conveyor forward against the face. He observes the conveyor movement, determines if the movement has been completed, removes obstacles and adjusts conveyor position as required. When he determines that the conveyor is against the face, the operator moves on to chocks 2, 3, and 4 and operates the valves pushing the conveyor ram forward. This conveyor snake operation is repeated for the remainder of the chocks.

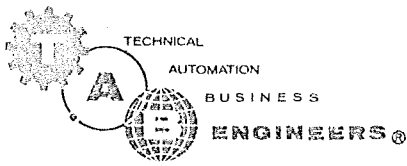


The chocks are advanced as soon as possible after conveyor snake. The operator determines that the conveyor pan at chock 1 is correctly positioned against the face. He determines that there are no obstacles in front of the chock. He operates hydraulic valve controls to lower the canopy and then pull the chock forward with the conveyor ram. He observes completion of the chock forward motion, removing obstacles and correcting movements as necessary. He pressurizes the leg cylinders with the valve controls and observes that the canopy is correctly seated against the roof, adjusting chock controls if necessary. He observes the leg pressure indicators (if so equipped) to determine that setting pressure has been reached.

The operator moves to the next chock and repeats the chock advance sequence for each chock in turn following the shearer travel.

3.2.1.2 Batch/Sequential

The Batch/Sequential systems raises chock mechanization to level 6, sequential control.



Sequencing is applied in two ways. First, hydraulic valving in each chock is arranged so that rams automatically operate in a sequence similar to that described in the manual system. Each hydraulic cylinder motion occurs after completion of the previous cylinder motion to accomplish the chock advance and conveyor snake.

The chock operator determines when each chock is to be advanced. He then activates the chock control cycle, which completes the chock's entire advance sequence. After observing the completion of the advance of the chock the operator moves to the next chock to repeat the advance cycle. Each chock is a level 6 mechanism. (Ref. 102, 184)

With this system, an operator helper is less likely to be required, and the chocks can be advanced faster.

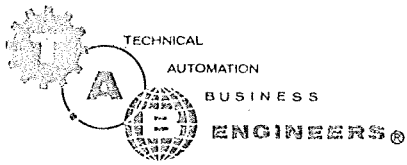
Second, sequential control is applied to a series (or bank) of chocks. When the first chock in a bank receives an actuating signal, it performs the series of advance motions. It then signals the second chock advance, and so on, to the end of the bank. The bank length is limited to the distance that the operator can safely see.

The operator positions himself at the first chock and observes conveyor snake. When he judges it to be far enough away (depending on bank length and speed of chock advance) he initiates advance. He observes completion of advance of all chocks, taking corrective action where necessary, and then moves to the first chock in the next bank. With the system each bank of chocks comprises a level 6 system. (Ref. 102, 184)

The two forms of the sequential system described above require one or more operators at the face. Speed of advance and operator safety is improved over the manual system, but the chock advance function remains at level 6. Also separate signals are still required to activate conveyor snake.

3.2.1.3 Remote Control

Remote chock advance is a level 7 operation. Electric or hydraulic lines extend from a remote control console outside of the face to the chocks. Hydraulic pressure switches and ram potentiometers at the chocks indicate the position of conveyor snake and verify that individual chocks have completed their advance. Sensors also signal the position of the shearer.



The console operator notes the progress of the shearer and determines when the conveyor should be advanced. He also verifies that chocks are in the correct positions. He then activates conveyor snake and chock advance for an individual chock. Snake and advance may be sequenced or operated separately from the console, depending on the system design. He determines that advance is complete, or takes corrective action.

(Ref. 155, 171, 175, 178)

In a variation of this system, a bank of chocks are sequenced. The console operator observes shearer position and advance completion of the previous bank. He determines when to advance the next bank and activates the bank master chock.

(Ref. 178, 184)

In another system variation, chock advance and shearer travel are interlocked. If the shearer is too far beyond the snake and chock advance, the shearer is automatically stopped. On the other hand, if the operator signals for the conveyor to advance and the shearer is too close, the signal is ignored. (Ref. 171)

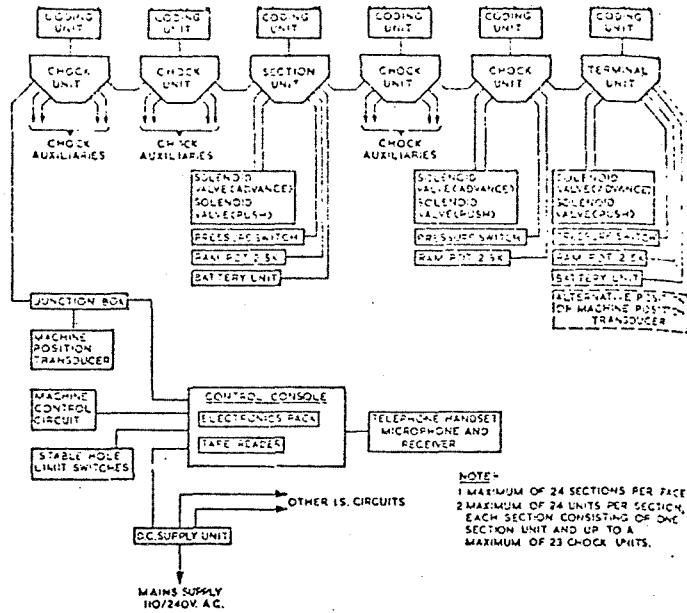
This variation provides greater safety by preventing operator error. However, the operator still is required at the main console. See Figs. 7 and 8.

3.2.1.4 Shearer Actuated

The final system raises mechanization to level 8 and eliminates the operator. Switches on the conveyor sense the location of the shearer and signal snake and chock advance at the appropriate points along the face. An additional control circuit stops the shearer if advance is not completed. This system is the most experimental. (Ref. 210.)

Reviewing chock advance systems, nearly all current systems require operator control of chock advance, either at the face or at a remote console. One experimental system removes the operator entirely from chock control, and theoretically provides precise position control to snake and advance.

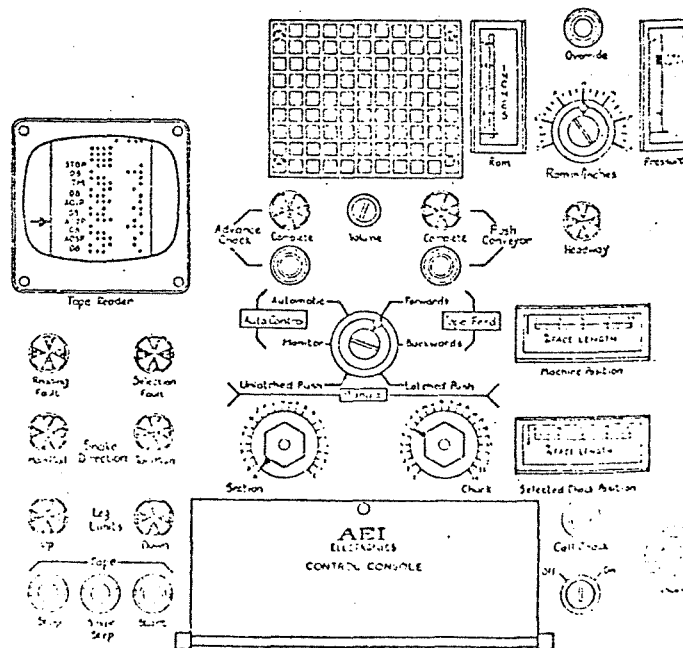
However, none of the systems provided the degree of observation and correction capability of a man at the face. For example, conveyor ram extension is sometimes measured and signalled by a



CHOCK SYSTEM SCHEMATIC

Fig. 7

Fig. 8
CHOCK CONTROL CONSOLE



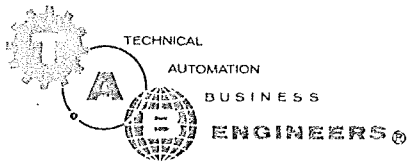
potentiometer. Support ram status may be measured by a pressure switch. An outbreak or other obstacle at the roof or floor may cause the chock to be incorrectly positioned. Without additional protection devices, an automatic shearer could proceed along the face and collide with the misaligned chock.

3.2.2 Plow System

Roof supports may be operated as conventional or "fixed incremental" systems.

3.2.2.1 Conventional Method

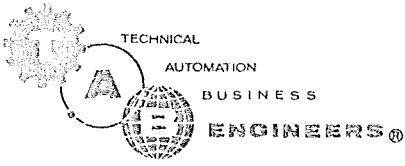
The ramming force requirements are less stringent for plow operation than for shearer operation. Consequently, there are usually fewer rams than roof support units; the ratios of 1 to 2 and 1 to 4 being common. The ram is also usually mounted between the roof support units by means of a chain link rather than directly mounted to the roof support base. In operation, a continuous pressure is exerted by the rams against the face conveyor and, in turn, the face conveyor holds the plow against the face. As the plow removes coal from the face, the conveyor, after passage of the plow,



will be moved forward by the urging of the continuous ram pressure. The conveyor can move forward in this fashion without moving roof supports until the end of the stroke of the ram is reached. In practice, however, the roof support is moved forward prior to the full extension of the ram.

A section of the face composed of about 15 chocks or frames is usually assigned to a particular roof support operator. Within his section he advances the roof supports often enough to keep up with the advance of the face. Since several passes are made by the plow in the course of one frame advance, the two operations are not closely synchronized. The operator makes observations and decisions (level 1) and operates hydraulic valves (level 4).

The operator observes that there are no obstacles in front of the frames to be advanced. The pressure on the conveyor push ram between the frames (if present) is released by means of a manually operated rotary hydraulic valve. The outboard half of the first frame is advanced by first releasing the setting pressure on the canopy, then pressurizing the frame advance ram which moves the frame-half forward. The canopy is then

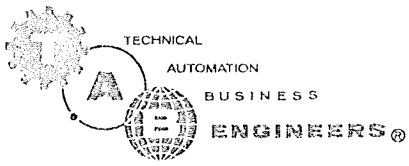


set by manual hydraulic valve operation. The operator verifies completion of these operations and makes adjustments as required.

The inboard frame half of the first frame is then advanced by releasing its setting pressure and then reversing the pressure on the double acting frame advance ram. The inboard frame-half advances and then the canopy is set by manual valve operation. After determining that the first frame is correctly positioned and set against the roof, the operator again pressurizes the conveyor push ram and moves to the next frame.

The inboard frame half of the second frame is advanced by releasing its setting pressure and pressurizing its advance ram to move forward. The canopy is set after successful advance of the frame half.

The outboard frame half of the second frame is advanced and set. Upon completion, the conveyor ram is pressurized to once again force the conveyor forward and the operator moves along to the next frame pair.



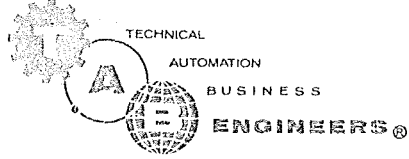
3.2.2.2 Fixed Incremental

In the fixed incremental system, the conveyor is moved forward by the conveyor cylinder a fixed distance for each plow pass.

The purpose of the incremental conveyor push is to control the depth that the plow cuts into the coal at all points along the face and keep the face in a straight vertical plane.

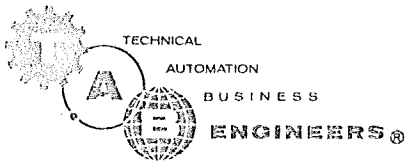
The incremental push method differs from the conventional procedure in the way that the conveyor is pushed forward.

After each passage of the plow along the face, the plow operator moves the entire conveyor forward at the same time. He determines that the plow has reached the end of the face and has stopped. He operates a hydraulic valve in the headgate, pressurizing the incrementing hydraulic line along the face. Dispensing cylinders on each roof support increment the conveyor forward. After waiting for the conveyor push to be completed, and observing that the hydraulic system pressure gage has stabilized, the plow operator is ready to begin the next plow passage.



Roof support operators in the face perform the support advance operations in the same way as in the conventional method.

In addition, the roof support operators observe the incremental push of the conveyor rams and the straightness of the conveyor. As needed, they operate roof support valve controls to adjust the conveyor position and adjust the stroke of the dispensing cylinder to modify the length of the incremental stroke.



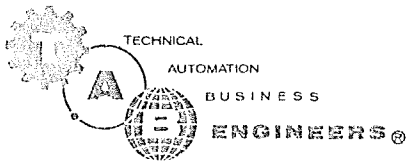
3.3 Haulage

Before starting haulage conveyors they are inspected. The man walks around each of the conveyors and looks for broken rollers, belt splices, control wires and flights, etc. He manually makes repairs as needed using hand tools. (levels 1 and 2). After the corrections have been made the system is ready for start-up.

The panel belt conveyor is started first. The operator actuates a switch, mounted on the conveyor (level 5). A centrifugal switch on the panel conveyor automatically starts the cross and a centrifugal switch on the cross conveyor automatically starts the entry conveyor. (levels 6). The face conveyor is started last from the headgate console. (level 7).

The haulage system when running is visually monitored to assure continued operation. One of the problems in the panel belt conveyor is the tendency for the belt to run out of line. Detection of the out-of-line condition is made by limit switches which stop the panel conveyor automatically (level 8) and at the same time stop the cross and entry conveyors.

The operator adjusts the position rollers manually until the belt runs true.

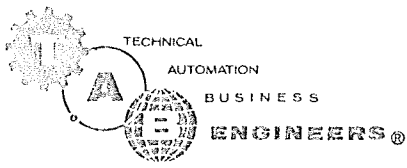


The restart is made by pushing a switch on the panel conveyor. The cross and entry conveyors are started in sequence as described before.

Pile-up of coal at the transfer points is detected by a wire probe preset to a specific level. When coal contacts the probe the conveyor is stopped automatically. (level 8). Contact of the pile-up detector at the cross-panel belt conveyor transfer point stops the cross conveyor and the entry conveyor. The operator at the console observes this stoppage and stops the face conveyor to prevent further coal pile-up. The panel belt conveyor continues to run. Crew men clean up the coal. After which the conveyors are restarted. The cross conveyor is started from the centrifugal switch on the cross conveyor.

Pile-up detection contact at the entry-cross conveyor transfer points stops the entry conveyor. The cross and belt conveyors continue to run. The face conveyor is stopped at the console operator when he sees the stoppage. Again the crew man cleans up the coal. The entry and face conveyors are restarted from the console.

The break-up of large pieces of coal is done manually by use of a sledge hammer. (level 2). These pieces



are picked up by hand (level 1) and thrown into the conveyor. A jackhammer is available and when used enables the man to break up the coal at level 3. If a crusher, (level 5) was added, the task of manual coal break-up would be virtually eliminated. The principal benefit from these additions is to accomplish the task without the man and free him for other tasks.

These equipments and the available sensors for motor temperature, belt breakage, slippage, and alignment, are typical of haulage mechanization today.

In searching for new frontiers for haulage two were found as potential candidates. The first is an experimental system which uses a flexible pipeline for underground coal transport (see ref. 23 in Appendix B). The coal is broken up into a four inch size by a crushing machine. This broken coal is then introduced into an injection pump and combined with water. The resulting slurry is pumped out of the face through the pipeline. The level of this system is 8. It provides uninterrupted coal flow for higher productivity. Greater safety is also provided and man power reduction may be possible.

The second method is a level 12 closed loop feedback control system. Inputs from belt sensors for belt load

are processed at the computer in central control which issues commands for control (See Ref. 45 in Appendix B).

3.4 Mechanization Profile Charts

Mechanization level charts on the following pages show the profile of automation for major longwall mining systems.

The mechanization profile charts show the sequence of operations that are performed in the operation of the longwall systems. The charts also graphically portray the overall pattern of automation incorporated into the systems.

The mechanization profiles cover present, typical operations as found in contemporary longwall mines, and also examples of advanced, state of the art systems that are either available or that can be developed by applying existing equipment and technology.

Profile charts are included for typical shearer and plow winning systems. Frontier charts are shown for shearer inspection and start-up systems, for nucleonic sensing horizon control, and for a turnaround system.

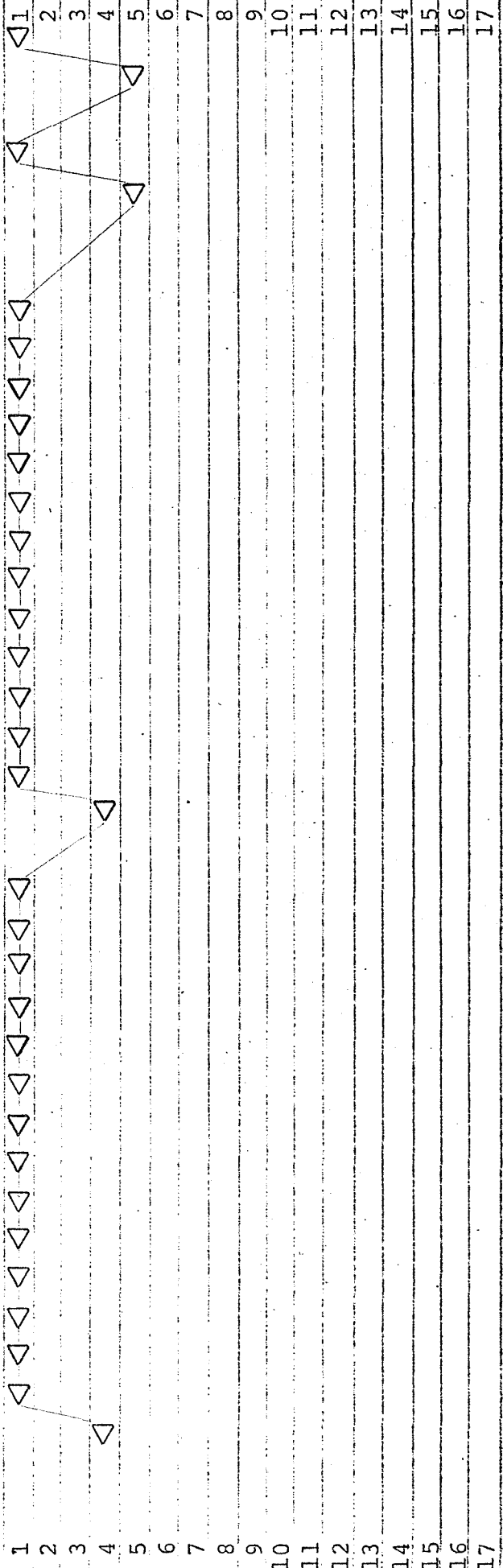
Profile charts illustrate a typical chock operation with a shearer as well as a chock-with-shearer system utilizing remote chock control.

Finally, profile charts are presented for typical and state of the art haulage systems.

WINNING
(PRESENT TYPICAL)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|--------------------------|------|------|-------|-------|-------|-------|-------|---------|----------------|----------------|--------|--------|------|----------|---------|---------|-------------|
| | HAND | HAND | POWER | POWER | POWER | POWER | POWER | ACTUATE | MEASURE | SIGNAL | RECORD | CHANGE | SORT | IDENTIFY | CORRECT | CORRECT | ANTICIPATE |
| | HAND | HAND | POWER | POWER | POWER | POWER | POWER | BY | CHARACTERISTIC | CHARACTERISTIC | | SPEED | | | AFTER | BEFORE | PERFORMANCE |
| Shearer | | | | | | | | | | | | | | | | | |
| Inspect | ▽ | | | | | | | | | | | | | | | | |
| Bits | | | | | | | | | | | | | | | | | |
| Machine | ▽ | | | | | | | | | | | | | | | | |
| Conveyor | ▽ | | | | | | | | | | | | | | | | |
| Face | ▽ | | | | | | | | | | | | | | | | |
| Machine alignment | ▽ | | | | | | | | | | | | | | | | |
| Conveyor alignment | ▽ | | | | | | | | | | | | | | | | |
| Electric controls | ▽ | | | | | | | | | | | | | | | | |
| Electric cables | ▽ | | | | | | | | | | | | | | | | |
| Water lines | ▽ | | | | | | | | | | | | | | | | |
| Other | ▽ | | | | | | | | | | | | | | | | |
| Correct as necessary | | ▽ | | | | | | | | | | | | | | | |
| Startup | | | | | | | | | | | | | | | | | |
| Decide to proceed | ▽ | | | | | | | | | | | | | | | | |
| Cowl Position | | | | | | | | | | | | | | | | | |
| Observe Position | ▽ | | | | | | | | | | | | | | | | |
| Reverse Position | | | ▽ | | | | | | | | | | | | | | |
| Drum Height Adjustment | | | | | | | | | | | | | | | | | |
| Observe roof height | ▽ | | | | | | | | | | | | | | | | |
| Observe cutter height | ▽ | | | | | | | | | | | | | | | | |
| Decide adjustment needed | ▽ | | | | | | | | | | | | | | | | |
| Adjust height | | | | | ▽ | | | | | | | | | | | | |
| Water Start | | | | | | | | | | | | | | | | | |
| Determine need | ▽ | | | | | | | | | | | | | | | | |
| Turn on valve | | | | | ▽ | | | | | | | | | | | | |
| Drum Motor Start | | | | | | | | | | | | | | | | | |

Determine need
 Activate control
 Travel Start
 Determine need
 Activate motor
 Running
 Drum adjustment
 Observe vibration
 Observe sound
 Observe coal color
 Observe sparks
 Observe lump size
 Observe geometry of rocks present
 Observe inclination of seam
 Observe height of seam
 Observe obstructions at face
 Observe support position
 Observe height of previous pass
 Other observations
 Decide to change drum height
 Adjust drum
 Travel motor
 Observe vibration
 Observe sound
 Observe coal color
 Observe sparks
 Observe size of lumps
 Observe geometry of rocks present
 Observe inclination of seam
 Observe height of seam
 Observe faults in face
 Observe obstructions at face
 Observe conveyor stopped
 Observe conveyor overfilled
 Observe support position
 Decide: manual/automatic mode
 Select Automatic or Manual mode



Manual mode

- Observe vibration
- Observe sound
- Observe sparks
- Observe size of lumps
- Observe geometry of rocks present
- Observe inclination of seam
- Observe height of seam
- Observe faults in face
- Observe obstructions at face
- Observe conveyor stopped
- Observe conveyor overfilled
- Observe support position
- Other observations

Decide to change speed or stop travel

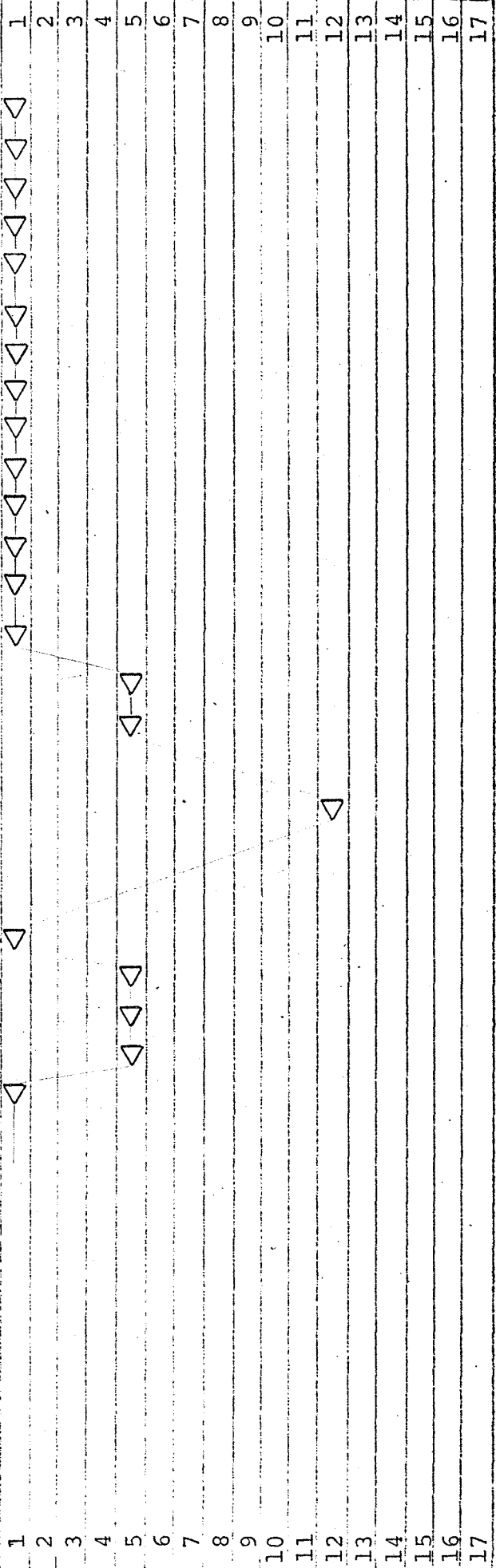
- Change speed
- Stop travel

Automatic mode

- Sense resistance to travel and change speed

Turnaround

- Observe end of face
- Stop travel
- Stop drum
- Stop water
- Wait for chocks and conveyor to be snaked into position
- Repeat cycle from Inspect



WINNING
(PRESENT TYPICAL)

1 HAND
2 HAND TOOL
3 POWER HAND TOOL
4 POWER TOOL, HAND CONTROL
5 POWER TOOL, FIXED CYCLE
6 POWER TOOL, SEQUENCE CONTROL
7 POWER TOOL, REMOTE CONTROL
8 ACTUATE BY WORK PIECE
9 MEASURE CHARACTERISTIC
10 SIGNAL CHARACTERISTIC
11 RECORD
12 CHANGE SPEED
13 SORT
14 IDENTIFY
15 CORRECT AFTER PERFORMANCE
16 CORRECT BEFORE PERFORMANCE
17 ANTICIPATE PERFORMANCE

| | | | | | | | | | | | | | | | | | |
|---------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|
| Plow | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Inspect | ▽ | | | | | | | | | | | | | | | | |
| Bits | ▽ | | | | | | | | | | | | | | | | |
| Machine | ▽ | | | | | | | | | | | | | | | | |
| Alignment | ▽ | | | | | | | | | | | | | | | | |
| Guide Shoes | ▽ | | | | | | | | | | | | | | | | |
| Conveyor | ▽ | | | | | | | | | | | | | | | | |
| Rails | ▽ | | | | | | | | | | | | | | | | |
| Alignment | ▽ | | | | | | | | | | | | | | | | |
| Electric Controls | ▽ | | | | | | | | | | | | | | | | |
| Electric Cables | ▽ | | | | | | | | | | | | | | | | |
| Water Lines | ▽ | | | | | | | | | | | | | | | | |
| Face | ▽ | | | | | | | | | | | | | | | | |
| Other | ▽ | | | | | | | | | | | | | | | | |
| Correct as necessary | ▽ | | | | | | | | | | | | | | | | |
| Observes conveyor advance | ▽ | | | | | | | | | | | | | | | | |
| Observes conveyor alignment | ▽ | | | | | | | | | | | | | | | | |
| Corrects as necessary | ▽ | | | | | | | | | | | | | | | | |
| Observes obstructions | ▽ | | | | | | | | | | | | | | | | |
| Observes plow alignment to face | ▽ | | | | | | | | | | | | | | | | |
| Adjust bits | ▽ | | | | | | | | | | | | | | | | |
| Communicate: Roof support oper. | ▽ | | | | | | | | | | | | | | | | |
| Adjust conveyor tilt jacks | ▽ | | | | | | | | | | | | | | | | |
| Start-up | | | | | | | | | | | | | | | | | |
| Decide to proceed | ▽ | | | | | | | | | | | | | | | | |
| Turn on drive motor | | | | | | | | | | | | | | | | | |
| Turn on water | | | | | | | | | | | | | | | | | |

WINNING
(Present Typical)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|--|------|-----------|-----------------|--------------------------|-------------------------|------------------------------|----------------------------|-----------------------|------------------------|-----------------------|--------|--------------|------|----------|---------------------------|----------------------------|------------------------|
| | HAND | HAND TOOL | POWER HAND TOOL | POWER TOOL, HAND CONTROL | POWER TOOL, FIXED CYCLE | POWER TOOL, SEQUENCE CONTROL | POWER TOOL, REMOTE CONTROL | ACTUATE BY WORK PIECE | MEASURE CHARACTERISTIC | SIGNAL CHARACTERISTIC | RECORD | CHANGE SPEED | SORT | IDENTIFY | CORRECT AFTER PERFORMANCE | CORRECT BEFORE PERFORMANCE | ANTICIPATE PERFORMANCE |
| Plow | | | | | | | | | | | | | | | | | |
| Running | | | | | | | | | | | | | | | | | |
| Select manual | ▽ | | | | | | | | | | | | | | | | |
| Observe sound | ▽ | | | | | | | | | | | | | | | | |
| Observe vibration | ▽ | | | | | | | | | | | | | | | | |
| Observe conveyor fill level | ▽ | | | | | | | | | | | | | | | | |
| Observe position of plow | ▽ | | | | | | | | | | | | | | | | |
| Stop plow at face corner | | | | | | | ▽ | | | | | | | | | | |
| Observe coal pile-up | ▽ | | | | | | | | | | | | | | | | |
| Clear, if necessary | | ▽ | | | | | | | | | | | | | | | |
| Press Reverse Switch | | | | | ▽ | | | | | | | | | | | | |
| Start Plow | | | | | ▽ | | | | | | | | | | | | |
| Observe progress | ▽ | | | | | | | | | | | | | | | | |
| Repeat at each end of face | ▽ | | | | | | ▽ | | | | | | | | | | |
| Select automatic | ▽ | | | | | | | | | | | | | | | | |
| Plow movement trips limit switch and reverses at each face end | | | | | | | | ▽ | | | | | | | | | |
| Observe sound | ▽ | | | | | | | | | | | | | | | | |
| Observe vibration | ▽ | | | | | | | | | | | | | | | | |
| Observe conveyor fill level | ▽ | | | | | | | | | | | | | | | | |
| Clear, if necessary | ▽ | | | | | | | | | | | | | | | | |

Turnaround

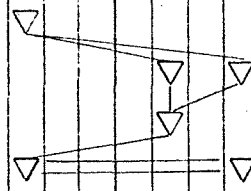
Observe end of face

Stop plow

Stop water

Repeat cycle from Inspect

| | |
|----|--|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| 11 | |
| 12 | |
| 13 | |
| 14 | |
| 15 | |
| 16 | |
| 17 | |



WINNING

(FRONTIER STATE OF THE ART)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|------|------|-------|-------|-------|-------|-------|---------|----------------|----------------|--------|--------|------|----------|---------|---------|-------------|
| | HAND | HAND | POWER | POWER | POWER | POWER | POWER | ACTUATE | MEASURE | SIGNAL | RECORD | CHANGE | SORT | IDENTIFY | CORRECT | CORRECT | ANTICIPATE |
| | TOOL | TOOL | HAND | TOOL, | TOOL, | TOOL, | TOOL, | BY | CHARACTERISTIC | CHARACTERISTIC | | SPEED | | | AFTER | BEFORE | PERFORMANCE |
| Shearer | | | | | | | | | | | | | | | | | |
| Inspection | | | | | | | | | | | | | | | | | |
| Monitor hydraulic pressure, temperatures, motor current, shearer alignment, water flow and others. Stop shearer, indicate problems, and activate alarm when fault occurs. | | | | | | | | | | ▽ | | | | | | | |
| Start-up | | | | | | | | | | | | | | | | | |
| Sequence operations: move cowl, adjust drum, turn on motor and water flow, start travel. | | | | | | ▽ | | | | | | | | | | | |
| Running | | | | | | | | | | | | | | | | | |
| Drum height adjustment with a nucleonic sensing horizon con- trol: Measure roof coal thick- ness, determine if thickness is greater or less than desired, adjust drum accordingly. | | | | | | | | | | | | | ▽ | | | | |
| Turnaround | | | | | | | | | | | | | | | | | |
| Sequence operations: Determine shearer at end of face, change drum height, reverse shearer, determine when conveyor snake completed, return shearer to end of face. | | | | | | ▽ | | | | | | | | | | | |

CHOCK ROOF SUPPORTS
(Present Typical)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|--|------|-----------|-----------------|--------------------------|-------------------------|------------------------------|----------------------------|-----------------------|------------------------|-----------------------|--------|--------------|------|----------|---------------------------|----------------------------|------------------------|
| | HAND | HAND TOOL | POWER HAND TOOL | POWER TOOL, HAND CONTROL | POWER TOOL, FIXED CYCLE | POWER TOOL, SEQUENCE CONTROL | POWER TOOL, REMOTE CONTROL | ACTUATE BY WORK PIECE | MEASURE CHARACTERISTIC | SIGNAL CHARACTERISTIC | RECORD | CHANGE SPEED | SORT | IDENTIFY | CORRECT AFTER PERFORMANCE | CORRECT BEFORE PERFORMANCE | ANTICIPATE PERFORMANCE |
| Advance Chock | | | | | | | | | | | | | | | | | |
| Move to Chock 1 | ▽ | | | | | | | | | | | | | | | | |
| Observe shearer location | ▽ | | | | | | | | | | | | | | | | |
| Determine when 5'-15' away | ▽ | | | | | | | | | | | | | | | | |
| Determine no obstacles | ▽ | | | | | | | | | | | | | | | | |
| Lower canopy | | | | | | | | | | | | | | | | | |
| Advance Chock 1 | | | | | | | | | | | | | | | | | |
| Raise canopy | | | | | | | | | | | | | | | | | |
| Observe completion | ▽ | | | | | | | | | | | | | | | | |
| Correct as necessary | | | | | | | | | | | | | | | | | |
| Stop shearer if chocks cannot be advanced | | | | | | | | | | | | | | | | | |
| Move to next Chock | ▽ | | | | | | | | | | | | | | | | |
| Repeat chock advance for all chocks, moving behind shearer | | | | | | | | | | | | | | | | | |
| Snake Conveyor | | | | | | | | | | | | | | | | | |
| Move to Chock 1 | ▽ | | | | | | | | | | | | | | | | |
| Determine no obstacles | ▽ | | | | | | | | | | | | | | | | |
| Advance ram | | | | | | | | | | | | | | | | | |
| Observe completion | ▽ | | | | | | | | | | | | | | | | |
| Correct as necessary | | | | | | | | | | | | | | | | | |
| Move to Chock 2 | ▽ | | | | | | | | | | | | | | | | |
| Release ram hydraulic lock | | | | | | | | | | | | | | | | | |
| Move to Chock 3 | ▽ | | | | | | | | | | | | | | | | |
| Release ram hydraulic lock | | | | | | | | | | | | | | | | | |

ROOF SUPPORT
(FRONTIER STATE OF THE ART)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|-----------|-----------|-----------------|--------------------------|-------------------------|------------------------------|----------------------------|-----------------------|------------------------|-----------------------|--------|--------------|------|----------|---------------------------|----------------------------|------------------------|
| | HAND TOOL | HAND TOOL | POWER HAND TOOL | POWER TOOL, HAND CONTROL | POWER TOOL, FIXED CYCLE | POWER TOOL, SEQUENCE CONTROL | POWER TOOL, REMOTE CONTROL | ACTUATE BY WORK PIECE | MEASURE CHARACTERISTIC | SIGNAL CHARACTERISTIC | RECORD | CHANGE SPEED | SORT | IDENTIFY | CORRECT AFTER PERFORMANCE | CORRECT BEFORE PERFORMANCE | ANTICIPATE PERFORMANCE |
| Chocks | | | | | | | | | | | | | | | | | |
| Advance | | | | | | | | | | | | | | | | | |
| Confirm shearer location | | | | | | | | | | | | | | | | | |
| Select section | | | | | | | ▽ | | | | | | | | | | |
| Confirm section selection | | | | | | | | | | | | | | | | | |
| Select chock | | | | | | | ▽ | | | | | | | | | | |
| Confirm chock selection | | | | | | | | | | | | | | | | | |
| Decide: Select manual or automatic mode | | | | | | | ▽ | | | | | | | | | | |
| Manual Mode | | | | | | | | | | | | | | | | | |
| Select push | | | | | | | ▽ | | | | | | | | | | |
| Select advance | | | | | | | ▽ | | | | | | | | | | |
| Automatic Mode | | | | | | | | | | | | | | | | | |
| Push start | | | | | | | ▽ | | | | | | | | | | |
| Confirm | | | | | | | | | | | | | | | | | |
| Balance of Chocks | | | | | | | ▽ | | | | | | | | | | |
| Similarly selected and advanced | | | | | | | | | | | | | | | | | |

HAULAGE
 (PRESENT TYPICAL)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|----------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|
| <u>Conveyors</u> | | | | | | | | | | | | | | | | | |
| Inspect | | | | | | | | | | | | | | | | | |
| Panel Belt | ▽ | | | | | | | | | | | | | | | | |
| Broken rollers | | | | | | | | | | | | | | | | | |
| Broken control wires | | | | | | | | | | | | | | | | | |
| Broken belt splices | | | | | | | | | | | | | | | | | |
| Cross | ▽ | | | | | | | | | | | | | | | | |
| Entry | ▽ | | | | | | | | | | | | | | | | |
| Face | ▽ | | | | | | | | | | | | | | | | |
| Broken flights | | | | | | | | | | | | | | | | | |
| Correct | | ▽ | | | | | | | | | | | | | | | |
| Startup | | | | | | | | | | | | | | | | | |
| Panel - Push switch on conveyor | | | | | ▽ | | | | | | | | | | | | |
| Cross - From panel switch | | | | | ▽ | | | | | | | | | | | | |
| Entry - From cross switch | | | | | ▽ | | | | | | | | | | | | |
| Face - From console | | | | | ▽ | | | | | | | | | | | | |
| Running | | | | | | | | | | | | | | | | | |
| Visual Checks | ▽ | | | | | | | | | | | | | | | | |
| Panel Belt out-of-line detection | | | | | | | | | | | | | | | | | |
| Contact by belt - stops conveyor | | | | | | | | ▽ | | | | | | | | | |
| Cross stop from panel switch | | | | | | ▽ | | | | | | | | | | | |
| Entry stop from cross switch | | | | | | ▽ | | | | | | | | | | | |
| Adjust | ▽ | | | | | | | | | | | | | | | | |
| Restart | | | | | | | | | | | | | | | | | |
| Panel - Push switch on conveyor | | | | | ▽ | | | | | | | | | | | | |
| Cross - From panel switch | | | | | ▽ | | | | | | | | | | | | |
| Entry - From cross switch | | | | | ▽ | | | | | | | | | | | | |

HAND TOOL
 HAND TOOL
 POWER HAND TOOL
 POWER TOOL, HAND CONTROL
 POWER TOOL, FIXED CYCLE
 POWER TOOL, SEQUENCE CONTROL
 POWER TOOL, REMOTE CONTROL
 ACTUATE BY WORK PIECE
 MEASURE CHARACTERISTIC
 SIGNAL CHARACTERISTIC
 RECORD
 CHANGE SPEED
 SORT
 IDENTIFY
 CORRECT AFTER PERFORMANCE
 CORRECT BEFORE PERFORMANCE
 ANTICIPATE PERFORMANCE

Stop

Coal overweight

Switch actuation stop conveyor

Confirm

Conveyors ahead of overweight conveyors stopped

Confirm

Confirm continued running of conveyor after overweight conveyor

Stop shearer

Confirm

Call crew man for cleanup

Clean up

Confirm completion of clean up

Restart

Select conveyor start

Confirm

Shearer start go-ahead confirmed with shearer operator

Start shearer

All other conveyors and shearer are similarly acted upon from stop to restart

Stop

Panel conveyor belt out-of-line

Detector switch contact stops conveyor

Confirm

Select stop for all conveyors ahead of belt conveyor

Confirm

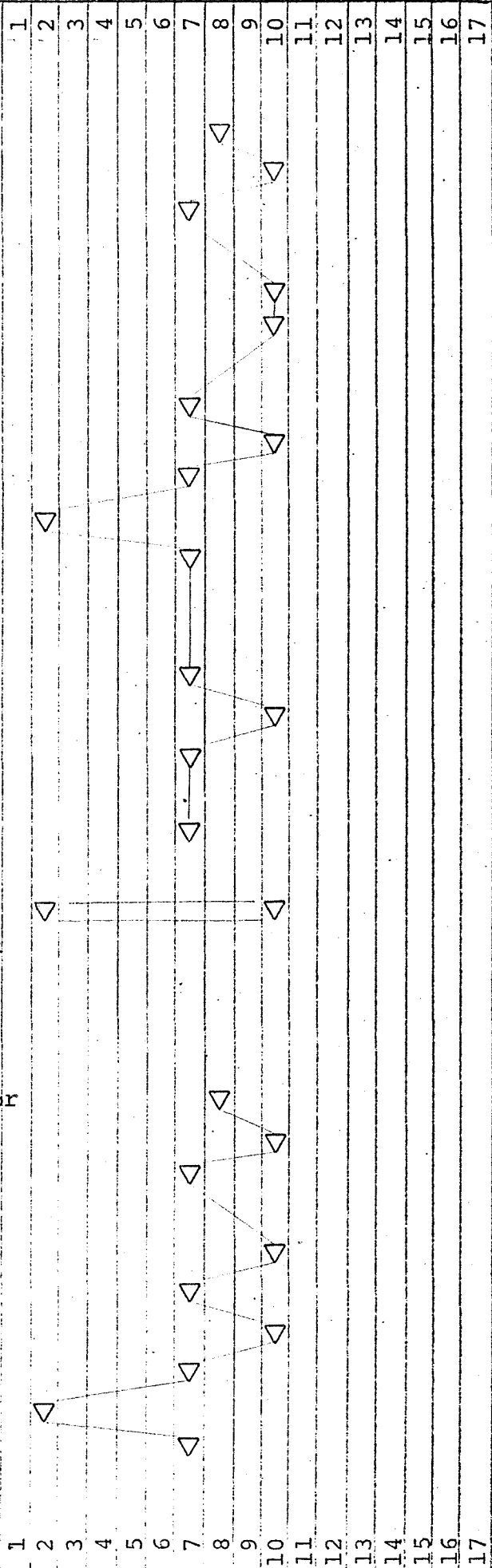
Stop shearer

Confirm

Call crew man for adjustment

Adjust

Confirm completion of adjustment



Restart

Select conveyor start

Confirm

Shearer start go-ahead confirmed
with shearer operator

Start shearer

| | |
|----|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | ▽ |
| 8 | |
| 9 | |
| 10 | ▽ |
| 11 | |
| 12 | |
| 13 | |
| 14 | |
| 15 | |
| 16 | |
| 17 | |

HAULAGE
(FRONTIER STATE OF THE ART)

| | | | |
|----------|----------------------|----|------------------------------|
| Inspect | Panel belt | 1 | HAND |
| | Broken rollers | 2 | HAND TOOL |
| | Broken control wires | 3 | POWER HAND TOOL |
| | Broken belt splices | 4 | POWER TOOL, HAND CONTROL |
| | Cross | 5 | POWER TOOL, FIXED CYCLE |
| | Entry | 6 | POWER TOOL, SEQUENCE CONTROL |
| | Face | 7 | POWER TOOL, REMOTE CONTROL |
| | Broken flights | 8 | ACTUATE BY WORK PIECE |
| | Correct | 9 | MEASURE CHARACTERISTIC |
| Start-up | Select conveyor | 10 | SIGNAL CHARACTERISTIC |
| | Select start | 11 | RECORD |
| | Confirm | 12 | CHANGE SPEED |
| Running | Monitor | 13 | SORT |
| | Coal weight | 14 | IDENTIFY |
| | Belt out-of-line | 15 | CORRECT AFTER PERFORMANCE |
| Stop | Normal | 16 | CORRECT BEFORE PERFORMANCE |
| | Select conveyor | 17 | ANTICIPATE PERFORMANCE |
| | Select stop | | |
| | Confirm | | |

Coal Pile-up Detect.

Detect. at Cross-Panel Pt.

Cross stop at detect. contact

Entry stop from cross switch

Observes

Stoppage

Communicates with crew man

for action

Face stop from console

Clean-up

Restart

Cross - From console

Entry - From cross switch

Face - From console

Detect. at Entry-Cross Pt.

Entry stop at detect. contact

Observes

Stoppage

Communicates with crew man

for action

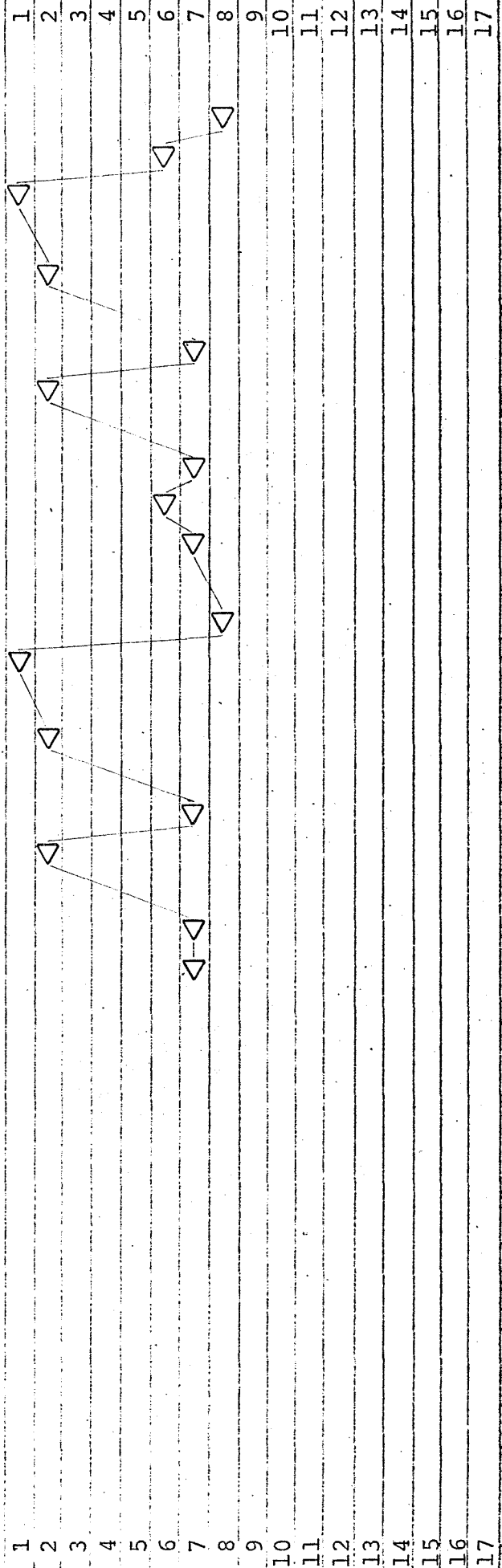
Face stop from console

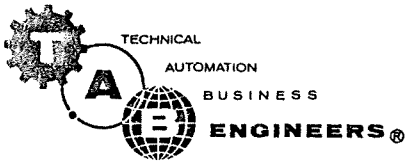
Clean-up

Restart

Entry - From console

Face - From console





4.0 AUTOMATION HARDWARE COMPONENTS

Progress in further automating a process is almost exclusively determined by economic considerations. The elevation of the present level of mechanization to a higher level becomes a certainty as the availability of inexpensive hardware increases. For example in recent years the dominant transition in industry and manufacturing has been from level 5 to level 6 operations. The sequencing of functions, that heretofore were performed separately, has been enabled by the flood of availability of inexpensive, solid state, digital controllers.

Production hardware and components can be classified as to the level of mechanization that is their usual point of application. Representative generic names are shown in Figure 9. The components are listed at the level in which they normally first appear as one ascends from level to level.

COMPONENTS CLASSIFICATIONS

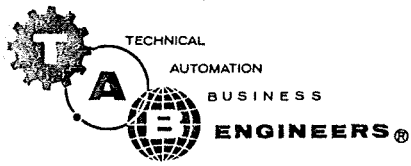
| CLOSED LOOP | CONTROL SOURCE | | POWER SOURCE | LEVEL NUMBER | LEVEL OF MECHANIZATION | COMPONENT EXAMPLES |
|-------------|----------------------|----------------------|---------------------|------------------------|--|-----------------------------------|
| | PERFORMANCE CONTROL | RESPONDS WITH ACTION | | | | |
| OPEN LOOP | MECHANICAL CONTROL | RESPONDS WITH SIGNAL | M E C H A N I C A L | 17 | ANTICIPATING REQD. PERFORMANCE AND ADJUSTING | |
| | | | | 16 | CORRECTING PERFORMANCE WHILE OPERATING | |
| | | | | 15 | CORRECTING PERFORMANCE AFTER OPERATING | |
| | | | | 14 | IDENTIFYING AND SELECTING APPROPRIATE ACTION | |
| | | | | 13 | SEGREGATING OR REJECTING PER MEASUREMENT | |
| | | | | 12 | CHANGE SPEED POSITION, DIRECTION PER MEAS. | |
| | | | | 11 | RECORDING PERFORMANCE | Strip chart, monitor, mag. tape |
| | MANUAL CONTROL | RESPONDS WITH ACTION | | 10 | SIGNALING THE MEASUREMENT OF VALUE | LED, display, fiber optic |
| | | | | 9 | MEASUREMENT OF A CHARACTERISTIC | Gage, meter |
| | | | | 8 | ACTUATION BY INTRODUCT. OF WORK PIECE OR MATL. | Limit switch, sensor, detector |
| | | | | 7 | POWER TOOL REMOTE CONTROL | Robot, manipulator |
| | | | | 6 | POWER TOOL, PROG. CONTROL (SEQUENCE FUNCTIONING) | Controller, N/C, screw machine |
| | | | | 5 | POWER TOOL, FIXED CYCLE (SINGLE FUNCTION) | Cam, geneva, conveyor |
| | | | | 4 | POWER TOOL HAND CONTROL | Slides, index tables, drill press |
| MANUAL | RESPONDS WITH ACTION | 3 | POWERED HAND TOOL | Drive, motor, actuator | | |
| | | 2 | HAND TOOL | Shovel, wrench | | |
| | | 1 | HAND | Eye, ear, hand | | |

Fig. 9

4.1 Measurement Components

As discussed in Section 3.0, further automation advances in shearer operation are dependent upon isolating and measuring characteristics that shearer operators now perform internally. An analysis must be made to determine if a measurement of sound and vibration, geometry (inclination, height, obstructions, lumps), face material property (hardness, overburden interface, faults, foreign content) or of some other physical property (color, sparks, texture) can be made to adjust a shearer, or must a human visual observation still be required in the final analysis.

The problems with adapting a video system would be immense but it may be required and could be done. The fire-fighting mole (Reference 32, Appendix B) utilized a video system successfully in a very harsh environment. NASA has successfully placed video systems in the harsh environments of outer space but at immense expense. The hardware cost of the TV camera carried by our first astronaut on the



moon was over \$1,500,000.

Devices to measure, analyse and record sound and vibration have become very plentiful and inexpensive in the last five years due to OSHA noise requirements for industry. Adaptation would be straightforward and relatively inexpensive for the mining environment.

Obstruction proximity and distance devices are available by the score. The advances in human member presence detection have been especially important and brought about by OSHA requirements that prevent manual feeding of active machine tools.

Although attempts to utilize radiation diffraction patterns to locate the coal/rock interface have met with some success, other approaches are conceivable as alternatives. Great progress has been made in utilizing a sonic system to identify density differences in various materials. For example, a fetus can be "x-rayed" by sonic means alone.

The sensitized pick experiments were jeopardized by componentry. Improved load cells, strain gages and solid state circuitry may transform the approach into

a successful one. If color, sparks, or texture must be measured, extreme difficulties are presented. Only limited progress has taken place in transducing measurements in these areas.

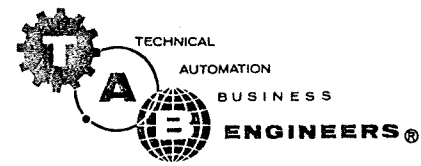
In summary, advances in the level of automation of the shearer are dependent on identifying appropriate control entities for measurement. Once identified, most entities can be readily transduced using today's technology.

4.2 Controller Components

As discussed in Section 3.0, further automation of roof support operations demands elevation to level 6, power tools sequence controlled, and level 7, remote control. In the last five years the greatest advance in automation hardware has taken place just at this level.

In order to achieve automatic sequencing of chock operations, a programming function must be performed. A wide variety of programming devices are commercially available.

An electronic, digital programmable controller is currently the most powerful and flexible of this group. The most important characteristic of these controllers is the ability to handle a large number of inputs and outputs. One controller can also independently control a number of different cycles, keeping activity in each cycle separate from the others. A remotely located controller could operate all chocks through electric control lines. Typical controllers are programmed with pin connections, interchangeable hard-wired circuits, and magnetic core memory.



The cost of programmable controllers (especially solid state models) has steadily fallen in the past several years as markets increased and technology advanced. On moderate to large scale applications, these controllers cost less than older types. They have also become the most versatile of the programmable controllers.

Feedback is another important aspect of sequenced operations. It may be necessary to incorporate a large number of feedback signals into a chock control system, for example. The controller that supervises the chock advance operations would have to be capable of processing the feedback signals rapidly and reliably.

The current cost, capacity, speed, and remote capability of magnetic core programmable controllers, for example, have greatly improved the economic and technical feasibility of longwall chock control.

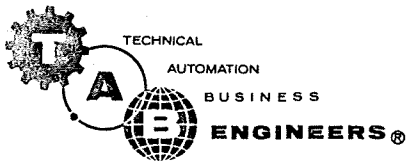
5.0 THE STATE OF THE ART

Blue sky concepts to elevate the level of mechanization for longwall mining have been available for some time. What has been lacking is an appropriate incentive to justify implementation of some of the concepts beyond the experimental stage. Prior to 1969, the major incentive was direct labor cost. Although labor costs were rising, the experimental systems that had been developed could not be economically justified and so were not adopted.

After 1969, safety incentives were increased. Systems that removed men from the point of local operations to adjacent and "remote" positions flourished. These systems are given active attention today and some of the more reliable ones are being justified and purchased by mine operators.

After the energy source deficiency crisis of 1973, an even greater incentive was incremented into the justification criteria. With the U.S. national intent to become energy-sufficient hinging in part on boosting coal production, broad mechanization concepts are now being considered.

Past attempts at automating winning (shearer, in particular) have revolved around isolating only one variable and



mechanizing it. We have seen that there are many variables. At present, the identity of each is somewhat vague. The ranking of each in a priority structure has not been done. The removal of a person from direct operation demands that a function analysis be performed that will enable creation of a control system concept.

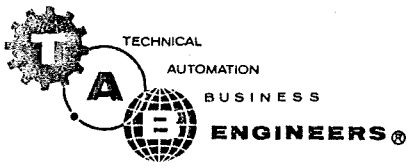
Past attempts at automating roof support systems have had technical success. With the increased availability of inexpensive control hardware and components and their increased reliability, the cost justification is much easier.

Since mine equipment manufacturers tend to specialize in either roof supports, or shearer, or haulage, complete integrated automation concepts have been lacking. In general each has tried to improve his product without too much consideration as to the final overall system concept.

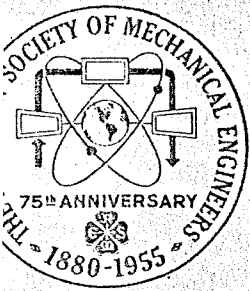
The overall automated longwall concept has the dual objective of increasing production and of removal of people from face operations. If only production increases were considered, many industrial engineering techniques could be successfully employed to accomplish the sought-after increases. If only removal of people from the face operations were considered, many simplistic systems could be envisioned to

accomplish the goal. The degree of compatibility in the dual objective has not been assessed. The composite incentive has not been determined. However, the creation of such an overall concept will in itself enable those determinations to be made, and the consequent automated longwall concept to be implemented.

APPENDIX



MECHANIZATION PROFILE



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THE MECHANIZATION PROFILE - A TOOL FOR MEASURING AUTOMATION

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ABSTRACT

Whether we like it or not, the phrase "automation" has become very much a part of our technical world, and there seems little doubt that it will stay with us for some time. But what does it mean? It has been applied to "automatic handling of work in process," to "automatic control," to "feedback control," to "program control of a machine tool cycle," to "self-regulating machinery," to "machines that think," to data processing or the mechanization of paper work," and to "decision-making machinery." No doubt one could identify dozens of other meanings and shades of meanings within this sphere, each having its ardent supporters. Yet in spite of these various meanings, the public (and I include engineers, management, labor and the press) use the word very loosely. Because of the enormous distortions of technical truth that have gone on under the label of automation, and because of the exaggerated claims as to the performance of automatic plants and automatic machinery, and because of the way labor unions have seized upon the word and ballooned it into a congressional investigation, it is evident that we need a more critical analysis of just what automation is all about. However, to offer another definition of automation is pointless. It would be worth no more than those that have gone before. Rather, it would seem that we need to understand the nature of mechanization and of the degree of mechanization employed in these so-called automated plants. Perhaps if we understand what is going on in the plant, we will then be able to understand the meaning of automation. We will at least be able to put the claims for "automatic factories" in their proper place, and to have a calmer, saner appreciation of the evolution of mechanization, as well as its potential impact on our industry.

THE MECHANIZATION PROFILE - A TOOL FOR MEASURING AUTOMATION

By James R. Bright

INTRODUCTION

During the past year, I have spent considerable time investigating, to different degrees and intensities, some 15 so-called "automated plants." As a result of this study, I am convinced that the level of automaticity is much less than the popular press would have us believe, and the spread of automaticity across or through a plant or across the presses is not nearly as great in practice as one might assume from current claims. In this paper I shall offer an analysis of mechanization and a method of charting it which has been proven to be useful in studying "automatic" production systems.

The production of goods involves a number of basic functions. The production operation - processing - is the thing we instinctively visualize as the heart of the "automatic factory." But design, handling, storage, maintenance, and measurement also are essential. Take measurement alone; it is a never-ending part of production, for quantity, quality, performance, even identity, must be established again and again throughout the cycle from receipt of raw materials to dispatch of finished goods. Each of the other functions also is present in varying degrees and in various areas of individual manufacturing operations. If the plant is to approach automaticity, even remotely, there must be a high degree of mechanization of each of those functions, not just of processing.

THREE QUALITIES OF AUTOMATION

As for the basic functions of production up to the point of shipment, a simple chart can be constructed that will suggest the nature of mechanization generally associated with these functions. Such a chart (Exhibit 1) does not need to be absolute and precise to show that today there is no such thing as an automatic plant or even a push-button plant, and that mechanization is not found equally distributed through any single production sequence, let alone any whole plant or industry.

Note, further, that automation can be analyzed in terms of three different qualities:

Span of Mechanization. Over what portion of a given total manufacturing sequence does the mechanization extend? Perhaps some of the activities, like forming, packaging, and testing, are handled by automatic or semi-automatic machines, but the others are scarcely mechanized at all.

Level of Mechanization. How high a degree of mechanization characterizes the particular function or activity? Thus, if toothpaste is continuously put into tubes, the tubes sealed and inserted in a box, and the boxes collected and arranged in a carton on one packaging machine, that would represent a high level of mechanization; but if handkerchiefs are folded on one machine, wrapped in cellophane on another, and then assembled and placed by hand in a carton, that would represent a lower level.

Amount of Mechanization. How prevalent is mechanization of a given function or activity in the industry as a whole? For example, most structural design work is carried out according to conventional formulas with the use of a handbook and no more mechanization than a slide rule. So the total of mechanization for this activity is low, despite the fact that in the designing of air frames digital computers are used to perform intricate calculations and explore the mathematical limits of structural strength.

MECHANIZATION PROFILE

The concept of degrees of mechanical art approaching automaticity in successive steps - levels of mechanization - suggests that there must be different things that machines do. In what way does machinery supplement man's muscles, his senses, his mental processes, and his judgment? Are there significant differences in the levels of mechanization? What characterizes them? And if automation is so different, where does it fit in?

It seems to me that it is quite possible to think our way through these things by a systematic qualitative analysis of the functions of simple and complex machinery. I have been able to distinguish 17 levels. Here is a detailed explanation. This particular breakdown cannot be defended too rigorously. Examples can be cited that would somewhat confound this or any other classification. Doubtless additional subdivisions could be defined. Furthermore, some of these levels may be inextricably tangled with much lower levels. Nevertheless, I have found the following to be fairly consistent and usable:

Level 1. Hand - The least mechanical way that man manufactures something is usually with his hands; occasionally with his feet, knees, elbows, or even his lungs (glass blowing). No tool of any sort is used. Examples are manual packaging operations, inspecting completed cigarettes prior to packaging and removing faulty ones, and many assembly operations.

Level 2. Hand tool - An enormous amount of work is performed by the human hand aided by a nonpowered tool. Even on an automobile assembly line many workers will be found tightening nuts and bolts with a hand wrench or inserting wires and rods through holes by the aid of pliers or similar devices. Other examples would include hand filing, hand painting, and a host of assembly and packaging activities in industries.

Level 3. Powered hand tool - The next step is to provide mechanical power to the tool held by the worker. The power screw driver, the portable drill, and the portable welding machine exemplify this level of mechanization. Power supplements the worker's muscles, but actual guidance of the tool still is under his control.

Level 4. Power tool, hand control - The simplest form of machine tool appears at this level. A drill press, for instance, provides power to the tool and also a framework that guides the tool. Application to the workpiece is physically actuated by the operator, who controls the amount of action as well as its duration. Other examples are the simpler forms of any machine tools - milling machines, lathes, grinders. The fork-lift truck and the electric hoist also could be considered as hand-controlled power tools. In other words, the machine performs within fixed dimensional limits and rates built into it, but the operator controls the application of such action. Such a machine can be mobile, as well as stationary.

Level 5. Power tool fixed cycle (single function) - At this step we see a machine which repetitively performs a single action that is mechanically fixed within definite limits. A drilling head arranged so as to advance, drill a 1-in. hole, and retract, all automatically, reflects this type of mechanization. A belt conveyor moving packages from the end of the production line to the shipping room at a set speed also performs a single action in an unvarying way. The dragline conveyor, the continuous annealing oven, many chemical processes, and many cam-controlled machine tools where the tool advances and then performs a certain action for a given distance or set amount of time are examples.

It is implied that this machine action is mechanically (automatically) controlled, even though an operator may have to push a button to start the machine and stand by as an observer. But this does not invalidate the basic point; the machine itself controls its actions over the desired range of performance.

Level 6. Power tool, program control (sequential functioning) - On every hand we can see the next step in mechanization taking place. It is similar to the previous step except that in addition the machine performs a series of actions in sequence, operating in one or both of two basically different ways: (1) The workpiece is held in a given position, and the different tools are brought to it for the period of their individual cycles - the principle of the automatic turret lathe. Or (2) each operation is performed at its own fixed station; then the workpiece is passed to successive stations under automatic timing, positioning, and materials-handling control - the principle of a dial-indexing machine tool. The automobile industry's transfer machine combines both of these concepts.

It is rather interesting that this level of mechanization is found in our current home appliances such as the automatic washing machine, the automatic drier, and the automatic dishwasher. All of these work on the first principle rather than on the second one. In the industrial plant, because of unique variations in the average product, we find more and more emphasis being put on the second approach for assembly work, though the first is still useful for processing.

It is quite possible that the operator not only may push a button to start this machine but may spend considerable time fixing the workpiece in the machine. In some cases he is even required to give constant attention to the machine to control the feeding and removal of material. Nevertheless the principle remains; the machine automatically performs a series of prescribed operations.

Level 7. Power tool, remote control - Meanwhile the control of the machine is undergoing some changes, too. While it might be argued that this is not a clearly defined level of mechanization since it is also found fragmentarily at least three levels earlier, this seems to be about the best place to establish remote control in the scheme of things.

The principle is that the control of the power tool is located a significant distance from the tool itself. Where a single tool is concerned, this holds no special significance. But, when a group of power tools is equipped with remote control, the impact on mechanization mushrooms. It becomes possible to assemble the control of a series of machines in one central location. Thus the whole industrial art is advanced a significant step closer toward automaticity.

Remote control implies fewer people, but this is not the most important implication. Centralization is far more important. It generally means much faster "reaction time" to the needs of the various production operations, particularly as they affect each other. Thus improvement in quality, reduction in scrap, and higher machine efficiency through optimum operation of the plant as a whole are likely to follow.

This level of mechanization eliminates the delays and errors inherent in the communication of information between human beings at widely scattered locations. The lack of this level of mechanization probably is responsible for the excessive paper work, elaborate production-control systems, and general inefficiency of flow apparent in the average job shop. (I do not mean to imply that it is always practical or economical to change procedure. Merely, I wish to emphasize that such "looseness" in control is the target of this seventh stage of mechanization.)

Level 8. Actuation by introduction of workpiece or material - In all the previous phases of mechanization, the human element is required to actuate the system. In advanced mechanization even this need begins to disappear.

It is no longer uncommon to find machines that "idle" or remain inactive until started by the introduction of the workpiece. This is a feature of many of the automobile industry's new compound machine tools, whereas the transfer machines of five years ago usually cycled continuously whether or not a workpiece was present. The newer machines, which do not operate unless a workpiece is in place, have the advantage of eliminating the need for human decision, hence human presence, at this point. It is now practical to link the materials-handling equipment with the production machinery, thus making the sequence of production operations quite automatic.

Level 9. Measurement of a characteristic - Now we begin to move into levels of mechanization where there is a new emphasis on control, rather than a pattern of operation. We see machines that not only change the form of the object but, with certain mechanisms added, also measure some characteristic of the object - weight, temperature, a dimension, a shape, a color - either before, during, or after production.

For example, a monorail track may include a scale so that materials passing over it can be weighed. A grinder may be linked up with some type of measuring system to indicate the dimension being produced. A chemical process may include instrumentation that indicates pressure, temperature, or some characteristic of the product being produced within it. Measuring is the essence of this stage of mechanization.

Level 10. Signaling the measurement value - A logical refinement of the previous level is to include a device that will signal when the measurement value is in a certain area or reaches a certain limit. In effect, the machine calls for human help. It has completed, or is about to complete, its job or is in difficulty or out of control, and needs further direction. Sometimes the machine is designed to yield several kinds of signals (different colored lights or sounds) so that the nature of the measurement value can be quickly grasped by the human machine tender. This is particularly useful in the case of errors or difficulties. Overdimensions or underdimensions might be so signaled.

It is a very short further step - so short that I do not regard it as more than a special case of this same level of mechanization - to have the machine shut down until it is "cleared" by its attendant. Thus, in an automotive-cylinder-block line, the work is mechanically inspected at several points; and, if it does not meet the standard, a light flashes and the machine stops. Signaling plus automatic shutdown are typical of many advanced machine tools, such as transfer machines.

Level 11. Recording performance - Often it is desirable to have a record of machine performance. This may range from a mere count of the number of pieces produced (or tons, gallons, yards, etc.) to a record of individual values of the characteristic measured almost moment by moment. A simple example is the punch press linked up with a counting device which records each machine cycle and thus measures output.

Far more elaborate are the data-scanning and recording systems for large control panels in oil refineries, chemical works, and power plants (particularly atomic energy). These systems continuously scan several hundred or even a thousand instruments and print the current value on each instrument in a properly patterned arrangement on a roll of paper.

A recent refinement has been to incorporate signaling along with recording. At least one such data-scanning device prints values in red if the value exceeds a preset limit for a particular instrument. Thus the panel attendant or engineer can see at a glance which values are out of control. This is extremely helpful for tremendously intricate chemical processes involving large amounts of instrumentation.

Level 12. Changing speed, position, or direction according to measurement -

One of the most important advances toward automaticity is the development of machinery that automatically modifies its action in accordance with the information received through some kind of sensing device - the principle of feedback.

However, the idea of feedback itself seems to employ different degrees of mechanization. At this particular level we are not talking about the correction of performance based on the quality of the output. Rather, the machine is controlled by a signal and is not influenced by the precision of its own processing action. For example, in a brewery a roller conveyor system counts the number of cartons coming down a line; and then, after 50 have passed, it switches to direct the next group of cartons to a different location. Similarly, in a feed mill, material is withdrawn from a bin into a weigh hopper until a given weight has been accumulated; and at that point a sensing device actuates a control to stop the delivery of more of that material, whereupon material is automatically fed from a different bin to a new weight limit.

Perhaps we might distinguish this phase of mechanization from earlier levels by saying that the performance of the machine is controlled by a signal rather than by a fixed program. It is more flexible in action and in the time dimension. But while this machine changes its action at a signal, it does not inspect its own performance.

Level 13. Segregating or rejecting according to measurement - Implicit in the previous level is the next step of automatically accepting or discarding a product that does not meet a prescribed standard. Note that in the automotive-cylinder-block line of Level 10, all the machine does is to inspect and signal for human help; it takes no action on the substandard work. But at Level 13 we find machines that not only measure and decide on acceptability but also dispatch the work accordingly. An example is found in a textile mill where picker laps coming from the picker room are automatically weighed just prior to dispatch to the looms. If the weight is not up to the desired standard, the individual lap is automatically rerouted back to the picker room for rework. Acceptable products automatically pass on to the loom room.

Notice that although this is a high level of mechanization in the sense that it employs decision and physical separation, the actual execution can be very simple indeed. "Measurement" here may be nothing more than the sensing of form and the adaptation of some kind of chute, divider, or separator that will direct one form one way and everything else another. In very elemental form, a punch press may be rigged to separate the scrap from the finished parts; or a bottling machine may include a weighing device which will separate out incompletely filled bottles. "Decision" is pretty much a "yes or no" choice, although it may involve a choice from three, four, or even more alternatives.

This level of mechanization is common in simple inspection of mass-produced metal parts and in the packaging phase of many mass-produced items such as food and toiletries. Fundamentally, we have here the automation of an inspection and associated materials-handling activity.

Level 14. Identifying and selecting appropriate action - Now we come to the machine that, in theory at least, takes more complex action. This machine examines the incoming product and adjusts itself to perform accordingly. For instance, a recently introduced machine tool receives two types of castings. It automatically distinguishes between them and puts each casting through a different set of machining operations as the two pass through the same series of work stations. Also, there are many chemical processes where the incoming material is constantly measured in terms of some characteristic and the processing operation changed appropriately.

Admittedly, this is not very much different from the preceding level. The significance lies in the fact that the response of the machine covers a wider range and is more complex. Instead of a single-action response - an inspection and materials-handling sequence - there may be a modification of performance involving a whole series of varying subsequent actions. Still, it is true that the difference may be narrow between this and levels 12 and 13.

Level 15. Correcting performance after operating - A great many machines include inspection operations after the production action. However, these are usually separate machine or work stations, and there is no tie-in with the machine that performed the operation; human action must bridge the gap. On Level 15, in contrast, we find the machine that examines its performance and then readjusts itself accordingly to turn out a more nearly perfect product. To a very limited extent, this feature has been employed in some machine tools, which will grind or perhaps otherwise remove material, inspect it, and then translate the inspection information into corrective action so that the next piece is machined properly.

But even though inspection and correction are automatic and tied together, the inspection after operation implies a time lag. And the more time, the more opportunity for faulty parts to be created before the correction is introduced.

Level 16. Correcting performance while operating - Theoretically the ideal machine would control itself so that it would never turn out a faulty part. It would inspect continuously and modify its performance quickly enough so that potential faults would be avoided.

It is hard to find machines that fully meet this definition. Perhaps the nearest are the electrical machinery devices with their marvelously precise output controls. They will maintain speed, torque, voltage, or current, as the case may be, within amazingly fine limits. Some chemical operations, particularly the control of temperature and the control of pressure, also fall within this area.

Level 17. Anticipating required performance and adjusting accordingly - There is still one higher level. We have a few isolated examples of machines that not only sense something and correct their actions but also extrapolate the governing data or act on a lead from the probability pattern (or otherwise anticipate the action needed to produce the required performance), and then regulate themselves accordingly. Self-guided missiles come to mind as the outstanding example.

Oil-refinery developments are beginning to get into this phase. Engineers visualize the application of instrumentation that will sense the change in a variable, predict what will develop and the corresponding series of changes needed in the process, and then change the various machine responses accordingly. This is more than the measurement of a characteristic and a response. It is the measurement of the rate of change in the characteristics, the anticipation of the control modification needed, and then the modification of a host of variables to hold the process with design limits.

THE MECHANIZATION PROFILE

If these levels of mechanization are arranged in order on a chart, certain important relationships between them fall into place. Consider the nature of the power used at each of these levels. Only the two lowest ones use manual power; all the rest are based on mechanical (nonhuman) power.

Even more significantly, the 17 levels are distinguished from one another by the nature of the control characteristic of each:

Notice that the first four levels of mechanization all employ manual control. There is an interesting difference between Levels 3 and 4. At Level 3 - the powered hand tool - manual control can be thought of as embracing two elements: application and guidance. At Level 4, however, we can see that one aspect of this control job has been further mechanized - the aspect of guidance. The construction of the tool fixes the limits of the physical action. The operator merely guides the tool or "controls" it within those mechanically fixed paths. He has only limited control in the three physical dimensions but retains complete control in "time."

In passing to the fifth level of mechanization - the fixed-cycle power tool - it is apparent that we have not only mechanized the guidance of the tool, but we also have mechanized its application in the time dimension. Other than starting and stopping the machine, or possibly modifying its speed, the tool is completely mechanically controlled. Level 6 is nothing but a more advanced form of Level 5. Level 7 has remote control, often applied to the next three lower levels; I insert it at this point because it enables the centralization of control of a number of machines. Finally, we have the machine controlled by introduction of the workpiece.

At the ninth level of mechanization a new force is becoming predominant in the control action. The environment, the product, or the nature of the operation itself at given moments becomes the initiating element of the system. Control here is no longer mechanical, fixed, or rigid; rather, it is variable according to performance. The control indication may be prior to, or during, or after the production act has been performed. Thus we see the basis evolving for still higher levels of mechanization. The principal importance - the principal distinction - at this point is that control itself is becoming a variable.

In the ninth, tenth, and eleventh levels the control response is not a specific action of the machine as much as it is a signaling action. We might say that the machine has verified the nature of the performance, and it either reports this performance and/or calls for human attention.

At the twelfth level a new quality to control has been introduced. The control responds with action. All the succeeding levels of mechanization embody the idea that the machine measures completed, current, or impending environment, and modifies its major functions accordingly. In the lower of these levels the action response is very limited in character. In the higher levels the response is not so much of a "yes or no" matter. It is broader, richer, much more complete

THE MEANING OF AUTOMATION

Some disciples of automation see it as embracing the idea of automatic control. To them control, rather than mechanical automaticity, is the dominant factor; indeed, automation is synonymous with automatic control. This group seems to be applying automation to the levels of mechanization from roughly 9 to 17. However, some of them insist that it is not really automatic control until it embraces only Levels 12 to 17.

Other enthusiasts lay heavy stress on feedback. They have said or implied in many ways that "true" automation embraces the idea of self-correction. Other steps toward automaticity, they maintain quite condescendingly, are nothing but mere "Detroit mechanization."

However, "automation" is not quite so simple as more careful analysis of these 17 levels will demonstrate.

Practical Levels

After looking at these levels and their application to a manufacturing sequence, what do we mean by automation? Where does automation fit in? Is automation new and different? What is unique about it?

It seems clear that practical industrialists who must use mechanization are interested in an end (i.e., automatic manufacturing), while many of the enthusiasts are obsessed by the means (i.e., automatic control, handling, or processing). Thus, to insist on automation as relating to just a certain aspect or certain levels of mechanization is downright foolish. Automaticity may or may not require self-regulation. It is important to realize that many highly automatic operations do not require performance control. There is nothing excellent, brilliant, or economic in employing higher levels of mechanization than are needed. Countless cases can be cited where automatic operation - or, more correctly, a high degree of mechanization - has been achieved on Levels 5 and 6. To the extent that the required activity is reasonably uniform in input, throughput, and output requirements, there is no need of automatic control. Indeed, to introduce automatic control into many of these situations becomes a ridiculous mechanical luxury. Often it leads to a downright reduction in economic efficiency through high engineering costs, high maintenance costs, and limited flexibility.

This is not to deny the steady growth and important application of controls to reach new, advanced levels of mechanization. Furthermore, experience is showing that direct labor reduction is not the only advantage - and often is not the major advantage - arising out of automaticity. Savings in material through reduction of scrap, reduction of inventory, and refinement in product design are often the major advantage. Improvement in quality has been the significant advantage in a number of cases.

Rather, I want to stress, and restress, that countless machines and groupings of machines already have achieved and will continue to achieve the most economic level of mechanization, far short of full automation. Let us consider two examples:

Unloading Flour

Consider the discharge of flour from a bulk railroad car into a storage bin. As currently conducted in a number of bakeries, a car is spotted alongside the unloading dock. One man connects a pneumatic suction tube to the discharge spout at the bottom of the car. He then walks to the control panel in the building, decides which bin shall receive this flour, and presses a button. Thus remote control - Level 7 - has been linked with the single-cycle power tool - Level 5. The flour is "automatically" transferred from tank car to the proper storage bin. Incidentally, it is passed through a device on the way to screen out foreign objects and also to remove any insect infestation; this additional function of inspection and segregation is fully automatic.

When discharge is complete, the machine is stopped. The operator then disconnects the hose from the bottom of the tank car, and the operation is over. Either prior to or during the discharge, samples may be taken for laboratory analysis of moisture content and chemical characteristics.

Is this whole process automation? Certainly it is highly mechanized. Would it make sense to strive for or to introduce an even higher level of mechanization? Technically it is entirely feasible to have the car automatically positioned, to have the hose automatically coupled, and the selection of the storage bin mechanically controlled. The machine could be actuated to shut off upon completion of discharge, and it would be possible to tap off samples of the flour to put them through a series of laboratory tests and to actuate or stop the unloading procedure in accordance with these laboratory results. All this could be done - note that I said "could be" - with no manual help at all.

But would it make sense? The cost of engineering these additional features into the system would be extremely high. Maintenance would almost surely increase. Flexibility would suffer. And what would be gained? A reduction in labor costs? Not worth mentioning. Precision in the laboratory analysis? Extremely doubtful. Greater speed in the laboratory analysis? Perhaps, but the equipment to do this probably would cost a small fortune.

Manufacture of Airplanes

Consider now the manufacture of Lockheed's huge new cargo plane, the C-138. As of late 1954, two of these planes were being constructed. Each contains about 38,000 parts. The size of future orders for this plane certainly is an unknown. The number of modifications that are going to be made, both by the firm's engineers and by the military services if they adopt it, are going to be enormous and continuous. Does this situation call for automation? What level of mechanization is sensible?

Of course the experiments at MIT with the tape-controlled machine tools are aimed at this very problem - or, rather, at a tiny part of this problem. The tape-controlled machine tool offers the hope that an intricate part could be automatically machined to the desired shape on a standard machine tool with little or no requirement for operator attendance and, more important, with little setup time. It is an effort to automatize the manufacture of certain kinds of parts on Level 6. I mean no disparagement of this development, nor any reflection on its economic worth, in pointing out that the number of parts on this plane which could be so produced represents a tiny fraction of the manufacturing effort required to conceive, develop, fabricate, and assemble the entire aircraft.

It is particularly significant that, in the aircraft business, assembly is the expensive job. As with so many industries and so many businesses, it is comparatively easy to make any single part or single material automatically if the volume is high enough. The difficulty lies in putting these pieces together. To assemble a C-138 automatically is next to a mechanical impossibility. Granted, it is theoretically possible to build a system of assembly machines to do this, but it is an economic certainty that it would take years and literally millions, if not billions, of dollars to build such a machine. And for what? To assemble two planes whose design inevitably will be changed a thousand times during the production run and which may be wholly obsolete within five to eight years.

Between these and similar examples the reader can see the fallacies in loose talk about automation, push-button factories, and similar generalizations that fail to consider the different qualities of automation and the relation of automation to the requirements of the total manufacturing cycle. The goal, again, should be the most economic level of mechanization, rather than automation per se.

Use of Profiles

I have plotted the level of mechanization as a part moves through the plant (i.e., made profiles) for some 15 actual operations, reputedly among the most advanced in their fields. Two of these profiles are shown in Exhibits II and III, and perhaps warrant some comment:

Production of Foam Rubber Mattresses

This basic system, now in use in close to half a dozen plants, is built around the idea of placing the mattress molds on a conveyor and pulling this past a filling point and through the ovens. Liquid latex is pumped in bulk to the filling point. The molded product is carried from the molding operation through finishing and packaging by conveyor.

Clearly, this is an enormous and important advance in the art, and it appears to be highly continuous and "automatic" to the observer. Productivity per molding department operator is about quadrupled! Product quality as received from the molding operation is up 50 per cent or so. Yet, look at the actual level of mechanization. It is not particularly high, although these plants have been frequently described as "automatic" and as using an "automation" system. In the assembly stages, handling is the major mechanization. Inspection and finishing depend on simple handwork.

This situation is typical of many other advanced plants. Enormous increases in productivity have been achieved with new levels of mechanization; yet the "automatic" part of the plant is not so very automatic after all and covers only a small portion of the required physical activity.

Automotive Engine Cylinder Block Line

This chart represents the level of mechanization in one of the finest engine plants. It covers only the manufacture of the finished block from the rough casting, which is the most "automatic" achievement in the plant. The reader should appreciate that many parts must be made, all must be assembled around this block, and the whole engine tested, painted, and shipped. Thus, in spite of automation, over 4000 are employed.

It is not indicated by the chart, but each of the production operations may literally accomplish from 4 to 40 or more separate cutting actions. Hence this represents a high degree of consolidation of machinery. Automation is thus furthered because handling between individual tools is minimized and control is centralized. Yet flexibility is reduced and individual tool down-times can compound within such a machine, if maintenance and tool changing are not controlled carefully.

As in much metalworking, many dimensional inspections are required, and most of these are on a manual basis. A number of other checks done at intervals are not shown. This chart does not reflect the handling of rejects from any point, which is a moving job at Level 3 or 4, plus repair work at Levels 2, 3, and 4. And notice that the assembly operation on this highly mechanized line is, again, a hand operation!

The significant element unifying operations here is the program-controlled handling system feeding the production process. This handling system requires no manpower. But close to 50 men are needed to operate, inspect and patrol (not maintain) the line.

From these and the 13 or so other profiles made of actual operations, it is clear that:

1 Most instances of "automation" turn out to be largely automatic operation systems not embodying self-regulation. There is little or no use of the higher levels of mechanization.

2 With the level of mechanization varying widely as between industries and between parts of the individual production cycle, "automation" is being used to describe something on a significantly higher level of mechanization than previously existed in that particular activity or plant, rather than any certain minimum level of mechanization or automaticity. What is called "automation" in the bakery business, for example, is everyday mechanization in the automobile industry. What is a significant advance in mechanization in metalworking, let us say, is commonplace in a brewery. This does not imply that one field is much more backward than another. Rather, economics, technical problems, and mechanical art vary widely between industries. One man's automation is another man's daily practice. Automation is relative, not absolute.

3 Automation usually covers a very small part of physical manufacturing activity and next to none of the mental activity required. Since automation is being introduced as islands of automatic operation in the total sequence, it suggests the need for a thoughtful look. Are these islands adapted to further integration, either as a whole or as part of a larger island? There is evidence that engineers should give more attention to long-range mechanization planning. Buying unrelated elements of automation piecemeal may be expensive, inefficient.

4 A major element in achieving automaticity is the mechanization of handling. The conveyer in some form, and occasionally the monorail, is the heart of most highly mechanized plants. Processing is being built around, on, and into the conveyer. Automatic production is impossible without automatic movement. The automatic processing machine is only the first step, rather than the last, on the road to the automatic factory.

5 A significant result of higher levels of mechanization is the reduction in space requirements for production facilities. With automatic controls, many machines are performing more functions than formerly, so there can be less equipment. Other machines are being placed close to each other for transmission of fabricated parts. Handling systems are linking major production centers with each other and with raw-material and finished goods storage. Less space is needed around production operations because there are fewer operators, traffic passageways, and materials in process. Certainly, the engineer who sees a long-range space problem should consider the possibilities inherent in automation.

6 We have a long, long way to go to reach full automaticity. Automatic processing is relatively easy. Automatic assembly is the glaring weak spot; next to nothing has been done in this area except in the bulk-materials and a handful of very high-volume, discrete-part manufacturing plants. Product inspection, in spite of certain dramatic advances, also is astonishingly unmechanized throughout industry. The human being's versatility, sensitivity, and power of discrimination, plus materials-handling ability, are unique. They make him far and away the most economic inspection "device" except for the very precise and/or the highly repetitive inspection activity. Where a combination of factors must be considered in inspection - for instance, cracks, flaws, appearance, texture, general quality - it is a rare machine that can beat him.

Theoretically Desirable

A mechanization profile can be made both of the actual level of mechanization and of the theoretically desirable level. A systematic comparison of these two curves will highlight important gaps, and the engineer can then consider whether or not the expense and the time necessary to raise the level of mechanization for a given operation seem to be reasonable. Even more important, such analysis will suggest whether this effort might be better directed elsewhere in the total manufacturing cycle.

CONCLUSION

This profile technique is new and unrefined. It should not be adopted blindly or overenthusiastically. Perhaps its greatest value is its use as an aid to orderly and careful consideration of new concepts and methods in mechanization.

Eventually, it may be possible to quantify the profile in some way so that the productivity could be related directly to the level and the span of mechanization. Perhaps different systems might be compared quantitatively and, therefore, more accurately. This might lead to the ability to measure mechanization in absolute terms so as to compare industries and systems and to measure historical progress.

However, the user should be very careful not to be misled by this rough tool. He should always remember these facts:

1 A profile can fall into lower levels of mechanization and still the operation may be quite "automatic." Many machines, which we take for granted, actually perform and tie together a number of operations. Thus the fixed-cycle machine provides a great deal of automaticity.

2 There is nothing economically virtuous per se in the higher levels of mechanization. A system is neither "good" nor "bad" because it is high or low on the profile chart. We should not assume that mechanical achievement implies economic excellence. The point of diminishing returns is just as true in mechanization as in anything else.

3 Automation is not an absolute, but a relative. It is not by accident, but by design, that I have avoided a rigid definition from the very beginning of this paper and have simply used a number of phrases to imply the act of doing things "more automatically." That is how automation actually shapes up - in current practice and for some years to come - as degrees, steps, levels in the advances of mechanization.

In short, an intelligent analysis of mechanization will help us to understand what is going on - to compare systems - to highlight weak spots. Thus the mechanization profile may become a useful tool to broaden our perspective of technical progress.

EXHIBIT III. MECHANIZATION PROFILE — CYLINDER BLOCK LINE

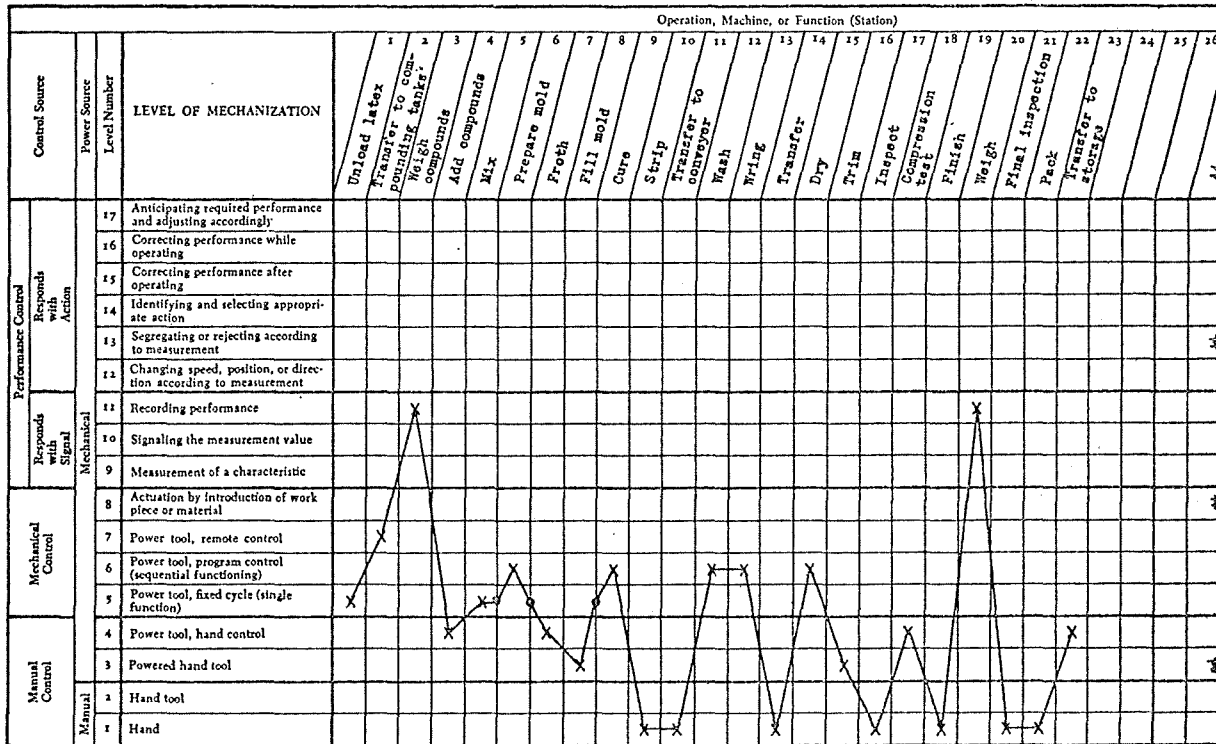
| Control Source | | Operation, Machine, or Function (Station) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---------------------|----------------------|---|---|--------|----------------|---------------|------|------|-------|------|------|-------|-------|-------|--------------|------|-----|-------|----------|----------|--------------|----------|---------------|----------------|------|--------------|------|-------|----------|------|--------|---------|-------|------|-------|----------------|--------|-----------------------------|----|----|----|----|----|----|----|--|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| Power Source | Level Number | LEVEL OF MECHANIZATION | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Resolve Space | Inspect Gauge | Broach | Inspect Broach | Inspect Drill | Bore | Mill | Drill | Test | Mill | Drill | Drill | Drill | Inspect Bore | Bore | Tap | Flush | Assemble | Assemble | Inspect Bore | Assemble | Bore - a mill | Inspect Broach | Bore | Inspect Bore | Rose | Flush | Assemble | Test | Repair | Salvage | Flush | Wash | Grade | Inspect Invert | Invert | Inspect Transfer to storage | PH | | | | | | | |
| Performance Control | Responds with Action | 17 | Anticipating required performance and adjusting accordingly | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 16 | Correcting performance while operating | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 15 | Correcting performance after operating | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 14 | Identifying and selecting appropriate action | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 13 | Segregating or rejecting according to measurement | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 12 | Changing speed, position, or direction according to measurement | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mechanical Control | Responds with Signal | 11 | Recording performance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 10 | Signaling the measurement value | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 9 | Measurement of a characteristic | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Manual Control | Manual | 8 | Actuation by introduction of work piece or material | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 7 | Power tool, remote control | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 6 | Power tool, program control (sequential functioning) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 5 | Power tool, fixed cycle (single function) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Manual Control | Manual | 4 | Power tool, hand control | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 3 | Powered hand tool | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 2 | Hand tool | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Hand | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

NOTE: (1) Dots on lines between operations represent the level of the materials-handling device. (2) If an additional "X" is shown in a column, it represents a distinctly different function at that particular station—that station is on the designated level. (4) Almost every manually, inspection before or after operation. (3) The machine tool on Level 8 is a Level 6 mechanism, actuated letter "P" means that only a part of the operation done upon receipt of work from the materials-handling device.

EXHIBIT I. SUGGESTING THE NATURE OF MECHANIZATION IN PRODUCTION

| | Basic function (pertaining to the span) | Major activities | Degree of mechanization (indicating the level) | Prevalence of mechanization in industry (indicating the amount) |
|---------------------------------|---|---|--|--|
| Largely physical action | Processing (creation of form utility) | Forming | Medium to extremely high | Almost entirely mechanized |
| | | Assembling | Very low, with a few high exceptions | Very little, with exceptions |
| | | Packaging | Very low to extremely high | Much in mass-production industries and bulk-material work (powders, liquids, etc.); little elsewhere |
| | Movement (creation of time and place utility) | Materials handling | Low to, extremely high | Moderate, but rapidly increasing |
| | | Transportation | Medium | Almost entirely mechanized |
| | Storage (creation of time and place utility) | Raw materials and finished goods storage | | Medium to very high |
| In-process storage | | | Low to medium | Very low, with a few exceptions |
| Warehousing | | Low to moderate, with a few high exceptions | Roughly proportional to volume and size of object stored | |
| Both physical and mental action | Maintenance (retention of utility) | Maintenance | Very low | Hand and hand tools universally used |
| Largely mental action | Design (conception, analysis, interpretation, planning) | Product design | Low to moderate, with a few high exceptions | Very little, except in highly engineered products such as aircraft |
| | | Process design | Low | Very little, with exceptions |
| | | Inspection | Low to moderate, with a few high exceptions | Much (particularly in mass production) |
| | Measurement | Testing | Moderate to very high | Much |
| | | Production control | Very low, with slight exceptions | Fairly common |
| | | Inventory control | Low to moderate, with a few high exceptions | Much |

EXHIBIT II. MECHANIZATION PROFILE — RUBBER MATTRESS UNIT



NOTE: Dots on lines between operations represent the level of the materials-handling device.

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| 168 | <p>"ROLF-Current Review and Future Prospects." J. Cope. <u>Mining Electrical and Mechanical Engineer 50</u> (582) April 1969. Experience gained with existing equipment since 1964 and the new equipment introduced since then. Describes the installations in 9 collieries, and the current state of development of machine steering and chock control sys- tems, instrumentation and radio control.</p> |
| 169 | <p>"Der Stand des folgegesteuerten und des automatischen Strebausbaus." Dr. H. Irresberger. <u>Gluckauf</u>, March, 1969</p> |
| 170 | <p>"Automatisierung und Fernwirktechnik im Bergbau." Dr. J. Olaf. <u>Gluckauf</u>. September, 1969</p> |
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Webb. Measurements and Controls. v1, n9 (September, 1968)
p.313-20.
Study of feasibility of automatic vertical steering
of conveyor mounted shearer on mechanized longwall face;
paper covers description of longwall face, need for control,
method of steering, error sensing, control system ob-
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along - face modes, and design and operation of scale
model.
- 173 "Longwall Developments in Great Britain." Sheppard.
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- 174 "Support Problems in Mechanized Mining." Binns. Mining
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the coal getting capacity of the electro-hydraulic ROLF
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J. N. Duncan. The Mining Electrical and Mechanical Engineer.
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- 181 "The Influence of New Developments on Control and Supervision of Mine Operations." T. W. Peters. Mining Engineer 126 (76) January, 1967.
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- 182 "ROLF 4 at Woolley colliery : Application of Automated Equipment to a Thin Seam." C. Round. Colliery Guardian 214 (5518) January, 1967.
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| 184 | "Powered Supports - 1965." N. H. McLeod. <u>Mining Engineer</u> . 125 (67) April, 1966. In the section on modern control systems, R.O.L.F. is briefly discussed. |
| 185 | "Preparations for R.O.L.F. at Marine colliery." R. E. Lindsay et al. <u>Mining Engineer</u> 126 (75) December, 1966. The design adopted envisages the use of advanced heading techniques with coal blasted off the solid and loaded by means of gathering arm loaders. Face and equipment and conditions in the gate road are discussed. |
| 186 | "Remote Control at the Coalface." D. Martin. <u>Transactions Society of Instrument Technology</u> 18 September, 1966. Automation of the coal face requires the application of coal-sensing and self-steering principles to the cutting machine to confine it within the vertical limits of the seam. Elaborate systems for the automatic control and movement of roof supports have had to be devised. To allow for the occasional presence of maintenance workers during operations, an efficient speech communication system and safety devices are essential. |
| 187 | "The Application of Remote Control Techniques and the Intensive Use of Plant Capacity." T. W. Peters. <u>Mining Engineer</u> 125 (69) June, 1966. Reviews progress in the installation of remotely controlled plant and discusses proposals implemented at Bevercotes. These activities are then discussed in the light of future operating conditions. Certain conclusions are drawn affecting future activities as to face length, face ends, face access, the space occupied by plant immediately behind the face, manriding, materials and dirt handling and coal clearance. |
| 188 | "The Role of Electronic Instrumentation As An Aid To Management." A. E. Bennett. <u>Mining Engineer</u> 125 (68) May, 1966. Synopsis of paper. |
| 189 | "The Role of Electronic Instrumentation As An Aid To Management." A. E. Bennett. <u>Mining Engineer</u> 125 (72) September, 1966. Discusses remotely controlled conveyor schemes and their associated manless transfer points. Considers the application of ROLF to improving machine utilization times. A case is made for the establishment of a surface remote indication centre and a production controlled responsible for the flow of coal from the face to the wagon. |

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- 191 "The Transfer of ROLF II at Ormonde colliery." B. G. Wright.
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Deals with the transfer of the equipment from Piper I seam to Piper 18.

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| 192 | "Anderton Shearer Loader Arranged with Independent Haulage for ROLF Operation." <u>Colliery Guardian</u> 211 (5443) August, 1965. Modifications made in the AB Sixteen Anderton Shearer Loader. |
| 193 | "Current Experience with Remotely Operated Longwall Faces and Their Future Application." J.H.R. Cope. <u>Mining Engineer</u> 124 (56) May, 1965. Synopsis of paper. |
| 194 | "Historical background of Remotely Operated Longwall Faces." W. Adcock. <u>Mining Electrical and Mechanical Engineer</u> 45 (533) March, 1965. In 5 parts: (a) remote control of face supports (b) remote control of all operations between stables (c) evolution of ROLF pilot installations (d) performance of ROLF pilot installations (e) future developments |
| 195 | "NCB." <u>Public Relations Department</u> . Mining by remote control. 1965. |
| 196 | "Philosophy and Future Developments of ROLF." J. Cope. <u>Mining Engineer</u> 125 (62) November, 1965. Gives details of the installation and beginning of operation of the first 2 ROLFS. Part 2 summarizes the results to date and analyses the operation of the separate developments. Also discussed is the philosophy involved in the project and the proposed extension of ROLF. |
| 197 | "Planning a Remotely-Operated Longwall Face." W. D. Alcock and K. Caswell. <u>Mining Engineer</u> 124 (52) January, 1965. Synopsis of paper. |
| 198 | "Remote Control of Electrical and Mechanical Equipment at the Coalface." R. F. Lansdown. <u>Mining Engineer</u> 124 (3) February 1965. A report on a symposium held by the AMEME in Harrogate, November 1964. |
| 199 | "Remote Control of Face Machinery : 1. Coal Winning Machines." B. Pidgeon and V. Thomas. <u>Mining Electrical and Mechanical Engineer</u> 45 (533) March, 1965. The main requirements for remotely controlled cutter-loaders: steering, haulage, power supply to the machine and associated controls, protective and auxiliary monitoring cable handling and tele-control techniques. |
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| 202 | "Some Impressions of the 1965 C.U.M.M. Exhibition." D. N. Simpson. <u>Mining Engineer</u> 124 (60) September, 1965, Exhibition by the Council Underground Machinery Manufacturers; includes a consideration of ROLF. |
| 203 | "Technical Means of Increasing Productivity in the British Coal Industry." <u>Mining Engineer</u> 125 (63) December, 1965. Study for the year 1964/65 by the Institution of Mining Engineers Junior Council. Includes a very brief consideration of ROLF on p168. |
| 204 | "Evaluation of Remotely Operated Longwall Face: 1 Shearer-Loader Automatic Vertical Steering System." R. Webb and D. Hartley. <u>National Coal Board MRE Report</u> 2292, 1965. Describes the evaluation trial. Results and supporting theoretical work show that the present automatic control system cannot provide satisfactory control of conveyor attitude and position over successive cuts. Using the knowledge gained, a stable control system can be evolved to steer the conveyor as the face advances, taking account of conveyor inclination towards the face and of vertical position in the seam. |
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| 206 | <p>"Coal-face Machinery Developments at Bretby." R.F.Lansdown. <u>Mining Engineer 123</u> (46) July, 1964. The section on developments as an aid to automatic operation contains a reference to R.O.L.F.</p> |
| 207 | <p>"Further Developments in Remote Control." <u>Colliery Engineering 41</u> (480) February, 1964 Describes a recently developed system utilizing a thin seam remote-hauled shearer for coal getting.</p> |
| 208 | <p>"Installation of ROLF II at Ormonde Colliery," G. Cook. <u>Colliery Guardian 209</u> July, 1964.</p> |
| 209 | <p>"Remote Function and Control of Coalface Operations." J. Sheldon et al. <u>Mining Engineer 123</u> (45) June, 1964. Traces the developments in mechanization ideas and techniques at the coalface which led to the design and operation of R.O.L.F. Early results from the operation of R.O.L.F. are given and the effects of further improvements, particularly the mechanization of face-end operations are discussed.</p> |
| 210 | <p>"An Automatic Control System for Self-advancing Roof Supports." E. J. Ferrier. <u>Collier Engineering</u>. August, 1964.</p> |
| 210a | <p>"Developments in Underground Remote Control and Monitoring Systems." L. A. Nordmann. <u>Proceedings of the AMEME</u>, June 1965</p> |

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| 211 | <p>"Coal Mining by Remote Control." <u>Process Control Automation</u> <u>10</u> (8) August, 1963. Account of the ROLF systems at Newstead and Ormonde collieries.</p> |
| 212 | <p>"Conventional Machinery Controlled from the Gate: First Step to Automation." <u>Steel and Coal</u>. <u>187</u> (4956) 12 July 1963. Separate descriptions of the Gullick support system at Newstead colliery, and the Dowty system at Ormonde colliery.</p> |
| 213 | <p>"Remote Control of Coal Winning and of Advancing Supports at the British Mines, Newstead and Ormonde, by F. Spruth. <u>Glueckauf</u> <u>99</u> (22) 23 October 1963. In German</p> |
| 214 | <p>"Remote Control of Coalfaces : Two Successful Installations in the East Midlands Division. <u>Colliery Guardian</u> <u>207</u> (5333) July, 1963. Two coalfaces operated by remote control are briefly discussed under basic design, coal sensing devices, com- munications, and power supplies.</p> |
| 215 | <p>"The Remotely Controlled Longwall Face." A. Bennett. <u>Mining Electrical and Mechanical Engineer</u> <u>44</u> (514) August, 1963. Outlines the basic system evolved by MRE and details the equipment installed at Newstead colliery.</p> |
| 216 | <p>"Remotely Operated Longwall Face." <u>Engineer</u> <u>216</u> (5606) 5 July 1963. Describes the operation.</p> |
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| 219 | <p>"Thin Seam Mining by Remote Control." <u>Engineering</u> <u>196</u> (5073) 12 July 1963. Discusses access to thin seams, equipment, power loading and roof supports.</p> |

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