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FACTORS RESPONSIBLE FOR VARIATION IN PRODUCTIVITY OF ILLINOIS COAL MINES

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INTRODUCTION

Productivity varies widely among coal mining operations in Illinois. In 1973 productivity of underground mines ranged from 9 to 30 tons per man-day. The spread was even greater for strip mining operations, productivity of which ranged from 13 to 84 tons per man-day.

"Productivity" herein has been calculated by dividing the tons of coal shipped during a year by number of man-days worked during that year. The man-days used in this calculation exclude man-days worked at the preparation plant, shop, loading dock, or office. The data on man-days worked at individual operations were obtained from the U.S. Bureau of Mines Safety Analysis Center in Denver, Colorado. Other data were extracted from original reports individual companies had made to various Federal and state agencies, including the Illinois State Department of Mines and Minerals, the U.S. Bureau of Mines, the U.S. Department of Mine Enforcement and Safety Regulations, and the Illinois State Geological Survey.

As approximately 40 percent of a mine's total operating cost goes for labor, the factors that affect labor's productivity should be evaluated. In this study, data from 29 underground mines and 32 strip mines that operated in Illinois from 1970 to 1973 are used to illustrate the relation between mine productivity and the various factors that seem to influence that productivity. The factors examined include the natural conditions in the mine, the production capacity of the mine, the age of the operation, the extent of coal preparation, and the effective use of mining equipment and time. In strip mines the additional factors of stripping ratio and method of mining were considered.

Because the various factors that influence productivity are interrelated, the precise relation between any one factor and productivity is difficult to determine. Throughout this study when the relation of any individual factor to mine productivity was considered, the influence of other factors also was taken into account wherever possible. In spite of this, the results obtained, as expected, were not sufficiently precise to single out any individual factor and quantify its influence on mine productivity. However, the relations revealed certain trends that could be useful in further analysis and evaluation of coal mine productivity.

UNDERGROUND MINING

Numerous factors influence underground mines productivity. The factors analyzed in this report include thickness of the seam mined, roof and floor conditions in the mine, size (annual production capacity) of the operation, age of the operation, quality of the finished product (coal preparation), and effective use of mining equipment. The presence of water in the mine, the quantity of methane emitted, and management philosophy could not be analyzed because of insufficient data.

Seam Thickness

The influence that the thickness of the coal seam being mined has on productivity has been demonstrated by Risser (1966), who showed that an increase in thickness of seams mined resulted in an increase in the productivity. The most obvious cause of a rise in productivity as the thickness of the coal increases is the greater amount of coal available per square mile (table 1). Thick coal seams also improve machine maneuverability and thereby improve the efficiency of the operation.

The thickness of coal mined in various underground coal mines in Illinois is published annually by the Illinois Department of Mines and Minerals. According to their 1973 report, the thickness of seams mined during that year ranged from 4.5 to 9 feet. More than 73 percent of the total Illinois coal production from underground mines came from seams 7 or more feet thick, and most of the operations that produce more than 1.5 million tons per year were concentrated in areas where the coal was more than 7 feet thick. In one mine, 1973 production from an 8-foot seam was less than 500,000 tons, but that mine was more than 30 years old. Most of the relatively small underground mines (producing less than 1.5 million tons) in Illinois are concentrated in areas where seams are generally thin.

TABLE 1—RELATION BETWEEN THICKNESS OF SEAM AND AVAILABILITY OF COAL*

Coal thickness (ft)	Tons/acre†	Tons/mile†	Tons/twp.†
1	1,800	1,152,000	41,472,000
2	3,600	2,304,000	82,944,000
3	5,400	3,456,000	124,416,000
4	7,200	4,608,000	165,888,000
5	9,000	5,760,000	207,360,000
6	10,800	6,912,000	248,832,000
7	12,600	8,064,000	290,304,000
8	14,400	9,216,000	331,776,000
9	16,200	10,368,000	375,248,000
10	18,000	11,520,000	414,720,000

* Tons in place and unrecoverable tonnage.

† Conversion factors: 1 acre-ft of coal = 1,800 tons; 1 sq mi ft of coal = 1,152,000 tons; 1 twp. (36 sq mi) of coal = 41,472,000 tons.

In figure 1, the productivity of operations is correlated with the thickness of the seams mined. Each point represents one mining operation. Despite a wide dispersion of points, productivity increases with the thickness of the seam mined, but it levels off at a thickness of 6½ feet for most operations. Two mining operations in particular (mines 1 and 2, fig.1) show higher than average productivity, and their records show that they are located in areas where natural conditions (particularly roof conditions) were considerably better than those in other areas.

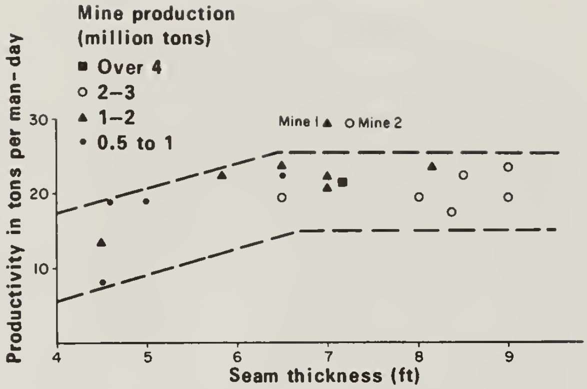


Fig. 1 - Relation of seam thickness to productivity of underground coal mines in Illinois in 1973.

The results obtained in this analysis are similar to those found by Shields et al. (1954) that showed productivity increased significantly with an increase in seam thickness up to about 84 inches and then tended to level off somewhat for thicker seams. Various explanations could be given as to why the productivity tends to level off somewhat for thicker seams. Given (1973) mentioned that increased difficulty of mining very thick seams reduces productivity.

Roof and Floor Conditions

A poor roof in an underground coal mine not only causes accidents from roof falls, but it also increases the number of man-hours spent on roof bolting, adding timbers and cribs for supplemental supports, cleaning up fallen rock, and, in some cases, recovering and repairing equipment buried by roof collapses. The man-hours lost in performing these activities reduces the productivity of an operation. Poor conditions have even resulted in complete abandonment of a section of a mine or have made continued operation of a whole mine uneconomical.

Poor roof conditions in a mine are related to the geological and physical characteristics of the 20 or 30 feet of rock strata directly overlying the coal seam. In Illinois the characteristics of overlying strata vary considerably from one mining property to another, or even within a single mine, and it follows that roof conditions in a mine or within a region also vary widely.

Floor upheaval in a mine also adversely affects mine productivity. In mines where such problems exist, many man-hours are lost in grading floors, with obvious losses in productivity. The problem in some mines is sufficiently severe to make further mining of a section impossible.

It is difficult to determine the magnitude of the impact of these natural conditions on mine productivity because the natural conditions in the mine cannot easily be quantified. Mine operators in Illinois estimate that bad roof or floor conditions could result in a loss of 10 to 35 percent in productivity in a given year.

Size of Operation

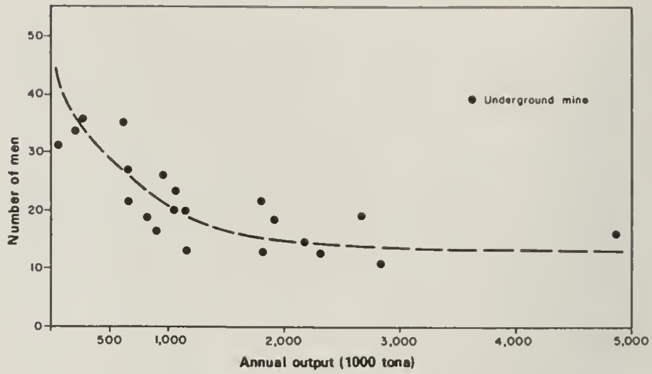


Fig. 2 - Workers needed to produce each 100,000 tons of coal from Illinois underground mines. Men working in office, shop, loading dock, and preparation plant are excluded.

The size of an operation also influences productivity. In underground mining, size of operation refers primarily to the number of production units used in the mine. A production "unit" in an operation that uses a continuous mining machine includes the "miner", two shuttle cars, belt conveyors, a feeder, and a roof bolter. A production unit in conventional mining includes a cutting machine, a loading machine, a coal drill, two shuttle cars, a roof bolter, shooting equipment, a feeder, and a belt conveyor. Theoretically, the output level achieved using either method of mining is about the same, but the conventional method of mining requires a crew of 12 to 14 men compared with an average crew of 7 to 9 men for continuous mining. Productivity of operations in conventional mining is, therefore, generally lower than that of similar operations using continuous mining.

In general, the output capacity of an operation could be increased by an increase in number of machine shifts worked per day, by adding more production units, or by replacing low-capacity equipment with higher capacity equipment. In underground mining, because the productive capacity of a mining unit is limited to about 800 tons per shift, any substantial increase in mine output requires additional mining units. When the number of shifts a unit is worked averages less than 2 per day, the production, but not necessarily the productivity, could be increased by increasing the number of shifts a unit is worked. However, only three 8-hour shifts can be operated in a day, which puts a limit on the gain in output. Any substantial increase in output capacity of an operation, therefore, necessitates additional units. In general, with the increase in number of units in an operation the number of men employed on the machines also increases (7 to 9 men for a continuous miner unit and 12 to 14 men for a conventional mining unit). However, supervisory, maintenance, and other required personnel do not necessarily increase in proportion to the number of units added. Therefore, there is a gain in productivity with an increase in size of operation or level of output.

Figure 2 shows the number of men required to mine 100,000 tons of coal annually at different levels of mine output. Up to a point, an increase in level of output brings a decrease in the number of additional men required, but once an output level of 2 or 3 million tons per year is attained this rate of decrease seems to level off. To operate a mine with a capacity of more than 3 million tons per year, the number of additional men required starts to increase somewhat in proportion to the number of mining units added. Therefore, very little gain in productivity can be realized from designing an operation with a capacity of more than 3 million tons per year.

TABLE 2—UNDERGROUND MINE CAPACITY, CAPITAL INVESTMENT, AND PRODUCTIVITY OF COAL MINES

Economic factors	Mine size by annual output (million tons) 1.06	2.04	3.18	4.99
Estimated capital investment	$21,850,700	$ 35,705,900	$ 50,494,100	$ 75,693,000
Estimated coal reserves required for a 25-year mine operation at 50% recovery rate (in tons)	53,000,000	102,000,000	159,000,000	249,500,000
Operating cost per year	$ 7,793,000	$ 13,830,000	$ 20,656,000	$ 32,211,300
Capital investment per ton of production	$20.62	$17.47	$15.87	$15.15
Operating cost per ton of production	$ 7.35	$ 6.77	$ 6.50	$ 6.45
Direct investment per mining unit*	$ 1,210,766	$ 1,049,354	$ 960,406	$ 929,431
Productivity in tons per man-day (based on total men employed)	15.86	21.82	22.98	22.89

Source: U.S. Bureau of Mines Information Circular 8632 (1974).
* Continuous miner.

Though there is a gain in productivity with size of operation, a large operation requires a large capital investment and vast coal reserves (table 2). The shortage of capital, the coal reserves available, and the market for coal have prevented several companies from designing large operations. In Illinois the availability of large blocks of thick coal, relatively good market potential, and the strong financial position of mining companies have favored the development of large mines. The number of mines with average annual productions between 1.5 to 3.0 million tons of coal has increased from 4 in 1964 to 11 in 1973 (fig. 3). In the same period, the number of mines with an average annual production of less than 1.5 million tons has decreased from 41 in 1964 to 12 in 1972. The large size of Illinois underground mines is one of the factors that makes them more productive than underground coal mines operated in other states (fig. 4). Illinois, Indiana, and western Kentucky, all in the Illinois Basin, have somewhat similar geologic conditions and lead the other states in productivity.

In figure 5, the output of underground mines in Illinois in 1973 is correlated with their respective productivities. As would be expected, there is a positive correlation between mine output and productivity. The mines that are located in areas where roof and floor conditions are generally good and the operations that are less than 5 years old achieve higher productivity than operations of a similar size that have average to poor roof or floor conditions or are older. One operation producing over 4 million tons per year (identified as mine 1 in figure 5) does not follow the general trend.

The size or capacity of an operation, therefore, has a definite influence on mine productivity. However, the real gain in productivity an operation might realize is affected to a considerable extent by the natural conditions under which the operation is performed.

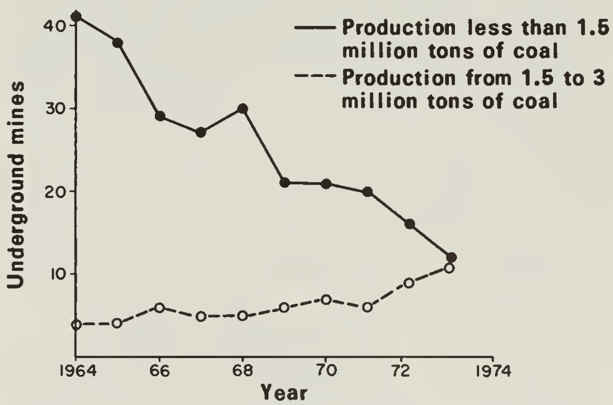


Fig. 3 - Trend toward larger mines in Illinois (Illinois Dept. Mines and Minerals, 1973).

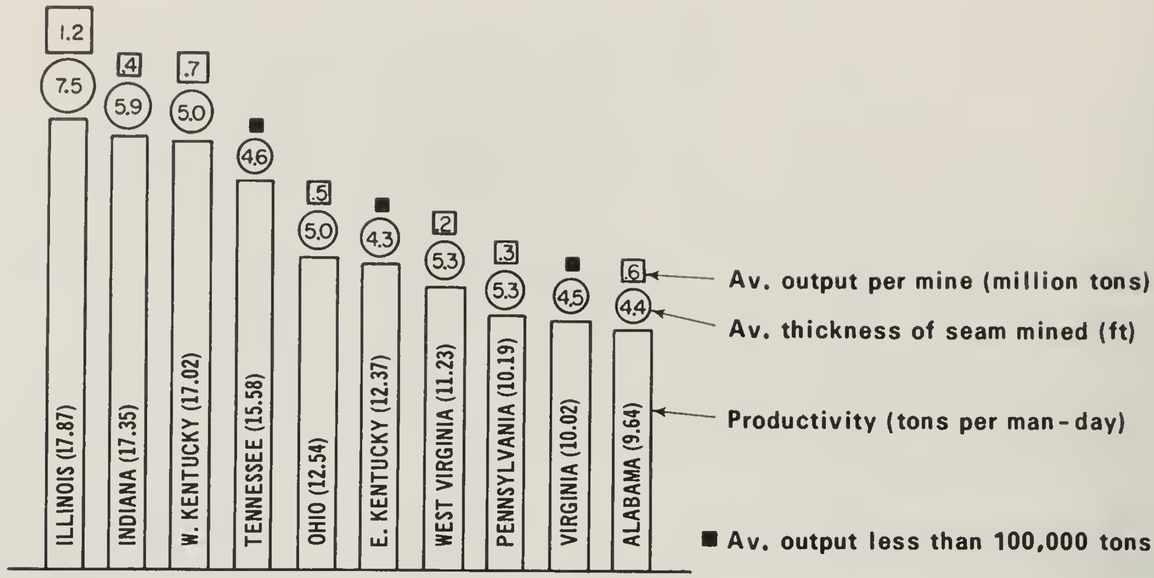


Fig. 4 - Comparison of underground mines in Illinois with those in other states, on the basis of mine size, seam thickness, and productivity (U.S. Bureau of Mines 1972 data).

Age of Operation

The age of a mine affects its productivity in several ways. As mining proceeds, the distance coal must be hauled and men transported to and from the operating face generally increases. Moreover, the mine area that must be maintained increases, and unless old or obsolete equipment is replaced equipment efficiency also decreases. In general, therefore, with increase in age the productivity of an operation normally declines.

In Illinois, as in other places, the age of active mines varies widely. According to the Illinois Department of Mines and Minerals Annual Report for 1970, the age of mines in 1970 ranged from a few months to more than 33 years*.

The influence of age on mine productivity is apparent in figure 6. For mines less than 7 years old, regardless of production level, there is a gain in productivity with age, but for mines over 10 years old the reverse is true. Figure 6 also shows that operations producing over 2 million tons of coal per year are all less than 20 years old. All operations over 29 years old record lower production capacity, less than 1 million tons per year.

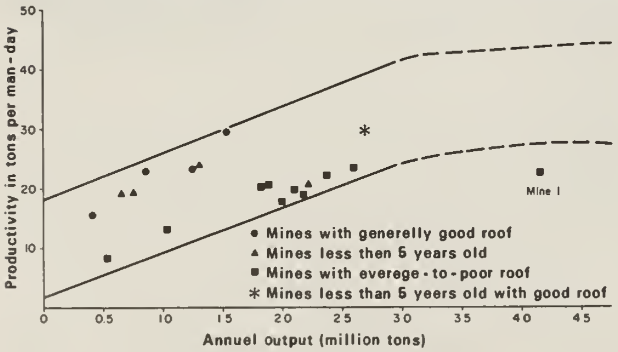


Fig. 5 - Output vs. productivity in underground mines.

The general increase in productivity with age for mines up to 7 years old is understandable when the productivity of certain individual mines is analyzed. In figure 7 the

* More recent data (1973) were available, but since no new underground mine began operation in the last 3 years, the later data were not considered adequate for this analysis.

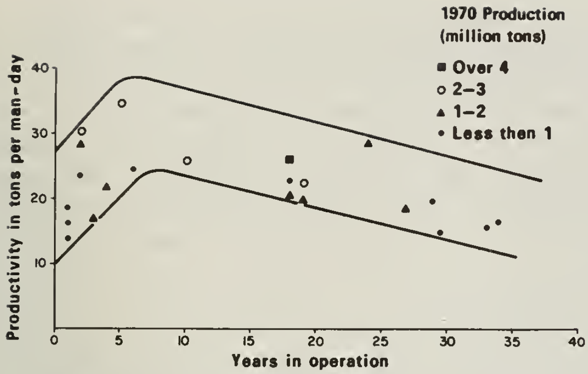


Fig. 6 - Age vs. productivity of underground mines.

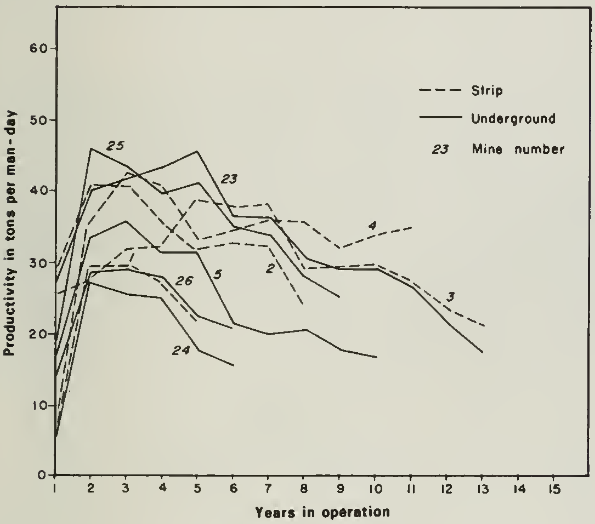


Fig. 7 - Trends in productivity of individual mines (Illinois Dept. of Mines and Minerals data, 1960-1973).

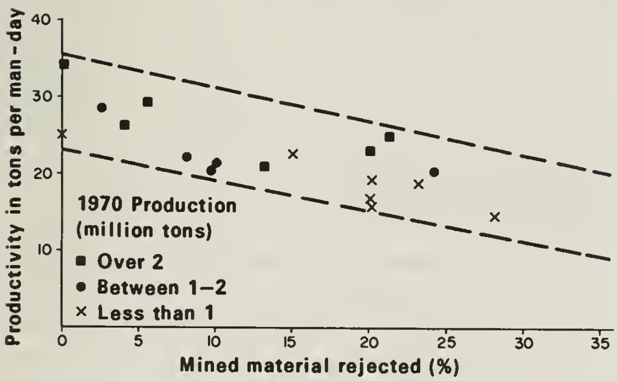


Fig. 8 - Productivity and percentage of material rejected during coal preparation (U.S. Bureau of Mines, 1970).

productivity achieved by individual mines during their initial years of operation is plotted. A sharp rise in productivity is noted during the first 2 years of operation. Productivity remains high for 5 to 6 years, after which it starts to decline. A steady decline in productivity for mines 25 and 23 is partly due to the poor roof conditions encountered as mining progressed. Mine 25 was eventually shut down in 1972, reportedly because of poor roof. The relatively high productivity during the initial 5 to 7 years of operation (fig. 7) reflects the general mining principle of first mining the areas easiest to reach to get a quick return on the capital investment.

Quality of Final Product Shipped

Productivity reported by the U.S. Bureau of Mines is based on the amount of coal shipped and not on the amount of raw coal produced. The average productivity of operations producing raw coal, therefore, generally is higher than that of operations of similar size that produce clean coal. This is obviously another factor responsible for variability of mine productivity.

In 1970, about 70 percent of the total raw coal produced in Illinois by underground mining was mechanically cleaned. More recent data on coal preparation were not available for analysis. The percentage of material rejected at individual mines in the process of preparing coal to meet certain specifications ranged from 5 percent to as high as 28 percent of the total coal mined. At several mines only part of the total coal produced was cleaned and the rest was shipped in raw form to utility plants. In other operations practically all the coal was cleaned before it was shipped to customers.

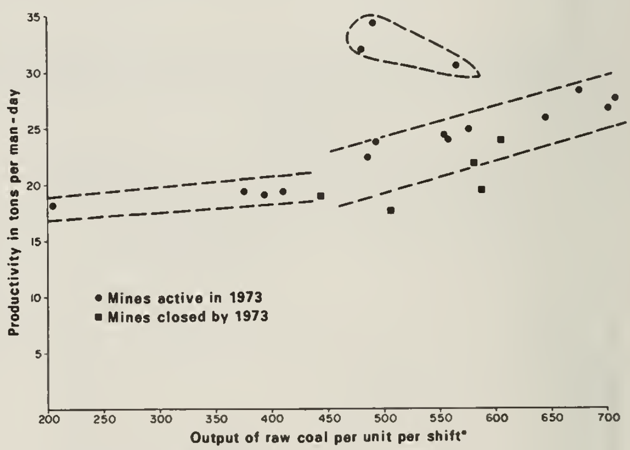
The percentage of material rejected at the mine is correlated with mine productivity in figure 8. The decline in productivity with increase in degree of coal preparation or increase in rejected material does not necessarily mean that an operation producing clean coal is less efficient than a similar operation producing raw coal. Rather, it reflects the amount of time or man-hours spent in the handling material that is eventually rejected at the plant site. This is one of the reasons specialty coal, such as metallurgical and industrial-grade coal, is more expensive than utility coal or raw coal.

Effective Use of Equipment

The efficiency with which the available equipment at a mine is utilized also affects mine productivity. Almost every machine has a considerable "margin" over and above the average production level. The higher level could be attained through effective use of available resources, such as labor, power, and management. The greater the proportion of production an operation derives from this margin the higher the gain in productivity will be.

In 1970, the average amount of raw coal produced per unit per shift in Illinois underground mines ranged from 200 to 710 tons. This variation could be attributed partly to differences in natural conditions, partly to the age of the equipment, and partly to difference in types of machines and methods of mining. The variation also reflects the difference in the skill of the machine operator and the ability of management to utilize machine capacity. The productivity of mines during 1970 is correlated with the average output per unit per shift in figure 9. A definite gain in mine productivity is evident as the output per unit per shift increases to more than 450 tons of raw coal.

In three mining operations the mine productivity gain was substantially higher than the general trend (fig. 9). A closer look at the data showed that these three mines were operated under the same management, and during 1970 most of the coal was produced by using continuous mining machines. The natural conditions under which the operations were performed were considerably better than those in the other mines plotted. Figure 9 also shows that mines that had an output per unit per shift somewhat lower than average during 1970, because of the age of the operation or poor mining conditions, had ceased operation by 1973.



*Number of shifts worked is based on information provided by individual operators to the Illinois Department of Mines and Minerals.

Fig. 9 - Machine output and productivity of underground mine in 1970. Number of shifts worked is based on information provided by individual operators to the Illinois Department of Mines and Minerals.

STRIP MINING

In strip mining as in underground mining, numerous factors may directly or indirectly influence an operation's productivity. Factors analyzed in this report include stripping ratio, nature of overburden, method of mining, capacity for which the operation was designed, age of operation, quality of final product shipped (coal preparation), and efficient use of equipment and time.

Stripping Ratio

The most important step in a stripping operation is removal of the overburden to uncover the coal. The amount of overburden that must be removed to recover a ton of coal varies widely because of the variation in topography and in the thickness of the coal seam. The ratio of the number of cubic yards of overburden removed per ton of coal recovered is called the stripping ratio. The stripping ratio may also be expressed as total thickness of overburden divided by the thickness of the coal seam.

In Illinois, in spite of the generally level regional topography, there is a significant variation in stripping ratio from mine to mine as well as within a single mine. In the northern and northwestern parts of Illinois, the thickness of seams mined during 1970 ranged from 3 to 5 feet, and the stripping ratio averaged about 18:1. In southwestern Illinois, thickness of seams mined during 1970 ranged from 4.5 to 6.5 feet, and the stripping ratio averaged about 11:1. In Gallatin and Saline Counties in southern Illinois, the thickness of seams mined was 3.5 to 4.5 feet, but the stripping ratio was almost the same as that in southwestern Illinois.

Because numerous man-hours must be spent in removing and rehandling overburden, especially where the stripping ratio is high, the productivity of the operation generally decreases as the stripping ratio increases. The true relation between the stripping ratio and mine productivity is difficult to determine because of differences in the nature of stripping equipment used, the nature of the overburden, the size of the operation, and the amount and degree of preparation the coal must undergo to be suitable for a specific market. In figure 10 the stripping ratios of 22 operations in Illinois are correlated with their 1970 productivity. (These stripping ratios do not take into account the rehandling of overburden material that was necessary at some operations because of limited space.) In spite of somewhat poor correlation, the figure shows a general decline in productivity as the stripping ra-

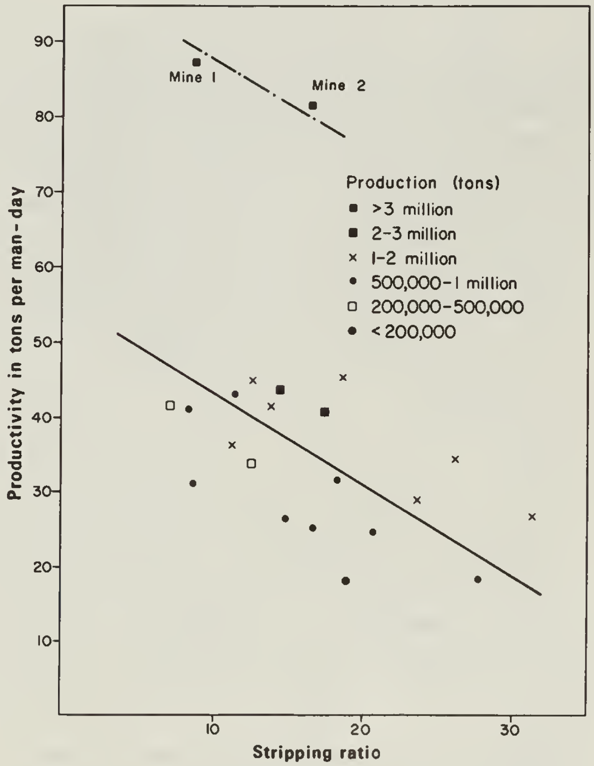


Fig. 10 - Stripping ratio and mine productivity of Illinois mines in 1970.

TABLE 3—OUTPUT, RATIO OF OVERBURDEN TO NET COAL RECOVERED, AND PRODUCTIVITY OF ILLINOIS STRIP MINES

Year	No. of strip mines	Total output of all strip mines (thousand tons)	Average output per mine (tons)	Average thickness of seam mined (ft)	Overburden removed per net ton of coal recovered (cu yd)	Productivity (tons/man-day)
1950	81	17,613	217,444	5.0	13.4	18.70
1955	68	18,675	274,633	4.8	12.8	23.87
1960	69	22,670	328,550	5.0	13.2	30.04
1965	49	32,669	666,715	5.3	13.6	37.54
1970	31	33,026	1,065,354	4.9	15.9	33.58

Source: U.S. Bureau of Mines.

tio increases. The increase in stripping ratio is one of the reasons the average productivity of Illinois strip mines declined from a record high of 37.54 tons per man-day in 1965 to 33.58 tons per man-day in 1970 (table 3).

Nature of Overburden

The nature of the rock strata overlying the coal also affects productivity of a stripping operation. In strip mining the material overlying the coal is broadly classified into two groups—consolidated (rock strata such as limestone, sandstone, and shale) and unconsolidated (generally soil, clay, silt, and sand). The kind of rock strata present in the overburden affects the performance of stripping equipment and determines the quantity of explosives, if any, needed to break up the overburden.

The overburden of northern and northwestern Illinois strip mines is somewhat different from that in the southern and southwestern parts of the state. In the latter area (Perry, Randolph, St. Clair, Williamson, Saline, and Gallatin Counties), the overburden contains a considerable amount of limestone, which requires blasting before it can be removed by stripping shovel or dragline. In the northern and northwestern Illinois operations (Knox, Stark, Peoria, Fulton, and Kankakee Counties), the unconsolidated overburden is thicker than that farther south and the consolidated overburden is mostly shale and sandstone, which requires only a small quantity of explosives, if any. The quantity of explosives used is correlated with stripping ratio (fig. 11). A positive correlation exists in southern and southwestern Illinois between the amount of explosives used per ton of coal pro-

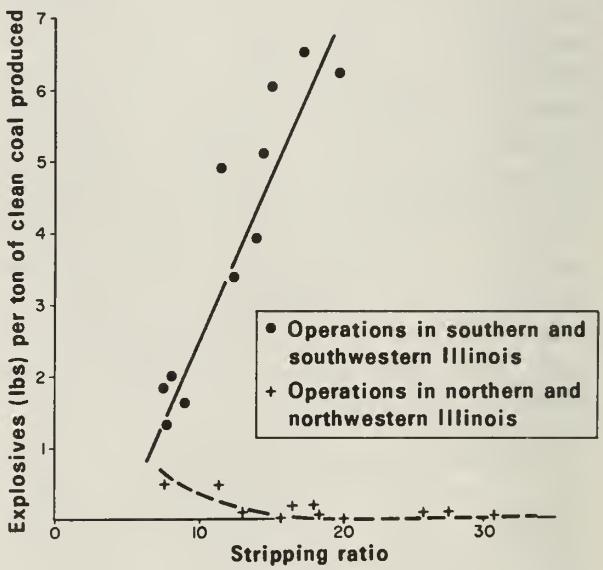


Fig. 11 - Correlation between quantity of explosives used and stripping ratio, 1970 (Illinois Dept. of Mines and Minerals, 1970).

TABLE 4—RELATIONS BETWEEN STRIP MINE CAPACITY, CAPITAL INVESTMENT, AND PRODUCTIVITY

Capacity of operation	Physical parameters: Average seam thickness (ft)	Average overburden thickness (ft)	Stripping ratio	Capital investment ($): Investment	Per ton	Operating cost ($): Per year	Per ton	Productivity (tons/man-day)
1 million tons per year								
Single seam operation	5.5	100	18.2:1	13,709,800	13.71	3,900,100	3.90	53.42
Two seam operation	10	100	10:1	8,280,100	8.28	2,984,000	2.98	53.42
3 million tons per year								
Single seam operation	5.5	100	18.2:1	24,870,100	8.29	7,748,400	2.58	111.6

Source: Based on U.S. Bureau of Mines Information Circular 8535 (1972).

duced and the stripping ratio. Operations located in the northern and northwestern parts of Illinois required little or no explosive to break up the overburden but generally had a higher stripping ratio, ranging from 10 to 30.

The coal-bearing rocks of the two regions also differ in the amount of extraneous material associated with the coal seams. In the north and northwestern region, the Herrin (No. 6) and Springfield (No. 5) Coals contain white-top, clastic dikes, and horsebacks. Similar structures are rarely noted in operations located in the southwestern part of the state (Damberger, 1974). These extraneous materials influence mine productivity in two ways. First, they lower the performance of stripping equipment, especially in areas where the white-top blends into the Herrin (No. 6) Coal. Second, many man-hours are spent in the mining, handling, and removal of extraneous materials that could have been devoted to producing coal.

The effect that variation in the nature of overburden has on productivity becomes evident in comparing the average productivity of strip mines from these two regions of Illinois. Operations in northern and northwestern Illinois that are producing about 1 million tons of coal per year had an average productivity of 31 tons per man-day in 1970, while operations of similar size in southern and southwestern Illinois had an average productivity of 44 tons per man-day. Part of this variation is probably due to differences in thickness of seam mined and stripping ratio, but the nature of the overburden and the presence of extraneous material associated with the coal contribute to the low productivity of northern and northwestern Illinois mines.

Method of Mining

The type of stripping method used also affects productivity. In Illinois the methods now in use can be classified into two groups—single-seam operations and two-seam or multi-seam operations. In 1973, the average productivity achieved in single-seam operations with annual output of 1 to 2 million tons was approximately 35 tons per man-day, whereas in multi-seam operations the productivity was as high as 90 tons per man-day for mines with annual mine production ranging between 3 and 5 million tons.

The high productivity achieved by multi-seam operations could be attributed to low stripping ratio (table 4) and to the availability of more coal. In multi-seam operations the amount of coal available per square mile averages

11,530,000 tons, while in single-seam operations it ranges from 3,456,000 to 6,912,000 tons per square mile. The large amounts of coal available in areas where more than one seam is present permit the planning of large-scale operations (output per year) that, because of the economy of scale, improve mine productivity. Even in small multi-seam operations more coal per square mile can be mined, reducing the per ton capital investment and operating costs (table 4).

The economic advantages of multi-seam operations are the main reason multi-seam operations in Illinois have increased from three in 1964 to seven in 1974. Production from multi-seam operations increased from 2,822,552 tons in 1964 to 12,134,814 tons in 1973. Although multi-seam operations provide definite benefits, the areas where they could be carried out in Illinois are unfortunately limited.

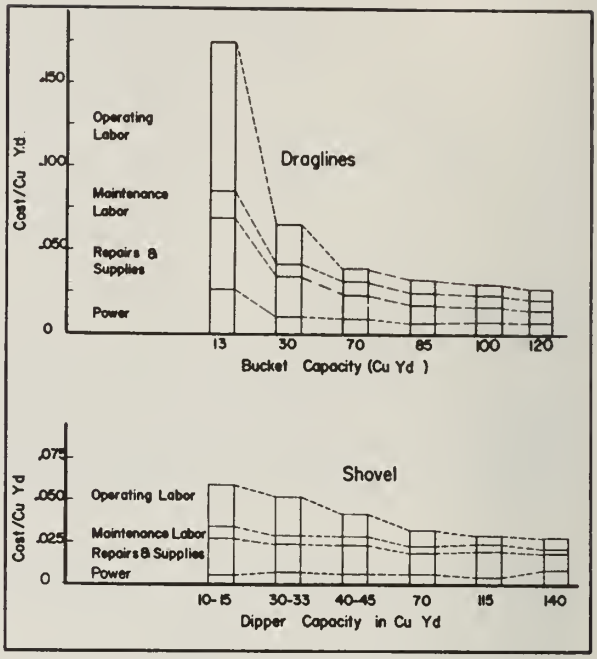


Fig. 12 - Relative gains made with larger equipment (after Weimer and Weimer, 1973).

In addition to stripping ratio, nature of overburden, and multi-seam mining, natural conditions that influence productivity include the quantity of water present, the slope of the pit, and the presence of unusually plastic underclay in the pit. Because information about these conditions was limited, their influence on productivity was not considered in this paper.

Capacity of Operation

In strip mining the capacity of the mining equipment depends to a large extent upon the size of the operation, in terms of output per year. The number of men required to operate large-capacity equipment, such as stripping shovels or draglines, is much the same as the number needed to operate small-capacity equipment. For that reason a definite gain in productivity occurs with the increase in capacity of equipment used. The reduction in cost of labor, maintenance, repairs and supplies, and power that accompany the increase in bucket and dipper capacity (fig. 12) were demonstrated by Weimer and Weimer (1973).

The annual output achieved in 1973 by Illinois strip mines, according to the Illinois Department of Mines and Minerals (1973), ranged from less than 50,000 tons to 4,673,688 tons. In figure 13 the level of output of Illinois operations is correlated with productivity. The figure shows a positive correlation between mine output and productivity. The high productivity level for mines 1 and 2 indicated in figure 13 was basically due to the designed capacity of the operation and to a lower stripping ratio achieved because these operations are multi-seam operations.

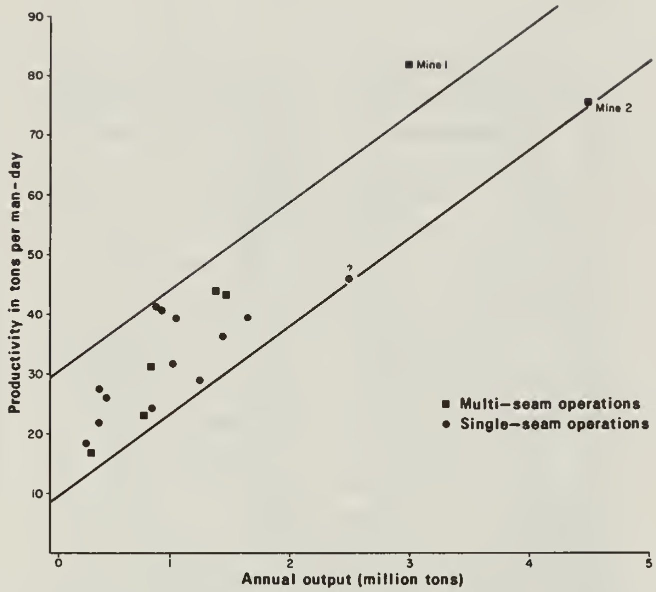


Fig. 13 - Annual output and productivity of Illinois strip mines in 1973.

In figure 14 the number of men required to mine 100,000 tons of coal per year is correlated with different levels of mine output. Up to a point, an increase in level of output brings a decrease in the numbers of additional men required, but once an output level of 1.5 million tons per year is attained the rate of decrease levels off. Since in strip mining, unlike underground mining, the smaller capacity equipment could be replaced by larger capacity equipment a gain in productivity could still be realized by increasing the size of the operation to over 2 million tons per year.

Age of Operation

As is true in underground mining, the age of a stripping operation adversely affects its productivity. The principal reason for the decline in productivity is the increase in stripping ratio that generally occurs, especially where coal seams are inclined or the terrain is somewhat rugged. In addition, the haulage distance from the working face to the loading facility generally lengthens as mining goes on, which necessitates expenditure of man-hours that could otherwise be productive.

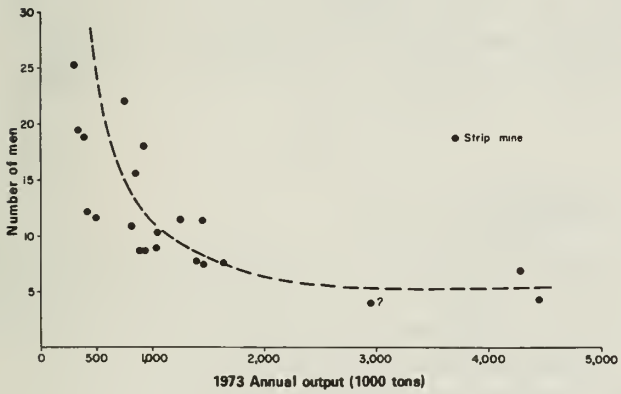


Fig. 14 - Workers needed to produce each 100,000 tons of coal from Illinois strip mines, exclusive of office, shop, loading dock, and preparation plant workers.

Four stripping operations for which there had been no significant change in mining equipment, in pit location, or in ownership were selected for analysis of influence of age on mine productivity. The trends in productivity of these mines during their initial 15 years of operation are plotted in figure 7. Productivity of the operations is high during the initial 5 to 7 years when mining is primarily concentrated in areas with a low stripping ratio and equipment is new. However, once such areas are mined out and the amount of time spent on equipment repairs and in hauling coal increased distances, the productivity of the operations declines.

Quality of Final Product

The quality of the final product, like that of the coal produced by underground mining, influences the *reported* productivity of an operation. According to the U.S. Bureau of Mines, in 1970 over 33 million tons, or about 86 percent of all Illinois strip mined coal, was mechanically cleaned. The extent of coal preparation at each operation varied, depending upon the amount of extraneous material present with the raw coal and on the particular use for which the coal was prepared. In general, at mines where a substantial amount of coal was prepared to meet the industrial coal market, or where clay dikes or white-top were mined along with coal, the amount of reject ranged from 15 to 40 percent. In operations that shipped coal primarily to utility companies and which produced coal relatively free from extraneous materials, the amount of reject was only 7 to 15 percent.

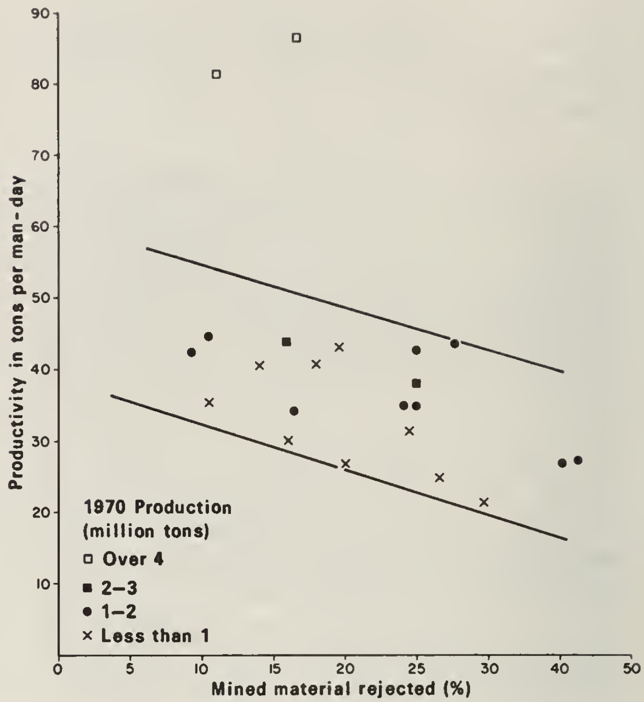


Fig. 15 - Strip mine productivity in relation to the percentage of material rejected in 1970.

In figure 15 the percentage of material rejected at several operations is correlated with mine productivity. The results obtained from this correlation are not satisfactory, but, in general, the data seem to indicate a decline in productivity as reject material increases. The size of operation seems to have no correlation with the amount of material rejected. Although the level of reject material seems to affect productivity, it does not necessarily mean that operations reporting lower ratios of reject to clean coal are more productive in terms of tons per man-day than operations reporting higher ratios.

Efficient Use of Equipment and Time

The efficiency with which an operation uses its available equipment influences productivity. To illustrate this influence the following approach was used. First, the total production of a mine, as reported to the Illinois Department of Mines and Minerals, was converted into output per day, based on the number of days the mine operated during the year. This level of production was then compared with the designed capacity of the operation, according to the figures given in the Keystone Coal Industry Manual (1970 and 1973). The percentage of the total designed capacity used in a particular year was then compared with the productivity level achieved for that year. In table 5, data for 17 strip mines are compared. The data show that the decline in effective use of planned capacity generally affects the productivity of the operation.

TABLE 5—PROPORTION OF DESIGNED CAPACITY USED AND ITS EFFECT ON PRODUCTIVITY OF ILLINOIS STRIP MINES

Mine code	1970 Rated capacity* (tons/day)	1970 Actual production† (av tons/day)	1970 Capacity used‡ (%)	1970 Productivity** (tons/man-day)	1973 Rated capacity* (tons/day)	1973 Actual production† (av tons/day)	1973 Capacity used‡ (%)	1973 Productivity** (tons/man-day)
A	25,000	15,085	60.0	81.75	25,000	14,838	59.3	76.08
B	13,000	9,261	71.2	38.63	13,000	5,683	43.7	36.16
C	9,000	8,128	90.3	40.36	9,000	6,299	70.0	28.80
D	8,000	7,466	93.3	44.81	8,000	7,695	96.2	39.68
E	8,000	12,879	160.9	87.13	8,000	8,724	109.0	43.28
F	8,000	5,453	68.0	34.0	7,000	4,134	59.0	39.28
G	7,000	6,543	93.3	44.5	6,400	5,346	83.5	31.44
H	6,500	3,655	56.2	20.53	6,500	2,958	45.5	27.36
I	6,500	4,164	64.0	35.95	6,500	4,293	66.0	24.08
J	6,000	5,345	89.0	43.13	6,000	5,616	93.6	43.76
K	5,000	5,031	100.6	27.91	5,750	4,422	76.9	12.80
L	4,750	4,687	98.7	42.20	4.750	4,264	89.8	40.88
M	4,200	5,213	124.1	41.97	4,200	4,934	117.5	43.20
N	4,000	2,881	72.0	38.10	4,000	2,407	60.0	26.00
O	3,500	3,652	104.3	34.31	3,500	3,543	101.3	31.28
P	2,800	3,516	125.6	24.97	2,450	1,876	76.6	21.44
Q	1,400	2,295	164.9	31.75	1,900	1,837	96.7	16.48

* Keystone Coal Industry Manual (1970, 1973).
† Illinois Department of Mines and Minerals, Annual Report (1971, 1974).
‡ For some mines capacity used is high because some of the coal was shipped without being processed in a preparation plant.
** U.S. Bureau of Mines Safety Analysis Center.

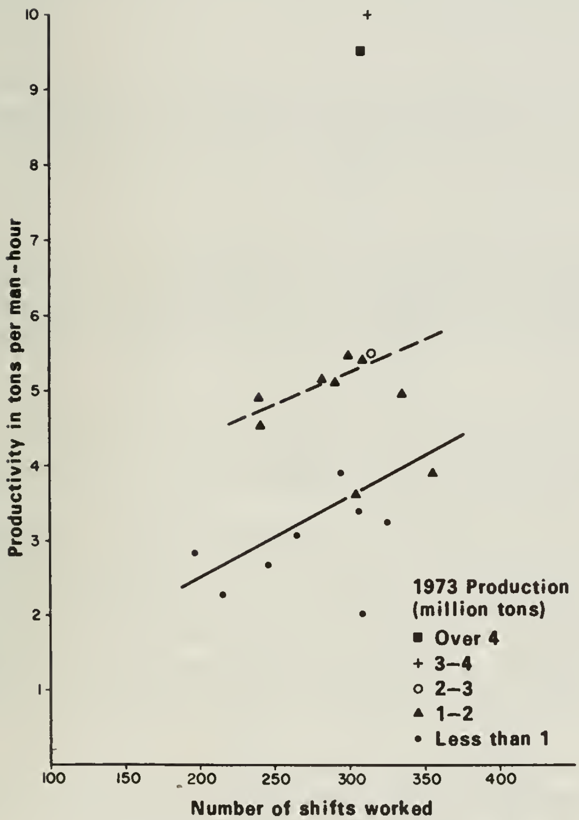


Fig. 16 - Productivity in relation to number of shifts worked in Illinois strip mines in 1973.

Comparison of an operation's productivity with its capacity (table 5) also shows that large operations generally achieve higher productivity than smaller ones, provided equipment is efficiently utilized.

Considering that the number of shifts a mine actively operates influences use of equipment, this use of time should also have some effect on mine productivity. To determine whether the variation in number of shifts worked had any influence on mine productivity, the number of 8-hour shifts worked at individual strip mines in Illinois in 1973 was calculated as follows:

$$\text{Man-hours} \div \text{number of working men} \times 1/8$$

and was correlated with the mine productivity in 1973 (fig. 16). The results show a definite correlation, indicating that an increase in number of shifts improves the productivity of an operation. The reasons why there is a variation in number of shifts worked could be attributed to various factors, including the size of the market available to a mine, labor problems at the mine, availability of mine cars, management philosophy, and equipment limitations.

CONCLUSIONS

From the correlations made of the various factors that are responsible for the wide range of productivity in Illinois coal mines, several conclusions regarding mine productivity can be drawn.

(1) In underground mining, a definite gain occurs in productivity with an increase in thickness of the seam mined. However, this gain in productivity levels off when the coal reaches about 72 inches.

(2) The productivity level a mine could achieve is substantially influenced by the nature of the roof and floor in the mine. Depending upon the extent of bad roof in a mine, a loss of between 10 and 35 percent could occur in productivity in a year's time.

(3) For underground mines, a positive correlation exists between the actual mine output and productivity. The gain in productivity attributable to level of output seems to level off when mine output reaches 2 to 3 million tons per year.

(4) The correlation between underground mine productivity and age of operation proved negative. Therefore, a decrease in productivity with age should generally be expected, especially after the initial 5 to 7 years of operation.

(5) In strip mining, the ratio of overburden to seam thickness (stripping ratio) has a negative correlation with mine productivity. At many Illinois strip operations the stripping ratio increases as the mining operation proceeds. Because of this trend the productivity of strip mines generally declines with age.

(6) The nature of overburden overlying the coal seams in Illinois varies widely from one region to another and in turn affects mine productivity.

(7) In strip mining operations a positive correlation exists between productive capacity of the operation and its productivity. Unlike productivity of underground mines, however, the productivity of strip mines continues to increase with the increase in level of output, at least up to a level of 6 million tons per year. In general, the gain in productivity realized per unit of increase in output is somewhat higher in strip mining than in underground mining.

(8) In both underground and strip mining, the degree of preparation coal receives before it is shipped to consumers has a negative correlation with mine productivity. Because the preparation that coal receives artificially reduces operation productivity, a high productivity level achieved by a mine shipping raw coal does not necessarily mean that the operation is more productive than operations of similar size that ship coal of metallurgical or industrial grade.

(9) The efficiency with which available equipment and time are used also influences mine productivity. In underground mining, any increase in output over 450 tons of coal per mining unit per shift adds to mine productivity. In strip mining the extent to which the operation's planned capacity is used has a substantial effect on mine productivity.

REFERENCES

Damberger, H. H., 1974, Physical properties of the Illinois Herrin (No. 6) Coal before burial, as inferred from earthquake-induced disturbances: 7th International Congrès de Stratigraphie et de Géologie du Carbonifère, Compte Rendu, v. 2, p. 341-350, 1973; Illinois State Geological Survey Reprint 1974-G.

Given, I. A., 1973, Room and pillar methods, *in* I. A. Given and A. B. Cummins, eds., SME Mining Engineering Handbook: v. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, p. 12-71.

Illinois Department of Mines and Minerals, 1971, 1974, Annual coal, oil and gas reports for 1970 and 1973: Illinois Department of Mines and Minerals, Springfield.

Keystone Coal Industry Manual, 1970, 1973, McGraw-Hill, Inc., New York.

Risser, H. E., 1966, Coal mines productivity—Some things averages don't tell: American Institute of Mining, Metallurgical and Petroleum Engineers Council of Economic Proceedings, Annual Meeting, New York, p. 226-240.

Shields, J. J., M. O. Magnuson, W. A. Haley, and J. J. Dowd, 1954, Mechanical mining in some bituminous-coal mines, *in* Progress Report 7, Methods of mining with continuous-mining machines: U.S. Bureau of Mines Circular 7696, Washington, D.C.

Weimer, W. H., and W. A. Weimer, 1973, Surface coal mines, *in* I. A. Given and A. B. Cummins, eds., SME Mining Engineering Handbook: v. 2, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, p. 17-148.

U.S. Bureau of Mines, 1970, Bituminous coal and lignite: U.S. Bureau of Mines Minerals Yearbook, Washington, D.C., p. 360.

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