HISTORICAL PERSPECTIVE AND FUTURE PROJECTION OF LONGWALL MINING IN THE UNITED STATES

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ABSTRACT

This report chronicles the historical development of longwall mining in the United States and speculates on future developments to the turn of the century. Five eras of technological development during the modern period are described and analyzed. These eras discuss the development of (1) mechanized extraction, (2) self advancing roof supports, (3) high capacity roof supports, (4) shield supports, and (5) system automation. Current trends are analyzed in terms of: longwall utilization, production capability, support capacity, face widths, and new technological developments. From these analyses, the future of longwall mining to the year 2000 is speculated. It is concluded that longwall mining will continue to grow in importance during the next decade and that the next major technological milestone will be the realization of a fully automated longwall mining system.

INTRODUCTION

Longwall mining is believed to have originated in Shropshire, England toward the end of the 17th Century and was introduced in the United States in 1875 by emigrating miners from Wales (1). Longwall mining currently accounts for nearly one third of the underground coal production and continues to set productivity records. But, it was only through a long history of successes and failures that this technology has developed into the safest and most productive underground mining system.

This report describes the mining practice associated with the first longwall installations and chronicles five eras of technological development from 1950 to 1990 that contributed significantly to the advancement of longwall mining in the United States. Measures of longwall utilization, contribution of longwall mining to underground coal production, and face productivity are analyzed and compared. These data provide a data base for analyzing past and current trends to forecast the future of longwall mining in the United States.

TECHNOLOGICAL ERAS IN LONGWALL MINING

The historical utilization of longwall mining in the United States is depicted in figure 1. As indicated in the introduction, two general periods of utilization are evident: (1) the period between 1875 and 1950, and (2) the period between 1950 and 1990.

Figure 1. Historical utilization of longwall mining in the United States.

EARLY PERIOD (1875-1950)

Longwall operations in the late 1800's and early 1900's were characterized as advancing faces
developed radially from a central shaft with hand-made packwalls and wood posts used to provide ground control (2.1) as shown in figure 2. The coal at the face was undercut, usually by hand and supported by sprags set on 4 to 6 ft centers. When undercutting was completed, the sprags were knocked out allowing the immediate face coal to break free. The coal was then loaded and transported from the face and an additional row of props was set near the new face prior to the next mining sequence.

Figure 2. — Early form of longwall mining.

Although better roof supports provided by steel props and improved haulage provided by slushers and face conveyors reduced manpower requirements from a typical face crew of 42 people to 25 (4), longwall mining remained a labor intensive effort with a productivity of only 3 tons per man-day (5). Maximum tonnages of 750 tons per day were reported (4).

MODERN PERIOD (1950 - 1990)

As mechanized longwall equipment became available, the profile of the panel changed from the circular geometries with a series of small faces to a single face developed across a large rectangular panel. Longwall mining as we are familiar with it today evolved through the implementation of several technological developments.

1950 - 1960 Era -- Mechanized Extraction

The modern longwall mining period began in 1952 with a Bureau-sponsored trial at the Stotesbury mine of Eastern Gas and Fuel Associates near Beckley, WV (2). The most significant technological development during this period was the introduction of the plow. The plow provided mechanized extraction and replaced the labor intensive method of undercutting. Early plow systems were limited to friable coals (Hardgrove Grindability Index of 70 to 80) (19).

The primary constraint to increased production during this era was roof support advance. Mechanical friction props and wood cribs were the predominant support system, and they had to be manually removed from contact, and in the case of the wood cribs, reconstructed as the face advanced. The first hydraulic props were also introduced towards the end of this era, but they also required manual labor for recovery and resetting, and the labor-intensive wood cribs were still required to provide additional support.

A summary assessment of longwall performance during the 1950 - 1960 era is shown in table 1. Average annual face production is estimated at 58,000 tons with an estimated productivity of 5 tons per man-day. Longwall utilization grew continually until the end of the era averaging 6 faces over this time.

Table 1. Assessment of longwall performance during 1950-1960 era.

<table>
<thead>
<tr>
<th>PERFORMANCE MEASURE</th>
<th>1950</th>
<th>1960</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization (number faces)</td>
<td>4</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Production (pot underground)</td>
<td>&lt;0.1</td>
<td>.15</td>
<td>0.1</td>
</tr>
<tr>
<td>Annual face production (tpy)</td>
<td>20K</td>
<td>70K</td>
<td>58K</td>
</tr>
<tr>
<td>Productivity (tpd)</td>
<td>4</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>

1960 - 1965 Era -- Powered Roof Supports

The introduction of self-advancing supports removed the productivity constraint caused by the labor-intensive wood cribs and friction jacks. Eastern
Associated Coal Company installed the first hydraulic, self-setting and self-advancing, roof support system in 1960. The first self-advancing roof supports were of frame-type construction wherein two hydraulic jacks were connected by a beam to form a frame construction (g). Longwall installations using self-advancing frame supports were successful in strata conditions where the roof caved easily behind the advancing supports. There were serious failures when these supports were installed under more competent roof strata, such as massive sandstone and limestone. The inadequacy of these low capacity support systems to control competent roof was best illustrated by several failures at Old Ben Coal Co. in Illinois, where six failures were experienced with low capacity support systems at their No. 21 mine between 1962 and 1971.

Another significant technological development that occurred during the 1960 - 1966 era was the introduction of the shearing machine, which provided active cutting of the face coal from an electrically-powered rotating drum. Kaiser Steel Coal Corporation installed the first shearer in the United States in their Sunnyeide mine in 1961 (g). The capability of active coal cutting alleviated the soft coal constraint of plow installations and hence expanded the application of longwall mining to other coal seams. Shearer extraction was adopted fairly quickly. From its inception in 1961, shearer utilization increased to 42 pct of the longwall operations by 1966 (see figure 3).

Performance during the 1960 - 1966 era is summarized in table 2. Utilization fell during the beginning of the period and then rose as the powered roof support technology was implemented. On average, the number of installations grew by 50 pct over the previous era (1950 - 1960). However, longwall mining was still limited in application and reports of failures in the Illinois Coal Basin stifled utilization. The number of faces reached only 18 by 1966. However, successful installations demonstrated improved production capability over the previous era. Annual face production increased by 72 pct and face labor productivity jumped 183 pct as the support advance constraint was removed by the self-advancing roof support technology. Longwall mining accounted for about 0.4 pct of the total underground production by the end of this period.

Table 2. Assessment of longwall performance during 1960 - 1966 era.

<table>
<thead>
<tr>
<th>PERFORMANCE MEASURE</th>
<th>1960</th>
<th>1966</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization (number faces)</td>
<td>10</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Production (pct underground)</td>
<td>0.15</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Annual face production (tpy)</td>
<td>70K</td>
<td>125K</td>
<td>100K</td>
</tr>
<tr>
<td>Productivity (tpd)</td>
<td>8</td>
<td>20</td>
<td>17</td>
</tr>
</tbody>
</table>

1966 - 1975 Era -- High Capacity Supports

Support capacities increased by a factor of 2 to 4 during the 1966 - 1975 era with four-leg supports providing resistances as high as 700 tons. Average support capacity was approximately 475 tons. A significant advancement in support design was achieved with development of the chock support, which can be thought of as a mobile crib. The chock support improved structural stability and increased roof contact area over the previous frame-type systems. Chocks were the preferred roof support for shearer installations because they could be placed quickly and provided better control of face alignment since each unit was
connected directly to the face conveyor.

In addition to improvements in support capacity and design, technological improvements were also made in extraction systems. The Gleithrobel ploow eliminated the troublesome guidance problems. Face-side haulage also provided more efficient utilization of haulage power to coal cutting, which allowed ploow application in harder coal seams.

Despite these improvements in ploow technology, the trend favored the use of shearing machines. A significant development in shearer technology that helped spur the application of shearing machines was the introduction of the double-drum and ranging-arm design. The primary advantage of the double-drum machine was its quick capability in cutting height adjustment. This was most advantageous in undulating coal seams and in conditions where cutting height had to be routinely adjusted to leave top coal in order to provide control of unstable immediate roof.

Operational improvements developed during the 1966-1975 era included the one-web back method of support advance. The one-web back system kept the supports one cutting web away from the face conveyor so that the supports could be advanced without having to first advance the conveyor. This allowed supports to be advanced immediately after the shearer passed, which improved roof control in friable roof geologies by minimizing the time during which the roof in front of the supports remained unsupported.

This era marked the first viable commitment to longwall mining by the United States. Utilization rose by 266 ppt from the previous era. By 1975, 58 longwall faces were operated by 28 different coal companies. The improved roof control provided by the high capacity supports contributed to significant improvements in both production and productivity. Average annual face production increased by 45 percent and productivity increased by 47 ppt from the previous era. On average, longwall faces were producing 196,000 tons per year at a productivity level of about 25 tons per man-day. By 1975, longwall mining accounted for 3.1 ppt of the total underground coal production. An assessment of performance during this era is shown in Table 3.

Table 3. Assessment of longwall performance during 1966-1975 era.

<table>
<thead>
<tr>
<th>PERFORMANCE MEASURE</th>
<th>1966</th>
<th>1975</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization (number faces)</td>
<td>18</td>
<td>58</td>
<td>33</td>
</tr>
<tr>
<td>Production (pct underground)</td>
<td>0.7</td>
<td>3.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Annual face production (tpy)</td>
<td>125K</td>
<td>157K</td>
<td>196K</td>
</tr>
<tr>
<td>Productivity (tpad)</td>
<td>20</td>
<td>30</td>
<td>25</td>
</tr>
</tbody>
</table>

1975-1985 Era -- Shield Supports

The development of the chock support and the increase in support capacity to control massive strata common to many U.S. coal seams led to the establishment of longwall mining as a potentially viable mining system. However, failures were still being experienced because of the inadequacy of the chock supports to control competent strata that tended to cave in large pieces exerting rotational moments or horizontal displacements on the support structure. It was not until the introduction of the shield support in 1975, with its improved lateral stability and more complete roof cover, that longwall mining proved successful. Shield utilization rose dramatically as shown in Figure 4 from its introduction in 1975. By 1965, over 90 pct of the operating longwall faces were supported by shields.

Figure 4. - Shield utilization.

The first shield-supported face installed in the United States was by Consolidation Coal Company at their
Shoemaker mine near Moundville, West Virginia. From the very beginning, encouraging results were obtained. The face produced 750,000 tons in its first year of operation (2). This compares with an industry average annual face production of 196,000 tons for the high capacity chock support era (1966 - 1975).

Although the development of the shield was the most significant technological advance of this era, several other advancements were made: (1) chainless shearer haulage, (2) in-web shearing machines for thin seam operations, (3) center-mounted face conveyor chains, and (4) water spray technology for dust control.

An assessment of performance during the shield support era is shown in Table 4. Clearly, longwall mining reached maturity during this era. Overall, utilization more than doubled by 1985 when as many as 118 faces were operating compared with 56 installations in 1975. Production grew from about 9 pct of the total underground production in 1975 to nearly 19 pct by 1985. When the utilization of shield supports became well established (1970), face production increased dramatically. Between 1978 and 1983, average annual face production increased by nearly 250,000 tons (16.5 pct) from approximately 150,000 to 400,000 tons per year. This compares with a nearly constant face production of about 200,000 tpy for the seven years preceding the establishment of the shield support. A record daily face production of 21,950 tons was set in 1984 at Island Creek’s Lohman mine in West Virginia. It is estimated that productivity averaged about 41 tuns per man-day during the shield era, an increase of 64 pct from the previous chock and frame support era.

1985 - 1990 Era -- Automation

The final major development in longwall mining was the introduction of electrohydraulic control systems for shield supports. The first electrohydraulically-controlled shield support system was installed in 1984 (10). Nearly all shields purchased since 1985 have been equipped with electrohydraulic control systems.

Table 4. Summary assessment of longwall performance during the 1975 - 1985 era.

<table>
<thead>
<tr>
<th>PERFORMANCE MEASURE</th>
<th>1975</th>
<th>1985</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall utilization (number faces)</td>
<td>58</td>
<td>118</td>
<td>94</td>
</tr>
<tr>
<td>Production (pct underground)</td>
<td>3.1</td>
<td>18.6</td>
<td>8.5</td>
</tr>
<tr>
<td>Annual face production (tpy)</td>
<td>157K</td>
<td>604K</td>
<td>269K</td>
</tr>
<tr>
<td>Productivity (tpmd)</td>
<td>30</td>
<td>64</td>
<td>41</td>
</tr>
</tbody>
</table>

The motivation for the development of these control systems was to provide a capability for moving a group of supports from a dust-free location. The electrohydraulic system also provided faster support advance with less labor. This allowed shearer cutting (haulage) speeds to increase, providing an increase in mining rate and hence overall coal production.

This technology was further developed to include a shearer-initiated control system (see figure 5), wherein the shearer emits a signal that is picked up by the shields which in turn activates the execution of the roof support and conveyor advance cycle.

Figure 5. - Shearer-initiated electrohydraulic control system.

The growth in longwall utilization actually fell during the automation era from a high of 118 installations in 1985 to 95 installations in 1990. This decline in utilization was partly due to economic and market conditions. Another contributing factor was the fact that the more productive longwall operations were able to meet market demands with fewer operations. Annual production for longwalls more than doubled from 1985 to
1950, despite a 19 pct reduction in the number of operations. By 1990, several installations were regularly producing 1 to 2 million tons per year. Average annual face production grew from 604,000 tons in 1985 to 1,131,000 tons in 1990. An assessment of longwall performance during the automation era is shown in Table 6.

Table 6. Assessment of longwall performance during the 1985 - 1990 era.

<table>
<thead>
<tr>
<th>PERFORMANCE MEASURE</th>
<th>1985</th>
<th>1989</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization (number faces)</td>
<td>118</td>
<td>92</td>
<td>102</td>
</tr>
<tr>
<td>Production (pct underground)</td>
<td>18.6</td>
<td>29.0</td>
<td>23</td>
</tr>
<tr>
<td>Annual face production (tpy)</td>
<td>604K</td>
<td>1131K</td>
<td>872K</td>
</tr>
<tr>
<td>Productivity (tpmd)</td>
<td>64</td>
<td>149</td>
<td>109</td>
</tr>
</tbody>
</table>

**TRENDS ANALYSIS AND FUTURE PREDICTIONS**

Historical trends in longwall development have been examined and future predictions for the decade of the 1990's have been made by extrapolation of current trends and speculation of anticipated behavior. Projections of continued and new technological developments are also made.

**UTILIZATION**

A review of longwall operations shows three general trends in longwall utilization as shown in Figure 7: (1) slow growth rate from 1950 to 1969, (2) fast growth rate from 1969 to 1982, and (3) a declining utilization from 1983 to 1990. The dramatic increase in growth beginning in 1969 can be attributed to the enactment of the 1969 Coal Mine Health and Safety Act, which provided incentive to pursue the longwall method, and to the technological advancements in equipment that made longwall mining a more viable mining method. The decline in utilization in the mid-1980's was a surprise to most analysts at the time, who were predicting continued longwall growth well into the 1990's. To some extent, longwall mining became a victim of its own success. The dramatic increases in production that was realized in the 1980's made it possible to meet supply demands with fewer operations, as evidenced by the continued increase in production during the decline in the number of operating longwall faces.

Contrary to the prediction of 200 or more installations by the early 1990's, the recent trend suggests a gradual increase in utilization to about

Figure 6 - Comparison of technological eras.

Figures 7. - Trends in longwall utilization.
installations by 1995. Longer term growth will depend largely upon market demand. It is unlikely that any one mine can realistically employ more than two operating longwalls. Constraints to longwall utilization per mine are primarily methane liberation (ventilation), transportation of the coal out of the mine, and prep plant capacity.

FACE PRODUCTIVITY

A historical perspective of average annual face production is shown in figure 8. Productivity increased gradually from 1950 to 1965 as longwall reached its initial stage of application by several mines. Productivity improved significantly for a short time from 1966 to 1969, largely due to the improved roof control provided by the high capacity support systems. Productivity then declined for three years as a result of ground control difficulties experienced in massive sandstone and limestone strata conditions and from consequences of the 1969 Coal Mine Health and Safety Act. A stagnant period existed from 1971 to 1975. After 1976, when shield utilization reached about 40 pct, productivity accelerated sharply.

Figure 8. - Trends in face productivity.

A continuation of the trend established since 1978 would suggest an average production of about 2.2 million tons per face by the year 2000. However, 20 - 30 pct increases in productivity are not likely to continue indefinitely. Performance during the past 2 to 3 years would suggest an increase in average annual productivity to only 1.35 million tons per face by the year 2000. As newer mines are built to accommodate high productive longwall operations, higher productivity measures are likely. Hence, it appears that a more reasonable expectation for annual longwall production by the year 2000 is about 1.75 million tons per face.

SUPPORT CAPACITY

A review of support capacity as shown in figure 9 shows four general trends. Support capacity increased gradually from 1950 to 1966, when higher capacity support systems were introduced. From 1966 to 1972, support capacity grew dramatically at a rate of about 5 times that of the previous trend. Capacity remained essentially constant at 4.75 tons for the next 8 years as the higher capacity chock supports were being replaced with lower capacity shields. In 1980, support capacity again grew at a rate similar to that of the 1950 to 1966 period as shield capacities again began to increase. At present (1990), there is some evidence that the increase in support capacities are again leveling off, suggesting that more optimal levels of support capacity are being employed.

Figure 9. - Trends in support capacity.

The average support capacity for longwall installations operating in 1959 was about 560 tons compared to 470 tons in 1986. The current trend established since 1980 suggests average support capacity for all longwall installations will be about 675 tons by the year 2000, although this estimate is sensitive to the replacement rate of older low-capacity supports. Maximum support capacities have increased from 700 tons in 1980 to 900 tons in 1990. Thirteen of the 96 longwalls operating in 1990 employed shields with capacities greater

11th International Conference on Ground Control in Mining. The University of Wollongong, N.S.W., July 1992. 105
than 700 tons and 44 had capacities greater than 600 tons. It is unlikely that maximum support capacity will grow much beyond 1,000 tons with current designs because of the size of the hydraulic leg cylinders required to accommodate larger capacities.

The increase in support capacity during the decade of the 1980’s has been justified under the premise that heavy-duty supports will last longer and provide more effective ground control in difficult seam conditions. However, experience has shown that increased durability has not been realized generally, as failures of high capacity supports continue to occur. It is speculated that the primary reason for the lack of improved durability with high capacity supports is that setting forces and shield stiffness have increased in direct proportion to the increases in yield capacity. Since about 80% of the total support loading is generated by actively setting the shield against the roof and the since stiffer high capacity supports react a larger load per unit face convergence, the higher capacity supports are stressed to roughly the same degree as the lower capacity supports. Hence no improvement in durability or life span is realized.

FACE WIDTHS

The historical trend has been an increase in face width of about 5 ft per year from 1970 to 1980 and about 20 ft per year from 1980 to 1990 as shown in figure 10. The average face width in 1980 was 650 ft, although there were 18 installations with face widths greater than 600 ft. The longest reported face width in 1990 was 915 ft on four installations in Ohio and Illinois. A continuation of the recent trend would suggest an average face width of about 1,000 ft by the year 2000.

It is also likely that maximum face widths are approaching an upper limit of about 1,200 ft with current technology. The primary constraint to further increases in face widths remains the power limitations and chain strength of the face conveyors. Capital equipment costs for the face supports and conveyors will eventually become a limitation as well. Average face widths are speculated to continue to increase throughout the decade of the 1980’s as operators are likely to continue to employ wider faces on newly developed panels.

Figure 10.- Trends in face width.

NEW TECHNOLOGICAL DEVELOPMENTS

Longwall automation is likely to continue to evolve over the next 20 years as current research is perfected and implemented into system design, providing an extension of the current automation era which began in 1985. The most predictable trend is a wider employment of shearer-initiated electrohydraulic control systems for shield support automation. By the year 2000, it is probable that all of the currently manually operated shield control systems will have been replaced by automated systems.

The most pressing automation requirement is for technology that can detect roof and floor boundaries [11]. This technology would provide automated shearer horizon control and hold the potential for removing the shearer operator from the hazardous environment near the active machine. A fully automated plow face using an automated shield advance system is currently in operation at U.S. Steel’s Mine No. 5 in West Virginia.

It is also likely that the basic equipment design of the near future will be much the same as it is today. The most significant equipment change probably will be an increase in shield canopy width from the current 1.5 m to 2.0 m. The benefits of the wider canopy design would be a reduction in support cost per unit foot of supported face, since a considerable portion of the support cost is the machining and manufacturing of the hydraulic leg cylinders. The wider supports are also more stable. This will be of benefit in thick seam applications. Some reduction
in face move time may also be realized since fewer supports will be employed.

CONCLUDING REMARKS AND SUMMARY

The contribution of longwall mining towards improving the safety and productivity of underground coal mining is unparalleled in mining history. It has been more than 50 years since mechanized loaders and continuous mining machines made a similar impact on the productivity of the U.S. coal industry. Longwall mining has become and will continue to be a major factor in the ability of the United States to remain a world leader in coal production. If current trends continue as shown in figure 11, longwall mining could account for as much as 50 percent of the underground coal mined in the United States by the year 2000.

![Figure 11. Trends in the amount of coal mined by the longwall method.](image)

Longwall mining has evolved into the safest, most productive, and most conservative of underground mining systems. Each of the six technological eras chronicled in the history of longwall mining made unique contributions to make its efficacy. The development of the shield support probably had the most impact. Figure 12 compares longwall utilization, annual face production, and total production for the pre-shield and post-shield era. Average face production increased by 290 percent from 286,000 tons per year to 1,131,000 tons per year, while utilization increased by 470 percent from an average of 17 faces prior to shield utilization to 97 faces after shield utilization.

![Figure 12. Comparison of longwall performance before and after the introduction of shield supports.](image)

Technological improvements will continue to provide gains in face productivity, but these advancements probably will not be as great as those experienced during the decade of the 1980s. The next major accomplishment likely will be a fully automated longwall system that can be operated at a remote location beyond the immediate face area. Prototypes of such a system should be in place by the turn of the century and again mark a major and possibly the final milestone in of longwall development.

While the future for longwall mining looks promising, there are some concerns that pose threats to its future utilization and development. The biggest concern is that of surface subsidence. U.S. coal fields are not typically located in heavily populated regions, but any damage to surface structures creates a hardship for those involved and negatively influences public perception. Environmental issues, such as damage to the water table, are important concerns that must also be addressed. Although subsidence is predictable, it is at present largely uncontrollable. Methods to control subsidence through backfilling behind the supports continue to be cost prohibitive.

Respirable dust is likely to remain the major health concern during the next decade. Longwall compliance rates are again declining as productivity outpaces current dust control technology. Only about 63 percent of the operating longwalls currently meet the regulated dust standards.

The Bureau of Mines is continuing a research program to improve the health and safety and productivity of longwall mining. This research includes: (1) continuing efforts to provide automated
Shearer horizon control, (2) efforts to optimize shield design and utilization, (3) dust control research to bring high productive longwalls into compliance, (4) pillar and gate road design to provide effective ground control while maximizing resource recovery, (5) improved subsidence prediction and abatement technologies, and (6) real time hazard warning systems to alert the operator of ground control and environmental safety hazards. Through these research efforts, it is believed that longwall mining will continue to be the safest and most productive mining system well into the next century.

REFERENCES
