Study of Continuous Face Haulage Systems

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Final Report

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A STUDY OF CONTINUOUS FACE HAULAGE SYSTEMS

INTRODUCTION

This study relates to continuous face haulage systems in underground coal mines, and was performed by Joy Manufacturing Company for the U. S. Bureau of Mines under the Bureau of Mines Contract No. HO 242025. The effective starting date for this work was June 14, 1974.

There were two main reasons for making this study, the first being to find a safer system to move coal away from the face than the currently predominant shuttle car system, and the second being to seek ways to advance the state-of-the-art of continuous face haulage as a means of increasing coal production.

Underground coal mining is a relatively dangerous industry. One of the activities that exposes mine personnel to injury is the operation of shuttle cars between the face and the secondary haulage facility. The Bureau of Mines believes that a practical continuous face haulage system would reduce haulage-related accidents by eliminating the fast-moving shuttle cars from the face area.

From a production standpoint, continuous face haulage appears to be an attractive alternative to shuttle car haulage, because typically the mining machines at the face experience a certain amount of lost time waiting for shuttle cars to get into a loading position. Theoretically, continuous face haulage allows the miner to mine more coal.

The potential advantages of continuous face haulage have been increasingly apparent since the introduction of continuous mining machines in the late 1940's, and there have been many attempts since that time to design haulage systems to do the job. Some of these systems have been built and tested, often at considerable expense, but very few of them have operated well enough to survive.

It was the objective of this study to analyze the continuous face haulage problem, and to also analyze the various attempts that have been made to solve it. With this information as a base, the purpose was to then determine which concepts of continuous face haulage have the potential to be developed into safe, practical, and cost-effective systems, using available hardware and technology.

The emphasis here is on development ideas that appear to be promising for near-term solution, without the need for long-range programs to develop new technology or hardware.

In addition to the objectives related to improving things that have been already tried, this study also undertook to uncover promising haulage ideas from other industries that could possibly be applied to underground coal mines. Nothing significant of this nature was discovered during this program.

Persons familiar with the underground coal mining industry are aware that the mining activity must be carried on in a complex and varied environment. An analysis and definition of this environment was attempted as an early part of this study. Because of this variety of mining conditions in underground coal mines, it was recognized before this study started that if there is a good answer to the continuous face haulage problem it is an answer that probably has several parts. In other words, more than one good system will probably be required to achieve continuous face haulage in a large number of mines. The findings of this study support such an idea.

The information forming a basis for this and preceding reports was gathered from several sources, the principle ones being as follows:

1. Mine visits to observe continuous face haulage systems.

2. Discussions with mine operating personnel and with mine management personnel.

3. Discussions with sales and engineering personnel of several mining machinery manufacturing companies, other than Joy Manufacturing Company.

4. Discussions with sales, service, and engineering personnel of Joy Manufacturing Company.

5. Various internal reports and records from mining and manufacturing companies.

6. Mining literature.

It should be noted here that since the conception of this study, certain developments in the continuous face haulage area have tended to preempt some of the objectives of this contract.

To expand on what has happened during this period, we can list the following:

1. The increasing acceptance by mine operators of improved designs of bridge carrier systems.

2. Ongoing design improvements of bridge carrier systems by the manufacturers as a result of an increasing amount of field exposure.

3. Development of improved designs of flexible conveyor belt systems by the manufacturers as a result of recent full-scale mine tests.

4. Establishment of several research and development contracts between the Bureau of Mines and various companies to advance the state-of-the-art of continuous face haulage.

The emerging energy problem of the past few years and the resulting emphasis on increased coal production has stimulated the effort to solve the continuous face haulage problem. Research on this and many other mining problems has been accelerated. One result of these efforts has been an advance in the state-of-the-art of continuous face haulage during the time span of this contract. However, after recognizing the gains of the past few years, it is obvious that improved continuous haulage systems will have to be developed before their use will spread to a predominant number of mines.

SUMMARY

The work under this contract was performed in five phases, as listed below:

Phase I	Service Requirements of a Continuous Face Haulage System
Phase II	Concept Investigation
Phase III	Performance Evaluation
Phase IV	Engineering Studies
Phase V	Program Plans

Reports covering these phases of the work have been submitted to the Bureau of Mines. In addition, a literature search and a patent search were included as part of the requirement of the Phase II concept investigation.

The literature search and patent search results were separately bound, because of bulk, as appendices to the Phase II report. The literature search results, Appendix A, consisted of seven volumes, and the patent search results, Appendix B, consisted of three volumes. All of this material was indexed according to type of haulage system, and was delivered to the Technical Project Officer responsible for this contract.

The following report has been structured around the five phases of the contract as listed above.

The Service Requirements section defines the specific requirements of a continuous face haulage system for underground coal mines, as to capacity, mobility, flexibility, and compatibility with the mining environment.

The Concept Investigation section investigates the various concepts that have been proposed or used in the attempt to develop a practical, continuous face haulage system.

The Performance Evaluation section covers an evaluation of the performance of the several continuous face haulage systems that have been built and tested, and which, in a very few instances, have become production items available to the mining industry. The criteria used for judging performance were developed from a review of the service requirements that were defined in the Phase I part of this study.

The Engineering Studies section deals with three objectives:

1. Identification of the systems that appear to have the highest potential for practical application.

2. Definition of the shortcomings of these systems.

3. Analysis of the shortcomings to determine whether they can be rectified by the application of existing technology, or by the relatively easy development of new technology.

The Program Plans section presents program plans to correct the shortcomings of the most promising systems.

CONCLUSIONS

1. The most promising continuous face haulage systems, among those covered by this study, are as follows:

    a. Bridge carrier systems, as currently manufactured by Jeffrey Mining Machinery Company, Long-Airdox Company, and West Virginia Armature Company.

    b. Flexible conveyor belt systems, as represented by the Joy Manufacturing Company developments known as the Joy Serpentix conveyor, and the Joy Flexible Conveyor Train.

2. Of the two systems listed above, the bridge carrier system is the more advanced as a commercial product.

3. Both of the systems listed above require more development to:

    a. Extend their use into a broader range of mining situations.

    b. Improve their performance and reliability.

4. The hydraulic conveyor system, as represented by the ongoing development of the Consolidation Coal Company at their Robinson Run Mine, is less advanced from an engineering standpoint than the two systems listed above, but on a long-term basis it appears to show a high potential for meeting many of the requirements of a good continuous face haulage system.

5. Other systems covered by this study appear to have the ability to provide continuous face haulage in limited, specialized mining plans. Included among these systems are:

    a. Extensible belt conveyors.

    b. Longwall conveying systems.

    c. Shortwall conveying systems.

6. The results of this study support the idea that the increased use of continuous face haulage in underground coal mines will probably involve several different systems, to cover the wide range of mining conditions that exists.

7. No significant idea for a new type of haulage system for use in underground coal mines was uncovered by this study.

THE SERVICE REQUIREMENTS OF A CONTINUOUS FACE HAULAGE SYSTEM

The interest in improving continuous face haulage systems in underground coal mines stems from two basic requirements, the first being to improve the safety aspect of the haulage part of the mining cycle at the face, and the second being to improve the productivity of the overall coal mining system.

Statistics on industrial accidents indicate that underground coal mining is the most dangerous occupation in the United States. While great progress has been made in improving safety in the mines, more remains to be done to remove or to reduce the hazards that still exist.

The most hazardous condition that the miner faces underground is falls from the mine roof and the ribs. The next greatest hazard is the equipment used to mine or haul the coal. It is the safety aspect of face haulage equipment that is one of the concerns of this report.

With regard to productivity in underground coal mining, it is believed by many that improvement of the face haulage part of the mining cycle could result in significant gains in coal output. The basis for this belief is that current face haulage systems are one of the several limiting factors in production due to their inability to carry coal away from the mining machines as fast as it is mined.

Continuous face haulage systems hold the promise of being able to improve both the safety aspect and the productivity aspect of the face haulage part of the mining cycle. The improvement in safety is expected because the movement of machinery in the confined space near the face would be reduced compared to shuttle car, scoop, or tractor-trailer haulage system. The improvement in productivity is expected because the face haulage process would be continuous, rather than interrupted, thus allowing the mining machines to work for a larger percentage of the shift.

These expected improvements depend on the continuous face haulage system meeting a stringent set of requirements both as to safety and performance. Attempts at continuous face haulage in the past have generally demonstrated some serious deficiencies.

The overall objective of this study is the improvement of continuous face haulage systems. As a first step, this section attempts to define what such a system must do, and what it must contend with and adapt to in the mining environment.

The first requirement that must be met by a continuous face haulage system in underground coal mines in the United States is compliance with Federal and State health and safety standards.

A successful system must then adapt to a wide range of mine environmental conditions, which present restricted, intricate passageways in which the haulage system must work, in harmony with several other activities that also involve men and machinery.

Some of the usual requirements for underground mine machinery, such as reliability and durability, establish part of the design criteria for a good continuous haulage system. In addition, there are other design criteria established by the nature of the face haulage problem, which demands the ability to handle large flow rates of material with a system that must have a great deal of flexibility and mobility.

The following paragraphs expand the definition of the service requirements for a continuous face haulage system.

A. Safety and health requirements in underground coal mines, and their influence on continuous face haulage.

Any continuous face haulage system used in underground coal mines in the U. S. must conform to mandatory health and safety standards that have been established by the Bureau of Mines. In addition, the various State mining agencies have their own requirements for health and safety, and in some cases these will affect the machinery intended for mining use. The various regulations that apply to mining machinery not only dictate certain features of the machine design, but they also require that operation of the machinery in the mine will not create unsafe or unhealthy conditions.

1. SAFETY STANDARDS

In general, the requirement for all mine machinery is for an inherently safe design. Specifically, mandatory safety standards for underground coal mines, as described in Part 75 of Subchapter 0, Title 30, Code of Federal Regulations, must be observed. These standards, in addition to the mandatory health standards that are described later, were established by the Federal Coal Mine Health and Safety Act of 1969, otherwise known as Public Law 91-173. Some of the effects of the safety standards in Part 75 on continuous face haulage are described in the following paragraphs.

a. Roof support

The standards for roof support cover three basic plans:

Full roof bolting plan.

Conventional roof control plan (using material other than roof bolts).

Combination plan, where both roof bolts and conventional supports are used.

For all three plans, the standards specify the maximum allowable width of the mine opening, and where conventional supports are used, such as posts, the maximum allowable width of roadway is specified.

For a full roof bolting plan, openings should not exceed 20 feet in width.

For a conventional roof control plan, openings should not exceed 20 feet and width of roadways should not exceed 14 feet on the straight and 16 feet on the curves.

For a combination roof control plan, openings should not exceed 30 feet in width, and roadways should be limited to 16 feet in width on both the straight and the curves.

These standards directly affect the space in which a continuous haulage system must operate.

b. Pillar criteria

Standards with reference to pillars establish the smallest dimension of the pillar at no less than 20 feet. As explained in later sections of this report, pillar size affects the required reach of a continuous face haulage system.

Where pillar recovery is practiced, standards are established for roof support in the pillar recovery area, and the presence of these supports adds to the difficulty of the haulage system being able to follow the miner as it mines the pillars.

c. Ventilation

The ventilation requirements established by the safety standards, particularly those applying to ventilation of the working face, requires the use of line brattices, ducting, or other devices in the working sections to provide adequate ventilation at the face. These devices take up space, and complicate the problem of maneuvering a haulage device behind the miner.

d. Combustible materials and rock dusting

The statutory provision of this section of the standards is that coal dust and loose coal must be cleaned up and not allowed to accumulate in active workings, or on electric equipment therein. This imposes a requirement on a continuous face haulage system not to spill large amounts of coal while it is in operation, and not to operate in a manner that allows dust to accumulate in large quantities on or around the machinery.

e. Electrical equipment

The safety standards require that all electric face equipment shall be permissible, and the machinery must be built in accordance with Bureau of Mines Schedule 2G.

Schedule 2G not only covers the electrical features of the machinery, but also requires that the entire machine shall be rugged in construction, and shall be designed to facilitate inspection and maintenance. Moving parts must be guarded, brake systems must be adequate, and in general the entire machine must be considered safe by the Bureau of Mines before approval for the machine to be used underground will be given.

2. HEALTH STANDARDS

The primary concern of the mandatory health standards, which are defined in Part 70 of Subchapter 0, Title 30, Code of Federal Regulations, centers around the presence of harmful quantities of respirable dust in the mine atmosphere, and the exposure of miners to harmful noise levels.

a. Respirable dust

Respirable dust is defined as dust particulates 5 microns or less in size. Effective December 30, 1972, mine operators must maintain the average concentration of respirable dust in the mine atmosphere during each shift to which each miner in the active workings of such mine is exposed at or below 2.0 milligrams of respirable dust per cubic meter of air.

The standards covering respirable dust impose a requirement on a continuous face haulage system to not generate respirable dust, during operation, in quantities that will exceed the allowable concentrations. Transfer points in a conveying system are typically dust-generating areas, and the design of such areas of the system must be given careful attention.

Water sprays can be used to control dust, but designs that do not generate dust have an advantage.

b. Noise

The mandatory health standards require that mine operators maintain the noise levels during each shift to which each miner in the active workings of the mine is exposed at or below the permissible noise levels set forth in the following table:

Permissible Noise Exposures

Duration per day (hours)	Noise level (dBA)
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
3/4	107
1/2	110
1/4 or less	115

Noise standards require attention, during machine design, to all noise-generating sources on the machine, including hydraulic pumps, hydraulic motors, gear boxes, and conveyor devices.

B. The underground coal mine environment, and its influence on continuous face haulage.

One of the most important aspects of the environment of underground coal mines is that no two mines are alike. Also, within a given mine, it is common to find a wide range of conditions. It is difficult, therefore, to establish a definition of a typical mine for the purposes of designing a continuous face haulage system. The various factors of the mine environment can be analyzed separately, however, and the demands that each factor makes on the haulage system can be determined.

The wide range of conditions that exists in coal mines makes it doubtful that any single system of continuous face haulage will satisfy all situations. The most successful system, or systems, will be those that adapt to the widest range of mine conditions.

The following discussion attempts to describe the factors of the mining environment that have the most influence on the continuous face haulage problem.

1. THE SPATIAL ARRANGEMENT OF THE MINE

The spatial arrangement of the mine, which determines the amount of room available for a continuous haulage system to function in, and to move in, is governed by several general considerations, including the following:

The configuration of the surface above the mine.

The depth of the mine.

The nature of the material above and below the coal seam.

The characteristics of the coal seam.

These influences, together with the method of mining that is to be used, govern the location, the size, the number, and the geometric pattern of the passageways that are made in the mine, and a continuous haulage system must function within these passageways.

a. Seam height

The seam height, or the thickness, of coal seams in the United States ranges from a few inches to over fifty feet. For the purpose of this study, seams in a general range from two feet to twelve feet thick will be considered.

From a machine design standpoint, mines with seam heights greater than five feet present relatively minor height-related problems in the design of mining machinery, including haulage equipment. In seams thinner than five feet, the height limitation imposed on the machinery can become one of the primary design problems.

Solving the machine design problems associated with height limitations becomes more important to the coal industry as the thicker, easier-to-mine coal deposits are exhausted, turning a larger percentage of the mining effort toward the thinner coal seams.

It seems likely at this time that seam height limitations will eliminate some otherwise promising continuous face haulage concepts from use in the thinner coal seams. There are systems available, however, which show possibilities for handling continuous face haulage in the seam heights ranging from two to four feet, an example being bridge conveyors working in conjunction with bridge carriers.

b. Mine development influences

The general considerations that influence the development plan for a mine were mentioned earlier in this discussion. The development plan that results from these considerations imposes special demands on any face haulage system, because the plan calls for mining specific sets of entries into the field of coal. The number of entries in a set is determined by the requirements of ventilation, haulage, escapeways, and various mine services, and the number can vary up through twelve or more.

As the sets of entries and crosscuts are advanced into the coal, following a given cut sequence, the mining machine is obliged to move from place to place. A continuous face haulage system serving the miner is obliged to follow. In addition, it frequently has to back up out of the way to allow the miner to make its move to the next place.

More entries in a set requires that the continuous haulage system must be able to reach farther, through a more complex pattern of passageways, to maintain the flow of coal from the miner to the secondary haulage system. The arrangement of the entires called for in the development plan therefore has a direct bearing on the required reach and flexibility of the continuous face haulage system.

Pillar size is another spatial factor that is established by the mine development plan, and which affects the continuous face haulage system - particularly in the matter of required reach.

The full subject of pillar design is considered to fall outside the scope of this study, but its influence on continuous face haulage should be considered here.

The size of pillars required to support the strata overlying the coal depends on such factors as the weight of the overburden, the strength of the overlying strata, the nature of the strata underlying the coal, and the strength characteristics of the coal itself.

Pillars are usually square or rectangular in section, with the dimensions of a side generally falling between 20 and 100 feet. If the crosscuts are put in at angles other than 90° to the entries, the resulting pillar sections become quadrilaterals having other than right angles, but the range of length of the sides will still generally be between 20 and 100 feet.

The size of the pillars in a mine directly influences the required reach of a continuous face haulage system since the haulage system will usually be required to extend past three or four pillars to reach from the miner to the end of the secondary haulage system.

The angle between the entries and the cross-cuts also affects the continuous haulage system design, because in following the miner through the network of passageways around the pillars, it is more difficult to move the system through a series of 90° turns than through a series of 60° turns. For this reason, where some continuous face haulage systems have had limited flexibility to negotiate turns, the mine development plan has been tailored to the haulage system by using crosscut angles less than 90°.

It would be desirable, in establishing design criteria for continuous face haulage systems, to consider the ability of the system to extend through five or six 90° turns as being an important feature. Reach requirements between the miner and the end of the secondary haulage can range from 200 feet to 600 feet, depending on the mining plan.

The mine development plan will also establish the width of the entries and crosscuts at various locations in the mine. Generally the width will be made as great as the roof conditions will allow, and typically the width will fall in a range from 15 to 30 feet. Assuming that no rock is taken above or below the coal, the seam height and the entry width establish the maximum cross section within which the continuous face haulage system must work. It is found commonly that some of this space is required for other things, such as roof support, electrical wiring, ventilation ducts, water lines, or conveyors. A continuous face haulage system must operate in the space that is left, without disturbing other systems that exist in the same space.

Narrow entries, demanded by relatively poor roof conditions, not only restrict the space in the entry, but also make turning corners more difficult because of the tighter turning radius that is required. Some flexible conveyors are operating with a turning radius, measured to the center of the belt, of twenty feet, and it is considered that a turning radius of fifteen feet would be more desirable.

Room and pillar mining is the most common way of mining the coal once the development work on the entries has been completed. In cases where the pillars are extracted after the rooms have been mined, the requirements for reach, flexibility, and mobility of the continuous face haulage system are most stringent, since the miner must work around the pillar to extract the coal, and the haulage system must follow. In addition, since the security of the roof may become questionable as the pillar is mined, the haulage system must be able to move back from the area quickly if this is required.

c. The effect of mining method on the spatial arrangement of the mine

Modern underground coal mines in the United States use mining systems that are classified as conventional, continuous, longwall, or shortwall. Each of these mining systems requires a different development plan for mining, which affects the spatial arrangement in which a continuous face haulage system must function.

In the conventional mining system the number of working places is governed by the number of separate operations in the cycle. Normally with conventional mining a minimum of five places will be worked in a section, and sometimes there will be as many as twelve or more.

The continuous face haulage system, to function with conventional mining, must be able to follow the loading machine from place to place. Since more places are required for conventional mining than for the other basic mining system, conventional mining imposes more stringent requirements on a continuous face haulage system with regard to reach, maneuverability, and flexibility than the other systems do.

With continuous mining, the number of places that the mining machine will be advancing, on a cyclic basis, will be governed more by the development plan that is required than by the number of operations in the cycle, as is found with conventional mining. Generally continuous miners will be advancing three to five entries, together with the required crosscuts. The movement of the continuous miner is easier for a continuous face haulage system to follow, therefore, than the movement of the loader in the conventional system of mining.

Providing continuous face haulage for longwall mining is relatively simple compared to providing it for conventional or continuous miners operating on room and pillar mining or on development work. With longwall mining, the haulage system is required primarily to move in a straight line, rather than around corners, and the problem of transfer of coal around corners occurs mostly where the face conveyor ends and the next haulage system takes over.

Shortwall mining is a combination of longwall mining and continuous mining. Blocks of coal are outlined by entry systems, as in the longwall method, but the face is mined with a continuous miner that moves across under the protection of the line of roof-supporting jacks.

A continuous face haulage system that operates in support of a shortwall system must follow the miner along the face, since the longwall face conveyor cannot be used. Ideally the face haulage system would also have the ability to move the coal around the corner, where the face intersects the side of the block being mined. When the miner retreats across the face to prepare for the next cut, the face haulage system must back up out of the miner's way.

If the four underground coal mining systems are listed in order of decreasing difficulty of the continuous face haulage problem, the list would appear as follows:

Conventional mining

Continuous mining

Shortwall mining

Longwall mining

If the mining systems are considered in order of importance relative to tons of coal mined, continuous mining and conventional mining share most of the total production, with longwall and shortwall systems sharing a small part of the production and increasing at a slow rate.

Between continuous mining and conventional mining, the trend over the past several years has been for continuous mining tonnage to predominate and to slowly increase its percentage of total tonnage mined.

From the standpoint of emphasis for development of continuous face haulage systems, the trends of tonnages mined would indicate that first consideration should be given to solving the haulage problems associated with continuous mining.

2. ROOF, FLOOR, AND RIB CONDITIONS

The preceding discussion covers the various factors that establish the space in which a continuous haulage system must function. This space, in turn, is complicated by the characteristics of the space boundaries, namely the roof, the floor, and the ribs of the mine.

a. The roof

The strength characteristics of the roof, as was mentioned earlier, are a factor in establishing the roof support plan for a mine and the design of the development plan, including the pillar size, all of which have a bearing on the design requirements for a continuous face haulage system.

In addition, the mine roof has irregularities referred to by such terms as slips, rolls, clay veins, horsebacks, kettle bottoms, niggerheads, dikes, cleavages, faults, and wants. These irregularities can complicate the continuous face haulage problem by reducing the headroom, and by presenting an unsatisfactory surface for anchoring where the haulage system is normally suspended from the roof.

b. The floor

The floor of the mine presents some of the same irregularities as the roof, including rolls, which in this case would be a smooth upthrust of the floor, and valleys. The presence of rolls can reduce the headroom, and the valleys can present mobility and flexibility problems for a floor-supported haulage system.

It is very common for the mine floor to consist of fireclay, varying in thickness from a few inches to several feet. This often tends to be a deteriorating surface, particularly in wet conditions and where traffic in the mine is heavy. Such conditions demand attention in the design of the haulage system to provide adequate ground clearance, adequate flotation from the tracks or tires, and adequate tractive effort and power to move the machine.

c. The ribs

It is important that movement of any machinery in the mine should not damage the ribs to the extent that the removal of the rib material would affect the strength of the pillar.

In mines where rib bursts occur, it is important that any haulage equipment adjacent to the rib, if damaged, be so designed that the damage itself will not present a hazard. An example would be a pipeline carrying large volumes of water or slurry, or a pipe carrying large volumes of air and entrained coal under pressure.

3. OTHER MINING ACTIVITIES

Another aspect of the mining environment that influences the acceptability of a continuous face haulage system is the presence of other mining activities in the same area where the haulage system is required to operate. The haulage system must be compatible with these other activities so that the overall mining system, of which the haulage system is a part, may function efficiently.

a. Ventilation

A continuous haulage system must not interfere with the various pieces of equipment that control the ventilation in the active workings, such as stops, brattice lines, auxiliary fans, and air ducting. It also must not interfere with the ability of the mine personnel to perform the installation of such equipment as mining progresses.

b. Roof support

Roof support devices in place must not be damaged by the movement or operation of a continuous face haulage system, and the haulage system must not interfere with the ability of the mine personnel to install roof support devices when the mining cycle demands the addition of more roof support.

The roof supporting operation generally requires the use of other machinery, and the haulage system must either get out of the area, or leave enough room to accommode the roof support equipment.

c. Supply

The face area must be accessible for supply vehicles, and the layout and method of operation of a continuous face haulage system must be such that the face operations may be supplied as required.

d. Rock dusting

Rock dusting operations must be carried on to within 40 feet of all working faces, so the face haulage system must allow for the presence and the operation of rock dusting equipment as required.

e. Personnel movement

A continuous haulage system must allow for the safe movement of personnel in the active workings. If the haulage system blocks the movement of personnel from one side of a place to the other, means must be provided for easily crossing the haulage system in a safe manner, or for moving or stopping the system so that personnel movement may be safely accomplished.

4. WATER

The presence of water in the mine is generally objectionable, both from the standpoint of interfering with the mining process, and from the standpoint of the comfort and convenience of the mine personnel.

If a continuous face haulage system uses water, either for dust control or for transporting coal or for other purposes, it should be contained and controlled so that it does not affect the working conditions in the active workings in an undesirable way.

5. MACHINE DESIGN REQUIREMENTS DICTATED BY THE MINE ENVIRONMENT

The various factors of the mining environment, some of which have been already discussed, present some very rigorous requirements for the mechanical design of mining machinery. Some of the features that must be built into mining machinery are discussed in the following paragraphs.

a. Size

One of the obvious limitations imposed on underground mining machinery is that of size, which has already been touched on in the discussion of seam height, which limits the permissible height profile of the machinery, and in the discussion of entry width, which places a premium on a compact width arrangement.

Attention must also be given to necessary clearances between the machinery and the roof, and between the machinery and the ribs, or posts. As an example, since several inches, and preferably a foot, is desirable as clearance between a moving machine and the roof, a continuous face haulage system for a 36 inch coal seam should be not more than 24 inches high.

b. Reliability

The basic concept of continuous face haulage creates the need for a high level of reliability in the haulage machinery, since it is a link in the chain of equipment that moves coal from the face to the secondary haulage system. If the haulage system becomes inoperative, production stops.

Probably the best insurance for providing reliability is through simplicity in the design, both in the concept and in the execution of the design details. Well proven, well designed components, and a minimum number of parts, will increase the statistical possibility for good reliability.

c. Durability

The mine environment subjects machinery to a lot of abuse. The coal and rock that has to be handled is heavy, and damaging to the machinery. The machines move over rough surfaces in dark and confined spaces, tending to cause damage from contact with mine surfaces and with other machinery. Falls from the roof and ribs will sometimes hit machinery in the area of the fall.

Such abuse should be accepted as routine, rather than exceptional and the structures and machinery should be designed rugged enough to withstand a great deal of abuse without failure.

d. Ease of service and maintenance

Routine service work, and maintenance work when problems develop on mining machinery, is difficult to perform at best, and thought should be given during the design process to making this work as easy as possible.

Lubrication requirements should be kept at a minimum, and access to lubrication points should be good. The requirement for exotic lubricants should be avoided, and the number of different kinds of lubricants should be kept at a minimum.

The need for machinery adjustments should be kept at a minimum. Access to adjustment points should be good. Adjustable parts should be rugged, with large fasteners, and the adjustment procedure should be simple.

Parts requiring periodic replacement should be designed so that removal and replacement is easy, requiring a minimum amount of labor and time.

Machinery that may have to be repaired should be accessible for repair, and easily removable if replacement is desirable.

The need for special tools and special fasteners should be avoided. Fasteners should be high grade, and oversized where possible.

Parts should be standardized as much as possible, and the number of parts should be kept at a minimum.

e. <u>Resistance to presence of abrasive particles</u>

Mine machinery must be well protected from the presence of coal particles and rock particles, since the normal mine environment contains this material in large quantities, both dry and in combination with water.

Bearing seals, shaft seals, and guards must be well designed and effective. Gear boxes must be designed to keep out dirt, with any necessary openings, such as breathers, being fitted with filters.

Hydraulic systems must be designed for cleanliness, to ensure long, trouble-free service from the hydraulic components. Good filtration must be provided. Dirt access into the hydraulic tank must be prevented, either through a pressurized system or through filters on tank breathers. Dirt must be kept out of hydraulic cylinders by installing effective wipers on the rod end of the cylinders.

C. Capacity requirements of a continuous face haulage system.

It is desirable to attempt to define the capacity requirements of a continuous face haulage system, in spite of the fact that this requirement will vary considerably depending on mining method, mining conditions, and other factors. If the capacity of a system is relatively large, it allows the system to adapt to a larger number of applications than a smaller system would. In general, the more adaptable systems will be the most acceptable.

1. STEADY STATE CAPACITY

At this writing, the requirement for steady state, or average, capacity for continuous face haulage appears to fall in a range from 8 to 12 tons per minute. Such a system should be able to handle the normal output from either continuous miners or loading machines.

2. SURGE FLOW

The output from miners and loaders will sometimes come in surges which, for a period of perhaps 10 to 20 seconds, will produce coal at approximately twice the average rate. This means that surge flows from miners and loaders will range from rates of 15 to 25 tons per minute, for periods up to 20 seconds.

It would be desirable to have the ability to handle such surges as a feature in any continuous face haulage system. However, if surge flows from the miner or loader presented problems for an otherwise satisfactory continuous face haulage system, the miner or loader could be operated in such a manner that surge flows would be minimized.

3. LARGE PIECES

Related to the capacity of a continuous face haulage system to handle flow is the ability of the system to handle large pieces of coal or rock without the flow being interrupted.

As an attempt to define the size of large pieces that may be discharged from miners and loaders, the following estimates are presented.

It is quite normal to have pieces of coal or rock in the miner or loader discharge up to a size that is 12 inches cubed. This would indicate that a haulage system should be able to handle this size material as a matter of routine.

Occasionally larger pieces will come off the miner or loader tail conveyor, and these could be as large as 12 to 18 inches thick and 3 to 4 feet on a side.

When large pieces appear, either the continuous face haulage system must have a built-in means for reducing them in size, or they must be handled on an exceptional basis by being broken up or moved aside by manpower.

4. SPILLAGE

In addition to being able to handle certain flow rates of coal, and handle large pieces, the continuous face haulage system must do so without excessive spillage of the material being handled. This is not only a requirement related to efficient operation. It is also a requirement of the mandatory safety standards of the Bureau of Mines, since loose coal must not be allowed to collect in any appreciable quantity in active workings.

D. Mobility requirements of a continuous face haulage system.

The general requirement for mobility of a continuous face haulage system is that it be able to follow the mining machine or the loading machine in an effective way. This leads to some specific requirements, which are discussed below.

1. SPEED

The speed of the haulage system must be at least as great as that of the miner or loader. Current designs generally operate at speeds of 60 feet per minute or less, but projections for speeds of newer designs range as high as 80 feet per minute.

The primary limiting factor in achieving higher speeds is horsepower. With this in mind, while it would be desirable to have higher speeds built into the haulage system to move back quickly at times, it would seem practical to establish the maximum speed requirement between 60 and 80 feet per minute in forward or reverse, with the ability to move smoothly at any speed between zero and maximum.

2. TRACTIVE EFFORT AND GRADABILITY

Traction systems, both crawler type and rubber tire type, should be designed for 100% traction, which means that they should be capable of producing a tractive effort between crawler pads and the ground, or between tires and the ground, equal to the weight of the machine. This amount of tractive effort can not be developed at all times because of poor ground conditions, but it will be required on occasion.

Producing high tractive effort is largely a matter of producing torque at the final drive unit through the use of gear reductions, whereas producing vehicle speed, particularly over bad ground conditions or up a grade, demands horsepower.

For design purposes, adequate power should be available to produce reasonable speeds on 25% grades for crawlers, and on 30% grades for tires.

3. FLOTATION AND GROUND PRESSURE

Ground-supported machines, either on crawlers or tires, in addition to tractive effort and power require a suitable support area between the pads and the ground or between the tires and the ground. Adequate support area provides flotation to the machine to prevent the crawlers or tires from sinking too deeply into soft ground.

Whether or not enough ground bearing surface is provided on a machine can be investigated by dividing the operating weight of the machine by the square inches of surface contacting the ground, to arrive at the ground pressure between the machine and the supporting surface.

A reasonable design goal for a crawler machine would be a ground pressure of 20 to 25 psi, but a pressure as high as 30 to 35 psi could be functionable.

A reasonable design goal for a rubber tired machine for underground use would be 80 to 100 psi, and lower figures would be better in all cases where they can be achieved.

The ground pressure for rubber tired equipment generally approximates very closely the internal pressure of the tire.

4. LONG MOVES

Another aspect of mobility that should be considered for a continuous face haulage system is the relative ease or difficulty associated with moving the system from one section of the mine to another. Systems that can make such moves without a great deal of difficulty would be advantageous.

5. GROUND CLEARANCE

For ground supported equipment, more ground clearance is generally required for rubber tired equipment than for crawler mounted equipment.

Crawler ground clearance, in practice, is sometimes as low as 3 inches. Better design, if conditions allow, would provide ground clearance minimums in the range of 5 to 6 inches. If the head room allows it, or if extremely bad bottom conditions demand it, ground clearance could be as high as 12 inches.

For rubber tired equipment, ground clearances of 6 to 12 inches are generally required, depending on wheel base, ground conditions, and other factors.

E. Flexibility requirements of a continuous face haulage system.

Previous discussions of the spatial arrangement aspects of underground coal mines pointed out the need for flexibility in a continuous face haulage system to allow it to be able to follow a miner or a loader through the mine labyrinth. The following paragraphs attempt to define some of the requirements that must be met in such a machine design to produce adequate flexibility.

1. BEND RADIUS IN A HORIZONTAL PLANE

A bend radius in a horizontal plane, measured to the centerline of the system, in a range from 15 to 20 feet, should be able to be achieved in a continuous face haulage system.

2. ANGLE OF TURN

It would be desirable to have the capability, in a continuous face haulage system, to negotiate 90° turn angles, in a horizontal plane.

3. NUMBER OF TURNS

It would be desirable to have the capability, in a continuous face haulage system, to extend the system through as many as 5 or 6 turns, simultaneously, in a horizontal plane, assuming the required reach is available.

4. REQUIRED REACH

Like a lot of other things, the reach required in a continuous face haulage system depends on the existing situation. Systems that are operating currently range up to 200 feet and 300 feet in length. Systems are being considered for lengths ranging from 400 feet to 600 feet.

5. FLEXIBILITY IN A VERTICAL PLANE

Floor and roof irregularities require a degree of flexibility in a vertical plane for a continuous face haulage system. It is suggested here that valleys of up to 18 inches deep in a 20 foot span should be accommodated, and that rolls in the roof and floor of up to 12 inches in a 15 foot span should be accommodated.

F. Other requirements of a continuous face haulage system.

1. COMPATIBILITY WITH THE COAL PREPARATION PROCESS

In handling coal, it is important that the continuous face haulage system should not degrade the size consist below desirable limits. Systems that cause excessive tumbling of the coal in transit should be avoided.

In certain cases, the presence of large amounts of water on the coal could be undesirable at the preparation plant, and should be avoided.

2. COMMUNICATION DEVICES

In the development of continuous face haulage systems of appreciable length, there will probably arise a need for communication means between mine personnel at the inby and outby ends of the system. Since personnel will be out of sight and hearing of each other, but concerned with the same equipment, it would appear that communication devices would increase both the safety and the efficiency of the overall mining operation.

G. Condensed service requirements of a continuous face haulage system.

For convenience, the following listing has been made from the discussion in the preceding paragraphs

1.	Safety requirement	Comply with mandatory safety standards, Part 75, Subchapter 0, Title 30, Code of Federal Regulations.
2.	Health requirement	Comply with mandatory health standards, Part 70, Subchapter 0, Title 30, Code of Federal Regulations.
3.	Seam height	Adapt to seams from 2 to 12 feet high.
4.	Entry width	Operate in minimum entry width of 15 feet.
5.	Pillar size	Adapt to pillar sizes up to 100 feet square.
6.	Crosscut angles	Adapt to crosscut angles up to 90°.
7.	No. of turns	Convey through up to 5 or 6 90° turns.
8.	Steady-state capacity	8 to 12 tons/minute.
9.	Surge flow capacity	15 to 25 tons/minute for 20 seconds.
10.	Large pieces	Handle 12 inches cubed as routine, 12 to 18 inches thick and 3 to 4 feet on a side as exceptional.
11.	Spillage	Operate without spillage.
12.	Speed	60 to 80 feet/min., forward and reverse.
13.	Speed control	Infinite.
14.	Tractive effort	100% of machine weight.
15.	Gradability	25% for crawlers, 30% for rubber tires.

16. Ground pressure .... 20-25 psi for crawlers, 70-80 psi for rubber tires.

17. Ground clearance .... 5-6 inches for crawlers, 6-12 inches for rubber tires.

18. Bend radius, hor. plane ..... 15 to 20 feet.

19. Required reach .... 200 to 600 feet.

20. Flexibility in a vertical plane . Accommodate valley of 18 inches in 20 foot span, roll in floor or roof up to 12 inches in 15 foot span.

21. Communication devices ...... Provide as required.

22. Degradation of coal size ..... Minimize.

23. Permissibility .... Comply with Bureau of Mines Schedule 2G.

CONTINUOUS FACE HAULAGE CONCEPTS

The objective for this phase of the overall study was to investigate the various concepts that have been proposed or used in the attempt to develop a practical, continuous face haulage system.

One of the aims of this contract was to limit the machinery considerations to existing technology and available state-of-the-art hardware. In this regard it is important to recognize the fact that for approximately twenty five years, since the introduction of continuous mining machines to underground coal mines, a practical solution to the continuous face haulage problem has been actively pursued by the entire industry, both at the machinery manufacturing level and at the mine operating level. During this time the people most knowledgeable about the problem have considered many ideas, some of which have been discarded before being implemented, and some of which have been developed into hardware and placed into coal mines for testing, usually at a considerable expenditure of money, time, and manpower.

As the following discussion will demonstrate, not many of the concepts that have been tried have survived, but the ones that have survived represent a distillation of a great deal of effort. It is probable, therefore, that we are most likely to find viable solutions to continuous face haulage for the near future among the systems still being investigated in the mines.

The concepts for continuous face haulage that are covered in this phase of the study have been grouped into thirteen categories, which represent all of the significant approaches to this problem that we are aware of at this time.

These thirteen categories will be discussed individually in the following parts of this report, generally in the order of importance, with the systems having the best acceptance or potential being listed first.

The following four categories represent the concepts that have any significant current use in U. S. underground coal mines:

A. Bridge conveyor-bridge carrier systems.

B. Extensible belt conveyor systems.

C. Flexible conveyor belt systems.

D. Longwall conveyor systems.

The term "significant current use" should probably be qualified, because the combined total of all of the operating continuous face haulage systems from the above four categories represents a very small percentage of the underground coal mining activity in this country. It is recognized that at this time the predominant method for moving coal from the face is by shuttle car. The four categories listed above include the systems that are running with some degree of success in the mines today, and that are, for the most part, available as production items.

A. Bridge conveyor-bridge carrier systems.

Bridge conveyor-bridge carrier systems are the most prevalent continuous face haulage systems to be found in U. S. mines at the present time. Approximately 150 such systems are operating, split roughly equally between belt-type and chain-type conveyor designs.

This type of system consists, in its modern version, either of two bridge conveyor units and a mobile bridge carrier unit, or of three bridge conveyor units and two mobile bridge carrier units.

The first combination is arranged with one of the bridge conveyors attached to the tail conveyor of a miner or a loading machine, with the outby end of the conveyor resting on a dolly that travels several feet along the inby end of the carrier. The outby end of the carrier supports the second bridge unit, whose outby end rests on a dolly that rides on the side frames of a room conveyor.

The second combination is strung behind the miner in a manner similar to the first, alternating bridge conveyors and mobile bridge carriers, to provide a system with a longer reach.

With 40 feet of length on the bridge conveyor, and 30 feet of length on the carrier, a three-unit system provides approximately 130 feet of reach from the face to the room conveyor. This reach becomes approximately 200 feet with a 5-unit system.

The bridge carriers have a conveyor running their full length, so that in operation coal is received from the inby bridge and carried back and transferred to the outby bridge.

A 5-unit bridge conveyor-bridge carrier system is shown in a side view in Figure 1. Figure 2 shows a plan view of this machinery arrangement in a 5-entry mine development.

Bridge conveyors range in length from 30 to 45 feet, and are independently driven with electric motors. The belt-type generally are equipped with 36 inch wide belts running at about 400 to 450 fpm, giving a capacity of 8 to 10 TPM. The chain-type bridge conveyors carry chain widths up through 28 inches, running at speeds up to 300 fpm, giving a capacity up to 8 TPM, with peaks to 11 TPM.

Bridge carrier units are currently crawler mounted, although some earlier designs were rubber tired. Crawler drive is generally hydraulic, and the carrier conveyor drive is electric.

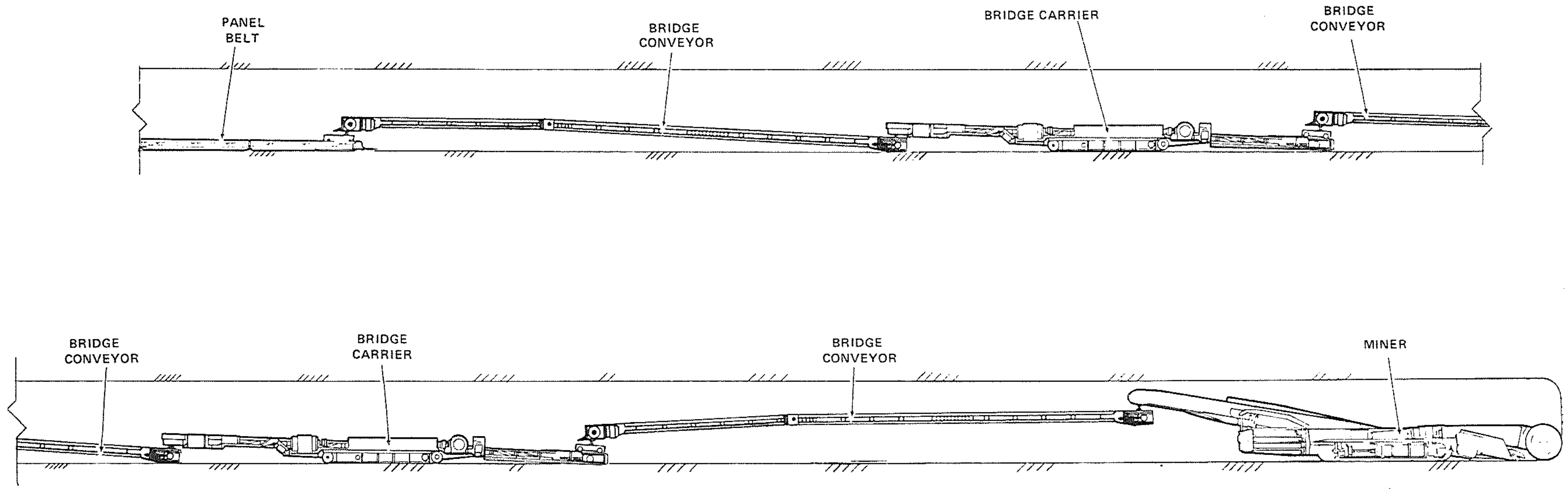


FIG. 1 BRIDGE CONVEYOR - BRIDGE CARRIER SYSTEM
SIDE VIEW

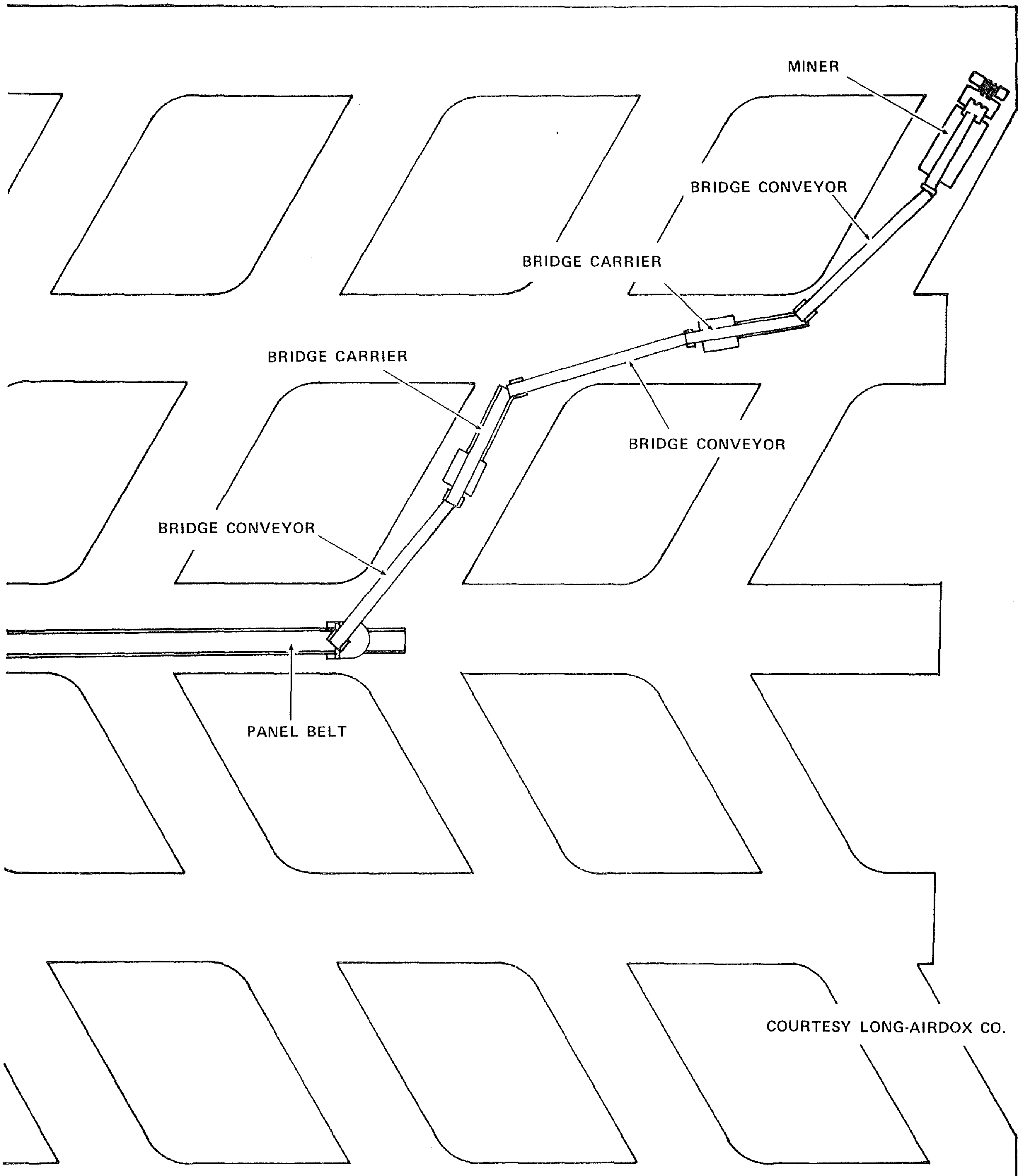


FIG. 2 BRIDGE CONVEYOR – BRIDGE CARRIER SYSTEM
PLAN VIEW

These systems have been marketed for approximately fifteen years, although the current designs are considerably improved over the early designs. Mechanical problems were quite prevalent with the early units, which appeared to discourage further use of the concept until improved designs appeared a few years ago.

In the form described above, these systems are manufactured by the following companies:

Jeffrey Mining Machinery Company
Long-Airdox Company
West Virginia Armature Company

The Jeffrey units are chain-type conveyors, and the Long-Airdox and West Virginia Armature units are belt-type conveyors.

Figures 3, 4, 5 and 6 show the arrangement of the various machine elements that make up the Jeffrey bridge carrier system.

Figure 3 shows the complete system, including a Jeffrey low-seam miner and a chain-type sectional room conveyor.

Figure 4 is a picture of the Jeffrey bridge carrier, showing the dolly on the inby end.

Figure 5 shows a Jeffrey chain-type bridge conveyor (the inby bridge conveyor) mounted on the bridge carrier dolly.

Figure 6 is a picture of the outby end of the bridge carrier supporting the outby bridge conveyor. This is an excellent view of the design of the conveyor transfer point, including the pivot joint that gives the system its flexibility.

The Wilcox Company markets chain-type bridge conveyor units that mount behind their mining machines, but these are not designed to be used with mobile bridge carriers.

The use of bridge conveyors preceded the introduction of the mobile bridge carrier around 1960. Bridge conveyors were used for approximately ten years prior to 1960 between miners and room conveyors, and between loading machines and room conveyors. In some applications, bridge conveyors connected miners or loaders to the tail piece of an extensible belt.

Connecting joints between the various units of the bridge conveyor-bridge carrier system allow the units to pivot to negotiate corners, and also allow the joints to flex to accommodate to undulations in the floor.

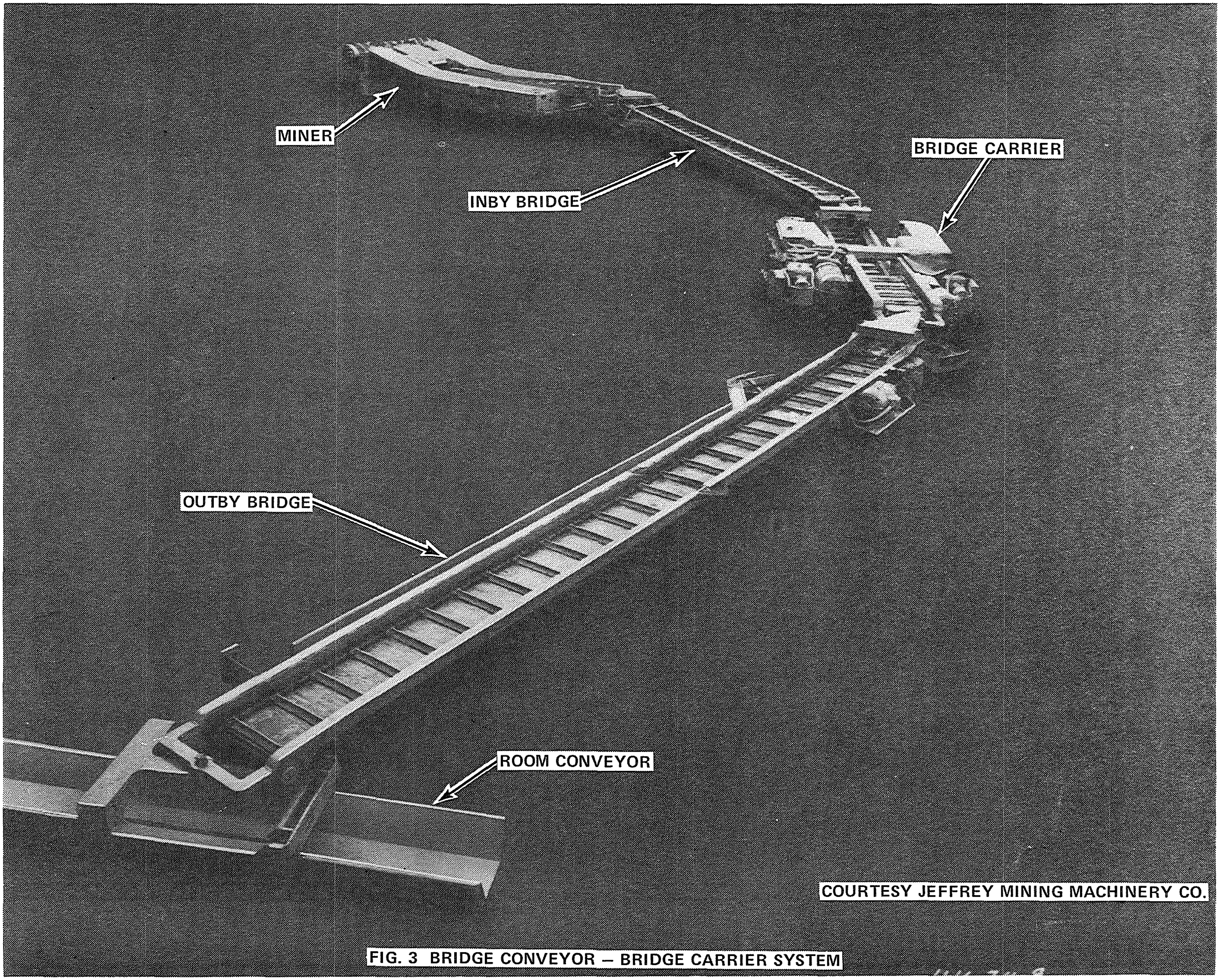


FIG. 3 BRIDGE CONVEYOR – BRIDGE CARRIER SYSTEM

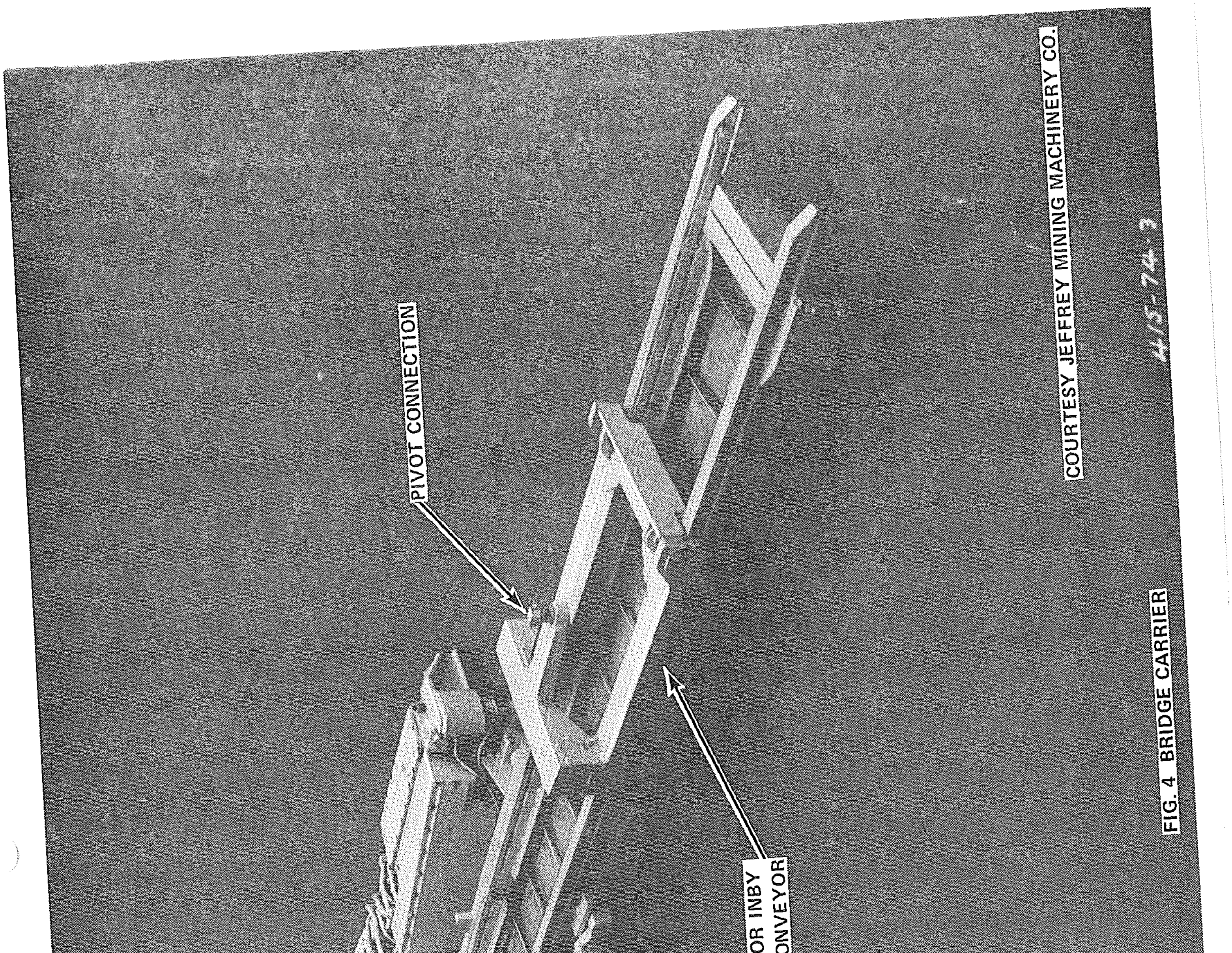


FIG. 4 BRIDGE CARRIER

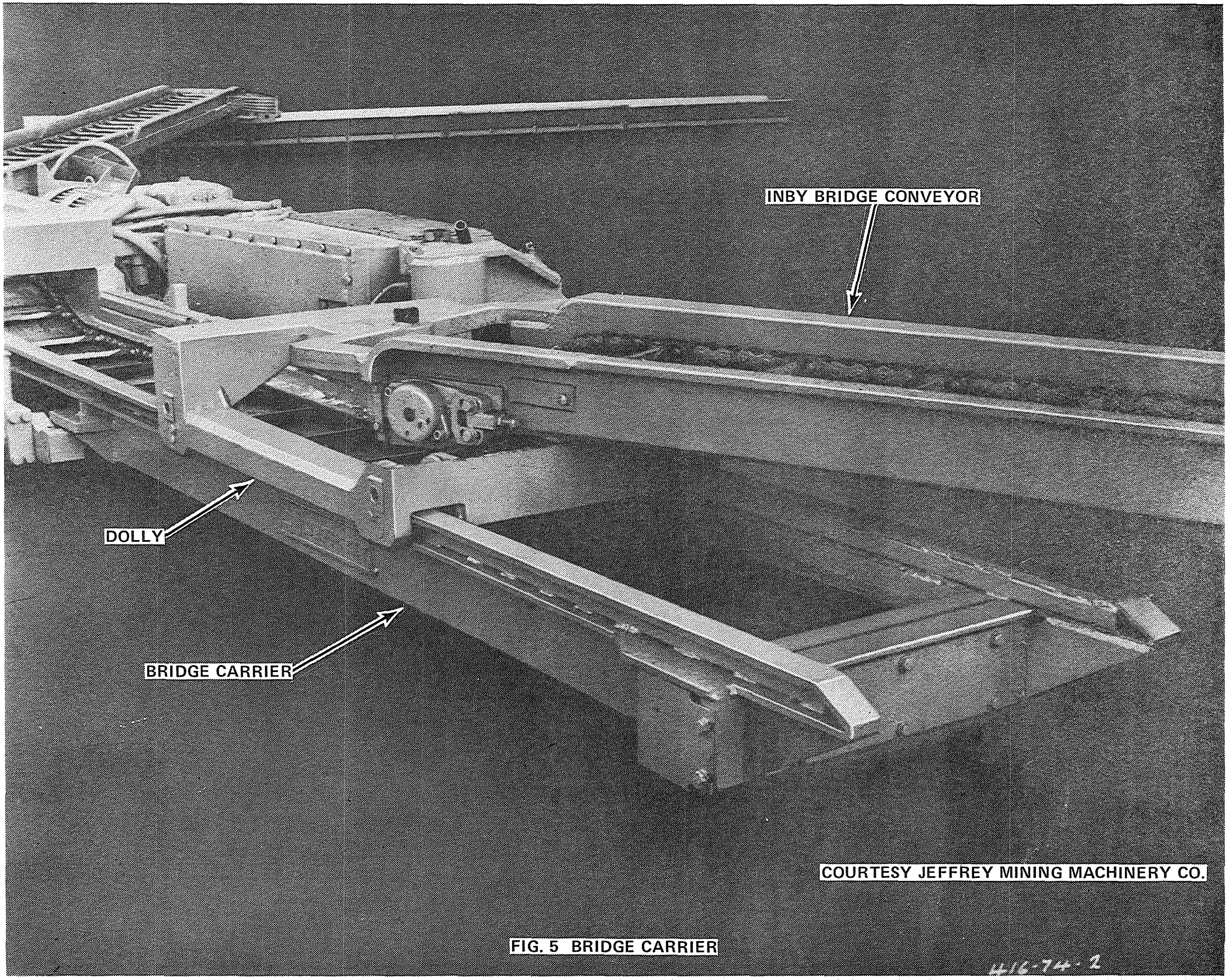


FIG. 5 BRIDGE CARRIER

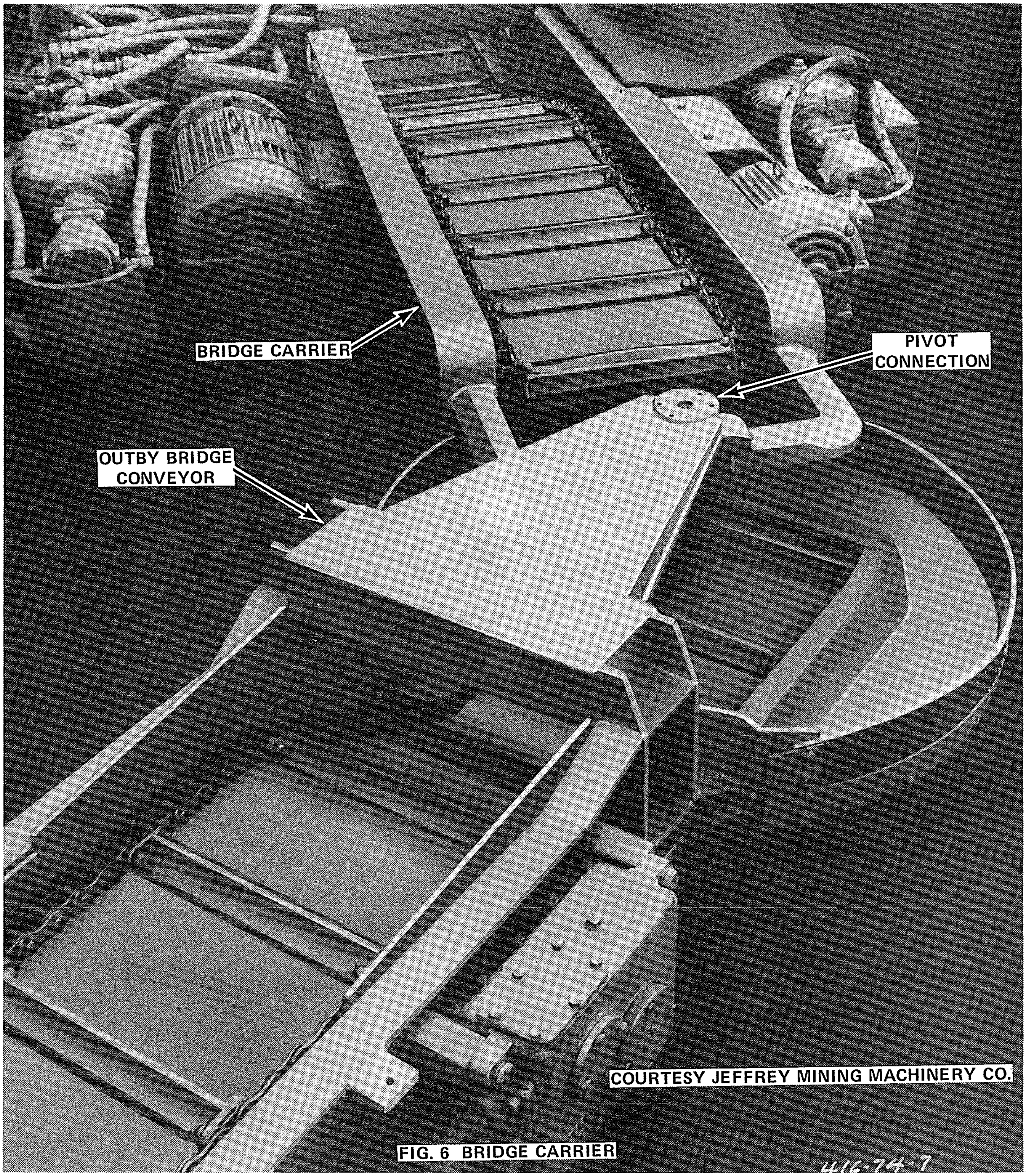


FIG. 6 BRIDGE CARRIER

Additional flexibility is provided the system by having the carrier so designed that the inby and outby ends of the carrier conveyor may be raised or lowered hydraulically.

The operators of the mobile bridge carriers follow the forward and backward movements of the miner by observing the movement of the carrier dolly that supports the outby end of the bridge conveyor. Coordination and communication between the miner operator and the carrier operators is improved in some cases where mine telephone systems have been installed between the miner and the carriers.

The low tail piece of the room conveyor that carries the dolly which supports the outby bridge conveyor is generally made long enough so that the entire miner-bridge conveyor-carrier string can be retreated until it is along the side of the room conveyor. This gives the miner, or loader, mobility to back out of one entry, make crosscuts, and mine in an adjoining entry.

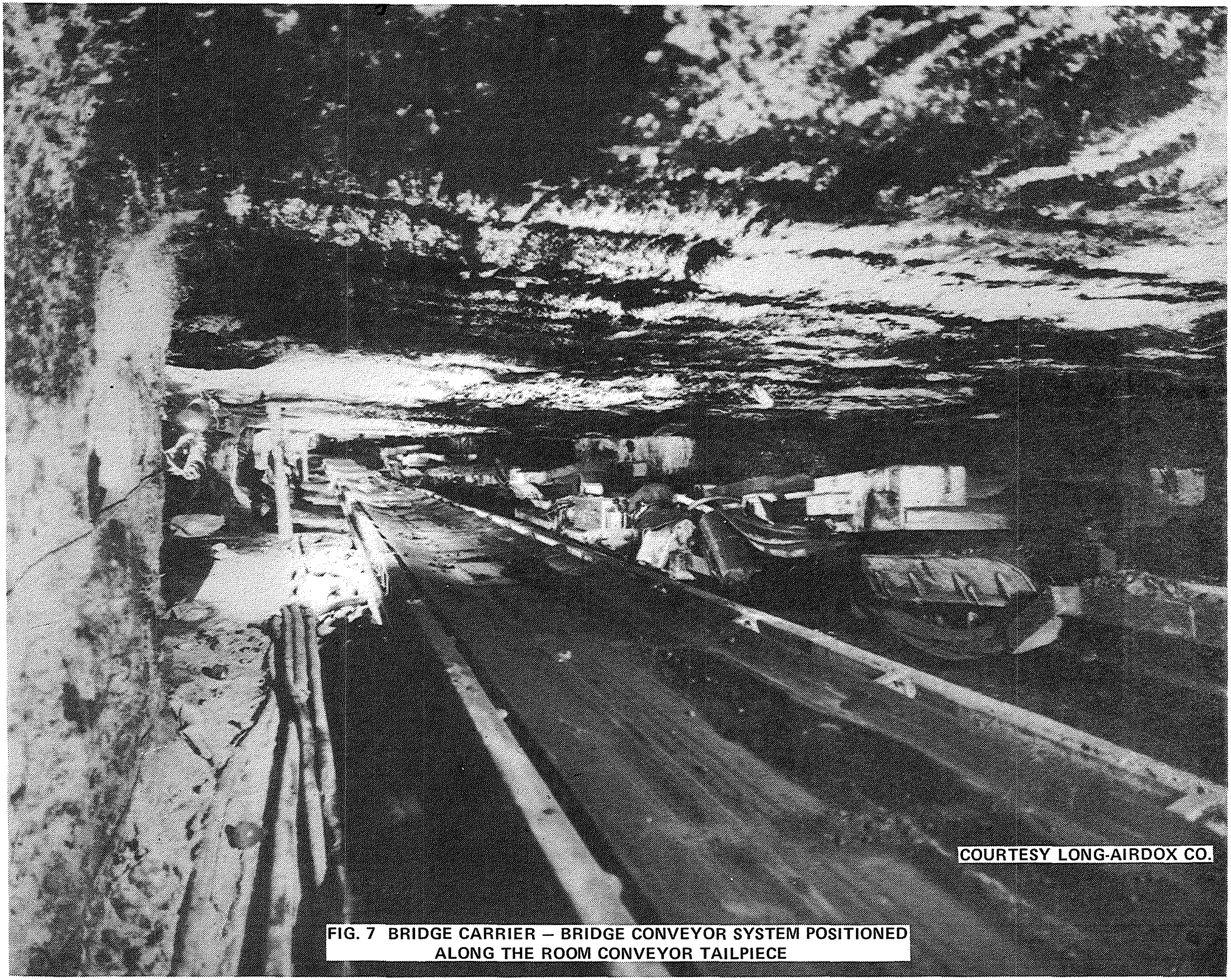
Figure 7 shows a Long-Airdox bridge conveyor-bridge carrier system in the retracted position beside the room conveyor tail piece.

The three-unit systems are generally used to mine a three-entry development plan, while the five-unit systems are used for a five-entry plan. In each case, the room conveyor is placed in the middle entry.

In some cases, where maximum reach is desired because of a certain cut sequence, five-unit systems have been used for three-entry development.

Most applications of bridge conveyor-bridge carrier systems are in coal seams ranging from 26 inches to 48 inches high, but their use can be extended into higher seams.

These systems appear to offer productivity advantages over shuttle cars in the lower seams, because of the reduced carrying capacity of shuttle cars that are designed for low coal applications.



COURTESY LONG-AIRDOX CO.

FIG. 7 BRIDGE CARRIER – BRIDGE CONVEYOR SYSTEM POSITIONED ALONG THE ROOM CONVEYOR TAILPIECE

B. Extensible belt conveyor systems.

Extensible belt conveyors appeared on the U. S. market in the early 1950's, and their use in underground mine applications apparently peaked in the 1960's and then declined. Joy Manufacturing Company sold over 100 installations over a period of about twenty years. Goodman Equipment Corporation sold several units, also, but at the present time extensible belt conveyors are not an active product with either company.

Lee-Norse is actively marketing their extensible belt design at the present time, and have about eight units operating in the field.

There seems to be a possibility of renewed interest in extensible belt systems because of their adaptability to longwall and shortwall mining systems. At the present time it is estimated that approximately fifty commercially-manufactured extensible belt systems are operating in U. S. underground coal mines.

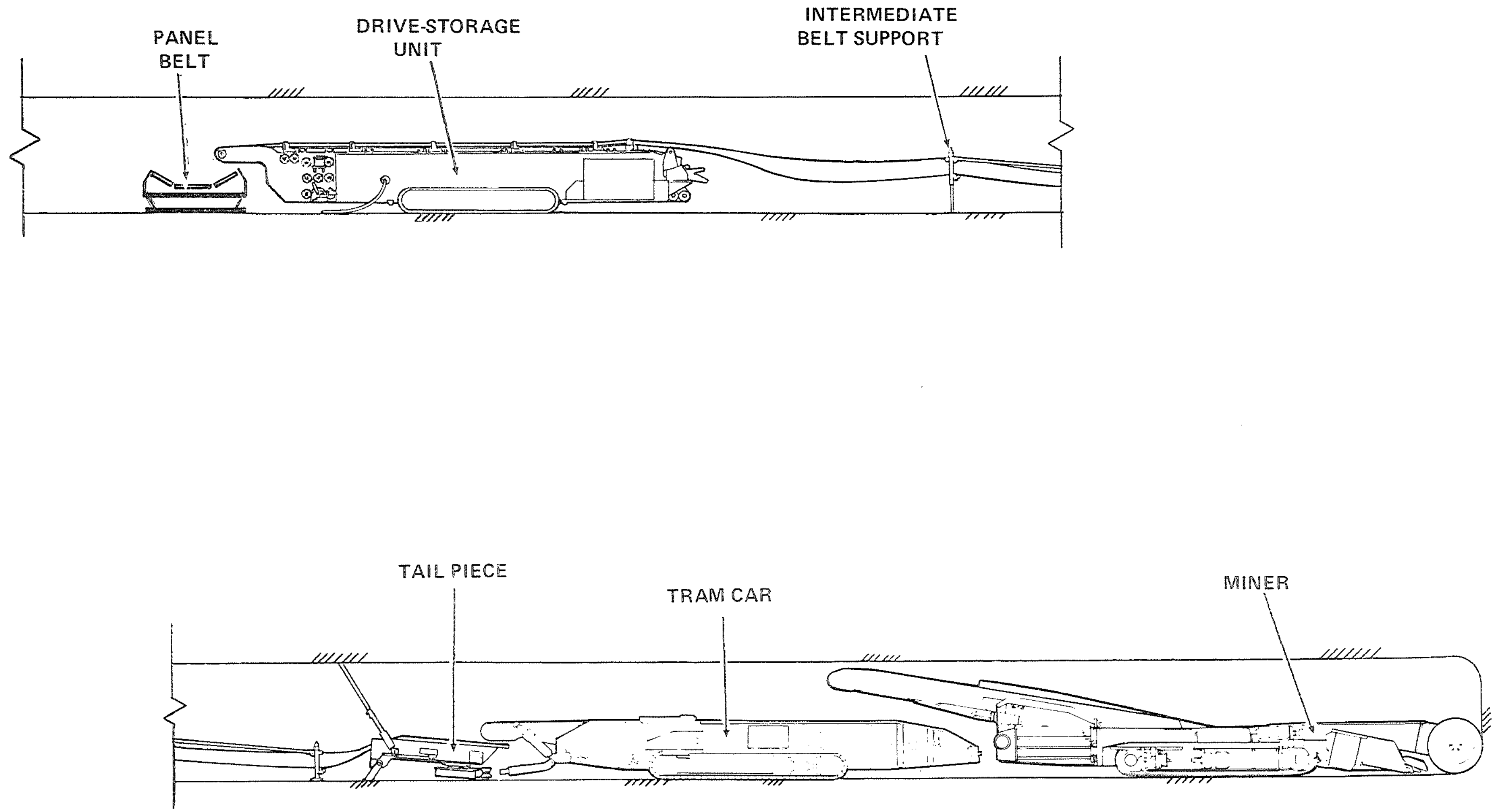
An extensible belt system consists of a drive-storage unit, a number of light support frames for the extended belt, and a tail piece.

The drive-storage units are generally crawler mounted, with belt drive, belt storage, and belt takeup all in one frame.

The tail sections on the Joy units are crawler mounted, with a short transfer conveyor and a pivoted tail pulley. The transfer conveyor is fitted with rails to support and guide the discharge end of a bridge conveyor. The bridge connection between the miner and the tail section allows the miner to cut breakthroughs to the right or left.

The tail section of the Lee-Norse unit is a skid-type design, and is arranged to be attached to and carried by the drive-storage unit when the belt is in the full retracted position. The tail section is pulled away from the drive-storage unit by a Lee-Norse tram car when the belt is extended. The tram car has a scissors hitch device that engages an hourglass hitch pin on the inby end of the tail section. The tram car design is very much like a shuttle car, with a large hopper shape at the inby end, a transfer conveyor running the full length, and an elevating discharge boom at the outby end.

Figure 8 shows a side view of a Lee-Norse extensible belt system, including miner, tram car, tail piece, belt, and drive-storage unit.



COURTESY LEE - NORSE CO.

FIG. 8 EXTENSIBLE BELT SYSTEM
SIDE VIEW

In operation the drive-storage unit of an extensible belt conveyor is positioned to discharge to another haulage means, generally a conventional belt system. As the tail section is advanced to stay in proper position with the miner, intermediate supporting frames are put in place to support the extended belt. When all of the stored belt is pulled from the drive-storage section (generally after a 50 to 60 foot advance of the tail section) belt is added in 100 to 120 foot lengths at the inby end of the drive. This is done by splicing in the new length of belt and returning the storage unit pulleys to their original position, which pulls the new length of belt into the drive-storage unit.

Like any conventional belt conveyor, the extensible belt conveyors must be operated in a straight line. The tail section must be kept in alignment with the drive-storage units, and the intermediate belt supports must be maintained in line with the drive unit and the tailpiece.

To provide system flexibility to follow the miner through cross-cuts and into adjacent headings, Lee-Norse sells three drive-storage units, complete with tailpiece, and one tram car. The first unit is positioned to discharge to a panel conveyor, and when the tram car has extended the tail section to a desired point, the tail section is anchored in place with sprag jacks. A second drive-storage unit, with its own tailpiece, is then positioned to discharge onto this anchored tailpiece, and the tram car can then extend the second belt in another direction. Direction changes are thus made by adding drive-storage units, complete with tailpiece. When a tailpiece is anchored, the tram car can act as a shuttle car between the miner and the tailpiece.

Figure 9 shows a plan view of the Lee-Norse extensible belt system in a typical mine development.

Maximum extended length for an extensible belt conveyor is usually in the 1000 foot range, but heavy duty units have been built that allowed up to 2000 feet of extension.

The height of the various units for extensible belt conveyor systems, including drive-storage units, tail sections, and tram cars, varies from 30 inches to 54 inches, depending on make, model, belt width, belt storage capacity, and ground clearance desired. Increases in belt width, storage capacity, and ground clearance result in a higher machinery profile.

Conveying capacity is listed in a Joy specification, for a 36 inch wide belt running at 500 fpm, as follows:

350 tons/hr average
500 tons/hr peak

This would indicate that extensible belt tonnage ratings are substantially less than fixed belt ratings, since published tables show a coal carrying capacity of approximately 700 tons/hr for a fixed belt 36 inches wide running at 500 fpm.

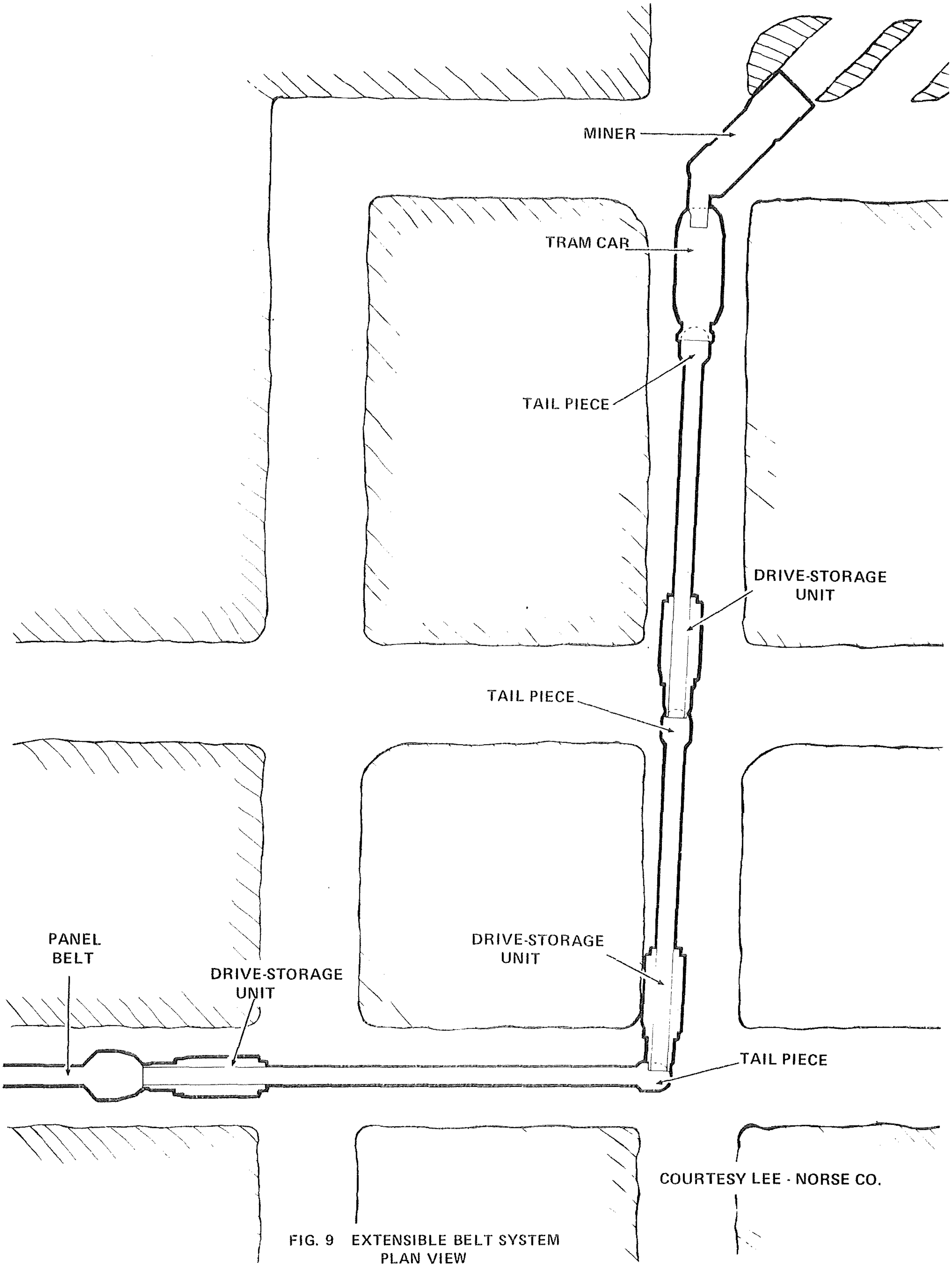


FIG. 9 EXTENSIBLE BELT SYSTEM
PLAN VIEW

C. Flexible conveyor belt systems.

Flexible conveyor belt systems, as described in this category of continuous face haulage systems, are continuous belt conveyors that have a capability of operating along a changing, winding path. This is opposed to conventional conveyor belts, which must operate on a straight line, and to conveyors that are designed to operate only around a fixed turn.

The patents covering flexible conveyor systems show concepts going back to 1941. The most significant among these patents, in terms of the flexible conveyor belt systems that are operating in the U.S. today, are the following:

1. Horth 2,836,283 assigned to Stubbe
   Horth 2,818,965 assigned to Stubbe
   Horth 2,818,962 assigned to Stubbe

2. Payne et. al. 3,707,218 (Serpentix General Corporation)

3. McGinnis 3,701,411 assigned to B.F. Goodrich Company

Most of the patents on flexible conveyor systems show the conveyors as floor-supported devices, usually being carried on a train of interconnected wheeled carts.

One of the distinguishing features of the patents listed above, other than the fact that they are the basis for the two systems that are currently operating in the U.S., is that they incorporate elastomeric materials in the conveyor, whereas the other patents listed under this heading in Appendix B are concerned with metal flight conveyor devices.

The patents listed in items 1 and 2, above, are related to the Serpentix conveyor, which was originally developed in Germany, and is made in the U.S. by Serpentix General Corporation, Denver, Colorado. The Stubbe patents cover a flexible conveyor that can operate around fixed turns. The Payne patent extends the concept so that it can be operated around a changing pattern of turns. Joy Manufacturing Company has the rights to make the Serpentix General Corporation version for use in underground bedded deposits.

At the present time there is only one Serpentix conveyor installation operating in a U.S. underground coal mine. This is located in the Peabody #10 mine near Taylorville, Illinois. This installation is supported on a roof-mounted monorail system. Peabody has ordered two more Serpentix installations, one for their Deercreek Mine near Huntington, Utah, and one for their Baldwin #1 mine near Marissa, Illinois.

The McGinnis patent listed above describes a mobile conveyor system that consists of an endless elastomeric belt supported on a chain of interconnected wheeled carriages, with a self-propelled tractor connected at each end of the chain. The belt is molded with embedded wire rope reinforcements, which limit belt stretching and also provide some stiffness to the belt cross-section.

The B. F. Goodrich Company and Joy Manufacturing Company have collaborated in designing and building two of these units, which are called Flexible Conveyor Trains, or FCT's. One unit has been operated behind a continuous miner at the Ireland Mine of Consolidation Coal Company, and the other has been operated in connection with a shortwall mining system at the Federal #1 mine of Eastern Associated Coal Company.

Further details of the Serpentix conveyor system and the FCT are given below.

1. JOY SERPENTIX CONVEYOR

The Serpentix conveyor that has been installed and is in use at Peabody #10 mine has a 32 inch wide belt and is 200 feet long. Belt speed is approximately 400 fpm, which gives an average carrying capacity of 8 to 9 tons/minute. This conveyor was furnished by Serpentix General Corporation, and Peabody has added units to the system to adapt it for continuous face haulage use. Newer designs of the Serpentix will be 400 feet long, will have 40 inch wide belts running at 360 fpm, and will have a carrying capacity of 10 to 12 tons/minute.

The system in use at Peabody includes the following equipment, beginning at the inby end:

1. Tram car. This also serves as a surge car behind the miner.

2. Bridge conveyor. This also serves as a draw-bar between the tram car and the Serpentix conveyor.

3. Monorail system. The monorails are fastened to the roof with conventional roof bolts, and the system includes switching devices at crosscut intersections.

4. Serpentix conveyor. This is supported from and moveable on the monorail.

5. Transfer conveyor. This is located at the outby end of the Serpentix to transfer coal to a panel belt which is set up parallel to the main monorail track.

6. Hydraulic power pack. This is also supported from the monorail, and connected to the Serpentix with a short drawbar so that they move together. It provides power to the Serpentix belt and to the transfer belt.

7. Panel belt. This is a 36 inch wide conventional rope-supported belt. Belt is added and the tail piece is advanced as required.

The tram-surge car is used to move the Serpentix conveyor. It is crawler mounted, hydraulically powered, and much like a shuttle car in general design. The tram car follows directly behind the miner, and transfers the coal that it receives to the bridge conveyor. Hydraulic power to operate the bridge conveyor is supplied by the tram car.

The bridge conveyor has a 30 inch wide troughed belt supported on a frame that is approximately 18 feet long. Ball joint couplings are provided at both ends for connection to the tram car and the Serpentix conveyor. The frame is more rugged than a normal bridge because it also serves as a drawbar.

The Serpentix conveyor is composed of a drive station end (outby) and a tail tension end (inby), joined together by a series of 8 foot long vertebrae sections, which produces a structure capable of operating on 15 foot radius horizontal turns. The structure also has limited vertical flexibility to adapt to the undulations of the roof-supported monorail.

The long string of vertebrae sections that form the spine of the Serpentix conveyor are supported at intervals of eight feet by hangars that connect to small trolleys that ride on the monorail.

The individual vertebrae pieces between hangar supports are separated by resilient spacers, and each eight-foot section of vertebrae and spacers is held together by a spine bar that passes through the center of the assembly. The spine bar is designed to allow lateral flexure while also providing the required support in a vertical plane.

The vertebrae pieces are so designed that when stacked together their shape produces channel-like guides along the top and along the bottom of the spine for the full length of the Serpentix. Roller carriages ride in these guides, and the roller carriages are fastened to an endless link chain that runs on the drive sprocket and the tail sprocket of the conveyor. Roller carriages occur 40 inches apart along the drive chain. Spaced every eight inches between the roller carriages are blocks fastened to the drive chain. The roller carriages and the intermediate blocks form supports for brackets that run the width of the belt, and these brackets support molded rubber belt pans, which are bolted to the brackets so that one rubber piece spans the distance between two adjacent brackets. Each rubber piece has a convolution, or hump shape molded into it that runs the width of the conveyor belt. The space between humps of adjacent rubber pieces forms a pan, and the convolutions allow for the flexibility required in the belt assembly when the belt goes around a turn or over a pulley.

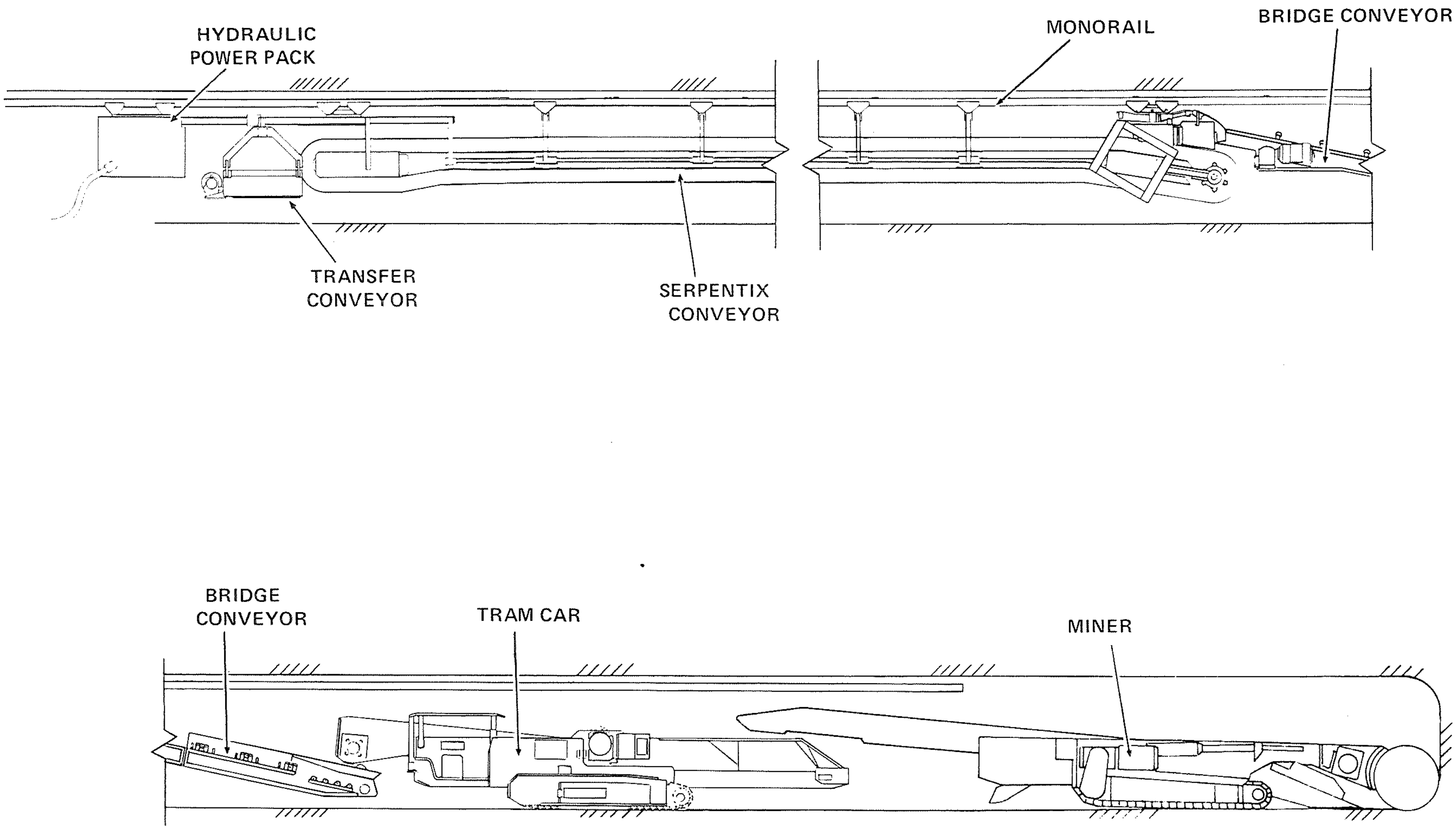
The monorail track that supports the Serpentix conveyor is made up of short lengths of a standard steel 5-inch I-beam. The average length is about 10 feet, and these track sections are bolted to the roof on 5 foot centers. Switches are installed in the monorail at breakthrough points to allow the Serpentix to follow the miner to either right or left, as may be required in the mining plan. Curved rails are used between the exits from the switches and the straight runs in the breakthroughs.

Figure 10 shows a side view of the machinery arrangement of a Serpentix conveyor system, from miner to room conveyor. It takes a minimum of seven feet of seam height to accommodate the Serpentix conveyor, in its present configuration, but newer designs are expected to be somewhat more compact.

2. JOY FLEXIBLE CONVEYOR TRAIN

Development of the Joy FCT was initiated in 1968 to investigate a new belt concept of the B. F. Goodrich Company.

The belt is a molded trough design with a relatively heavy center section that carries steel cable tension members. The side portions of the belt, which angle up from the center section at 45°, are fluted, or convoluted, which allows the edges of the belt to stretch when the belt moves around turns or passes over pulleys. The fluted side sections of the belt are reinforced with molded-in wire inserts to help maintain the belt cross-section shape when the belt edge bears against guide rollers. The belt is designed to operate around turns with a minimum turn radius in a range from 20 to 30 feet.



COURTESY JOY MANUFACTURING CO.

FIG. 10 SERPENTIX CONVEYOR
SIDE VIEW

Figure 11 and Figure 12 show the top load-carrying strand of the FCT belt, and they serve to illustrate the general configuration of the belt and the guide and support roller system.

Splices in the belt have been made with bolted plate systems, and also with a combination of a vulcanized splice in the center section and bolted plates on the fluted side sections.

The FCT belt has been operated at velocities up to 670 fpm, with no material handling problems. Belt capacity at 600 fpm is about 12 tons/minute.

The belt is mounted on an articulated train of light weight, two-wheeled cars that are 8 feet long and about 5 feet wide. The cars carry roller stands at 2-foot intervals for supporting and guiding the conveyor belt. The roller stands at the car ends are swivelled and controlled to maintain proper guidance to the belt when the cars are negotiating a turn. Overall length of the FCT is about 300 feet.

The end car on the inby end of the train contains a drive unit for the return side of the belt. The outby end car also contains a belt drive unit, and provides hydraulic take-up for the belt.

The intermediate two-wheeled cars of the FCT are not powered. The train of cars is moved foward by a loading machine, and is pulled backward by the rear unit of the train, which is mounted on four wheels, all of which are powered. The rear unit is skid steered. The train of cars are designed to track, to follow whichever end is doing the pulling, but portable roller frames are installed against the corners of pillars on the inside of turns to provide additional guidance for the train.

The FCT conveyor discharges to any suitable secondary haulage system. At the Ireland mine a cross conveyor at the outby end of the FCT transfers the flow of coal to a panel belt that parallels the outby length of the FCT. Another arrangement has the FCT discharging to a bridge conveyor, that transfers the coal to a roof-suspended monorail transfer conveyor. The transfer conveyor runs parallel to, and above a conventional panel belt.

Figure 13 shows the FCT assembled above ground when it was undergoing tests. Figure 14 is a side view of one of the two-wheeled cars during underground tests.

In its present configuration, the FCT requires a minimum seam height of 6 to 7 feet. Newer designs of this concept are expected to be more compact.

The last section of this report that discusses program plans describes a monorail-mounted version of the FCT that is to be built by Joy under a Bureau of Mines research and development contract.

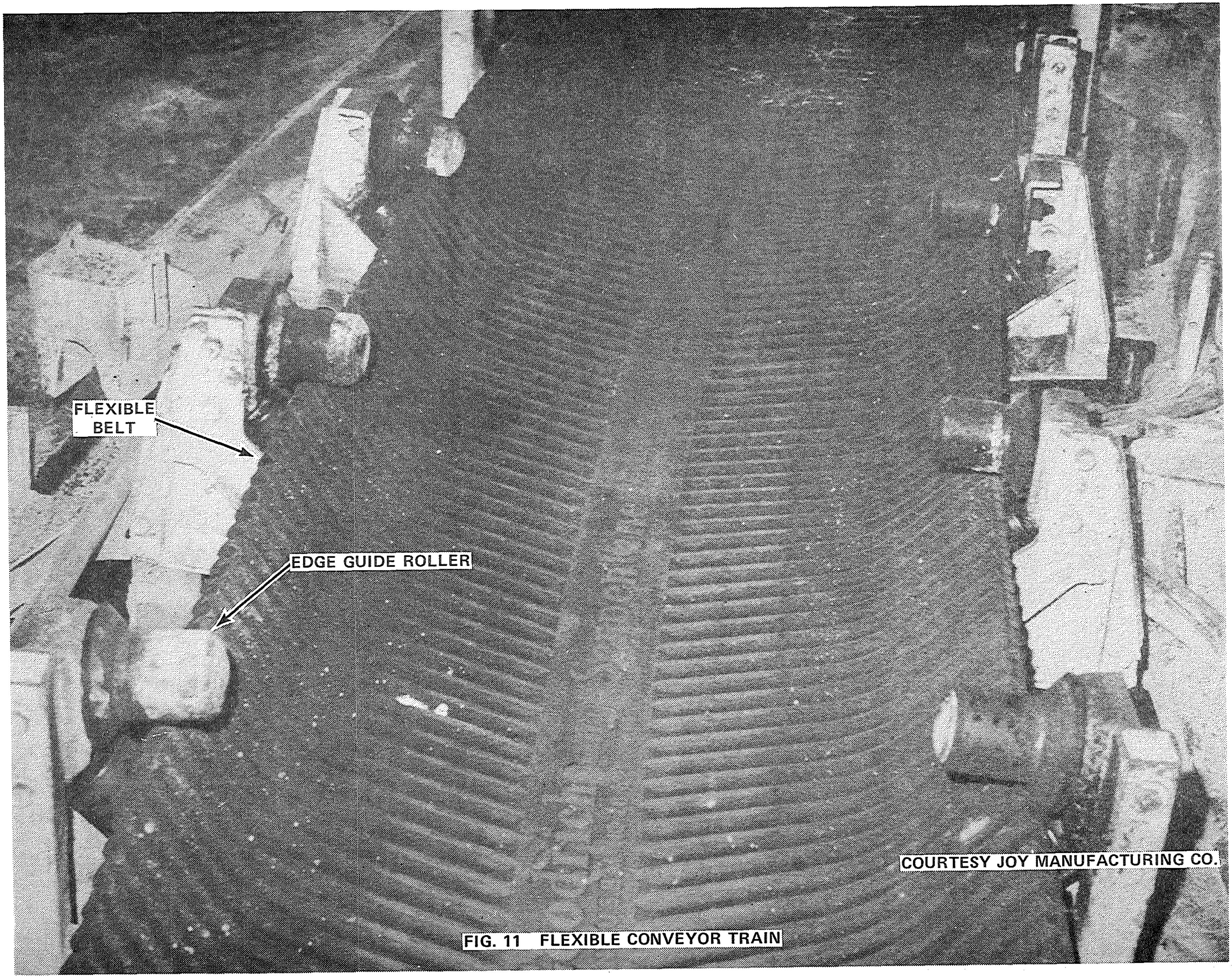


FIG. 11 FLEXIBLE CONVEYOR TRAIN

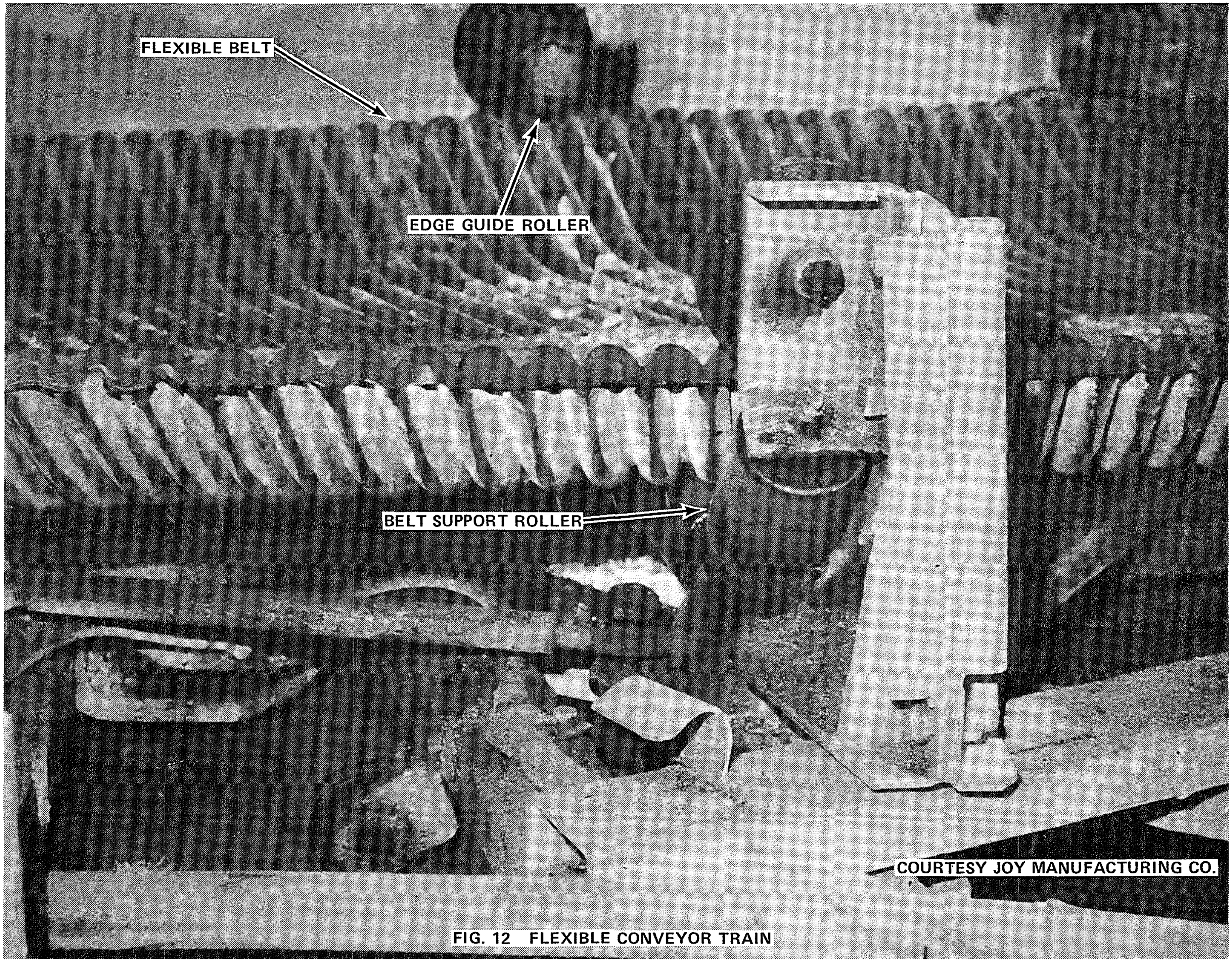


FIG. 12 FLEXIBLE CONVEYOR TRAIN

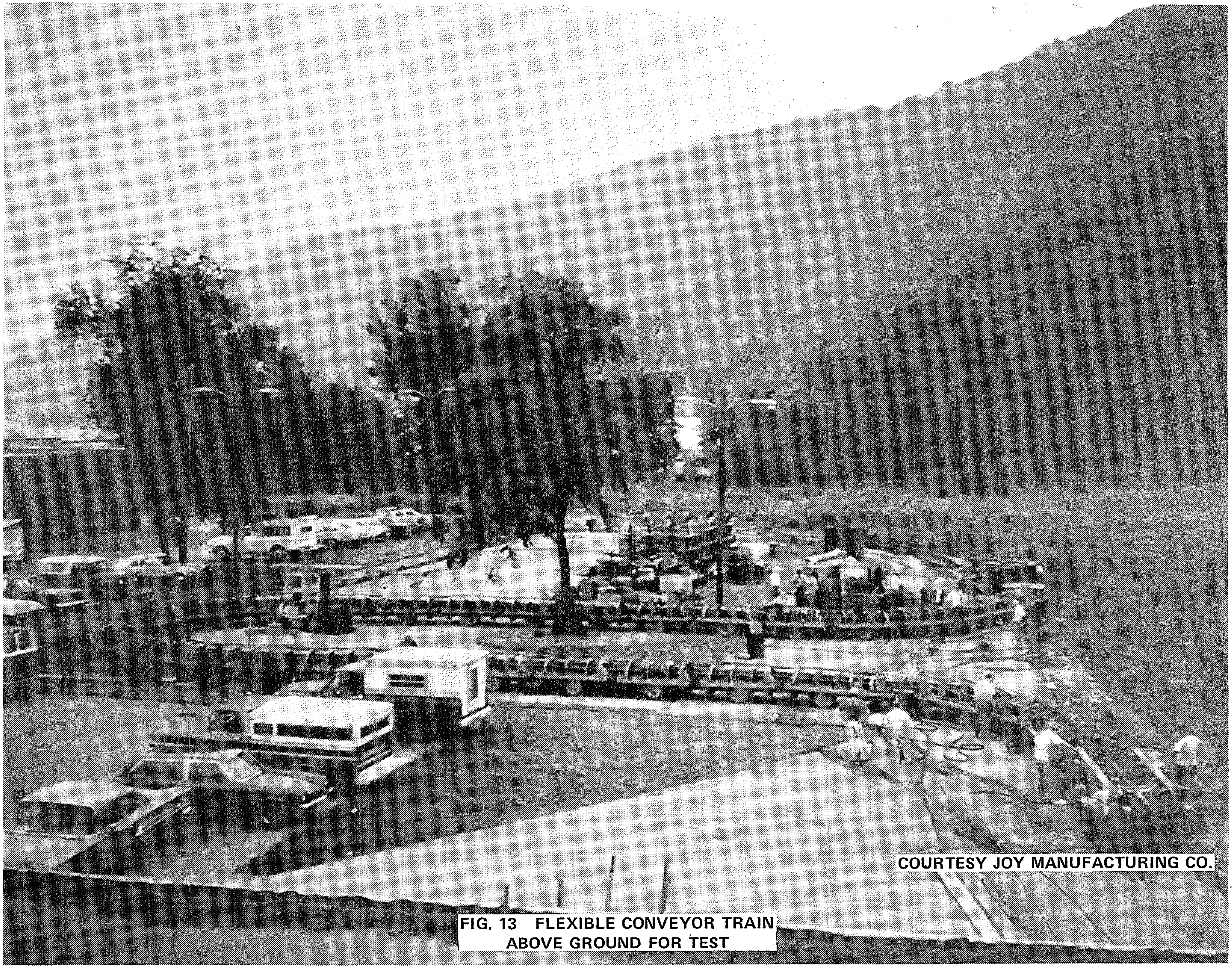


FIG. 13 FLEXIBLE CONVEYOR TRAIN ABOVE GROUND FOR TEST

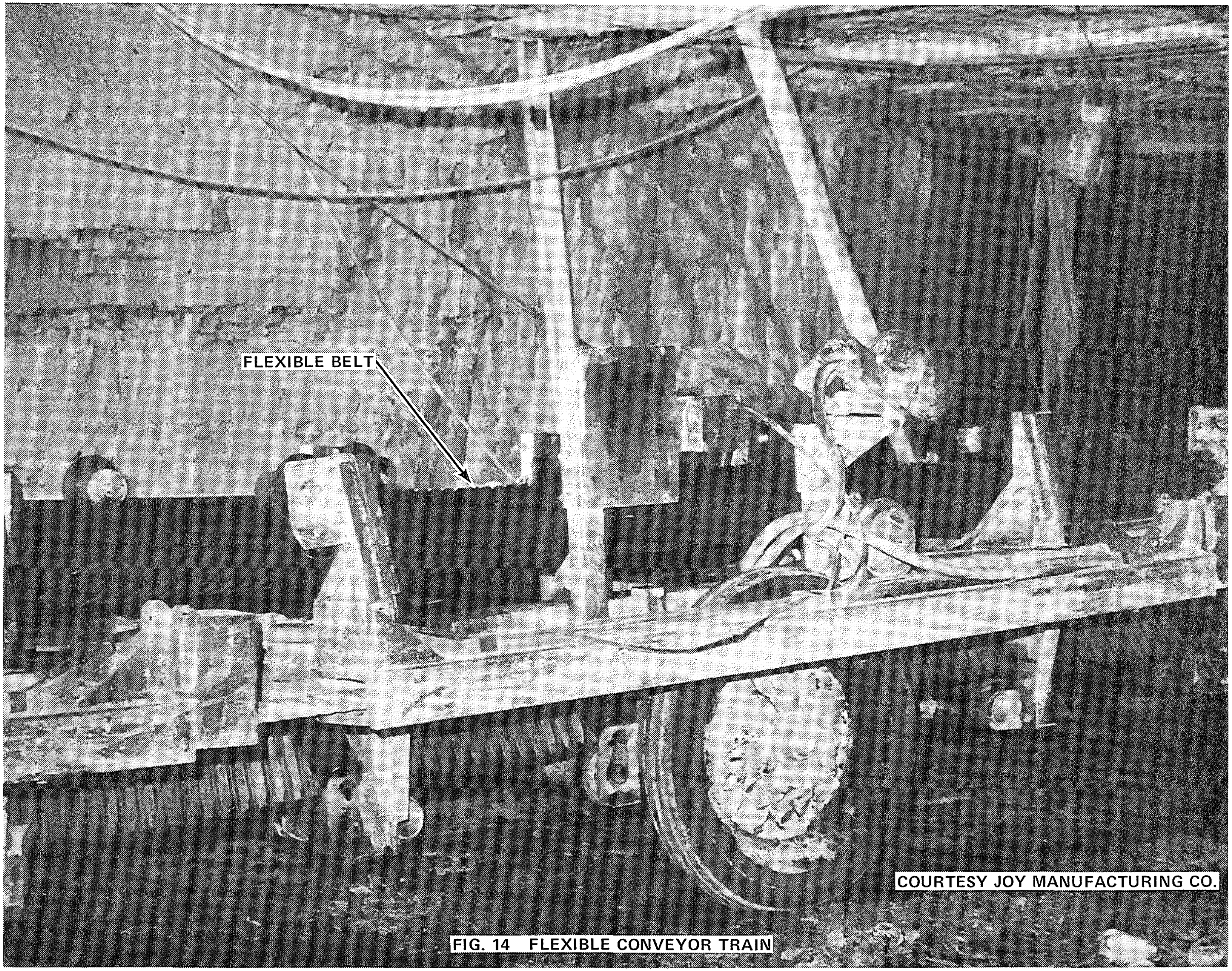


FIG. 14 FLEXIBLE CONVEYOR TRAIN

D. Longwall conveyor systems.

This category of continuous face haulage concepts is included as a special case, since the combinations of haulage devices that have been applied with considerable success to longwall mining operations cannot be applied in the same form to conventional mining, continuous mining, or shortwall mining. Longwall conveyor systems, however, provide a good illustration of workable continuous face haulage.

A longwall conveyor system is generally made up of three elements; an armored face conveyor, a stage loader, or transfer conveyor, and an extensible belt conveyor.

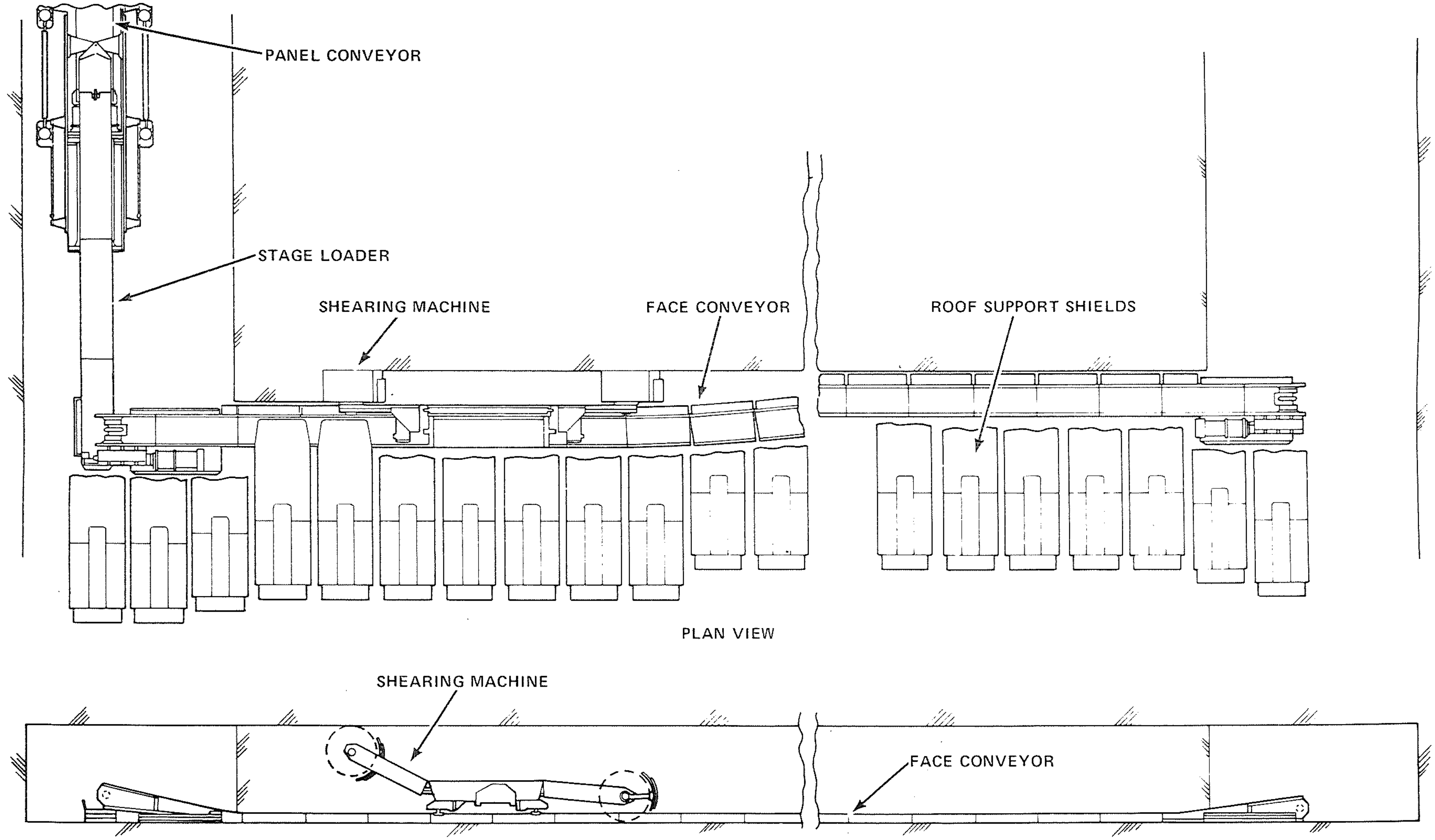
The armored face conveyor is installed parallel and adjacent to the longwall face. It consists of heavy trough sections that are flexibly interconnected. Single-chain or double-chain flights ride in the troughs, and the sides of the troughs form a support track for the face cutting machinery. The face conveyor design is heavy and rugged to provide the necessary structural support for the cutters, and to resist damage from the impact of rock and coal. As coal is mined across the longwall face, the trough sections are pushed forward by hydraulic rams that are mounted on the roof supports.

At the termination of the face conveyor in the head entry, the face conveyor discharge is elevated to transfer the flow of coal to the stage loader. The stage loader is generally a chain-type conveyor of relatively heavy construction to withstand the impact of the heavy lumps of rock and coal that come off the face conveyor. The stage loader conveyor section is relatively short, and it serves to even out the flow of coal from the face conveyor and centralize it on the panel conveyor. The stage loader is generally advanced as required by hydraulic rams that are mounted on the roof supports in the head entry.

The panel conveyor, which receives coal from the stage loader, is normally some form of an extensible belt conveyor, although on a longwall mining operation it starts out in an extended position when the longwall panel is started, and is retracted as mining progresses. The panel conveyors may be commercially manufactured extensible belt conveyors, but are often home-made units that incorporate a belt storage device and a hydraulic belt tensioning device.

The panel belt must be capable of handling the large lumps of rock and coal that come off the stage loader, and toward this end a wider belt is sometimes used than the flow of averaged size coal would call for.

The various machinery elements of a longwall mining system, including the conveying devices, are shown in plan view in Figure 15.



SIDE VIEW

COURTESY JOY MANUFACTURING CO.

FIG. 15 LONGWALL CONVEYING SYSTEM

E. Cascading conveyor systems.

This category of continuous face haulage systems covers the several concepts that have been developed that consist of a string of relatively small, individually driven conveyors, usually wheel-mounted and interconnected so that they operate as a train. The outby ends of each conveyor in the train are elevated to discharge onto the next conveyor in the line. The articulation at the connection points between conveyor units in the train gives the required flexibility to negotiate turns and undulations in the floor.

Bridge conveyors and bridge conveyor-bridge carrier systems are also cascading conveyors, in a sense, but they have been treated as a separate category in this report because they have been developed into workable systems that continue to be manufactured and used, which is not the case for any of the other cascading conveyor systems described below.

1. THE JEFFREY MOLEVEYOR

The Moleveyor was developed by Jeffrey in the early 1950's, and was first used behind a Colmol mining machine by the Sunnyhill Coal Company. This machine was later redesigned by Jeffrey, or another unit was built, in the early 1960's, and this unit was operated by the Bethlehem Steel Company for several years. As far as can be determined, no Moleveyor systems are operating at the present time, but there is a recently negotiated research and development contract between Jeffrey and the Bureau of Mines for building a re-designed version of the Moleveyor for further testing and evaluation of the concept.

The Moleveyor consisted of a 4-wheeled receiving end, a train of 4-wheeled intermediate cars, and a 4-wheeled discharge end. Each unit of the train had an individually-powered conveyor running the full length, with the discharge end elevated to transfer coal to the next unit in line. Steering articulation between each pair of cars was 45° each side of center.

The end cars had 4-wheel drive and 4-wheel steer, and were arranged so that crab steering was available if required. The intermediate cars all had 4-wheel drive, and had steering linkages that were interconnected between cars so that the total train had very good tracking capabilities.

The early versions of this design had belt-type conveyors, but the later designs used chain-type conveyors. The chain conveyor has also continued to be used by Jeffrey in the bridge conveyors and bridge carriers that they are still producing.

Overall height of the latest design of the Moleveyor was a maximum of 25 inches on all units of the train. Two mines that used the Moleveyor quite extensively had seam heights in the 38-40 inch range.

Winches were eventually added to every other car in the string to allow for position adjustments to be made to the train when it failed to track in bad bottom conditions.

The discharge end of the train was fitted with a short conveyor section that could be swung or elevated hydraulically. This was used to discharge coal to the side onto a panel belt.

The Moleveyor appears to have been a well-built, rugged machine that operated with considerable success. Capacity was about 4 tons/minute. Since each of the twelve units in the string was roughly equivalent to a shuttle car in construction, and in cost, the Moleveyor was quite expensive. This has been mentioned as a reason for the Moleveyor not meeting with more acceptance from the mining industry.

Figure 16 is a side view of the Moleveyor machinery. Figure 17 shows a plan view of the Moleveyor in a typical mine development.

2. THE HEWITT-ROBINS MINEVEYOR

The inventor of the machine that is known as the Hewitt-Robins Mineveyor was Arthur L. Towles. Mr. Towles came up with sketches of his ideas for continuous face haulage in 1959, when he was General Superintendent of Bell & Zoller's Ziegler #4 mine, Johnston City, Illinois. The final engineering of this concept was completed by the Hewitt-Robins Company under an agreement with Ben & Zoller. The original machine was built in the Ben & Zoller shops.

Exact information on how many of these units were built is not available, but at the present time only two are known to be operating. One unit is operating in the Federal #1 Mine of Eastern Associated Coal Company, on a shortwall section, and one unit is operating in a potash mine in Saskatchewan.

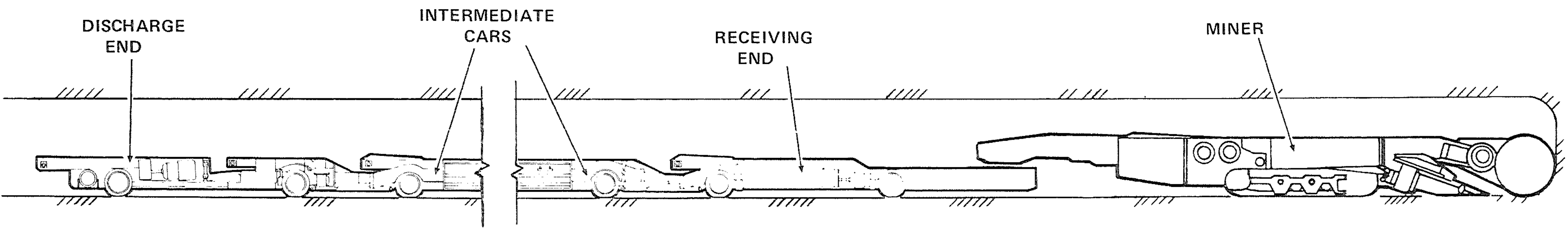


FIG. 16 JEFFREY MOLEVEYOR
SIDE VIEW

COURTESY JEFFREY MINING MACHINERY CO.

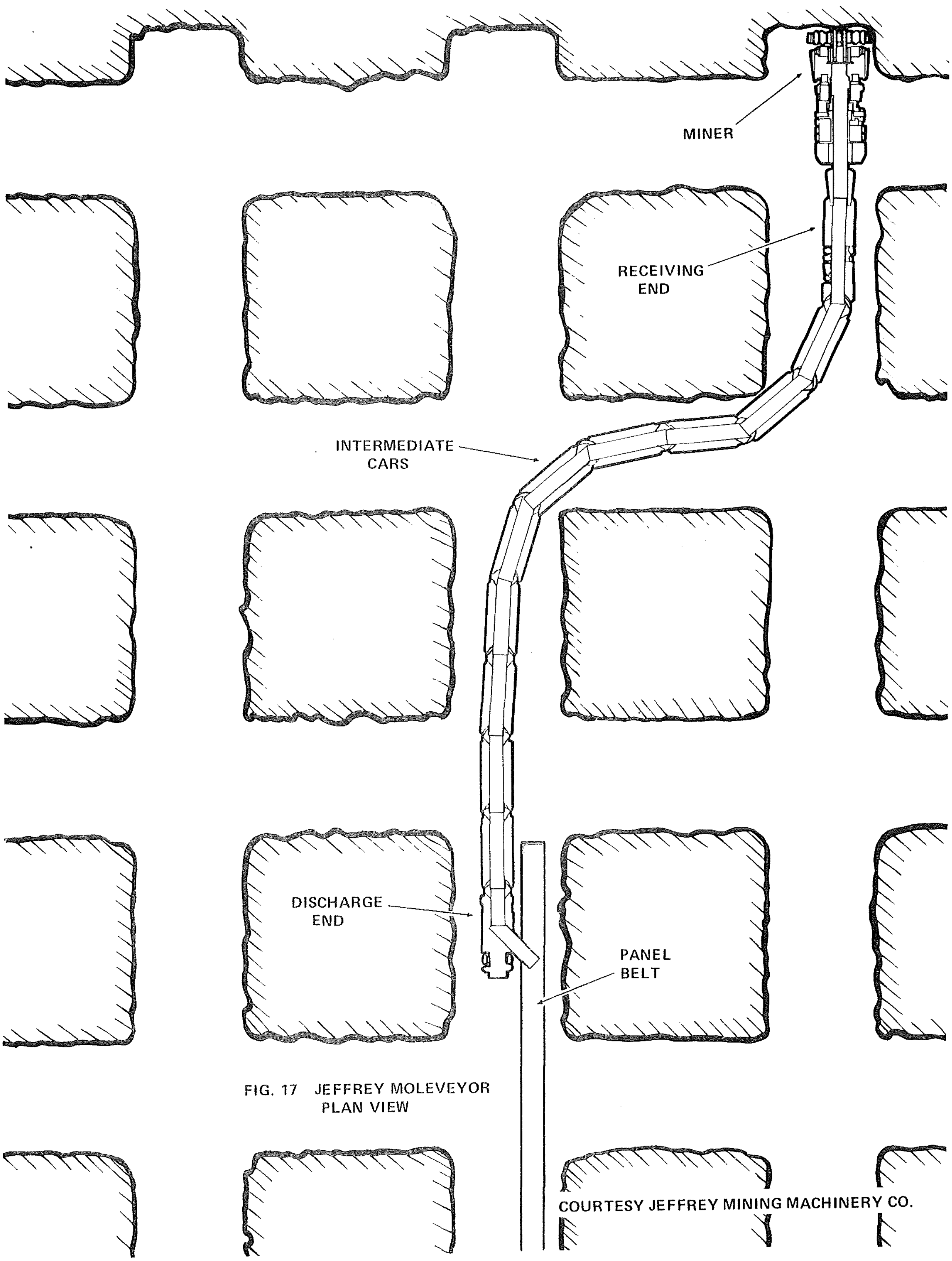


FIG. 17 JEFFREY MOLEVEYOR
PLAN VIEW

The Mineveyor was a mobile bridge conveyor that was conceived as a belt conveyor device to provide continuous face haulage with maximum flexibility, and toward this end it was designed so that no mechanical connection would be required between either the miner and the bridge system or between the bridge system and the panel belt.

The mobile bridge conveyor consisted of a series of self-powered two-wheeled bridge conveyors (usually three to five) and a self-powered four-wheeled discharge unit. All tramming and steering functions on these units were hydraulic powered. The inby ends of the bridge conveyors were supported on two wheels, and the outby ends rested on a carriage on the next outby unit. The carriages on the bridges rode on small wheels, which allowed one bridge to telescope over the next outby bridge a distance of about 15 feet.

The connections between bridges, and between the outby bridge and the discharge unit, were designed to allow steering articulation 90° each side of center, as well as to provide joint flexibility in other planes so that the train could adapt to rough bottom conditions.

The four-wheeled discharge cart was designed to straddle a low extensible panel belt that was specially designed for this application. In operation, the discharge cart always remained above the panel belt. The two-wheeled bridges were also designed to straddle the panel belt, so that the entire train could be pulled back to a position where it was parallel to and above the panel belt, with all wheels of the train straddling the panel belt.

The hydraulic power pack for the complete unit was located on the discharge cart. Duplicate sets of tramming and steering controls were arranged on each side of this cart, and the controls allowed each set of wheels to be steered or trammed independently, or collectively. When the wheels were all trammed together, the bridge units moved in unison. When it was desired to telescope the bridge sections, the wheel units were powered individually, or in combination to give the desired telescopic effect. By turning one or more pairs of wheels through 90°, a part of the bridge could be moved laterally.

In addition to the tram and steer controls on the discharge cart, other sets of controls for tram and steer were located at the inby end of the train. In practice, two men were used to tram and steer the unit, one inby and one outby. The man on the discharge cart also controlled a hydraulically operated chute that directed the coal onto the panel belt.

Following are some general specifications:

Bridge belt width	36 in.
Length of each bridge	32 ft.
Overall height	4 ft. 9 in.
Loading height at tail	3 ft.
Width overall	8 ft. 3 in.
Width of frame	4 ft. 6 in.
Conveying capacity	450 tph
Tram speed	0 to 50 fpm
Horsepower (total for unit)	40 hp

Ben & Zoller worked out special mine development plans to utilize the Mineveyor behind continuous miners. The Mineveyor apparently performed well for this company on entry driving, room development, and pillar recovery work. The conveyor system had great flexibility and mobility, and the exact reasons why the system is not used more today are not known at this time.

It is understood that there is a future possibility for further refinement and development of this design by Robins Engineers, who are now organized as a division of Litton Industries.

3. THE JOY PUSH BUTTON MINER TRAIN

In 1960 Joy built a remote control mining system based, in part, on some development work that had been done previously by the Union Carbide Corporation. The machine built by Joy was known as the Push Button Miner.

The Push Button Miner design incorporated a 1000 foot conveyor train, that was, essentially, a continuous face haulage system. This machine was operated for a period of time in an Ohio strip mine.

In operation, the conveyor train followed a multi-head boring type miner into an opening in the strip mine highwall. Coal coming out on the conveyor was discharged to a transfer conveyor, which was part of a large, mobile structure that was used to store and launch the conveyor train.

The conveyor train consisted of a series of sixty 2-wheeled cars, which were coupled at intervals of 16.5 feet. Each car mounted a 64-inch wide, double-chain cross-flight conveyor that was 18.5 feet long and was side-boarded to a width of 90 inches. Each conveyor was driven by a 7.5 hp motor-reducer unit at a conveyor chain speed of 105 fpm.

The conveyor unit of each car was pivotally mounted at the inby end of the car, in such a way that the outby end was raised so that the discharge could cascade onto the next outby unit. In addition, the conveyor on each car was designed so that the outby end could be lifted from a latched, in-line position on the car element and swung to the side to allow discharge to the transfer conveyor. With this arrangement, the conveyor units outby the discharge point were always empty, which facilitated their storage on a helical ramp portion of the launching structure.

In operation the train was coupled at the inby end to the miner, and received the coal discharge directly from the miner. Initially, alternate conveyor cars were powered for traction with a 4 hp drive synchronized to the speed of the miner. Traction problems with this arrangement were experienced on the storage ramp and in the mined entry, which led to applying traction power to all of the cars. A later version of this system, which operated with 700 feet of conveyor train and no helical storage ramp, was functional when only alternate cars were powered for traction.

The conveyor system on the Push Button Miner had a conservative conveying capacity of six tons/minute. Overall height was 34 inches.

At the present time, there are no systems of this type that are still operating.

4. THE CONSOLIDATION COAL COMPANY BANANA WAGONS

The continuous face haulage system that was designed and built by Consolidation Coal Company around 1950 is called the Banana Wagons by the mining community. More formally, the 1961 Poundstone patent, patent #3, 003, 612, calls it an articulated, self-tracking conveying apparatus.

Only one Banana Wagon conveying system was built. This machine was put together and operated for a period of time at the Osage #3 Mine of the Consolidation Coal Company, and further development and use of the machine was eventually discontinued.

The complete conveying apparatus consisted of a receiving section, a number of intermediate sections, and a discharge section, all of which had an independent conveyor belt, and were interconnected to form a train of cascading conveyors that were pulled behind a continuous miner. The concept could also be applied to operate behind a loading machine.

For movements toward the face, the train was pulled by a cable winch that was fastened to the rear of the miner. This gave the miner freedom to make small moves without having to move the conveyor train.

For moving the conveyor in an outby direction, a winch was used part of the time, and a loading machine was used on other occasions. This was an expedient to eliminate the necessity of designing a special tramming discharge section.

All units of the system were mounted on two wheels and were interconnected by a ball-joint connection that provided the flexibility required for the train to turn a corner and to adapt to uneven bottom conditions.

None of the wheels were equipped with steering means, but since the axle on each unit was located midway between the connecting pivot pins at each end, the train units were supposed to track each other when they were pulled forward by the miner or backward by the shuttle car.

The prime mover for powering all of the conveyors on the various units was an electric motor mounted on the discharge section. This connected into a drive shaft that was located longitudinally underneath the discharge section conveyor belt. Each of the other inby units of the train also had a longitudinal drive shaft, and all of the drive shafts were interconnected through double universal joints. The universal joints were located directly below the center line of the pivot connections between units. Gear belt sprockets provided power take-offs from the drive shafts on each unit, and these sprockets drove through gear belt connections into right angle gear boxes on each unit, which in turn powered the conveyor belt drive pulleys at the inby end of each conveyor.

5. THE JOY 2 PC - PORTABLE CONVEYOR

This continuous face haulage concept was tried by Joy Manufacturing Company in 1949. It was intended for use behind Joy continuous miners in room and pillar work.

The portable conveyors were a series of narrow, lightweight belt conveyors that were designed to be manhandled into place behind the miner as it advanced. The aluminum frame elements were mounted on a pair of rubber-tired wheels and were balanced so that they stood in place with the inby end of the conveyor on the ground and the outby end elevated. This allowed the coal flow to cascade from one unit to the next as it was carried back to a panel belt.

The unpowered wheels on each portable conveyor were normally positioned for longitudinal movement of the unit, but they could be unlocked from this position and swung through 90° and locked to permit moving the unit sideways into the conveyor line.

The proportions of the portable conveyors were designed to allow nesting of the units, so that they could be telescoped to produce an overlap of 8 to 12 feet, depending on the model. A movable hopper was fitted to each conveyor which could be adjusted so that coal coming from the next inby unit would fall onto the hopper regardless of the overlap between units.

Each conveyor belt unit had its own electric drive. Each of the units had a long, permissible cable connection to allow them to be interconnected electrically as they were added to the train.

Following are some general specifications:

Overall length	19 ft.
Maximum width	4 ft.
Height (depending on wheel size)	34 to 48 in.
Belt width	18 in.
Belt speed	360 fpm
Capacity	1 to 1.5 tons/min.

There were no provisions in this design for mechanically connecting these conveyor units in a train. Two systems, each using about 15 conveyors, were built and saw limited underground use. None of these units are operating at the present time.

F. Shaker conveyor systems.

Shaker pan conveyors have been employed in coal mines, in the past, but are no longer used extensively. They consist of a series of troughs bolted together, which are driven with a slow forward motion followed by a fast return motion. This motion of the conveyor produces a sliding of the coal stream in the direction of the slow forward motion. The average stroke of this type of equipment is 8 to 9 inches, at a frequency of approximately 75 strokes per minute.

This type of conveyor was manufactured well into the 1950's by a number of U.S. companies. It was estimated in 1951 that approximately 2000 shaker conveyors were operating in U.S. bituminous coal mines. They were effectively used in hand-loading mining systems and with low-production conventional mining equipment. The relatively light-weight conveyor pans were easy to move into place to extend the conveyor system, and devices were available to convey the stream of coal around corners.

The reciprocating pan lines were usually chain-suspended, either from roof timbers or from floor stands, and the relatively shallow depth of the pans and the elimination of a return strand made the shaker conveyor adaptable to low coal seams.

Widths of shaker conveyor pans ranged from 16.5 to 24 inches, and competent drive units could handle conveyor lengths up to 300 feet. Conveying capacity was somewhat dependent on mine conditions, most notably favorable or adverse grades, but the maximum capacity was in the 1.5 to 2 tons/minute range.

A loading device known as a power duckbill was often used in conjunction with a shaker conveyor, during the period when the shaker conveyor was popular as a haulage device.

Wet coal, or coal containing wet fire clay, was difficult to convey with a shaker-type system.

Joy Manufacturing Company, in the 1950's developed an experimental prototype of a shaker belt conveyor. This device never showed enough promise to warrant further evaluation underground, but the following information will serve to describe the concept.

The shaker belt concept was built around a 30-inch flexible stainless steel belt, which was preformed to assume a trough shape. Maximum length of the prototype shaker belt was 300 feet. The belt was stored on a reel at the outby end of the system, and the inby end was designed to be anchored to the continuous miner, through either a mechanical or a hydro-pneumatic spring device. The longitudinal reciprocation or shaking of the belt was to be generated either by an oscillation of the reel or by a reciprocating motion of the reel carriage. The belt was to operate over low idler stands on the mine floor, with the return stroke of the belt to be powered by the spring device on the miner.

Material transported by the shaker belt was to be discharged outby, either by moving it over the storage reel, or by removing it from the shaker belt by a plow device onto the secondary haulage means.

Several aspects of this design weighed against its further development, most notably a high power requirement, high loads and limitations imposed on the miner, and sluggish material movement.

Vibratory conveyors have been included in this investigation, since they are related in principle to shaker conveyors. However, this study did not disclose any proposals for, or developments of, continuous face haulage concepts that were based on vibratory conveyors.

A basic difference between shaker-type conveyors and vibratory conveyors is that vibratory equipment operates at higher frequencies and with a vertical acceleration component that causes the material on the conveyor to leave the conveyor surface during part of the conveying interval. Vibratory equipment normally operates between 4 to 120 cycles per second, with displacements respectively, in the range from 4 inches to 0.050 inch. Low frequency equipment operates at relatively large displacements, while high frequency equipment operates at relatively small displacements. The above figures compare to a stroke frequency for shaker conveyors of about 1.3 cycles per second, with about an 8-inch displacement.

The literature on vibratory conveyors indicates that they are relatively heavy and expensive devices, for a given conveying capacity, compared to a belt conveyor, as an example. The conveying speed that can be achieved is also relatively low, in the range of 60 to 100 fpm, and wet or sticky materials are a problem. It appears, therefore, that there are some inherent limitations to vibratory conveying that make this type of system unsuitable for continuous face haulage.

G. Hydraulic conveyor systems.

One striking fact that became obvious from the literature search that is part of this study is the large quantity of literature that is available covering the subject of hydraulic transport of solids in pipelines. So much information was gathered covering the past ten to fifteen years that it seemed redundant to include articles on this subject back through to 1948, which had been selected as a limit for the general search. Consequently, 1955 was used as an arbitrary cutoff for literature on this subject.

The literature on hydraulic transport covers both the theoretical aspect and the practical aspect, with many excellent reviews available on operating results of slurry pipelines throughout the world. It is interesting to note that one of the earliest slurry pipelines began operation in 1952 in France to pump over 4000 tons of coal per day through a 15-inch diameter pipeline that is six miles long.

The material handled in slurry pipelines covers a wide range of minerals and other solids, including coal, iron ore, copper concentrate and tailings, limestone, gilsonite, and sewage wastes.

This discussion will not attempt to cover the theoretical aspects of hydraulic transport of slurries in pipelines, except for those considerations that affect the application of this haulage method to underground coal mines. A good review of the general theory of this subject will be found in the various articles of the literature search in Appendix A under the "Hydraulic Conveyor Systems" heading.

Before describing the major developments in underground hydraulic conveying, some of the differences between conveying slurries in overland lines and doing the same thing underground should be mentioned.

The engineering groups that have approached the problem of underground hydraulic conveying of coarse coal have discovered that much of the empirical data that has been developed over the years for overland slurry pipelines, which generally covers material that has been reduced to small particle size, does not provide a sufficient basis for the design of a slurry system to carry coarse coal.

Space limitations at the face requires that size reduction of the mined coal to facilitate hydraulic transport be kept at a minimum, so that the 8 mesh by 0 size which is typical for slurry coal in overland hydraulic conveying becomes unreasonable to achieve.

Size reduction of coal at the underground face should be based on the maximum size that can be handled in the projected pipe size, and tests have indicated that this is approximately one third of the pipe diameter. With a 10-inch diameter pipe, this means a size reduction of coal at the face to about 3.5 inches.

Pipeline pressure-drop losses for coal slurries of this coarseness have had to be developed by the engineering groups during the early phases of the underground system design.

The most obvious difference between the engineering problems of overland and underground hydraulic conveying is the space limitation underground. This creates the need for special designs of almost all of the machinery and hardware that is required in the underground system.

The safety aspect of the underground system is also unique, and this consideration has a great deal of influence in the determination of the machinery for the coal mine application.

The predominant effort in the U.S. today toward applying hydraulic conveying in underground coal mining is the full-scale development being conducted by the Consolidation Coal Company. Started in 1969, this project concentrated on a single-face hydraulic haulage system, and after pilot systems were built and tested, an underground prototype was designed and built and put into operation in 1973. This installation is at the Robinson Run mine of Mountaineer Coal Co.

A patent covering the general concept that forms the basis for the Robinson Run prototype system was granted to E.H. Reichl in 1966. This patent, #3,260,548, is assigned to Consolidation Coal Company. It is included in Appendix B of this report.

The Robinson Run project will eventually transport coal in slurry form from the face to the preparation plant through an uninterrupted 10-inch diameter line. The work has been planned in two phases, however, with the first phase only providing slurry transport to replace belt and rail haulage. This phase is in operation, and face haulage is handled with shuttle cars. Extending the hydraulic conveying system to the face represents the second phase of this development, and this part of the system was scheduled to go into operation late in 1974.

In the first phase operation, shuttle cars carry the coal to the injection pump station, where it is reduced in size, mixed with water, and pumped through 2950 feet of 10-inch diameter steel pipe to the preparation plant outside the mine. This pipeline run does not include any appreciable rise going out of the mine but it does include a 115-foot rise at the preparation plant.

Slurry flow rate is approximately 3000 gpm, with a slurry that contains 30% coal by volume, 38% by weight. This represents about 5 tons/minute of coal. The projected capacity of the 10-inch line is 4000 gpm at up to 50% coal by volume. This slurry flow would represent about 10 tons/minute of coal.

The pipe system between the injection pump and the preparation plant consists of two lines, one to carry slurry out, and another to carry recycled water back in. About 10% makeup water has to be added to the return line to compensate for system water that is lost with the coal.

Extending the system to the face requires a flexible pair of pipelines to follow the progress of the mine face, in addition to compact, mobile machinery for crushing, mixing, and pumping the coal at the face.

For the flexible lines, special rubber hoses have been developed, which are designed to be supported on a series of wheeled carts. The twin hoses are laid into a large loop in the mine development between the fixed steel lines and the mine face. This loop provides the length of additional hose required to follow the miner advance.

Considerable design and development work has been done, and continues to be done, to develop compact, efficient machinery for the inby end of this system. The crushing, mixing, and pumping machinery that has already been developed on this project is being refined as a result of the experience so far realized. The current approach appears to be toward a single-unit design that will include all functions of crushing, mixing, and pumping.

The size envelope for the cross-section for this machinery has been established at a 4-foot height and a 12-foot width.

Handling the twin 10-inch hoses at the inby end of this system has turned out to be a problem. The loaded weight of the hoses is considerable and the elongation of the hoses under pressure presents difficulties.

One of the questions that seems to occur to most people concerns the problems that are encountered when a pipeline full of coal slurry is shut down. On any slurry pipeline built, this has been a major concern, and has been the subject of a great deal of research.

All indications from the literature show that this has been a manageable matter in overland pipelines, and that shut-down and start-up procedures have been successfully worked out. While the underground situation of this sort presents its own problems, experience to date would suggest that this problem area can be handled. It is already known that clay content in the coal will compound the re-start problem.

The problem areas for the underground hydraulic conveyor system that will be part of this continuing development include the following:

1. Hardware designs to provide efficient face machinery and flexible hose lines.

2. Emergency shutdown procedures.

3. Dewatering techniques.

4. Wear of machinery and pipeline surfaces.

5. Corrosion of inside pipe surfaces.

6. Control functions for a production system.

7. Health and safety aspects of the complete plan.

H. Pneumatic conveyor systems.

Pneumatic conveying systems have been used extensively for industrial applications for about 30 years, with their general acceptance by industry starting during World War II. They are widely used today for the bulk handling of such items as flour, grain, cement, plastics, and for coal handling in power plants.

In such applications, pneumatic conveyors have demonstrated some desirable attributes. They are flexible as to routing, they are clean, they are easy to automate, and they are reliable. Characteristically, the capital costs for original installation and the overall operating cost are less than for an equivalent mechanical conveying system.

On the negative side, the power requirements to move a given amount of material can be many times the power requirements of a mechanical system.

With all of the obvious advantages, pneumatic conveying has logically seemed an attractive possibility as a continuous face haulage concept, and several investigations in this area have been made by various companies. Experimental work in this area has also been conducted by the Bureau of Mines.

Pneumatic conveying has been successfully applied in some coal mines in Europe for pneumatic stowing, or backfilling, where longwall mining is practiced. Installations of this type are operating in Great Britain, Belgium, Holland, and Germany. These systems, however, are not handling coal.

Installations of pneumatic conveying systems have also been made in noncoal mines in the U. S., Mexico, and Canada during the past few years, but to our knowledge, no pneumatic conveying system is currently operating that is handling coal underground.

While some investigations are still being made relative to pneumatic conveyor systems for handling coal underground, and while there are proponents for such applications, some of the knowledgeable people who have pursued this idea have come to the conclusion that pneumatic conveying of coal cannot be considered an acceptable continuous face haulage device for use behind a continuous miner.

As in the discussion of hydraulic conveying systems, it is not intended to present in this discussion the complete theory of pneumatic conveying. This type of information is contained in the literature search in Appendix A under the Pneumatic Conveyor Systems heading. The following discussion is limited to some of the practical aspects of pneumatic conveying that affect the suitability of such a system for the continuous face haulage of coal in an underground mine.

All pneumatic systems contain four basic elements, as follows:

1. A prime mover, in the form of a blower, or fan.

2. A material feeder, such as a vacuum system intake, or a pressure system airlock.

3. A conveying duct.

4. A separator, in the form of a cyclone separator, filter, expansion box, or a combination of these.

The two types of pneumatic conveying systems that have been considered for conveying coal both use these four elements, but in a different arrangement.

A vacuum system has the prime mover near the discharge end of the system, downstream from the separator. A pressure system has the prime mover near the intake end of the system, upstream from both the material feeder and the separator.

In the vacuum system, the material is introduced into the air stream at atmospheric pressure and conveyed to a point of higher vacuum. In a pressure system, the material is introduced through the feeder device into a high pressure air zone in the pipe and conveyed to the discharge point, which is usually at atmospheric pressure.

The vacuum system has a distinct advantage over the pressure system for handling coal, because any leak or rupture in the system draws air into the system, which means that the air-coal-methane mixture being carried will not excape into the mine atmosphere. The possible consequences of a leak or rupture in a pressure system, however, that is carrying an air-coal-methane mixture in a mine, is serious enough that it has eliminated the pressure system from consideration in the minds of many investigators.

A limitation of the vacuum system compared to the pressure system, and this holds for any application, not only coal, is that an exhauster, or vacuum blower, is generally limited to producing an absolute pressure of 6 to 7 psi at the downstream end of the duct. Rotary positive displacement blowers, however, can supply pressures up to 30 psi absolute, which means that a given weight of air, and therefore a given weight of coal, can be handled in a pipe cross section roughly four times smaller with a pressure system than with a vacuum system. This means that the vacuum system pipe diameter must be roughly twice as large as that of an equivalent pressure system.

Assuming that a vacuum system could be considered safe for coal mine use from the standpoint of containing the air-coal-methane mixture, other general considerations for its use as a continuous face haulage system would be:

1. Duct size required for the desired capacity.
2. Horsepower demand.
3. Mobility and flexibility.
4. Length limitations.
5. Coal degradation.
6. Separation problems.
7. Duct explosion possibilities.

Experimental work by various groups has shown that for a vacuum system of about 500 feet in length, to handle 10 TPM of coal would require approximately 66,000 cfm of air, a pipe size about 34 inches in diameter, and would have a power requirement of approximately 2000 hp. A relatively modest system to handle 5 TPM would require approximately 33,000 cfm of air, a pipe size about 24 inches in diameter, and would have a power requirement of approximately 1000 hp.

The limitations imposed on the mobility and flexibility of a face haulage system based on duct systems of this size are obvious. One concept for handling the duct sections is illustrated in the Densmore patent, #3,362,752, which appears in Appendix B.

The overall length of a pneumatic system is influenced by the characteristic of velocity increase of the air stream as it progresses along a duct of uniform diameter. This is caused by the progressive expansion of the air as the pressure drops along the length of the duct. Calculations have shown that sonic velocities are reached in vacuum systems as the length reaches approximately 1000 feet, unless the pipe diameter is increased. Therefore, unless the duct diameter is increased, we find that 1000 feet is a length limit for a conventional pneumatic conveying system of the vacuum type.

Coal degradation must be a concern in any pneumatic conveying system, since experimental work has indicated that this does occur, to an extent that depends on the design of the system, and that impact of the coal at bends in the duct are the main problem.

The size and maintenance problems associated with the equipment that separates the coal and coal dust from the air stream are formidable problems, when one considers the volume of air and material that must be handled.

The possibilities of explosions occurring in the stream of air-coal-methane inside the duct of a pneumatic conveying system appear to be remote, considering the proportions of air-to-coal and air-to-methane that would be created by the high rate of air flow. This matter has been considered for experimental evaluation, however.

J. Angled belt conveyor systems.

In 1956 the Vesta-Shannopin Coal Division of Jones & Laughlin Steel Corporation experimented with an extensible belt design that was made to be able to negotiate one or more 90° corners with the aid of corner turning devices. This development was under the direction of William G. Kegel, who was then Assistant General Master Mechanic.

The corner turning devices developed by J & L were frames that held straight pulleys that were set at an angle to the direction of belt travel. These frames were anchored at room intersections with the aid of jacks. Experimentation showed that the extensible feature of the belt still worked when the belt was reeved through two of the corner turning devices.

A preliminary unit of this conveyor design was operated underground for a period of several weeks, following which some design modifications were made in the extensible belt tailpiece and the corner turning devices. A complete prototype installation was then made with a Joy 30-inch wide extensible belt in the J & L Shannopin mine, working with a three-entry mine projection that was especially designed for the new equipment. A bridge conveyor was used between the miner and the extensible belt tailpiece.

After some months of operation, use of this face haulage system was discontinued due to some problems that still remained unsolved. The mining plan required that the corner units be reset in new intersections as mining progressed. The weight of these units made moves difficult, since even after re-design they ran to 1300 lbs. Belt life was a problem, also, since the turn unit pulleys were kept small to keep weight down, and the angled pulleys created a scuffing action.

Two patents were found covering the angled belt concept. The 1966 Murphy patent, #3, 253, 698, was a Joy development that grew out of the collaboration between J & L and Joy that has been described above.

The McWhorter patent, #2, 873, 021, which is assigned to Goodman Manufacturing Co., shows a belt-angling device mounted on crawlers.

Both of these patents appear in Appendix B.

K. Monorail-mounted conveyor systems.

This category of continuous face haulage system is quite abbreviated, and overlaps other categories, for example the monorail-mounted Serpentix, which was thought to belong more in the Flexible Conveyor Belt System classification. Monorails may be either floor supported or roof supported, but this discussion is limited to roof-supported systems.

There have been installations made in mine haulage systems that have included monorail-mounted lengths of straight belt conveyors. Such a system has been proposed as a transfer conveyor device between a Joy Flexible Conveyor Train and a panel belt. In this instance, the FCT would discharge to a bridge conveyor, which in turn would discharge to the monorail-mounted belt. The bridge connection between the FCT and the monorail belt also serves as a drawbar to move the belt along the monorail when the FCT advances or retreats. The monorail-mounted belt runs directly over the panel belt, so that along the length of the monorail run, the rail-mounted belt can discharge directly onto the panel belt below.

With this system, the FCT gives the flexibility to follow the miner around corners, and the monorail-mounted conveyor handles the transfer of coal to the panel belt.

The discussion on hydraulic conveying systems covered the concept of supporting the flexible-hose part of this system on a train of wheeled carts. Since this hose assembly is quite heavy, it is conceivable that difficulties with this arrangement on bad mine bottom will lead to the use of a monorail support for this section of the hydraulic conveyor system. Such a system has been designed by the Lee Engineering division of Consolidation Coal Company, and carrier hardware has been built and tested. The results of these tests are not available at this writing.

Monorail systems are not new in European mines, where over 1000 miles have been installed, primarily for hauling men and supplies. Articles 40 and 49 in the literature search describe a monorail system installed in a U. S. anthracite mine around 1970. This was apparently one of the first such systems used in this country. Coal was handled in bottom dump cars that were attached to the monorail trolleys with flexible pin joints.

The success that some of these monorail developments have achieved would indicate that a roof-supported monorail could be a key element in a successful continuous face haulage system.

L. Modular conveyor systems.

Two modular conveying systems that have received considerable exposure in the technical journals over the past few years are the Dashaveyor system, made by the Dashaveyor Company, a subsidiary of The Bendix Corporation, and the Seccam system, manufactured in France by Societe Industrielle Dalattre Levivier. Both of these systems consist of a train of trough-like cars that travel on special rail systems.

These systems do not appear to be serious contenders for service as mobile continuous face haulage systems for underground coal mines, because they both require rather elaborate rail systems for operation. They should be considered as secondary or main haulage devices, rather than face haulage devices.

The literature search articles in Appendix A, under the Modular Conveyor Systems heading, contain articles that describe both of these systems in detail. Articles 15, 60, and 69 cover the Dashaveyor system, and articles 29, 56, and 60 describe the Seccam system.

M. Screw conveyor systems.

This category is not included in this study to infer that the screw conveyor is a promising device for a mobile continuous face haulage system, because the limitations of the screw conveyor, at the present state of the art, would indicate the opposite. Rather it is included to recognize a special application of the screw conveyor principle in continuous auger mining equipment, and to discuss the reasons why this successful idea cannot be extended to satisfy the requirements of continuous face haulage.

Auger mining is done mainly in highwalls left by strip mining, and in outcrop coal. It is attractive because it recovers coal that would otherwise be lost, and because it yields a high tonnage per man-day. The cutting head attached to the auger string cuts the coal, and the helical auger flights convey the coal to the outside of the hole.

Without considering how the problems of mobility and flexibility could be handled with a screw conveyor face haulage device, a consideration of other factors is enough to discredit this concept.

Published information on screw conveyors would indicate that it would take a 24 inch diameter screw conveyor helix to transport about 4 tons per minute. Such a unit would not be able to handle lumps bigger than 3 to 4 inches without danger of jamming, and the 4 tons per minute capacity would be reduced if the system had to run up a slope. This would indicate that a system to handle 10 tons per minute would probably be at least 36 inches in diameter, and it is difficult to conceive how the size and weight of the components for such a system could be handled to provide the flexibility and mobility that a good face haulage system demands.

N. Semi-continuous haulage concepts.

A review of continuous face haulage concepts should mention the various intermediate systems that have been tried, that fall somewhere in between the intermittent haulage provided by shuttle cars, and the continuous haulage that we have been talking about. These would include:

1. Using a surge car with shuttle cars.

2. Using surge storage on the mine floor, to be picked up by a loading machine.

3. Shuttle trains.

The first two practices are commonly understood, and don't need any particular discussion.

The shuttle train concept is designed and manufactured by Hagglunds of Sweden, and has been put into service in a number of European mines and tunnel projects. The patent search uncovered three patents in this area:

1. Patent #3, 552, 586. Edlund patent assigned to Aktiebolaget Hagglund and Soner Ornskoldsvik, Sweden.

   This patent describes a track-mounted shuttle train consisting of several cars, with each car having a conveyor extending along the full length of the car. The cars are designed so that they can be telescoped slightly into each other, with the conveyors partially overlapped. This train would operate in principle like a shuttle car, but would have a much larger capacity.

2. Patent #3, 307, 718. Sjostron patent, same assignee as above.

   This patent is similar to the one above, except that the outby ends of the cars have to be elevated, and the cars moved closer together, to create an overlap between conveyors for unloading.

3. Patent #2, 420, 009. Osgood patent assigned to Joy Manufacturing Company.

   This patent describes a train of rubber-tired conveyor cars, with a special tramming-loading section on the inby end, and a tramming-discharge section on the outby end. All units of the train have conveyors running their full length. The end units provide all steering and tramming, while the intermediate units are designed as trailing cars.

CONTINUOUS FACE HAULAGE SYSTEM PERFORMANCE

This report section covers an evaluation of the performance of the several continuous face haulage systems that have been built and tested, and which, in a very few instances, have become production items available to the mining industry. The criteria used for judging performance have been developed from a review of the service requirements that were defined in the Phase I part of this study.

Among the continuous face haulage concepts that have been tried, which were described in the previous section, the only ones that have demonstrated encouraging performance, relative to future use, are the following:

1. Bridge conveyor-bridge carrier systems.

2. Flexible conveyors.

3. Extensible belts.

4. Hydraulic conveyors.

The bridge conveyor-bridge carrier systems, as currently manufactured by Jeffrey Mining Machinery Co., Long-Airdox Co., and West Virginia Armature Co., are the most advanced production machines available to achieve the continuous face haulage performance that was defined in Phase I of this study.

Flexible conveyors, as represented by the Joy Serpentix conveyor and the Joy Flexible Conveyor Train, have been operated as prototypes with considerable success, but they are limited in their current designs to high coal seams, 6 ft. or more, and further development is underway to extend their use into lower seams and to improve certain operating factors, such as belt life.

The performance of extensible belts as continuous face haulage systems must be severely qualified, because they operate only on a straight line and must be used in combinations to negotiate corners. They appear to be restricted, therefore, to special mining plans, such as shortwall mining, and lack the flexibility and mobility required to adapt to a wide range of entry development or room and pillar mining plans.

Hydraulic conveyors for underground coal mine applications are not yet available as production items. The principle development work on this concept is now being conducted by the Consolidation Coal Co. at their Robinson Run mine in West Virginia. Detailed information regarding the performance of this system is not available, and could not be obtained for this study. From published information concerning the Consol hydraulic conveyor, it would appear that the system has a high potential for continuous face haulage, assuming that a successful solution can be found for some of the problems that have not yet been solved. These include the development of a compact face unit for crushing, mixing, and pumping the coal, and the development of some practical means for handling the heavy flexible hose assemblies that are used for carrying supply water and the water-coal slurry in the face area.

Until Consol or some other organization has made further progress on this concept, and until more information is made available regarding such systems, a detailed performance evaluation of hydraulic conveyors as underground continuous face haulage systems can not be made.

Probably the most obvious fact that should be noted relative to the performance of the various continuous face haulage systems that have been built is that most of them are no longer being used. We are interested, as part of this study, in why this is so, and in the degree of success that each system did achieve.

To provide a basis for evaluating and comparing these systems, the Service Requirements for continuous face haulage systems, as defined in Phase I of this study, were reviewed. A list of Performance Characteristics was established from this review that could then be used for evaluating, or rating each system. The following performance characteristics are the result:

1. Dust generation
2. Noise generation
3. Low seam adaptability
4. Capacity, steady state
5. Capacity, surge flow
6. Ability to handle large pieces
7. Spillage and carryback
8. Advance-retract speed
9. Traction-tracking ability
10. Ability to convey around corners
11. Reach capability

In addition to the above performance characteristics, two general design characteristics have been added:

12. Design simplicity
13. Inherent safety

The intent here is to concentrate on an evaluation of the concept of each system rather than on the detailed execution of each mechanical design. In some cases these designs were executed with a minimum amount of engineering and with limited manufacturing facilities. In several cases only one prototype, or a limited number of units, were made to try out a concept, so the benefit of progressive development and refinement of mechanical design through a period of experience was not realized. In other cases, most notably the bridge conveyor-bridge carrier systems, the designs that are now in production have evolved through several years of development under rigorous field conditions, and the engineering of the product continues to benefit as more machines are sold and exposed to use.

It is felt that where a concept rates high, based on the above thirteen points, any mechanical design deficiencies can be eliminated through refinement of design. For this reason the rating system used here does not consider individually such items as permissibility, serviceability, or ruggedness of design, except in a general way under the heading of design simplicity.

The ratings applied to each system, for the thirteen performance and design characteristics, have been awarded on a scale of zero through twelve, and represent only the judgement of the writer. In some cases, information for making these judgements has been very sketchy, since some of the concepts covered in this report were tried out some years ago and have not been well documented. However, it is believed that the relative ratings produced by this approach are useful, and it may be significant that the higher ratings generally represent the surviving concepts.

The results of this rating system are shown on Figure 18 and the totals from Figure 18 are rearranged on Figure 19 to show the various continuous face haulage systems ranked according to rating totals.

Certain assumptions and conditions apply to the ratings shown on Figures 1 and 2:

1. The rating has been made, in most cases, on the basis of current design, or on the basis of design at the time the system was abandoned.

2. The ratings for the two pneumatic systems are hypothetical, based on tests and anticipated performance underground, since no underground systems of this type have been operated in coal, to our knowledge.

3. The hydraulic conveyor rating is also hypothetical, since it is based in part on the assumption that some of the outstanding problems currently under development will be solved successfully. These have been mentioned earlier in this discussion.

Key:
(12 - excellent
(9 - good
(6 - fair
(3 - poor
(0 - very bad

	dust generation	noise generation	low seam adaptability	capacity, steady state	capacity, surge flow	ability to handle large pieces	spillage and carryback	advance-retract speed	traction-tracking ability	ability to convey around corners	reach capability	design simplicity	inherent safety	Totals
Bridge carrier systems	9	9	12	12	3	3	6	12	12	12	9	9	9	117
Lee-Norse extensible	9	9	6	9	9	6	6	3	9	9	12	6	9	102
Joy extensible	9	9	6	9	6	3	6	3	12	0	3	12	9	87
Joy Serpentix	9	6	0	12	9	6	6	12	12	12	12	9	9	114
Joy FCT	9	9	3	12	9	6	3	12	6	12	12	6	9	108
Jeffrey Moleveyor	6	6	9	6	3	6	6	9	6	12	9	6	9	93
Hewitt-Robins Mineveyor	9	9	3	9	3	3	6	9	6	12	9	9	9	96
Joy PBM	3	6	6	9	3	3	3	9	3	9	12	6	9	81
Consol Banana Wagons	3	9	6	6	3	3	3	6	3	9	9	3	9	72
Joy 2PC	3	9	6	3	3	3	3	0	6	12	12	12	6	78
Shaker conveyors	6	6	9	3	3	6	9	0	6	9	9	9	9	84
Hydraulic conveyors	12	6	6	12	6	9	12	6	3	12	12	6	9	111
Pneumatic (pressure)	0	3	0	12	9	9	12	0	0	9	12	3	0	69
Pneumatic (vacuum)	12	3	0	9	9	9	12	0	0	6	12	3	9	84
Angled belts	6	9	6	9	3	3	3	3	6	6	12	6	6	78
Shuttle car system	9	12	6	9	12	12	9	12	12	12	12	12	9	138

Figure 18. Rating of Continuous Face Haulage Systems Showing Shuttle Car System For Comparison.

Rank		Rating
Shuttle car system	A	138
1. Bridge carrier systems		117
2. Joy Serpentix	B	114
3. Hydraulic conveyors		111
4. Joy FCT		108
5. Lee-Norse extensible		102
6. Hewitt-Robins Mineveyor	C	96
7. Jeffrey Moleveyor		93
8. Joy extensible		87
9. Shaker conveyors		84
10. Pneumatic (vacuum)		84
11. Joy PBM		81
12. Angled belts	D	78
13. Joy 2 PC		78
14. Consol Banana Wagons		72
15. Pneumatic (pressure)		69

General Classifications

A. Rating goal, to be met or exceeded.

B. Most promising systems.

C. Systems with some potential.

D. Unworkable, or severely limited systems.

Figure 19. Ranking of Continuous Face Haulage Systems, Showing Shuttle Car System For Comparison.

The ranking of the fifteen continuous face haulage systems shown on Figure 18 shows the systems divided into four general classifications, with the shuttle car system included for comparison purposes.

When the shuttle car haulage system was rated on the same thirteen performance characteristics that were used to rate the continuous haulage systems, the total rating for the shuttle car added up to 138, which was a higher rating than any of the continuous haulage systems. The best rating among the continuous haulage systems was 117 total points for the bridge carrier systems. The biggest advantage that the shuttle car showed over the bridge carrier system, in the ratings, was the ability to handle surge flows from the miner, and to handle large pieces of coal or rock.

In the general classifications shown on Figure 19, the shuttle car rating was established as a rating goal for the continuous face haulage systems, to be met or exceeded through future developments of the continuous haulage systems to eliminate their shortcomings.

The bridge carrier systems, the flexible conveyors, and the hydraulic conveyor were placed in a "most promising" classification because their performance rating and field results show that they come closest to meeting the flexibility, mobility, and adaptability requirements for continuous face haulage that we established earlier.

The Lee-Norse extensible conveyor and the Hewitt-Robins Mineveyor and the Jeffrey Moleveyor have been classified as showing "some potential", because they either fit reasonably well into special mining plans, as does the Lee-Norse extensible conveyor, or they showed enough promise in their original form to be considered logical candidates for further development, as is the case with the Mineveyor and the Moleveyor.

The last group of systems has been classified as "unworkable, or severely limited," and these systems are not considered to fit very closely the requirements for continuous haulage that we have defined, and they do not appear to warrant further development.

Consideration should be given here to one design feature that is shared by the two most successful systems, bridge carrier systems and the Joy Serpentix conveyor. This is the feature of having positive guidance of the system when it works around corners.

The bridge carriers are individually steered by bridge carrier operators, and properly trained operators can maneuver the bridge conveyor string around corners so that the machinery is consistently free from contact with the ribs and the corners of pillars.

The Joy Serpentix conveyor is positively guided on a roof-supported monorail. Switching units are located at the crosscuts, and curved rail sections carry the flexible conveyor assembly around the corners so that it is always free from contact with the pillars.

This positive guidance feature begins to assume some significance when it is noted that most of the abandoned systems did not have it. Systems made up of trains of wheeled carts, for instance, that have depended on tracking of the train to negotiate corners, have all given various degrees of trouble. They tend not to track around a corner when subjected to the rough bottom conditions and slippery going that is experienced in most mines at some time. This problem has been offset in some cases by resorting to roller assemblies or bumpers installed on the corners of the pillars. In some cases winches have been installed on the carts so that they can be pulled back into alignment. It seems, however, that the use of such devices to guide a continuous face haulage system is troublesome in service, in some cases to the point where the system can become unacceptable.

To expand on the part that the coefficient of friction between the ground and the tires plays in this situation, it should be observed that the two forces acting on a string of cars going around a corner, the pulling force and the rolling resistance of the trailing cars, act at an angle to each other, and the resultant force tends to move the cornering cars sideways into the corner of the pillar. The cars will track around the corner only if the coefficient of friction between the ground and the tires is high enough to prevent the cars from sliding sideways. Eventually, on loose material or on wet, slippery surfaces the friction coefficient will be too low to prevent sliding, and the tracking geometry will break down.

A. Bridge carrier systems.

As has been suggested in other parts of this study, the bridge conveyor-bridge carrier system comes closest, among the systems covered by this study, to meeting the overall service requirements for continuous face haulage that were defined in the Phase I report.

This study was probably conceived at least a year and a half to two years ago, with the purpose being to determine which concepts of continuous face haulage could be developed into a safe, practical, and cost-effective system for application in underground coal mining. Since the conception of this study, within the past two years, one of the rapid developments in continuous face haulage has been the introduction and acceptance of improved designs of bridge carrier systems.

Recognizing that further improvements in these systems are needed, and also that some of the current problems have already resulted in design modifications that will soon appear on machines in the field, it seems that the bridge conveyor-bridge carrier concept can already be considered to be a safe, practical, and cost-effective system.

Not all applications of this system have been successful, and at mines where the system is working it appears that certain conditions contribute to satisfactory results. The overall impression, however, of the experience covered by this study, is that there will be an expanding use of bridge carrier systems in the future.

Bridge carrier systems seem to operate most effectively when the following conditions exist:

1. When mining is taking place in a large, regular-shaped area of coal.

2. In seam heights of 4-1/2 ft., or less.

3. Where the system has strong support from the mine management.

4. Where the attitude of the miners is positive and co-operative toward making the system work.

Certain physical characteristics of a mine can cause severe operating problems for bridge carrier systems. Among these are the following:

1. Very wet bottom conditions.

2. Large quantities of broken rock coming off the roof or the floor of the mine.

3. Abrupt undulations in the coal seam.

Taking the above points in order, a large, regular-shaped area of coal is an asset to bridge carrier use because a certain amount of initial development work must generally be done in a given area of a mine to create the space that is required to install the bridge carrier system. This development work is normally done with other haulage equipment, such as shuttle cars or scoops, and it is required when new panels are started or when the mining plan must be projected off in a new direction. The amount of such development that is required in each instance varies with the length of the bridge carrier system that is to be used, but it generally requires special development of the entry system for a length ranging from 120 to 180 ft. With large, regular-shaped areas of coal, the mining plan can be advanced for long distances, using the bridge carrier haulage system, without the need for interrupting the normal mining to bring in other equipment for establishing a change in direction.

Most of the bridge carrier systems that are now operating are in relatively low coal seams. In seam heights of 4-1/2 ft. or less, the bridge carrier systems, when operating satisfactorily, appear to be very competitive from a production standpoint. Particularly in very low seams, in a range from 30 to 36 inches, where shuttle car capacities are low, the bridge carrier system can be very attractive, sometimes outproducing shuttle cars by a two to one margin.

In most cases where bridge carrier systems have operated successfully, the strong support of mine management has been evidenced by a willingness to take time to train personnel in the use of the equipment, and by recognition of the fact that the mining plan must be adapted to the limitations of the bridge carrier system. Crosscuts laid out at 60° or 70°, instead of 90°, allow the long bridge conveyors to negotiate corners more easily. The mine plan must be mined on very accurate centers, also, for best results, so that full reach into entries on both sides of the center entry can be achieved. Also, in most cases, some local mine condition or peculiarity requires special measures or special planning to make the haulage system effective. These factors require understanding, application, and patience from the mine management.

One of the comments heard most frequently at mines where bridge carrier systems were observed to be working successfully was to the effect that the miners have to want to make the system work before any results can be achieved. This would seem to emphasize the need for great attention to training and indoctrination of mine personnel wherever equipment of this type is introduced. The management at one mining company, where several sections have been operated with bridge carrier haulage systems, considers that about three months is required to develop the necessary coordination between the miner operator and the bridge carrier operators to make the system fully effective. This mine develops on a five-entry plan, which requires three bridge conveyors and two bridge carriers operating behind each miner.

One of the mine conditions that causes a severe operating problem for bridge carrier systems in very wet bottom. In addition to the obvious traction problem, the main problem is an accumulation and buildup of wet material underneath the load-carrying side of the belts. This material must periodically be cleaned out, which is a slow, laborious job, and frequent shutdowns for this purpose can become prohibitive.

Another physical characteristic of the mine that can cause severe operating problems for bridge carrier systems is large quantities of broken rock coming off the roof or the floor of the mine. The larger pieces of this material will eventually block the flow of coal at the conveyor transfer points. This requires a shutdown of the system until the blockage is cleared, and any delay in shutting down will result in the spillage of large amounts of coal. Where this problem has been severe, consideration has been given to the design of a special feeder-breaker unit for use between the miner and the bridge conveyor system, but no such unit is available at the present time, to our knowledge.

A side benefit from such a feeder-breaker unit would be its surge capacity, which would tend to even out the flow of coal between the miner and the conveyor system. Also, breaking up the larger pieces of rock and coal would reduce wear and tear on the belts and extend the belt life.

Abrupt undulations in the coal seam, particularly in low coal, can impede the movement of the long bridge conveyor sections, which tend to wedge against the roof or the floor of the mine. Some of the bridge conveyors are designed with a screw-operated hinge in the center, which is manually operated to jack the center part of the bridge conveyor up or down to provide additional clearance with relation to the floor or the roof, as needed, when seam undulations are encountered.

Bridge carrier system ratings for thirteen performance characteristics

1. Dust generation.

A "good" rating of 9 points was applied under this heading, because although the conveyor transfer points and the Long John conveyor tail pulley tend to generate dust if no counter measures are taken, water sprays at these points have controlled the dust effectively. The best solution seen in the field was control of the dust by adequate water spray at the miner cutter head. Coal adequately wetted at the face did not give a dust problem at the conveyor transfer points.

2. Noise generation.

A "good" rating of 9 points was applied under this heading. Belt-type conveyors tend to be quieter than the chain type, but one mine with Jeffrey chain-type bridge carriers recorded 93 dbA as the operator noise level exposure, without coal on the conveyor. This allows up to 5 hours of exposure time, so this mine figured that they had no problem.

3. Low seam adaptability.

An "excellent" rating of 12 points was applied under this heading, because bridge carrier systems are currently operating satisfactorily in seams as low as 30 inches.

4. Capacity, steady state.

An "excellent" rating of 12 points was applied under this heading because these systems can convey coal away from the miner or loader within the 8 to 12 tons per minute requirement. Probably the normal capacity is on the low end of this range, and some improvement in conveying capacity would be desirable.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading because of the limited capacity of the bridge conveyors to handle surge flow from the miner. This generally has been a minor problem where care has been exercised to minimize the surges of coal.

6. Ability to handle large pieces.

A "poor" rating of 3 points has been applied under this heading, because large pieces of rock or coal tend to clog the conveyor transfer points.

7. Spillage and carryback.

A "fair" rating of 6 points has been applied under this heading, because coal tends to spill at the transfer points, particularly as the angle between conveyor sections is increased. Improvement in the design and durability of the flexible aprons at these points is required.

8. Advance-retract speed.

An "excellent" rating of 12 points has been applied under this heading, because the bridge carrier tram speed is adequate to keep up with the miner.

9. Traction-tracking ability.

An "excellent" rating of 12 points has been applied under this heading because the crawler-type bridge carriers appear to be adequately powered, and the steering ability of the bridge carriers allows the tracking of the system to be fully controlled.

10. Ability to convey around corners.

An "excellent" rating of 12 points has been applied under this heading, because within the limitations of its overall length the bridge carrier system can convey coal around corners easily. A limitation in this regard has been mentioned earlier, with reference to having crosscuts at a 60^{o} to 70^{o} angle rather than 90^{o} to allow the longer bridges to be used.

11. Reach capability.

A "good" rating of 9 points has been applied under this heading. The reach of a system comprised of 3 bridges and 2 carriers is about 200 ft., which is at the low end of the desired 200 to 400 ft. bracket.

12. Design simplicity.

A "good" rating of 9 points has been applied under this heading. The newest designs of this equipment are the result of several years of experience.

13. Inherent safety.

A "good" rating of 9 points has been applied under this heading. While there is considerable movement of machinery involved as the bridge carriers follow the miner, the movement is relatively slow and is not likely to endanger miners in the area. It should be recognized that these machines have not been used in quantity long enough for an accident pattern to have been established.

B. Joy Serpentix conveyor.

The Joy Serpentix conveyor system that has been described in the Phase II report of this study has been used in a 5 entry mining plan at the Peabody Coal Company #10 mine at Pawnee, Illinois. The entries are on 60' centers, with crosscuts that are placed on 70' centers at a 60° angle to the entries. The crosscuts are a full stagger opposite each other. Entries and crosscuts are 22' wide.

The monorail system that supports the Serpentix conveyor has universal switches at each crosscut location that allow travel of the conveyor to the right or to the left of the entry. Curved sections of rail, on a 15' radius, carry the Serpentix into the crosscuts. This system of monorail has functioned quite well, and the conveyor follows the miner through the crosscuts and into the side entries without difficulty. The combined length of the miner, tram car, and bridge conveyor is enough to reach from breakthrough to breakthrough in the side entries.

The 200' length of the Serpentix conveyor that has been used up to this time requires short, frequent moves of the panel belt tail piece. The final length of 400' that is planned for this installation will improve the belt move situation.

Roof control has been a problem in areas where crosscuts have been turned 90° to drive butt entries. This problem is being solved by a slight modification in mining plan in these areas. The butt entries will follow basically the same mining plan as the other entries, with a slight modification in the crosscuts to facilitate room mining. Rooms will be mined to the full combined reach of the miner and the Serpentix system.

At this point in time, the operation with 400' of Serpentix conveyor is an unknown. The present 200' unit has been used to make 60° and 90° turns without difficulty. The additional weight of 200' more of conveyor will require greater tractive effort from the tram car. It will also require more power on the conveyor drive. This will result in a higher load on the conveyor chain which drives the belt. All of these elements are sized to handle the 400' unit.

The system as it is currently operating does require 7' of clear height for best operation. Anything less than 6-1/2' of roof height results in damage to the belt going around the bottom side of the sprocket at the inby end.

Extreme angular relationships of the tram car, bridge, and inby end of the conveyor result in spillage at the transfer points. Care in positioning the tram car can reduce this spillage, and the use of a longer bridge conveyor would help to reduce the angularity.

The carriage rollers are covered with polyurethane, and this has been a problem. The first cover stock was too hard, and shelled off after a short period of operation. Later stocks were softer and have performed better, but further improvement is required in this area.

Early problems were experienced with the fasteners used to secure the pans and the attachments to the pans. These have been cured by use of Huck fasteners, which are an aircraft-type pin and swedged collar arrangement. A damaged pan, which is 8" long, can be removed from the conveyor without great difficulty. The chain and belt can be shortened in increments of 8" as the chain wears.

Sound measurements that have been made in the vicinity of the Serpentix conveyor indicate that the system is relatively noisy. Some sound readings have registered in excess of 100 dbA. Part of this may result from carriage rollers that have lost their polyurethane cover. Part of the noise results from excessive clearance between some of the vertebrae members. It is felt that the sound level can be reduced by proper maintenance and by a modification of the vertebrae fit up.

Use of the Joy Serpentix conveyor system over the period of development has increased production from approximately 800 tons/shift with shuttle car haulage to 1100 tons/shift with the Serpentix system. One of the best shifts was 264 minutes of operation for 1505 tons production. Proper maintenance and correction of some of the operating problems should result in shift production averages of 1200 to 1400 tons or better.

Joy Serpentix conveyor ratings for thirteen performance characteristics

1. Dust generation.

A "good" rating of 9 points was applied under this heading. There are various transfer points in this system where the coal can generate dust, but water sprays can be used at these locations to control dust, or sufficient water can be applied at the face by water spray from the miner cutter head to prevent a dust problem from developing at the conveyor transfer points.

2. Noise generation.

A "fair" rating of 6 points was applied under this heading, due to noise levels in excess of 100 dbA. It is expected that design modifications will reduce this level to more acceptable figures.

3. Low seam adaptability.

A "very bad" rating of zero was applied under this heading, because in its present configuration this system requires 6-1/2 ft. of roof height. Future designs are expected to be more compact to allow this system to be used in lower seams.

4. Capacity, steady state.

An "excellent" rating of 12 points was applied under this heading, because the present design, using a 32 inch wide belt running 400 fpm, gives a carry capacity of 8 to 9 tons/minute, and newer designs, with 40 inch wide belts running 360 fpm, are expected to have a carry capacity of 10 to 12 tons/minute.

5. Capacity, surge flow.

A "good" rating of 9 points was applied under this heading, because this system includes a tram car which accepts coal from the miner, and one function of this car is to even out the surge flow from the miner.

6. Ability to handle large pieces.

A "fair" rating of 6 points was applied under this heading, which could be improved if a breaker unit was included in the design of the tram car.

7. Spillage and carryback.

A "fair" rating of 6 points was applied under this heading, because some spillage problems exist at the transfer points at the inby end of the system, which have already been discussed.

8. Advance-retract speed.

An "excellent" rating of 12 points has been applied under this heading, because the tram car speed is adequate to keep up with the miner.

9. Traction-tracking ability.

An "excellent" rating of 12 points has been applied under this heading because the tram car appears to be adequately powered, and the positive guidance feature of the monorail assures the tracking of the system around corners.

10. Ability to convey around corners.

An "excellent" rating of 12 points has been applied under this heading, because the monorail system and the length of the Serpentix allow the conveyor to move coal around several corners without any difficulty.

11. Reach capability.

An "excellent" rating of 12 points has been applied under this heading, because the reach capability of this system ranges from 200 to 400 feet.

12. Design simplicity.

A "good" rating of 9 points haş been applied under this heading.

13. Inherent safety.

A "good" rating of 9 points has been applied under this heading. This system involves the movement of considerable machinery as the conveyor follows the miner, but this movement is relatively slow and follows along the monorail, so the path that is followed is well defined.

C. Hydraulic conveyors.

Conoco and Consolidation Coal Company undertook a long range research and development program several years ago to see if basic improvements could be made in underground mining systems. They decided at an early stage that the key to improvement was a truly flexible, continuous, high-capacity haulage system. They felt that the successful development of such a system could provide the basis for the development of more sophisticated methods of mining at the face.

Uppermost among the requirements for continuous transporation, it was concluded, was adequate reach for the system in any direction, and a design that could be used with narrow width headings and crosscuts.

After considering a number of approaches, hydraulic transportation using flexible rubber hoses was chosen as the best potential answer to the problem.

Early in the program it was decided that a fine coal slurry, similar to that used in overland hydraulic conveyor lines, would not be used underground due to the problems associated with crushing and grinding coal underground, and the problem of processing the fines at the preparation plant. The process decided upon was to take raw coal from the miner, crush it to a reasonable top size, and pump it in slurry form into a flexible pipeline that would follow the miner. This is essentially the system that Consol has been developing. Work has included slurry pumping in test loops, development of the necessary mechanical components, and most recently the installation and testing of the system underground.

Initial tests demonstrated that coarse coal slurry pumping was feasible, and that coal crushed to a 4 inch top size could be pumped using available pumps, valves, and controls, with acceptable pressure losses and power requirements. A carrying capacity of ten tons of coal per minute was established for the section equipment, and a 10 inch inside pipe diameter was selected after considering the required velocity, concentration, and material flow rate valves.

So far the underground work on this project has included successful operation of the pipelines between the preparation plant and the mine for water supply and slurry transport, and development of crushing hardware for slurry conditioning, and design of a pump vehicle for pumping and controlling the slurry.

Equipment that has yet to be successfully developed and proven out includes a mobile crusher and pumping unit for operation at the face, the flexible pipeline to the face, including means for handling it, and the gathering tanks and pumping systems for handling the slurry output from several sections.

Since detailed performance data is not available from Consol, the following ratings are based on published data, which is quite general in content.

Hydraulic conveyor ratings for thirteen performance characteristics

1. Dust generation.

An "excellent" rating of 12 points was applied under this heading, since with this system the coal is in slurry form, and the transfer points are closed to the mine environment.

2. Noise generation.

A "fair" rating of 6 points was applied under this heading, since it is anticipated that the crushing, mixing, and pumping equipment at the face will be quite noisy. This is conjecture, at this point, since this equipment in its final form has not yet been developed.

3. Low seam adaptability.

A "fair" rating of 6 points was applied under this heading. The size envelope for the cross-section of the face machinering for this system has been established at a 4 foot height and a 12 foot width. This would limit the system to a minimum 4-1/2 to 5 ft. seam height.

4. Capacity, steady state.

An "excellent" rating of 12 points was applied under this heading, because the system is being developed to handle ten tons per minute of coal.

5. Capacity, surge flow.

A "fair" rating of 6 points was applied under this heading, since the most advanced idea for the crusher-mixer-pump unit at the face has been projected with limited surge capacity.

6. Ability to handle large pieces.

A "good" rating of 9 points was applied under this heading, since the face equipment includes a crushing unit.

7. Spillage and carryback.

An "excellent" rating of 12 points was applied under this heading, since the coal-water slurry is completely contained.

8. Advance-retract speed.

A "fair" rating of 6 points was applied under this heading, because even though the hose-handling system has not been defined yet in its final form, considerable difficulty is expected in handling the weight of the two flexible hoses.

9. Traction-tracking ability.

A "poor" rating of 3 points was applied under this heading, primarily because of the difficulties that are anticipated with the train of supporting wheeled carts that have been proposed for hose handling, in reports that have been published to date.

10. Ability to convey around corners.

An "excellent" rating of 12 points was applied under this heading, because once the hose handling problem has been worked out, this system will handle the flow of coal around several corners without any difficulty.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading, since this system should have no difficulty providing 200 to 400 feet of flexible conveyor reach.

12. Design simplicity.

A "fair" rating of 6 points was applied under this heading, primarily because of the design problems associated with the face equipment and the equipment for handling the flexible hose assemblies.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading. The safety problems associated with the handling of the heavy flexible hose assemblies, and with the face equipment, are unknowns at this time, but the advantages of conveying the coal in slurry form in pipes has obvious safety advantages underground.

D. Joy flexible conveyor train.

Two prototype installations of the FCT were made in 1974. One went into a shortwall panel in northern West Virginia, and the other went into a conventional room and pillar operation in the same state.

The FCT used in the shortwall operation was about 210 feet long, to accommodate a nominal 150 ft. shortwall. Modified chocks were used for roof control and coal was mined with a drum type miner, which discharged to the head of a loader or onto the floor.

Attached to the loader by a flexible cable hitch was the inby hopper end of the FCT. The FCT was towed inby by the loader, and was towed outby by the outby terminal unit of the FCT. The FCT at its outby end was attached to and discharged to a 36" belt conveyor that was mounted on a roof-supported monorail.

The monorail belt was mounted over and discharged to a 36" panel belt. In operation, the monorail-mounted belt followed the FCT through a flexible tow-bar arrangement between the outby terminal unit of the FCT and the inby end of the monorail belt.

The shortwall mining system required the FCT to move through one 90° bend, of 30 ft. radius, from the belt entry to the shortwall face.

Initial operation of this unit uncovered problems with material transfer and carryback at both the loading and the discharge points of the FCT. Also, due to unexpectedly bad floor conditions, some traction problems were experienced. Hopper and tow-bar revisions effectively overcame the transfer problems, and the installation of a modified outby terminal unit provided reasonably adequate traction.

With these modifications, productivity through late summer and early fall of 1974 of this section was encouragingly higher than with shuttle car haulage behind the loader. Production potential was frequently qualified by limitations in the main haulage system, including derailments, shortage of empties, and breakdowns in the car-mover system.

The FCT had no difficulty in handling the output of the miner in this application, although the belt often ran full at the 480 fpm belt speed. This operation was influenced by mining problems unrelated to the FCT, so the production capability of the FCT system was difficult to evaluate. Throughout the relatively few shifts of what could be called normal operation, however, output was about 925 tons of raw coal per shift, compared to 500 tons/shift with shuttle cars.

The belt on the FCT, which was run over minimum diameter drive and tail pulleys, showed signs of distress shortly after installation. The major damage was severe cracking, originating at the belt edge and following the roots of the convolutions toward the centerline of the belt. This problem progressed rapidly along the full belt length, but it was discovered that even with these cracks the belt tracked adequately through a 90° turn, and spillage along the run and turn of the train was negligible.

Bolted plate splices in the FCT belt were troublesome, with some splice failures experienced, and with some serious wear caused on the pulley laggings. The minimum diameter pulleys probably accelerated, and perhaps initiated, both the belt edge tearing and the splice problems.

Operation of this unit has recently been discontinued, pending a solution to some of the belt problems.

The second FCT prototype went into a 4-entry panel development section for room and pillar extraction. The conveyor train was approximately 350 ft. long, taking coal from a loader which followed behind a drum head miner. The inby terminal arrangement of this FCT was basically the same as the first unit except for a hydraulic towing cylinder that formed the connection between the loader and the inby terminal element.

At the outby end, the FCT terminal unit moved parallel to a panel belt, and discharged to this belt by means of a short transfer conveyor.

This FCT was fitted with 50% larger drive and tail pulleys than were on the first unit, and the belt was run at approximately 650 fpm.

This system operated around as many as four 60° curves, whose radius was about 30 ft. A corner roller was set against the corner of a pillar to handle possible tracking problems at the first corner only. Other than some skid steering difficulties in handling the outby terminal unit alongside the panel belt, there were no significant traction or tracking problems with this installation.

As with the first unit, edge splitting occurred in the belt in spite of the larger pulleys. The belt splices on this application were vulcanized at the center tension section and plate bolted in the fluted side portions, which gave much improvement in lagging wear and noise. And again, even with badly split edges on the belt, spillage was insignificant.

The most serious problems with this installation were with spillage at the outby transfer conveyor and with carryback of coal fines that tended to lodge in the convolutions of the belt. The carryback problem was never satisfactorily resolved, and required substantial clean-up manpower to avoid safety citations.

In spite of the above problems, this FCT section was able to produce very respectable tonnages. The best shift handled 1100 tons, and in one one-hour period 340 tons were moved over the FCT. The ability of the belt to move material around the curves was impressive.

This FCT unit was removed from the mine late in 1974 on completion of the panel.

The performance of these two FCT prototypes has proven the ability of a train of this general configuration to drive and support an edge guided flexible conveying element, and to service competently a mining unit into and out of most underground mining systems, within its height limitations.

The problems that were defined with the flexible belt were:

1. Its unacceptably short life.

2. Cleaning and carryback problems with the current belt design.

Modifications in belt design and construction are now in process and are being evaluated.

Joy Flexible Conveyor Train ratings for thirteen performance characteristics

1. Dust generation.

A "good" rating of 9 points was applied under this heading. While there are transfer points in this conveyor system that could be dust generating areas, water sprays at these points can be effective in controlling dust, or water can be applied in sufficient quantities at the face to minimize the dust problem on the conveyors.

2. Noise generation.

A "good" rating of 9 points was applied under this heading, since this system proved to be relatively quiet in the prototype tests.

3. Low seam adaptability.

A "poor" rating of 3 points was applied under this heading. The outby terminal unit is the highest piece of machinery in the FCT system, and its overall height has ranged from 44 to 58 inches, depending on what ground clearance was required to meet mine buttom conditions.

4. Capacity, steady state.

An "excellent" rating of 12 points was applied under this heading. The FCT belt has been operated at speeds up to 670 fpm, with no material handling problems, and at 600 fpm the belt capacity is about 12 tons per minute.

5. Capacity, surge flow.

A "good" rating of 9 points was applied under this heading. The inby hopper end of the FCT has surge capacity to even out the flow of coal from the loader.

6. Ability to handle large pieces.

A "fair" rating of 6 points was applied under this heading. Although the hopper end can be equipped with a grizzly to catch large pieces and keep them off the conveyors, the pieces must be cleared or broken up by hand.

7. Spillage and carryback.

A "poor" rating of 3 points was applied under this heading. The tendency of the convoluted belt to trap fines and carry them back on the return side of the belt has already been discussed. The spillage problem has been improved by design modifications at the transfer points.

8. Advance-retract speed.

An "excellent" rating of 12 points was applied under this heading. The FCT had speed enough to follow the miner or to back out of the way without causing delays.

9. Traction-tracking ability.

A "fair" rating of 6 points was applied under this heading. Some traction problems were experienced with the outby terminal unit, and the need for corner rollers to assist tracking of the train is considered as an undesirable factor in the rating.

10. Ability to convey around corners.

An "excellent" rating of 12 points was applied under this heading. This feature is probably the most outstanding one on the FCT, and the performance on moving material around corners encourages further development to solve the problems that remain in this system.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading, since the 350 ft. length of the longest prototype falls at the high end of the 200-400 ft. reach range that we established as a design goal.

12. Design simplicity.

A "fair" rating of 6 points was applied under this heading, with the main detracting influence being the large number of wheeled carts, with rollers and roller articulation features required.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading. Movements of the machinery units are generally made at relatively low speeds.

E. Lee-Norse extensible conveyor.

The Lee-Norse extensible conveyor, which was described in detail in the Phase II report, has the limitation that it can only operate in a straight line, which is also the case with extensible conveyors made by other manufacturers. Design features have been incorporated into the Lee-Norse design, however, to allow their extensible conveyors to be used in combination, so that one unit can transfer coal to another, and in this way they can be used in multiples to convey coal around a series of corners.

To use the extensible conveyors in this manner, it is desirable that the units be as mobile as possible, and toward this end the tail piece of the Lee-Norse extensible is designed to be carried by the crawler mounted drive-storage unit when the belt is in the retracted position. The crawler mounted tram car that is used with this system extends the belts when required by hitching to the tailpiece and pulling it.

The tram car is also designed to serve as a shuttle car between the miner and the most inby extensible belt tailpiece when the miner advances in a direction that this tailpiece cannot follow. This procedure is satisfactory only for short shuttle distances, however, since the tramming speed of the tram car is too low for normal shuttle car service, and the hydraulic system of this machine is not able to operate for extended periods of tramming without overheating.

It would appear that the limitations on the mobility of this system, including the speed with which the system can be advanced, retracted, or set up in a different place, would restrict the use of the system to special mining plans such as shortwall or longwall operations. The system is currently being proposed for entry development and room and pillar work, and is working in this kind of plan in a few mines at the present time. Some engineering modifications are taking place in the extensible belt units as a result of this experience, so judgment should probably be reserved for a time regarding the adaptability of this system to certain mining plans.

Lee-Norse extensible conveyor ratings for thirteen performance characteristics

1. Dust generation.

A "good" rating of 9 points was applied under this heading. There are conveyor transfer points in this system that can be sources of dust, but water sprays at these points, or at the face, can be used effectively to control the problem.

2. Noise generation.

A "good" rating of 9 points was applied under this heading. Although no sound level readings were obtained for this system, the equipment that was observed operating during this study was relatively quiet.

3. Low seam adaptability.

A "fair" rating of 6 points was applied under this heading. The overall height of the drive storage units ranges from 41 to 45 inches, depending on the ground clearance required, which means that this system is limited to seams approximately 4 feet high, or more.

4. Capacity, steady state.

A "good" rating of 9 points was applied under this heading. Normal capacity of the 36 inch belt should run about 6 to 8 tons/minute, but a maximum capacity as high as 11 to 12 tons/minute has been claimed.

5. Capacity, surge flow.

A "good" rating of 9 points was applied under this heading, since the miner loads into the tram car with this system, which provides considerable surge capacity.

6. Ability to handle large pieces.

A "fair" rating of 6 points was applied under this heading. Although the tram car is provided with a grizzly to catch large pieces and keep them off the conveyors, the pieces must be cleared or broken up by hand.

7. Spillage and carryback.

A "fair" rating of 6 points was applied under this heading. The spillage problem can be considerable with this system if the alignment of the belts is not maintained and if the intermediate belt supports are poorly placed.

8. Advance-retract speed.

A "poor" rating of 3 points was applied under this heading because of the time required to extend or retract the system, which could involve the movement of the tram car, hitching or unhitching to the tail pieces, adding or removing intermediate belt supports, and moving the drive-storage units.

9. Traction-tracking ability.

A "good" rating of 9 points was applied under this heading, since the tram car and the drive-storage unit crawlers appear to be adequately powered, and the tram car operator has steering control to enable him to keep the belt straight when he is moving the belt tailpiece.

10. Ability to convey around corners.

A "good" rating of 9 points was applied under this heading, since the belt combinations, when properly set up, can convey coal around corners without difficulty.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading, since a practically unlimited reach is available with this system if enough units are used together in series.

12. Design simplicity.

A "fair" rating of 6 points was applied under this heading, with the main detracting influences being the complexity of the drive-storage unit and the need to use hand-placed intermediate belt supports.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading, because any required movement of the machinery units is generally made at relatively low speeds.

F. Hewitt-Robins Mineveyor

The Hewitt-Robins Mineveyor design concept was developed by Mr. Arthur L. Towles of Bell and Zoller Coal Company in the early 1960's, and the final design and manufacturing of the units was done by the Hewitt-Robins Company, through an agreement with Bell and Zoller.

The revised prototype designs were operated with considerable success by Bell and Zoller at their Ziegler #4 mine at Johnston City, Illinois, through a one to two year period, starting in 1965. Mining with this system was stopped when very difficult mining conditions were encountered where it was being used.

Apparently only a few more units of this system were manufactured by Hewitt-Robins before development of the system was discontinued and production stopped. This seems surprising considering the good performance of the units that were built.

Bell and Zoller used the Mineveyor successfully in a variety of mining plans, including three-entry development work, mining of rooms at 60° and 90° to the entries, and on pillar recovery. Peak outputs from the system, which operated behind a Goodman 400 miner, ran to 300 tons per hour, with shift outputs running close to 900 tons per shift. This mining was done in a seam that averaged 7-1/2 to 8' in height.

The production from the Hewitt-Robins system exceeded the production from shuttle car sections in the same mine by approximately 30%.

Mechanical experience was extremely good with this haulage system, indicating a well conceived design and a good job of working out the design details. One comment that was received that would indicate an area for design improvement suggested that the tramming circuit lacked power. This comment applied to the prototype machine, however, and it is possible that this feature was improved in later production models.

The tramming of the bridges was hydraulic, with the power coming from the outby discharge cart, which also served as a hydraulic power pack for all components of the bridge system. Published reports on this system indicate that before development was discontinued there were plans to make each bridge unit self-contained, with its own electrical and hydraulic system.

Hewitt-Robins Mineveyor ratings for thirteen performance characteristics

1. Dust generation.

A "good" rating of 9 points was applied under this heading, assuming that water sprays for dust control will be used at the transfer points or at the face.

2. Noise generation.

A "good" rating of 9 points was applied under this heading, assuming that this system should be similar to the bridge carrier system from a noise standpoint.

3. Low seam adaptability.

A "poor" rating of 3 points was applied under this heading, since the various units of the bridge system were designed to straddle the panel belt. This gave an overall height of the bridges of 4' 9", which makes the system essentially a high seam system.

4. Capacity, steady state.

A "good" rating of 9 points was applied under this heading, since the 36 inch belts running on angled rollers at 400 fpm had a capacity of 8 to 10 tons/minute.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading, because the inby hopper end of this bridge system had a limited capacity to handle surge flow.

6. Ability to handle large pieces.

A "poor" rating of 3 points was applied under this heading, because the transfer points are susceptible to clogging from large pieces.

7. Spillage and carryback.

A "fair" rating of 6 points was applied under this heading, although this equipment has not been observed running. However, the spillage problem is probably similar to what is experienced on the bridge carrier systems, since the machinery arrangement is similar.

8. Advance-retract speed.

A "good" rating of 9 points was applied under this heading, since the Mineveyor had adequate speed to advance or retract with the miner without causing delays.

9. Traction-tracking ability.

A "fair" rating of 6 points was applied under this heading, with the negative factors being the relatively small wheels supporting the bridges, and reports that the tramming circuits lacked power.

10. Ability to convey around corners.

An "excellent" rating of 12 points has been applied under this heading, since experience with this equipment underground demonstrated the ability to convey material around 90^{o} corners without any problem.

11. Reach capability.

A "good" rating of 9 points has been applied under this heading, since this system was proposed with up to six bridges connected in series, which would give an overall reach between the face and the panel belt of approximately 200 feet.

12. Design simplicity.

A "good" rating of 9 points has been applied under this heading. The clean design of this equipment gave very good availability in underground use, and the maintenance cost of the system was claimed to be considerably less than for shuttle cars used on other sections in the same mine.

13. Inherent safety.

A "good" rating of 9 points has been applied under this heading, since machinery movements are made at relatively low speeds with this system.

G. Jeffrey Moleveyor.

There is not a great deal of information available regarding the Jeffrey Moleveyor performance. Only a few units were built, and as far as can be determined there are no units currently operating, and no units have operated for the last several years.

The Moleveyor unit owned by the Bethlehem Steel Company may have been the last one to operate. Use of this unit was discontinued several years ago after several years of use. One of the reasons given for abandoning this system was that the mine where it was used went to full roof-bolting to replace timbering for roof control. With timbering, the progress of the mining was more steadily foward than with roof bolting, where the miner and the haulage had to be moved back after every 20 feet of advance. Apparently the Mineveyor lacked the necessary mobility to be considered practical if frequent moves had to be made.

The Moleveyor system was bothered by bad bottom conditions. The units had limited ground clearance and relatively small wheels. The intermediate units between the receiving end and the discharge end would fail to track properly around corners, at times, and this required the addition of winches to each car. These were used to pull the units of the train back into alignment when tracking problems occurred.

A study of layout drawings and patent detail drawings of the Moleveyor units reveals quite a complex design, with involved articulation linkages and considerable machinery designed into each element of the train. This produced a very high first cost for the system, and must have resulted in relatively high maintenance costs in use. No figures have been found that would indicate what the availability of these units was in service, but the design suggests that there were a lot of built-in possibilities for down time.

These units appear to have been well-designed and well built, in spite of the rather complex machinery that was involved.

Jeffrey Moleveyor ratings for thirteen performance characteristics

1. Dust generation.

A "fair" rating of 6 points was applied under this heading. One of the disadvantages of this system is the large number of transfer points involved in the train, since the intermediate conveyor cars are only 15 feet long.

2. Noise generation.

A "fair" rating of 6 points was applied under this heading. The large number of cars, each with their own wheel and conveyor drives, adds up to a lot of sources for noise generation.

3. Low seam adaptability.

A "good" rating of 9 points was applied under this heading. Layout drawings show a maximum height of 25 inches for the tram height of all units of the later designs. Somewhat more height than this would be required for operating the swinging, elevating transfer conveyor that is located on the discharge end of the system. The unit operated by Bethlehem was in a 40 inch seam.

4. Capacity, steady state.

A "fair" rating of 6 points was applied under this heading, since the Moleveyor capacity has been reported as 4 to 5 tons/minute.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading, since drawings of the receiving end of the system show a hopper with very limited surge capacity.

6. Ability to handle large pieces.

A "fair" rating of 6 points was applied under this heading. The transfer point design between each pair of units is fairly open, and appears to be less susceptible to clogging then some of the other cascading conveyor designs.

7. Spillage and carryback.

A "fair" rating of 6 points was applied under this heading. The large number of transfer points aggravates the spillage and carryback problem, and photographs of one of these systems shows considerable material on the ground at each transfer point.

8. Advance-retract speed.

A "good" rating of 9 points was applied under this rating, since the Moleveyor demonstrated adequate speed to follow the miner.

9. Traction-tracking problems.

A "fair" rating of 6 points was applied under this rating. The small wheels were a disadvantage in bad bottom conditions, and the tracking of the cars around corners was not good when bad bottom conditions occurred.

10. Ability to convey around corners.

An "excellent" rating of 12 points was applied under this heading. The steering angle between cars was only 45° off center to the right or left, but the short 15 foot length of the intermediate cars allowed the system to make turns with a minimum radius of about 18 feet.

11. Reach capability.

A "good" rating of 9 points was applied under this heading. With ten intermediate cars between the receiving end and the discharge end, the reach from the face to the panel belt was about 200 feet.

12. Design simplicity.

A "fair" rating of 6 points was applied under this heading, with the main detracting factors being the large number of units required to make up the train, the large number of mechanical drives required, and the complex mechanical steering linkages in the design.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading. The movement of the train, when required, was at relatively low speeds.

H. Joy extensible conveyor.

The Joy extensible conveyor, and similar units made by other manufacturers, have generally operated with relatively low output miners, handling coal outputs from the miner in the 4 tons/minute range, or less. These units can only convey material in a straight line.

In the early 1960's, Joy developed what they called the Kangaroo extensible, which was basically an extensible belt drive-storage section with a scoop shaped platform to carry a small crawler mounted tail unit. The overall length of the drive and its platform was about 29 feet. When extended the overall length of the conveyor, from the tail unit to the discharge end of the drive storage unit was about 104 feet. Development of this concept was not continued, but the system had the potential to be used to convey material around corners by using units in series, in a manner that has been described under the discussion of the Lee-Norse extensible.

The normal version of the extensible conveyor, which is limited to conveying material in a straight line, is still being used successfully in some mines that have worked out special mining plans. The extensible conveyor is normally used behind miners that are mining long rooms. In some cases bridge conveyors are used between the miner and the extensible belt tailpiece to improve the reach of the miner for making crosscuts. When the rooms have been extended full length, the miner in some cases moves through a crosscut into the adjoining entry to mine out a pillar. Shuttle cars are used between the miner and the extensible belt for this part of the mining cycle. This system uses the continuous haulage feature of the extensible belt as much as possible, and also takes advantage of the flexibility of shuttle car haulage.

Where roof bolting must be used for roof control, the extensible belt system is handicapped by the need to pull the miner out after short advances to allow the roof bolting operation to take place. Where timbers can be placed, the advance of the miner can be relatively steady, and the advantages of the extensible belt can be better used. Where the proper mining conditions exist, there still seems to be a place for the use of extensible belt systems.

Joy extensible conveyor ratings for thirteen performance characteristics

1. Dust generation.

A "good" rating of 9 points was applied under this heading. The long run of the extensible conveyor, without the cascading of coal at transfer points, make the extensible conveyor a relatively dust-free system.

2. Noise generation.

A "good" rating of 9 points was applied under this heading. The simplicity of the extensible conveyor machinery produces a low noise level system.

3. Low seam adaptability.

A "fair" rating of 6 points was applied under this heading. The overall height of the various units, including the drive-storage section and the tail section, ranges from 30 inches to 54 inches, depending on make, model, belt storage capacity, and ground clearance desired.

4. Capacity, steady state.

A "good" rating of 9 points was applied under this heading. Normal capacity of a 36 inch belt adequately powered should be in the 6 to 8 tons/minute range.

5. Capacity, surge flow.

A "fair" rating of 6 points was applied under this heading, since the normal tailpiece did not have a great deal of surge capacity. An adequately sized feeder unit serving as a tailpiece, however, could provide satisfactory surge capacity for the miner outputs that would normally feed into an extensible conveyor system.

6. Ability to handle large pieces.

A "poor" rating of 3 points was applied under this heading. Clogging of the coal flow by large pieces would be a particular problem if a bridge conveyor were used between the miner and the extensible conveyor tail piece.

7. Spillage and carryback.

A "fair" rating of 6 points was applied under this heading. The extent of the spillage problem depends on the care taken with belt alignment and placement of the intermediate belt supports.

8. Advance-retract speed.

A "poor" rating of 3 points was applied under this heading, since moves can require the adding or removal of belt sections and intermediate belt supports.

9. Traction-tracking ability.

An "excellent" rating of 12 points was applied under this heading, since with an adequately powered crawler tailpiece there should be no problem in moving the belt in either direction.

10. Ability to convey around corners.

A "very bad" rating of zero points was applied under this heading, because the extensible belt by itself is essentially a straight line conveying system. The addition of a bridge at the inby end gives a very limited ability to make short crosscuts.

11. Reach capability.

A "poor" rating of 3 points was applied under this heading, because although the reach of the extensible conveyor is good in a straight line, it does not meet our requirement of being able to reach into other entries.

12. Design simplicity.

An "excellent" rating of 12 points was applied under this heading.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading.

J. Shaker conveyors.

Shaker conveyors, of the pan type, were manufactured by several companies well into the 1950's, and were among the earliest successful systems for continuous face haulage of coal underground. Inherent limitations in capacity, however, particularly against adverse grades, have largely eliminated shaker conveyors from consideration for haulage in modern mines.

In the days when a hauling capacity of 1.5 to 2 tons/minute was acceptable, the shaker conveyors had certain advantages to offer. The relatively light weight pans were easily moved into place to extend the system as mining progressed, and devices were available to move the coal around corners. The shallow depth of the pans and the absence of a return strand made the shaker conveyors adaptable to low coal situations.

The design feature that we have established for mobility in a continuous face haulage system did not exist with shaker conveyors, because the pan installation was not adapted to mining plans where frequent or rapid retreats of the miner were required.

Because the shaker conveyor falls in a classification of haulage system that is severely limited, by today's standards, the following performance ratings are interesting only from a comparison standpoint relative to the more promising systems.

Shaker conveyor ratings for
thirteen performance characteristics

1. Dust generation.

A "fair" rating of 6 points was applied under this heading. Although the transfer points in this system are minimal, the sliding action of the coal in the pans generated a certain amount of dust.

2. Noise generation.

A "fair" rating of 6 points was applied under this heading.

3. Low seam adaptability.

A "good" rating of 9 points was applied under this heading, because this system was adaptable to low coal seams.

4. Capacity, steady state.

A "poor" rating of 3 points was applied under this heading, because, as explained earlier, the system had an inherent limitation of 1.5 to 2 tons per minute.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading, because the very low steady state capacity of the system gave it a very poor capability for handling surge flow.

6. Ability to handle large pieces.

A "fair" rating of 6 points was applied under this heading.

7. Spillage and carryback.

A "good" rating of 9 points was applied under this heading.

8. Advance-retract speed.

A "very bad" rating of zero points was applied under this heading, since the relatively fixed nature of the shaker conveyor installation precluded making frequent moves.

9. Traction-tracking ability.

This performance characteristic probably does not apply to shaker conveyors in the same sense that it does to those systems that have mobility, but a "fair" rating of 6 points was applied under this heading to recognize the ability to extend the system fairly easily by adding pan sections.

10. Ability to convey around corners.

A "good" rating of 9 points was applied under this heading, because the special devices used to convey around corners apparently worked effectively.

11. Reach capability.

A "good" rating of 9 points was applied under this heading, because the reach of these systems was extended at times to 300 feet.

12. Design simplicity.

A "good" rating of 9 points was applied under this heading because the entire shaker conveyor system, including the drive unit, was simple and rugged.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading.

K. Pneumatic conveyors (vacuum).

Any performance evaluation of a pneumatic conveying system used as a continuous face haulage system must be hypothetical, since to our knowledge there has been no full-scale underground installation of this type used in coal. The evaluation shown in Figures 18 and 19 for such a system is based largely on the results of extended tests conducted by Joy Manufacturing Co. at Franklin, Pennsylvania several years ago.

Joy began a comprehensive program to investigate pneumatic conveying in 1964, and the work was continued over a period of about 4-1/2 years. Early in the program a 400 ft. long test loop was constructed at Franklin featuring a 12 inch I. D. pipeline with associated equipment that included a coal storage tank, a feeder device, a fan, and dust collecting equipment.

The test installation was scaled to 1/4 the size that was expected to be required for a full scale system for underground coal mine use. Thus the 12 inch pipe used in the test installation, which handled about 1-1/4 tons/minute, would become a full sized 24 inch pipe to handle approximately 5 tons/minute. This scaling down of the test installation was done to simplify the material handling problem and to reduce the size of the test equipment.

The test loop at Franklin was built to investigate the feasibility of pneumatic conveying of coal underground, and to obtain design data for designing pneumatic conveying equipment for use with coal mining machinery. The Franklin tests were related primarily to the conveying of coal in horizontal pipelines, using a vacuum system. Among the basic information that was sought was the following:

1. The amount of air required to move a specific amount of coal.

2. How the above air requirement varies with the size of the coal.

3. The practicability of conveying material pneumatically where the material has a wide range of particle size.

4. The minimum air velocity required to avoid the deposit of coal in the pipe.

5. The extent of wear on the inside pipe surfaces.

6. The effect of wet coal on conveying ability.

7. Correlation of test data with other published data on this subject.

8. The pressure drops to be encountered in the system, and the resulting values of horsepower required to operate the system.

9. The degree of degradation of coal size caused by pneumatic conveying.

10. The possibilities for explosions in the system.

The performance of the test installation yielded the following information concerning the above items:

1. Where intake air accelerates the coal into the system, approximately 2.7 lbs of coal can be moved from the system intake by 1.0 lb of air.

2. The air requirement to move a specific amount of coal remains relatively constant with the size consist of the coal, up through the 2 inch maximum size used in these tests.

3. These tests handled fines and lumps up through 2" without problems, and an occasional larger lump thrown in was successfully carried through the system. Other research has shown that maximum lump size should not exceed one-third the diameter of the pipe, to avoid plugging.

4. The lowest air velocity in the system is at the intake end, assuming a constant diameter pipeline. This velocity must be at least 100 ft/sec for a 12" diameter pipe. The minimum velocity requirement increases with pipe size as the square root of the ratio of the diameters.

5. The extent of wear on the inside pipe surfaces throughout these tests was not significant. However, reports on coal movement through pneumatic pipelines for power plant applications indicates that over a period of time such wear can be severe, particularly at bends in the pipeline.

6. The effects of normal amounts of water on the coal, such as would be used for controlling dust, were not detrimental to operation of the system.

7. Correlation of Joy test data with other published data on this subject was reasonably good, although there was a divergence of opinion regarding extrapolation of horsepower requirements for moving high tonnages of coal, in the 10 to 12 tons per minute range. The Joy figures appeared to be lower than some other published data.

8. Through these tests methods were established for calculating system pressure drops and horsepower requirements. The details of these procedures are considered to be outside the scope of this paper, but the following examples will illustrate the requirements for a 500 foot long vacuum conveyor:

    a. To move 5 tons/minute requires:
        24" I.D. pipe
        33,000 SCFM of air
        1170 hp

    b. To move 10 tons/minute requires:
        34" I.D. pipe
        66,000 SCFM of air
        2050 hp

9. These tests, and the results of other research, have shown appreciable degradation of coal size from pneumatic conveying. This occurs mostly at bends in the pipeline, and the extent of the degradation would depend on the design and the overall length of the system.

10. The possibilities for explosions in a pneumatic conveying system appear to be remote, primarily because the high rate of air flow results in favorable air-to-coal and air-to-methane ratios.

The conclusion made from the results of the Joy tests of pneumatic conveying was that this is not a practical haulage method for use in underground mines behind a miner. The main disadvantages are:

1. The large diameter of pipe that is required, with the related handling and supply problems.

2. The large amount of horsepower required to move the normal outputs from a miner.

3. The lack of mobility and flexibility in the face area that seems to be inherent with any conceivable design concept utilizing the pneumatic principle.

Pneumatic conveyors (vacuum) rating for thirteen performance characteristics

1. Dust generation.

An "excellent" rating of 12 points was applied under this heading. The system by itself does not tend to generate dust, and aids in controlling airborne dust present at the face by drawing large volumes of air into the system intake. Leaks that develop in a vacuum system tend to draw air in, rather than expel air and dust into the mine atmosphere, as would be the case with a pressure system leak.

2. Noise generation.

A "poor" rating of 3 points was applied under this heading. The noise level in any pneumatic system is expected to be high.

3. Low seam adaptability.

A "very bad" rating of zero points was applied under this heading. The pipe size, approximately 3 feet in diameter, with related handling equipment, does not lend itself to low seam use.

4. Capacity, steady state.

A "good" rating of 9 points was applied under this heading, assuming one accepts the large pipe size and the large horsepower requirement associated with moving 8 to 10 tons per minute with a vacuum pneumatic system.

5. Capacity, surge flow.

A "good" rating of 9 points was applied under this heading, assuming that some sort of feeder-breaker unit with surge capacity is included in the system between the miner and the vacuum system intake.

6. Ability to handle large pieces.

A "good" rating of 9 points was applied under this heading, again assuming the use of a feeder-breaker behind the miner.

7. Spillage and carryback.

An "excellent" rating of 12 points was applied under this heading, since with this system all material is completely confined once it leaves the face area.

8. Advance-retract speed.

A "very bad" rating of zero points was applied under this heading, since the mobility of any conceivable design concept of a vacuum system appears to be quite poor.

9. Traction-tracking ability.

It is difficult to apply a rating under this heading when a design concept has not been defined, but the problems that are anticipated in handling heavy pipe sections for this system, and the lack of mobility that is expected, suggest a "very bad" rating of zero points here.

10. Ability to convey around corners.

A "fair" rating of 6 points was applied under this heading, reflecting the difficulty in establishing flow around corners with any type of flexible and mobile pipe arrangement in the large diameters that are required.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading, because this system has a potential reach of several hundred feet, assuming the other problems could be solved.

12. Design simplicity.

A "poor" rating of 3 points was applied under this heading, because any conceivable design concept would involve a substantial amount of pipe handling machinery. The elements of the vacuum system, by themselves, are fairly simple.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading. The large volumes of air entering this system at the face help to control dust and methane accumulations in the face area, without presenting any apparent explosion probabilities within the vacuum system itself.

L. Joy PBM (Push Button Miner).

The haulage system associated with the Joy Push Button Miner has been included in this study as a special case, since it was designed and built to be a part of a sophisticated mining system that was highly automated and was used for one particular type of coal mining. The Joy PBM was designed to punch long straight entries into exposed seams in strip mine high-walls. The conveyor train associated with the PBM followed a multi-head boring type miner into an opening in the high-wall, discharging coal at the pit to a transfer conveyor which was part of a mobile conveyor storage structure.

The PBM conveyor train was subject to many operating problems. Some of these were peculiar to the application, but many were associated with the design concept of the conveyor train.

The conveyor train of the PBM consisted of 60 2-wheeled cars, which were coupled at intervals of 16.5 feet. Each car had a conveyor, driven by a 7.5 hp motor-reducer unit, and each car also had a 4 hp traction drive. With 60 units in the train, each carrying two drive mechanisms consisting of a motor, motor control, and high ratio reducer, and with all units being interdependent, the statistical possibilities for reliability were not too good, and this proved out in practice as well as theory. Re-design to simplify the drive components was undertaken to improve system reliability, but the mechanical breakdown problem was never satisfactorily solved. There were too many parts.

The side swing discharge feature on the conveyor cars added a complication to the car structures, and this contributed to the overall maintenance problem.

The maintenance problem on the conveyor cars was further complicated by the helical ramp storage structure that was used to provide compact storage for the 1000 ft. long conveyor train. The conveyor cars, when stored on the ramp, were inaccessible for maintenance work. The ramp structure also placed heavy demands on the traction system and coupling arrangements of the cars, and this compounded the other mechanical problems.

The problems of dust and spillage that occur to some extent in any cascading conveyor system were particularly troublesome with this conveyor system, because the conveyor worked in an unmanned place. Efforts to control the amount of spillage were reasonably successful, but the small quantities of material that did escape from the conveyor were distributed throughout the length of the entry and built up over a period of time to create serious clearance and traction problems.

Joy PBM ratings for thirteen performance characteristics

1. Dust generation.

A "poor" rating of 3 points was applied under this heading, because the large number of transfer points at the connections between the cars created a severe dust problem.

2. Noise generation.

A "fair" rating of 6 points was applied under this heading. The main problem regarding noise with this system was the large number (120) of drive units.

3. Low seam adaptability.

A "fair" rating of 6 points was applied under this heading. The overall height of the car units was just under 3 feet.

4. Capacity, steady state.

A "good" rating of 9 points was applied under this heading. The PBM conveyor had a conservative rating of 6 tons/minute.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading, since no surge car unit was located at the inby end of this train.

6. Ability to handle large pieces.

A "poor" rating of 3 points was applied under this heading.

7. Spillage and carryback.

A "poor" rating of 3 points was applied under this heading. Shrouding reduced the spillage at the transfer points, but it remained as a considerable problem.

8. Advance-retract speed.

A "good" rating of 9 points was applied under this heading, since the conveyor train had no trouble keeping up with the miner.

9. Traction-tracking ability.

A "poor" rating of 3 points was applied under this heading because of traction problems that occurred in the entry and also on the storage ramp.

10. Ability to convey around corners.

A "good" rating of 9 points was applied under this heading, although as used this system primarily conveyed coal in a straight line.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading, since this system had a reach of 1000 feet.

12. Design simplicity.

A "fair" rating of 6 points was applied under this heading. The principle negative aspect of this design was the large number of parts, as has been explained earlier.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading.

M. Angled belt conveyors.

The development work that was performed by Jones and Laughlin Steel Corporation in 1956 on the angled extensible belt conveyor concept was primarily directed toward building a light, strong, compact turn unit that had a low height profile.

The most advanced turn unit design that was developed had a 28-1/2" overall height. To get this height, small diameter pulleys had to be used for changing the belt direction. This was a design compromise that was not conducive to long belt life, and this remained as one of the problems when development work on this idea was discontinued.

The lowest weight of the turn unit that was achieved was about 1300 lbs. Since the turn units had to be repositioned frequently in use, the manhandling of these heavy assemblies became one of the main disadvantages of the system.

The turn units were designed for a 90^{o} change in belt direction, so right angles were mandatory in the mining plan. Belt alignment proved to be quite critical, and if this were not done carefully the belts would move along the angled pulleys until they jammed, which could result in shutdowns of 2 to 3 hours to allow the belts to be reset.

It was found necessary to anchor the turn units securely to the bottom with a set of timber jacks. Additional jacks were set in line with the room run and the butt run to anchor the turn unit against the tension of the belts.

The turning of the belt 90^{o} by running the belt around a pulley set at 45^{o} to the belt runs resulted in a scuffing action of the belt along the axis of the pulley. This resulted in a very short life for the splice joints in the belts, with failure sometimes occurring in less than a week.

In summary, the problems that hindered the performance of the angled belt extensible conveyor concept could be listed as follows:

1. Difficulty in moving the turn units to new positions in the mine as mining progressed.

2. Sensitivity of the system to belt misalignment.

3. Belt life problems.

Angled belt conveyor ratings for thirteen performance characteristics

1. Dust generation.

A "fair" rating of 6 points was applied under this heading. The places along the belt where the coal stream changed direction were dust generating areas.

2. Noise generation.

A "good" rating of 9 points was applied under this heading. The rating for noise is essentially the same as for an extensible belt conveyor.

3. Low seam adaptability.

A "fair" rating of 6 points was applied under this heading. The overall height of the turn units was eventually reduced to 28-1/2 inches, but the height of the conveyor drive storage units falls into a 30 to 54 inch range. The prototype system was run in a 6 ft. coal seam.

4. Capacity, steady state.

A "good" rating of 9 points was applied under this heading. Although only a 30 inch belt was used in tests of this system, with a capacity of 4 to 5 tons/minute, there is no reason that the system could not use a wider belt and achieve 8 tons/minute.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading.

6. Ability to handle large pieces.

A "poor" rating of 3 points was applied under this heading.

7. Spillage and carryback.

A "poor" rating of 3 points was applied under this heading.

8. Advance-retract speed.

A "poor" rating of 3 points was applied under this heading. The main problem here is the lack of mobility of the turn units.

9. Traction-tracking ability.

A "fair" rating of 6 points was applied under this heading. Although the extensible belt tailpiece for this unit was crawler driven and reasonably mobile, the lack of mobility of the turn units detracted from the performance of the system as a whole.

10. Ability to convey around corners.

A "fair" rating of 6 points was applied under this heading. Factors that detract from the rating here are the problems associated with belt alignment, and the requirement for adhering to precise 90° turns.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading.

12. Design simplicity.

A "fair" rating of 6 points was applied under this heading. The added complication of the turn units detracts from the rating of the extensible conveyor by itself.

13. Inherent safety.

A "fair" rating of 6 points was applied under this heading. The manhandling required in moving the heavy turn units is considered to be a disadvantage from a safety standpoint.

N. Joy 2PC.

The portable belt conveyors built by Joy in 1949, which carried the designation 2PC, were intended for use behind the Joy 3JCM miners in room and pillar work.

The field problems encountered in the use of the two prototype systems that were built and that saw limited underground use included the following:

1. The manhandling of the individual conveyors required more men than had been planned.

2. Storage of the unused units until they were required was a problem.

3. With about 15 conveyor units in the string, each with its own belt drive and with its own electrical connections, reliability became a problem for the system as a whole.

4. Spillage and dust were a problem at the transfer points.

5. The manhandling of the individual conveyors was considered to be a safety hazard.

6. Material handling capacity, at 1 to 1-1/2 tons/minute, was considered marginal even for the limited output of the face equipment that the conveyors were intended to serve.

Joy 2PC rating for thirteen performance characteristics

1. Dust generation.

A "poor" rating of 3 points was applied under this heading. The large number of transfer points (15) made dust a considerable problem with this system.

2. Noise generation.

A "good" rating of 9 points was applied under this heading.

3. Low seam adaptability.

A "fair" rating of 6 points was applied under this heading. Maximum height of the individual conveyor units ranged from 34 to 48 inches, depending on the wheel size used.

4. Capacity, steady state.

A "poor" rating of 3 points was applied under this heading, reflecting the low 1 to 1-1/2 tons/minute capacity.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading, since no surge capacity was built into the inby end of this system.

6. Ability to handle large pieces.

A "poor" rating of 3 points was applied under this heading. The conveyor belts were only 18" wide, and the hopper area at the transfer points was quite small, so large pieces would tend to interfere with the flow of material.

7. Spillage and carryback.

A "poor" rating of 3 points was applied under this heading. Spillage was a particularly bad problem with this system.

8. Advance-retract speed.

A "very bad" rating of zero points was applied under this heading. Since the individual conveyors had to be moved into or out of line by manpower, the mobility of this system was inadequate.

9. Traction-tracking ability.

It is difficult to apply a rating under this heading when the units were not self-propelled, but a "fair" rating of 6 points was applied to reflect the lack of mechanical power for moving these units.

10. Ability to convey around corners.

An "excellent" rating of 12 points was applied under this heading, because with all of their limitations, once these portable units were properly set up they could convey material around corners without difficulty.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading, because the individual conveyor units could be strung in series to reach as far as desired.

12. Design simplicity.

An "excellent" rating of 12 points was applied under this heading, because the system is extremely simple in concept, although also very limited in performance.

13. Inherent safety.

A "fair" rating of 6 points was applied under this heading. The major negative aspect of this design from a safety standpoint is the manhandling requirement for moving the conveyor units.

O. Consol Banana Wagons.

The patent drawings of the Consol Banana Wagons, which were 2-wheeled conveyor units designed to be connected in series, show basic similarities of design to other cascading conveyor systems that have been covered in this report.

There is little detailed information regarding the performance of this unit through the short period that it was in service in the early 1960's. The design would indicate that it would share with other similar concepts the problem of multiple transfer points along the length of the system, with the attendant problems of dust and spillage of material.

Consol Banana Wagons ratings for thirteen performance characteristics

1. Dust generation.

   A "poor" rating of 3 points was applied under this heading, reflecting the large number of transfer points along the system.

2. Noise generation.

   A "good" rating of 9 points was applied under this heading.

3. Low seam adaptability.

   A "fair" rating of 6 points was applied under this heading. The design of the intermediate cars suggests an overall height of about 36", but the height of the discharge section was apparently somewhat greater.

4. Capacity, steady state.

A "fair" rating of 6 points was applied under this heading.

5. Capacity, surge flow.

A "poor" rating of 3 points was applied under this heading.

6. Ability to handle large pieces.

A "poor" rating of 3 points was applied under this heading.

7. Spillage and carryback.

A "poor" rating of 3 points was applied under this heading.

8. Advance-retract speed.

A "fair" rating of 6 points was applied under this heading.

9. Traction-tracking ability.

A "poor" rating of 3 points was applied under this heading.

10. Ability to convey around corners.

A "good" rating of 9 points was applied under this heading.

11. Reach capability.

A "good" rating of 9 points was applied under this heading.

12. Design simplicity.

A "poor" rating of 3 points was applied under this heading.

13. Inherent safety.

A "good" rating of 9 points was applied under this heading.

P. Pneumatic conveyors (pressure).

The most serious disadvantage of the pressure-type pneumatic conveying system for use in underground coal mines is the safety-related problem of leaks or ruptures in the system, which could result in the escape of large quantities of coal dust and methane to the mine atmosphere. It seems unlikely that this hazard could be tolerated, particularly in a mobile and flexible system where the integrity of the various joints would be hard to maintain.

Although a pressure-type pneumatic conveying system could be considerably more compact than a vacuum type, using pipe sizes roughly half the diameter required for an equivalent vacuum conveyor, the problem of handling and installing the pipe in an underground area is still formidable. The problem remains, also, of providing in a pipeline system the mobility and flexibility that is necessary to follow the miner through various mining plans.

A pressure-type system presents a complication for underground use that is not present in a vacuum system - the need for an airlock feeder unit at the face area. To handle the required tonnage, this unit presents problems in bulk and complexity.

Another drawback of a pressure-type system is the need to have the fan or blower at the upstream end of the system. This puts another piece of equipment in the face area.

Pneumatic conveyors (pressure) rating for thirteen performance characteristics

1. Dust generation.

A "very bad" rating of zero points was applied under this heading, mainly reflecting the problems associated with leaks or ruptures in the pipeline system.

2. Noise generation.

A "poor" rating of 3 points was applied under this heading. The principle noise generating sources at the face would be the breaker unit necessary to reduce the coal to a required size, and the air blower.

3. Low seam adaptability.

A "very bad" rating of zero points was applied under this heading, reflecting the design problems associated with the required face machinery and the pipe handling machinery.

4. Capacity, steady state.

An "excellent" rating of 12 points was applied under this heading, since a 10 to 12 tons/minute capacity is conceivable for this system, assuming that the machinery to achieve this flow can be tolerated.

5. Capacity, surge flow.

A "good" rating of 9 points was applied under this heading, assuming that some sort of feeder-breaker unit with surge capacity is included in the system between the miner and the airlock feeder.

6. Ability to handle large pieces.

A "good" rating of 9 points was applied under this heading, again assuming the use of a feeder-breaker behind the miner.

7. Spillage and carryback.

An "excellent" rating of 12 points was applied under this heading, since all material is completely confined once it leaves the face area. This assumes an intact pipeline, without leaks or ruptures.

8. Advance-retract speed.

A "very bad" rating of zero points was applied under this heading, since the mobility of any conceivable design concept of a pressure system appears to be quite poor.

9. Traction-tracking ability.

The lack of mobility expected with this system suggests a "very bad" rating of zero points under this heading.

10. Ability to convey around corners.

A "good" rating of 9 points was applied under this heading.

11. Reach capability.

An "excellent" rating of 12 points was applied under this heading, since this system has a reach capability of several hundred feet.

12. Design simplicity.

A "poor" rating of 3 points was applied under this heading, reflecting the design problems anticipated with the face equipment and the pipe handling equipment.

13. Inherent safety.

A "very bad" rating of zero points was applied under this heading, reflecting the safety hazard associated with pipe leaks or ruptures.

ENGINEERING STUDIES OF SYSTEMS WITH THE MOST POTENTIAL

The continuous face haulage systems that will be scrutinized in this section and the succeeding section, on the basis that they represent the systems with the most potential, are as follows:

1. Bridge carrier systems, as currently manufactured by Jeffrey Mining Machinery Company, Long-Airdox Company, and West Virginia Armature Company.

2. Flexible conveyor belt systems, as represented by the Joy Manufacturing Company developments known as the Joy Serpentix conveyor, and the Joy FCT, or Flexible Conveyor Train.

The above conveying systems ranked in the top three among the systems that were rated in the performance evaluation of Phase III. The third system among those classified as "most promising" was the hydraulic conveyor, where a coal-water slurry is pumped through pipes.

As has been explained in earlier reports, the most advanced development underway in the field of underground coal slurry pipelines is the Consolidation Coal Company project, at their Robinson Run Mine. Detailed information on the latest progress of this work is not available for use in this study.

The exclusion of the coal slurry pipeline system from further study in this contract should not interfere with the overall objective, however, since the two types of systems that will be considered, the bridge carrier and flexible belt systems, are believed to be considerably further advanced from an engineering standpoint, and are more representative of practical and cost-effective systems, than is the hydraulic conveyor at its present state of development.

Both the bridge carrier system and the flexible conveyor belt system have certain shortcomings, which will be explained later in this report. In their current configurations, the bridge carrier system appears to be most effective in the lower coal seams, 4 to 5 feet and below. The flexible conveyor belt systems, primarily because of the height profile of current designs, is limited to coal seams 6 feet and above. It would seem a logical development that future designs of both systems will extend their use into a wider range of coal seam heights.

The shortcomings of both types of systems appear to fall into two broad categories:

1. Mechanical problems, where the need for design refinement within existing technology has been indicated by field experience.

2. Performance shortcomings that require major changes or additions to the systems, and which require in some cases the type of development program which is aimed at extending existing technology, so that the results of the program may not be completely predictable.

In most cases, enough field experience has been gained with both systems that the mechanical problems are quite well defined, and engineering changes have either been made, or are contemplated, for correcting most of the mechanical problems that were observed during this study.

Unfortunately there is evidence that the machines in the field do not always represent the best state-of-the-art in either design or in fabrication. The reasons for this are no doubt varied, and the same observation could be made on mining machine products other than continuous face haulage systems, and in industries other than mining.

However, referring strictly to the continuous face haulage machinery observed during this study, the following was evident:

1. The level of engineering capability among the companies represented appeared to vary widely.

2. With the more experienced companies, the level of engineering excellence in the execution of design concepts is sometimes lower than it should be, considering their experience.

3. A lack of quality control at the manufacturing level seems to be a universal problem.

One of the results of the above is that too often the machine concept is penalized by poor mechanical design or poor manufacturing.

The performance shortcomings that require major changes or additions to the systems seem to provide most of the opportunity to suggest program plans for further development, which will be our concern in the last section of this report.

A. Bridge carrier systems.

1. MECHANICAL PROBLEMS

a. Crawler units

Problems with crawler units on the bridge carriers made by two manufacturers were reported on field visits to several mines. The troubles ranged from electric drive motor problems, speed control problems, drive component failures, track adjustment, and traction problems. A follow-up on this with the manufacturers indicated that redesigned crawler units are either in the field or ready to be phased into production in the near future.

It would seem that very little trouble should be experienced in the crawler unit of this type of machine if the best engineering knowledge available is applied.

b. Cable handling

Handling of electric cables continues to be a problem, particularly at the inby end of the bridge carriers where several feet of dolly travel must be accommodated by a loop of cable. In some instances the loop of cable is carried on a spring-loaded pulley. This problem is still receiving study by the manufacturers.

c. Grounds in electrical system

This problem was reported and also observed at first hand, and seems to fall into a category that should be virtually eliminated if the best state-of-the-art is practised in the design and installation of the electrical system.

d. Pivot connection failures

Failure of the pivot connections at both ends of the bridge conveyors, where attachment is made to the miner or to the bridge carrier, was one of the commonest problems observed.

Failure was frequently caused by the failure of the bridge carrier operator to move quickly enough to follow the motion of the miner. In this case, when the dolly on the carrier reaches the end of its travel, the full drawbar pull of the miner is applied to the pivot joints at each end of the bridge conveyor.

One manufacturer felt that the pivot pins should not be strengthened, because they served as a weak link and prevented damage to other parts of the structure. Another felt that the pivot joints should be able to withstand the full drawbar pull of the miner, and attempted to design against breakage.

In all cases, however, the pivot points have received a great deal of design attention, and indications are that the newer designs will be considerably less apt to break. One troublesome pivot pin, which was a welded fabrication, is now being milled from solid bar stock to improve its strength.

e. Sideboards and skirting problems

To prevent spillage of material at the conveyor transfer points, most of the bridge conveyors and bridge carriers are equipped with sideboards or skirting to control the flow of coal. These have proved to be inadequate at times, and some modification of the arrangement and installation of the skirting, or aprons, has been tried both by the manufacturers and by the mining companies.

This problem is compounded because the aprons are vulnerable to damage in service, from the flow of material and from contact with the mine surfaces. If damaged aprons are not replaced, spillage of coal at the point of damage can be severe.

In some cases these parts are made from a rubber type material to allow them to yield if they contact the roof or the rib, but some installations of this type appear to tear too easily, and some redesign effort is currently being applied to this problem by the manufacturers.

f. Weld problems

Inadequate or poor quality welds were observed on several pieces of equipment. In some cases this could be attributed to a lack of quality control during manufacturing, but in other cases the mines were observed adding weld to new machines before they went underground, changing skip-welded joints on the structure to full-welded joints. Apparently the mines viewpoint on what constitutes an adequate weld doesn't always coincide with the manufacturers viewpoint.

g. Conveyor motors

Failures of conveyor drive motors was reported repeatedly during the mine visits of this study. This applies only to those bridge conveyor units using belting, as opposed to chain.

Most of the belt-type bridge conveyors in the field use two 10 hp motors on each bridge to drive the belt. One manufacturer has recently increased the conveyor drive to two 15 hp motors because of problems experienced in the field. This company discovered that a rash of conveyor motor burn-outs at one mine occurred where the mine voltage was very low, but to be on the conservative side they are increasing the power of their motors.

One mine that was experiencing conveyor motor burn-outs, primarily on the inby bridge, increased the motor size from 10 hp to 15 hp on this bridge only, on the theory that the inby bridge had to handle and even out the surges from the miner, and therefore required more horsepower than the outby bridges.

The belt-type bridge conveyors apparently require considerably more horsepower than the chain-type. The advertised horsepower of the 8 tpm Jeffrey bridge conveyor is one 15 hp motor, as opposed to the two 15 hp motors now considered to be required on the belt-type bridges. The higher requirement on the belt-type bridge seems to be due to the high friction that takes place between the belt and the steel plate that it rides on, particularly when the belt is wet.

The belts supplied by the manufacturers of belt-type bridge conveyors and bridge carriers are thinner and of lighter construction than normal mine conveyor belting. This makes it easier to drive, but the drive motors can be overloaded when, as is the practice in some mines, regular belting is used to replace the original belting when the original belt wears out or is damaged.

h. Belt life

The bridge conveyors and bridge carriers made by Jeffrey carry chain-type conveyors as opposed to the belt-type conveyors supplied by Long-Airdox and West Virginia Armature. This reflects two schools of thought on what constitutes the best conveyor, and a difference of opinion exists at the mine level in addition to the difference found among the manufacturers.

The majority opinion among the mine people contacted during this study seemed to favor the advantages of chain-type equipment, although in some cases the persons expressing such an opinion were using belt-type machinery.

The advantages attributed to chain were as follows:

1. Less maintenance.
2. Less spillage.
3. Narrower width.
4. Less fire hazard.
5. Better for rock.

The disadvantages mentioned regarding chain were:

1. More noise.

2. Heavier.

3. More expensive.

Wide variations were experienced in comments received regarding the service life of belt and chain on these conveyors. Mine operators reported belt life ranging from one to six months. Some claims by the manufacturers of belt-type bridge conveyors were as high as a year for average belt life. A good chain conveyor should handle 500,000 tons of material, which projects out to a life of a year or more based on a 500 ton/shift, 15 shift/week production.

Manufacturers of both types of conveyors indicated they were prepared to go either way, belt or chain, depending on what the field requirement is. They are currently making what they think the field wants. Two mine conditions that would seem to favor the use of chain-type conveyors are the presence of a lot of rock, or sulphur balls, and very wet mining conditions.

j. Bridge structural problems

Among the basic design requirements for the bridge conveyors are that they be strong and light in weight. One of the complaints heard from the field is that these structures are "too delicate", and some units have been badly damaged from contact with the roof or the rib.

Improvement in the bridge structure design appears to be within reach by increasing the section modulus in both the vertical and the horizontal plane, and by resorting to better material.

Some bridge conveyor sideframes observed in the field were channel sections, as opposed to box sections which provide more strength in bending and in torsion. The newer designs do have box sections, and in many cases the material is structural rectangular tubing.

The steel in structural rectangular tubing is normally a type A36, so the yield point is not what is required where one of the design criteria is high strength and low weight. A better grade of steel for this application would be one of the high-strength low allow steels that could be used to almost double the yield strength with only a nominal increase in cost. This might preclude the use of structural tubing, which is a convenient steel shape to use for this product, but the objective of strength with low weight should take priority in this case.

k. Gobbing under belts

The accumulation of wet coal fines between the belt and the steel plate on which the belt rides was a severe problem at some of the mines visited. This required a shutdown two or three times in a shift, in some cases, to allow for a cleanout of the wet coal, and this was a tough, laborious procedure.

This was discussed with the manufacturers, and it was learned that openings have been cut in the steel plates beneath the belts on some machines in the field to help relieve this situation. At this time the problem seems to be still under study, with no specific plan formulated for changing the production machines to eliminate the accumulation of this material.

2. PERFORMANCE SHORTCOMINGS

a. Problems with large pieces

Large pieces of coal coming off the face, and particularly large pieces of rock from the roof or the floor, can block the flow of coal at the conveyor transfer points. Sulphur balls in the coal seam also contribute to this problem. In addition to blocking the flow of coal, these large pieces can cause severe damage to the belts, and can drastically reduce belt life.

The severity of this problem varies considerably from mine to mine, but the problem seems to exist to some degree in almost all mines.

One solution which has been considered is the addition of a mobile feeder-breaker unit to the system. This unit would follow the miner and receive the material discharge from the miner tailpiece. The inby end of the first bridge conveyor would be supported by the feeder-breaker.

One of the design problems associated with such a unit would be achieving the required low profile to match the rest of the system, and still maintain the necessary ground clearance.

The design of the breaker unit would also present special problems, because it would have to function in such a way that it would break up thin slabs as well as chunks, because slabs are particularly troublesome at the transfer points.

The addition of a feeder-breaker unit would add a man to the crew requirement, but it could also be the factor that would make continuous haulage practical in a mine where large pieces of coal or rock are prevalent.

b. Problems with surge flow

The bridge conveyor attached directly to the miner tailpiece has a very limited ability to handle surges of material, particularly surges in excess of a 10 tpm rate. By the time the flow of material reaches the first bridge carrier the worst of the surge has been evened out, but sometimes with the result of considerable spillage of coal behind the miner. The uneven placement of coal on the first bridge can interfere with the smooth transfer of coal to succeeding units of the system, also.

The feeder-breaker unit mentioned in the preceding paragraphs could be designed to provide the surge capacity needed to smooth out the flow of coal on all of the conveying units. This should be effective in reducing the spillage of material at all of the transfer points of the system.

It should be noted here that at least one manufacturer of bridge carrier systems believes that the rating applied in this study to the surge flow capacity of their system is lower than it should be. They point out that the 10 to 12 tpm capacity of their conveyors can normally handle the maximum output of any miner, particularly if the miner operator controls his sumping and cutting so that he puts an even flow on the system.

We established, in the first part of this study, that surge flows from miners could range from rates of 15 to 25 tpm, for periods up to 20 seconds, and consequently it would be desirable to have the ability to handle such surges as a feature in any continuous face haulage system. Our rating was made on this basis, but the above criticism could be a valid one.

c. Dust at transfer points

This problem varied considerably among the applications that were visited during this study. In some cases dust was being produced in such quantities at the conveyor transfer points and at the panel belt tail pulley that the job was in danger of being shut down. In other cases the dust problem was negligible, largely because of the effective use of water sprays.

The most effective use of water for dust control that was encountered was a good spray system on the miner, which wetted the coal sufficiently at the face so that no sprays had to be used on the conveyors.

One mine that was spraying the coal quite heavily was experiencing a lot of gobbing of the wet coal under the conveyor belts. It appears that the amount of water used for dust control must be controlled quite carefully to avoid over-wetting, with its attendant problems.

For spraying systems to work properly there must be adequate water pressure at the spray nozzle. To get adequate water pressure at the face it is sometimes necessary to use booster pumps in the water lines. In one mine visited, the addition of a booster pump in the water line was the thing that made their water spray system effective in controlling dust along their bridge carrier system.

d. Communication problems

The proper operation of a bridge carrier system requires good teamwork and coordination between the miner operator and the bridge carrier operators. Adding a second bridge carrier to the system increases the difficulty of coordinating the movements of the various units in the chain.

The bridge carrier operator relies mostly on watching the dolly travel on the inby end of his carrier to signal the movement of the miner. Often the miner is out of sight around a corner.

While some crews become very adept at moving the system through the mine, it would seem that better communication among the operators would make the system more efficient.

Two suggestions for doing this are the use of telephone communication among the operators, and the addition of remote control as a feature for the bridge carriers.

The value of the phone system is obvious in allowing all of the operators to communicate their situation to the others.

The mine operators that have expressed an interest in remote control for the bridge carriers believe that having the ability to operate the bridge carrier off to either side would give the operator better visibility, and improve his ability to guide the carrier behind the miner.

Both of these ideas appear to be within the reach of present technology, and the main problem would appear to be the development and installation of dependable systems, so that they did not turn out to create more trouble than they eliminated.

e. Length limitations

With 40 feet of length on the bridge conveyor, and 30 feet of length on the carrier, a system comprised of two bridges and a carrier provides approximately 130 feet of reach from the face to the room conveyor. This reach becomes approximately 200 feet if the system includes three bridges and two carriers.

In some applications, a longer reach is desirable, and a potential to reach 400 feet was established as one of the design parameters for an ideal continuous face haulage system in Phase I of this study.

Some mines visited during this study that have had considerable experience with bridge carriers, and have given some thought to extending their range, have considered the use of three carriers and four bridges, which would give approximately 270 feet of reach.

What the problems would be in coordinating this chain of units is difficult to foresee, but the coordination required by the carrier operators should not be much different with three carriers than with two.

The amount of telescoping ability of one unit over another could conceivably be increased to advantage, with longer systems, because the overall length of the system is useful when advancing, but becomes a detriment when the system is required to retreat.

One mine operator suggested bridge conveyors that would have the ability to telescope within their own length, in addition to being able to overlap adjacent units. If this could be achieved, it would allow the system to expand and retract, within limits, as required. This would be a difficult concept to design, and keep within reasonable weight and bulk limits.

f. Flexibility limitations

The need for a flexible bridge conveyor system, to negotiate several turns, conflicts with the need for length and reach, because the longer the bridge conveyors become, the more difficult it is to negotiate corners.

The 40' length bridge conveyors need entry widths of 20' or more, plus crosscut angles of 60°, preferably, to ease the cornering problem. If the entry narrows to 18', shorter bridge conveyors of 30' length are more suitable.

This means that the reach capability of a bridge carrier system can be compromised in mine situations where entries have to be kept to minimum widths.

With the present system configuration, this requires that the mining plan must be adapted to the limitations of the conveyor system, in the matter of reach and in the ability to move around corners.

This problem suggests a string of shorter bridge conveyors, with more units being used to achieve the necessary length. If a bridge carrier is used between the bridge conveyors, the requirement for carrier operators then becomes prohibitive, from a manpower cost standpoint.

One mine operator suggested the use of a monorail suspension system for a chain of short bridge conveyors, which would eliminate the need for bridge carriers and carrier operators. This idea seems to have some merit. One disadvantage of the monorail is the space that it requires, which could become critical in a low seam application. The numerous transfer points with a lot of short conveyors suggests a dust problem, also, but this should be controllable with proper spraying. Another disadvantage of multiple, independent conveyors used in series is the requirement for multiple drives, with the resulting increase in the statistical chances for mechanical problem.

This thinking really leads to the idea of a flexible, continuous belt, which is the subject covered in the last parts of this section.

g. Need for prior entry development

In most instances where bridge carrier systems are put into operation in mines, there appears to be a need for some entry development prior to the introduction of the bridge carrier system. This requires the use of other haulage equipment such as shuttle cars or scoops, and the entry development must be extended from 120 to 180 ft. with this equipment to provide the necessary space to install the straight length of rigid-side-frame panel conveyor that constitutes the outby end of the bridge carrier system.

As has been explained in preceding sections of this report, if the need for this type of development becomes too great, because of frequent changes in direction of the mining plan, the use of the bridge carrier system for continuous face haulage becomes marginal.

This difficulty seems to be related to the fact that the rigid-side-frame panel conveyor, that the outby bridge rides on, has to be straight, in its present configuration. If mobile corner units could be inserted into this length, to convey material around corners, then the need for the special haulage equipment to change mining direction could be eliminated. These cornering conveyors would have to be able to carry the outby bridge dolly around the corner, also, so that the entire bridge carrier system could go in or out past the cornering unit. Preferably, the angle of turn that could be provided by the cornering unit would be adjustable, so that the system would be adaptable to various mining plan geometries. The panel belt would be designed to be extendable inby of the cornering unit.

Such a concept would have to be investigated in more depth for practicality, but the design of the units would appear to fall within existing technology.

B. Flexible conveyor belt systems.

1. THE JOY SERPENTIX CONVEYOR

Earlier sections of this report, which covered the Concept Investigation and the Performance Evaluation phases, describe a Joy Serpentix installation that is installed and operating at the Peabody #10 mine at Pawnee, Illinois. At the present time this appears to be a successful continuous face haulage system.

Two additional installations are about to be placed in Peabody mines in the immediate future. One of these will be installed in an 8' seam at the Deercreek Mine, near Huntington, Utah, and the other will be installed in a 6' to 7' seam at the Baldwin #1 Mine near Marissa, Illinois.

Some significant changes have been made to the two new units that are going into service. The belt length will be 400 ft., as opposed to the 200 ft. length of the original installation. The width of the belt has been increased from 32 inches to 40 inches, and belt speed has been reduced from 400 fpm to 356 fpm.

The vertebrae section castings that form the belt support are a new, more compact design, so that overall height of the conveyor is reduced by 6 inches.

The primary drives on the system have been changed from hydraulic to electric. This includes the Serpentix belt drive, the bridge conveyor drive, and the crawler and belt drives on the tram car.

The tram car is a new design, which includes a drum-type breaker equipped with picks. The tram car drive is powered by a 2-speed A-C motor.

At the Deercreek installation, the Serpentix conveyor will be mounted directly above the panel belt, and coal will be transferred from the Serpentix to the panel belt with the aid of a chute.

At the Baldwin installation, the panel belt will be to one side of the Serpentix conveyor, and a transfer conveyor will be used to move the coal from the Serpentix belt to the panel belt.

The performance of the Serpentix with the above design changes will have to be evaluated after these two new installations have been placed into service.

In the redesigned version the Joy Serpentix still requires 6 ft. or more of coal seam. Further development is underway to extend the use of this system into lower seam heights.

The monorail system for this conveyor, which has been described in some detail in earlier reports, appears to be quite successful, but not without some problems. There are occasions when the bridge conveyor operates at an angle to the centerline of the monorail track. Since the bridge conveyor also serves as a drawbar to move the Serpentix along the monorail, either forward or backward, certain side forces are sometimes imposed on the monorail track by the bridge conveyor. This can result in damage to the monorail if caution is not observed in moving the tram car. There are times when tram car movement must be made slowly and smoothly, which puts a premium on the speed control and smoothness of the tram car drive, plus care on the part of the operator.

2. THE JOY FLEXIBLE CONVEYOR TRAIN

The Joy FCT is not as far advanced as a commercial product as is the Joy Serpentix conveyor. Considerable development work remains to be done in the area of improving the load carrying member, or rubber belt, and in designing a suitable supporting structure for mounting and moving the belt.

The performance of two prototype installations of the FCT were described in the Performance Evaluation section. Both of these flexible belts were mounted on trains of two-wheeled carts that rode on the mine bottom. Experience with these prototypes proved the ability of this general configuration to drive and support a flexible edge-guided belt, and to convey coal around a series of bends. The conveyor showed promise for fulfilling the continuous face haulage requirement for most underground mining systems, recognizing that in its present configuration it is not a low seam system.

The problems that were defined with the flexible belt were:

1. Its unacceptably short life.

2. Cleaning and carryback problems with the current belt design.

A comprehensive belt development program is currently underway, participated in by B. F. Goodrich and Joy, to design, fabricate and test some improved belts that will attempt to correct the problems associated with the prototype belt design. The design modifications will include changes to make the belt structure more durable, particularly in areas that developed tears after short periods of service. The belt configuration will also be changed to eliminate some of the crevasses that tended to hold coal fines in service, which contributed to the belt-cleaning and carryback problem experienced with the prototypes.

The train of two-wheeled carts that supported the prototype FCT belts were useful in allowing the belt concept to be tested, but were a source of considerable mechanical trouble. Since the concept of the wheeled train as a practical supporting device for the FCT is presently under review, as a result of the performance of the prototypes, a detailed analysis of the mechanical problems that were experienced with these units would not be very significant.

Some of the engineering people that were associated with these tests still firmly believe that the wheeled ground-supported concept is workable for a flexible conveyor belt system. There were not a lot of problems with the prototypes that were related to the mobility and traction capability of the wheeled prototype conveyors. There were some, however, including wheel failures, steering difficulties with the skid steering, inadequate flotation from the wheels, and damage to the bottom from repeated wheel action. There were also some occasions when the cars got hung up on the rib when negotiating corners, and some occasions when the train got hung up on bad bottom when the car frames bottomed out.

The success of the monorail suspension associated with the Serpentix conveyor, together with some of the problems associated with the wheeled, ground-supported concept tried on the FCT, have been factors in a consideration of monorail support for the FCT. One of the advantages that this concept presents, however, is obvious, and that is that the monorail allows the FCT to be suspended directly above a panel belt. This would eliminate the carryback problem associated with the FCT belt, since this material falls off the return strand within 20 to 30 ft. of the outby end of the FCT, and with the monorail suspension, the carryback material would fall onto the panel belt and be carried out with the normal coal stream.

A more detailed description of a monorail-mounted FCT is presented in the last section of this report. The prototype of this system will be built by Joy Manufacturing Company under a Bureau of Mines research and development contract.

PROGRAM PLANS

The objective of this part of the study has been to develop program plans to correct the shortcomings of the most promising systems, thereby achieving machine designs for continuous face haulage which are safe, practical, and cost-effective.

Toward this end, the succeeding paragraphs discuss program plans for the following systems:

1. Bridge carrier systems, as currently manufactured by Jeffrey Mining Machinery Company, Long-Airdox Company, and West Virginia Armature Company.

2. Flexible conveyor belt systems, as represented by the Joy Manufacturing Company developments known as the Joy Serpentix conveyor, and the Joy FCT, or Flexible Conveyor Train.

The last part of this section of the report describes a Bureau of Mines research and development contract recently obtained by Joy Manufacturing Company to build and test a continuous face haulage system for a shortwall face.

The program plans in this report that relate to bridge carrier systems are presented under two headings, one of which covers mechanical problems for the attention of the manufacturers, and the other covers broader problems that relate to performance shortcomings that require system improvements.

The program of mechanical problems on bridge carrier systems, for the attention of the manufacturers, is essentially a restatement of the mechanical problems that were analyzed in the Engineering Studies section.

The performance shortcomings of bridge carrier systems lead to several suggestions, the major ones being:

1. The development of a low-profile feeder-breaker units, to be used between the miner and a bridge carrier system, for the purpose of breaking up large pieces of coal and rock before they reach the conveyor system, and also for providing surge flow capacity to handle surge flows of material from the miner.

2. The development of a flexible portable panel conveyor, capable of conveying material around one corner, and capable of carrying the dolly for the outby bridge conveyor, so that the bridge carrier system can be used to mine new entries off existing entries without the need for other types of haulage equipment.

The program plans in this section that relate to flexible conveyor belt systems are also presented under two headings, one of which covers development programs of the manufacturer that are already underway, and the other covers a Bureau of Mines contract that has been negotiated relative to flexible conveyor belt developments.

A. Bridge carrier systems.

1. MECHANICAL PROBLEMS FOR THE ATTENTION OF THE MANUFACTURER

All of the following mechanical problem areas on bridge carrier systems do not occur on each of the product lines of the three major manufacturers, since the designs in some cases were adequate, and in other cases the designs have been corrected or are in the process of being corrected as a result of field experience with the equipment. This listing of problem areas can serve as a check list, however, to allow the manufacturers to check their designs against the most common problems that were observed during this study.

a. Crawler units

Crawler unit design should be evaluated relative to reliability of the power source (electric or hydraulic motor), smoothness of the speed control, ruggedness and reliability of the drive train components, and performance of the track adjustment feature.

b. Cable handling

Adequacy of cable-handling devices should be evaluated, particularly where several feet of cable must be looped to accommodate dolly travel.

c. Grounds in the electrical system

This problem appears to relate closely to the cable-handling problem, since many of the ground faults that were observed or reported were associated with parts of the cable system that are required to flex in service. Fixed wiring properly guarded does not normally give trouble. Electrical wiring and cable arrangements should be reviewed to minimize conditions contributing to ground faults.

d. Pivot connection failures

This was one of the commonest problems observed. Considerable re-design has been made in this area. Designs should be reviewed to ensure reliability at all pivot connections.

e. Sideboard and skirting problems

Design in this area should be evaluated not only from a performance standpoint, relative to preventing spillage of coal, but also from a durability standpoint, since the parts must resist damage in use to remain effective.

f. Weld problems

Designs should be reviewed for adequate weld call-outs, and quality control of welding in the manufacturing process should be maintained.

g. Conveyor motors

Field experience should be reviewed to evaluate conveyor motor horsepower. On the belt-type bridge conveyors, two 15 hp motors have been installed in some instances to provide adequate power.

h. Belt life

Improved belts should be developed to provide longer life and greater resistance to damage.

j. Structural problems

Structure designs should be reviewed in an attempt to provide stronger and lighter construction of both bridge conveyor and bridge carrier units.

k. Gobbing under belts

The conveyor design should be studied to seek ways to minimize the tendency for coal fines to accumulate between the belt and the belt support plates.

2. PERFORMANCE PROBLEMS REQUIRING SYSTEM IMPROVEMENTS

The lowest ratings applied to the performance characteristics of bridge carrier systems were related to the capacity of these systems to handle surge flow and large pieces.

The idea of adding a feeder-breaker to the system, between the miner and the bridge-carrier units, was discussed at several mines and with all of the bridge-carrier system manufacturers. Agreement seemed to be quite widespread that this would be a useful device to provide surge capacity and to break the material down to a maximum size that would convey with fewer problems. The consensus also seemed to be that while not all applications of bridge-carrier systems needed a feeder-breaker, some applications would benefit from such a unit a great deal. In some mines, where rock is prevalent, the use of a feeder breaker could be the factor that would make the bridge carrier system workable.

In addition to providing surge capacity and breaker capacity, a feeder-breaker would support the inby bridge unit, thus freeing the miner from attachment to the conveying system and giving the miner more freedom of movement.

The feeder-breaker concept has been discussed with more than one machinery manufacturer by mine managements who would like to buy such a unit.

At this writing the Bureau of Mines has drafted a Request For Proposals, No. HO 166005, related to a hopper-feeder-spillage cleaner unit, which would essentially serve the purpose of the feeder-breaker that has been discussed above.

The Bureau RFP requests "proposals from organizations having the capability to study the feasibility of, to design, to fabricate, and to demonstrate a prototype machine with the capabilities to be the interface between a continuous miner and a continuous haulage system. This machine will be the inby traction unit for a continuous haulage system and will carry out various supporting services so that the mining system can advance 100 feet without programmed delays."

The Statement of Work of this RFP indicates that "a machine is needed that will perform the following functions: pull the face haulage conveyor into position behind the miner or loader; act as a surge hopper, feeder-breaker, loader to clean up spillage behind the miner; and if possible, (provide) rock dusting, roof bolting, and extension of ventilation facilities."

Another performance limitation of bridge-carrier systems that suggests a program plan for further development concerns the difficulty experienced in changing the direction of the mining plan when bridge-carrier systems are providing the face haulage. This problem was covered in the Engineering Studies section under the heading, "Need for prior entry development."

The bridge carrier system, in its present configuration, requires approximately 120 to 180 ft. of straight entry for its installation, because the length of rigid-side-frame panel conveyor that supports the outby bridge dolly cannot adapt to a curve or turn in a horizontal plane.

This normally means that when the mining direction must change for any reason, other haulage equipment such as shuttle cars or scoops must be brought in to develop the entries in the new direction for the distance required to permit re-installation of the bridge carrier system.

A program plan aimed at relieving this problem would be one that would examine the feasibility of a panel conveyor tailpiece, for use with a bridge-carrier continuous face haulage system, which tailpiece would have the ability to accommodate itself to a bend in a horizontal plane, and at the same time be able to carry the outby bridge dolly around the bend, so that the bridge carrier system could pass freely in either direction around the panel conveyor bend.

The above program plan would also involve the design, fabrication, and demonstration of the flexible panel conveyor tailpiece and related dolly parts.

One conveyor form that could lend itself to such a design is the universal conveyor chain that is typically used on the discharge conveyors of miners. The universal joint links on this type of chain allow the conveyor to operate on a radius of a few feet.

B. Flexible conveyor belt systems.

1. MANUFACTURERS PROGRAMS

The Engineering Studies section of this report described two new installations that are being made of improved versions of the Joy Serpentix conveyor. One of these is at the Peabody Deercreek Mine near Huntington, Utah, in an 8' seam, and the other is at the Peabody Baldwin #1 Mine near Marissa, Illinois, in a 6' to 7' seam.

At this writing the start-up of the unit at Deercreek appears to be about a month away. Equipment for the Baldwin unit is still being designed, and built, so this installation is probably several months from a start-up date.

Pending operation and evaluation of these two installations, no further development of the Serpentix is contemplated.

Design and development of a modified form of the Serpentix is being pursued, however, with the aim of achieving a design concept of a flexible conveyor that can work in lower seams. Previous discussions of the Serpentix have taken note of the fact that a minimum seam height of 6' to 7' is required for the Serpentix in its present configuration.

A program plan for further development of the Joy Flexible Conveyor Train has already been defined and started by the Joy engineering department, with the aim of solving the two major problems that were experienced in underground mine tests with prototype versions of this system. The problems are mainly associated with the belt itself, and as described in the Phase IV report, they are:

1. Unacceptably short belt life.

2. Cleaning and carryback problems with the original design.

Belt redesign and accelerated belt life tests have been undertaken as a joint activity by Joy and the B. F. Goodrich Company, who are the developers and manufacturers of the special flexible belt that has been described in earlier reports. The results of this work to date are encouraging, from the standpoint of improvements that have shown up in the accelerated life tests as a result of belt design changes.

Some of the design changes that are contemplated for the flexible belt are aimed at reducing the cleaning and carryback problem. The surface shape of the belt will be modified to make cleaning easier and to reduce the tendency of coal fines to be trapped in the belt convolutions.

Another part of the program plan for the FCT is the design of a monorail-supported version of the flexible belt. The outby end of the monorail FCT would be supported directly over a conventional panel conveyor, which simplifies the transfer of material to the panel conveyor and relieves the problem of carry-back, since carryback material from the FCT would be deposited onto the panel belt.

The original wheeled, ground-supported version of the FCT still has its advocates, but the thinking at this time is that the monorail, roof-supported concept will provide improved mobility to the system. There are problems related to the monorail itself that still have to be solved, however, among those being the installation of the monorail at the inby end of the system. This becomes more of a problem when the mining cycle is improved to allow the miner to make an uninterrupted advance in excess of the normal 20'. With the normal miner advance, the monorail system can be extended when the miner leaves a place to allow roof-bolting to be done. With a longer miner advance, the monorail must be advanced while mining is taking place. Means to circumvent this problem are currently under study.

2. BUREAU OF MINES PROGRAM RELATED TO THE JOY FCT

Under a recently signed contract with the Bureau of Mines, Joy Manufacturing Company has agreed to design, build, and test in an underground coal mine a prototype mobile 400 foot long flexible conveyor train that will be suspended from a monorail track mounted to the roof. The system will be capable of following a continuous miner in a room and pillar system to provide continuous haulage of coal from the face to a standard floor-mounted panel belt.

This FCT system consists of the following units:

1. A feeder-breaker tram car that follows behind the miner.
2. A bridge conveyor unit that connects the tram car to the inby end of the FCT.
3. The monorail-mounted FCT.
4. The roof-supported monorail system.

The arrangement of these units is shown in a side view in Figure 20.

The feeder-breaker tram car is basically a modified Joy 10SC22 shuttle car. The modifications include a special slow-speed AC-DC tram control, the addition of a breaker unit, and a chain conveyor speed compatible to the FCT belt speed.

The function of the tram car is to receive the flow of coal from the miner, to accommodate and even out any surge flows from the miner, to crush and size the material, to deliver a controlled rate of flow to the outby conveyor units, and to provide a towing force for the FCT, for both advancing and retreating.

The bridge conveyor connects to the outby end of the tram car and the inby end of the FCT. It provides a flexible link between these units for drawbar purposes and for the transfer of material from the tram car to the FCT.

The FCT consists of a special continuous, flexible belt which has been described in earlier sections. The belt is supported on a train of (48) 8 foot long cars which are flexibly coupled to permit free operation over irregular rolls and through turns. The cars carry roller stands at 2 foot intervals which provide support and edge guidance for the flexible belt.

Inby terminal and outby terminal units complete the FCT structure, with the inby terminal incorporating a belt drive for the return strand, and a receiving hopper to direct the material from the towing unit to the belt. The outby terminal unit incorporates a belt drive motor with a hydraulic pump PTO to provide belt takeup. The outby terminal unit is suspended over the panel belt and discharges material directly to this belt.

The FCT structure is supported by hangar units that attach to trolley units that roll on the monorail track. One hangar unit supports each car, and additional hangars support the inby and outby terminal units.

The monorail track is made from 5" I-beams, and is extended during the roof-bolting phase as the face advances, or is removed as the mining retreats. The monorail is reusable.

The mining plan proposed for this system consists of five entries, and the monorail track is installed in the center entry and into the crosscuts, as required. Switching units allow the FCT to move from the center entry into the crosscuts. The entries on either side of the center entry are mined by using the combined reach of the miner, the tram car, and the bridge conveyor.

It is anticipated that by the time this prototype system is ready to run, the belt development program mentioned earlier will have produced an improved belt design, and the improved belt will be installed for the mine tests of this system.

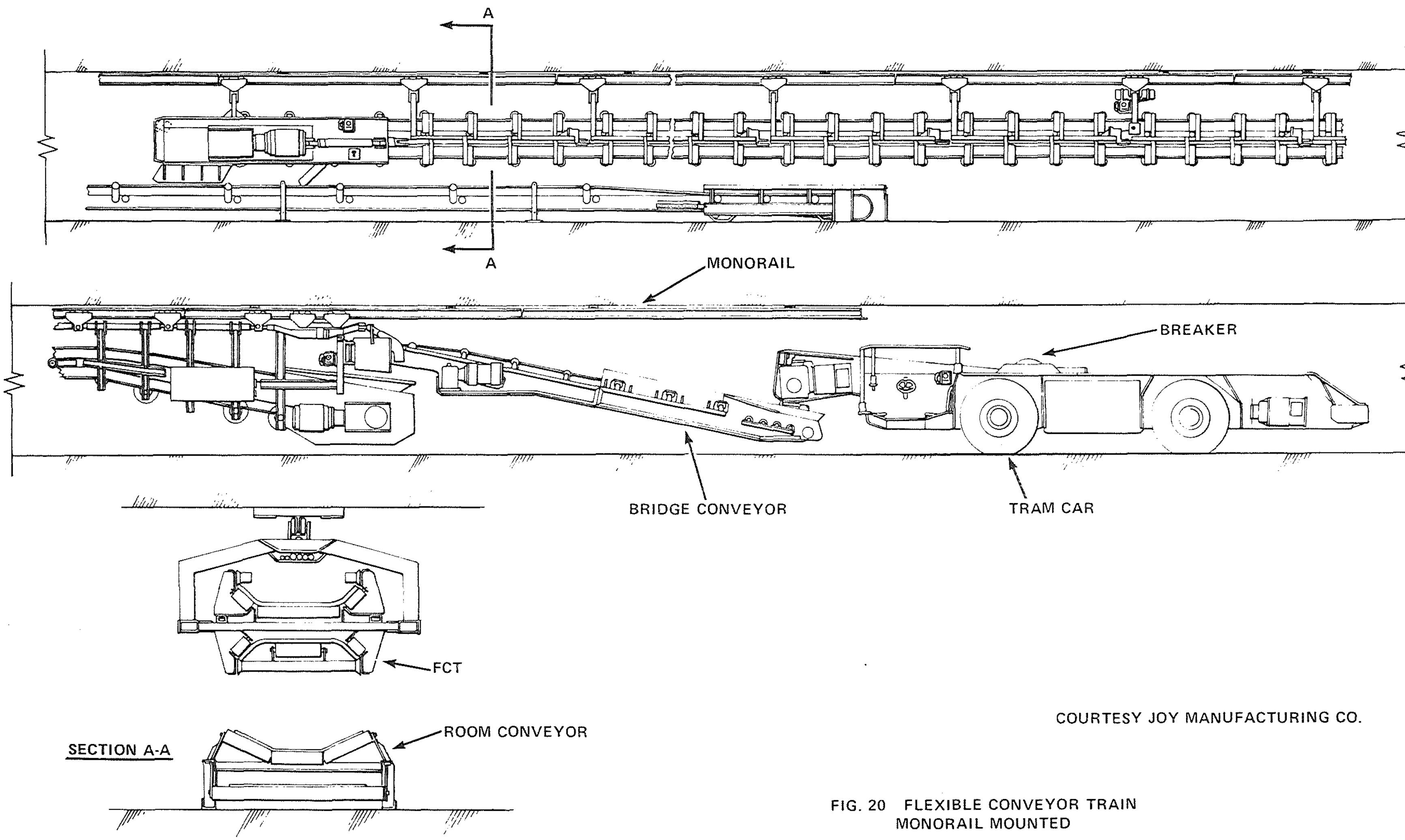


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FIG. 20 FLEXIBLE CONVEYOR TRAIN
MONORAIL MOUNTED

C. Bureau of Mines Program for continuous haulage at a shortwall face.

The Bureau of Mines recently negotiated a research and development contract with Joy Manufacturing Company to provide a continuous haulage system for a shortwall face. This system will use an articulated chain conveyor on the face and a mobile transfer conveyor suspended from a monorail in the head entry.

The Bureau of Mines is currently operating an experimental shortwall system at Hendrick #22 Mine of Beth Elkhorn at Jenkins, Kentucky. Joy manufactured the roof support system for this shortwall face under U. S. B. M. Contract HO 133001. Coal haulage from the continuous miner to the panel belt conveyor on this experimental face is by Joy 21SC shuttle cars.

Studies on this shortwall operation have indicated that the continuous miner waits for the shuttle cars about two-thirds of the available time. Recognizing the potential for increased productivity, Joy has designed the continuous haulage system for a shortwall face that is involved in the above mentioned contract.

Joy has proposed that the equipment called for in this contract be installed and tested on an experimental shortwall face at Mine #3 of Valley Camp Coal Company at Tridelphia, West Virginia. The Bureau of Mines is presently cooperating with Valley Camp at this mine in the operation of an advancing tailgate shortwall face which is equipped with a Joy shortwall roof support system identical in design to the Bureau of Mines experimental face at Beth Elkhorn.

The proposed face conveyor design uses an articulated chain conveyor placed between the chocks and the continuous miner along the entire length of the face. The chain conveyor replaces the spillplate which is currently used to connect the chocks. The face conveyor is a 28" wide single chain articulated conveyor made up of 13'-6" long pans. The length of the individual pans is based on having the rams of three roof support chocks attached to each face conveyor pan. This provides a stable base, or beam, with which to pull the chocks toward the new face. The pans are joined by chain connectors on both the face and the gob sides, which provides the necessary flexibility when the conveyor is pushed toward the new face.

The face conveyor transfers the coal to a modified loading machine in the head gate entry. The loading machine will incorporate a breaker unit. The outby end of the loading machine is connected to the inby end of a mobile transfer conveyor which is suspended from a monorail mounted to the roof in the head gate. The outby end of the mobile transfer conveyor is suspended directly over a 36" wide floor-mounted panel belt that is 18-1/2" high.

Figures 21, 22, and 23 illustrate the system described above.

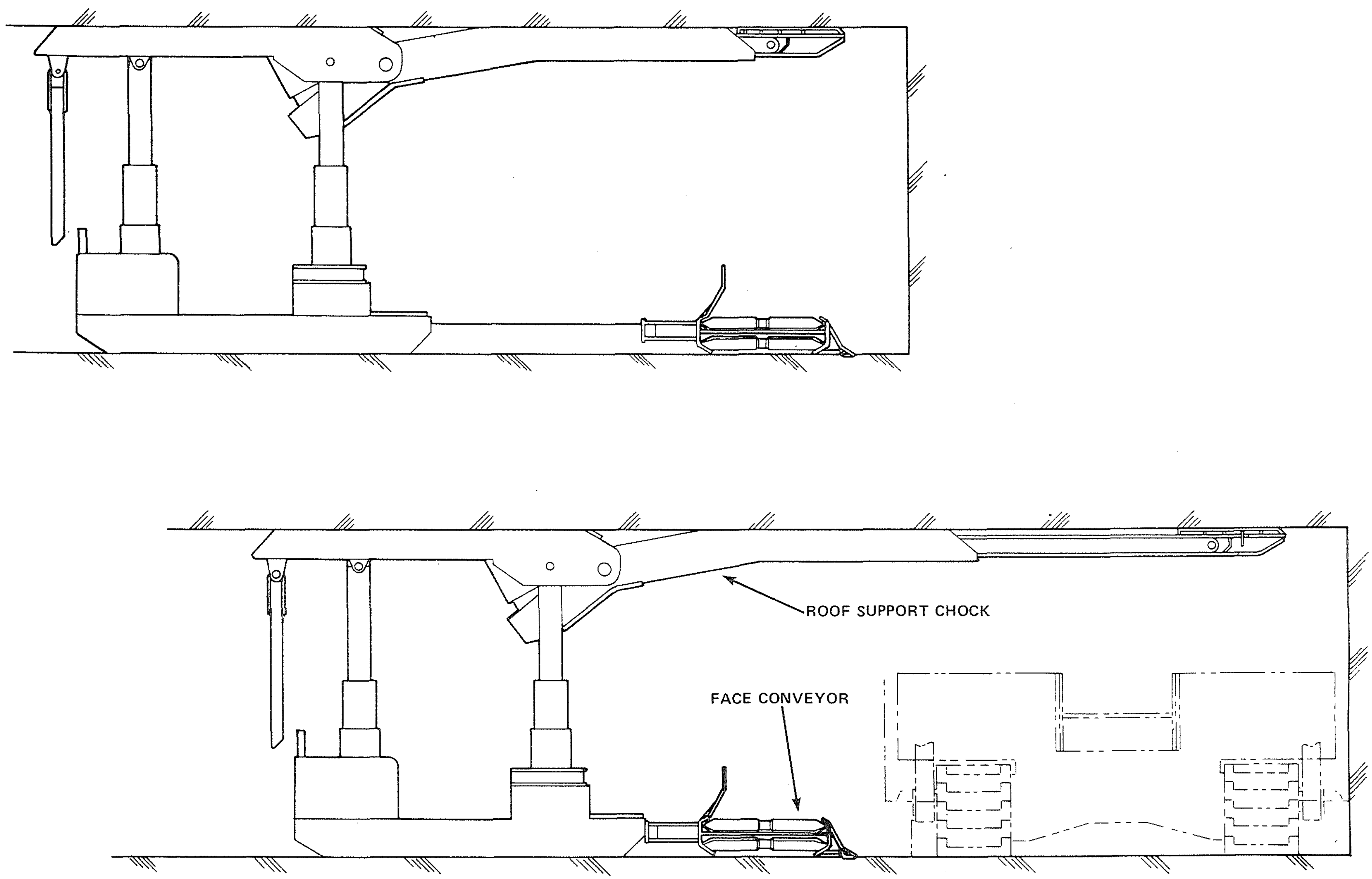
Figure 21 is a section through the face showing the roof support chocks and the face conveyor arrangement.

Figure 22 is a plan view showing the machinery arrangement at the face.

Figure 23 is a side view showing the machinery arrangement of the conveyor system in the head gate entry.

When the continuous miner starts a new cut across the face, it will be in the head entry with the loading machine behind it. The loading machine follows the miner as it starts its cut, with the head of the loading machine under the discharge conveyor of the miner. When the loading machine advances far enough that its head can be positioned under the discharge end of the face conveyor, the discharge conveyor of the miner is swung to dump onto the face conveyor, and the face conveyor is started. The continuous miner is now in position to mine straight ahead for the length of the face.

When the miner finishes the cut, it trams in reverse back to the head entry. As the miner is tramming out, the loader trams the mobile transfer conveyor in an outby direction to give the miner room to start the next cut. After each cut a section of monorail is taken down, and after every twenty cuts the panel belt is shortened.



COURTESY JOY MANUFACTURING CO.

FIG. 21 SHORTWALL FACE CONVEYOR – SECTION THROUGH FACE

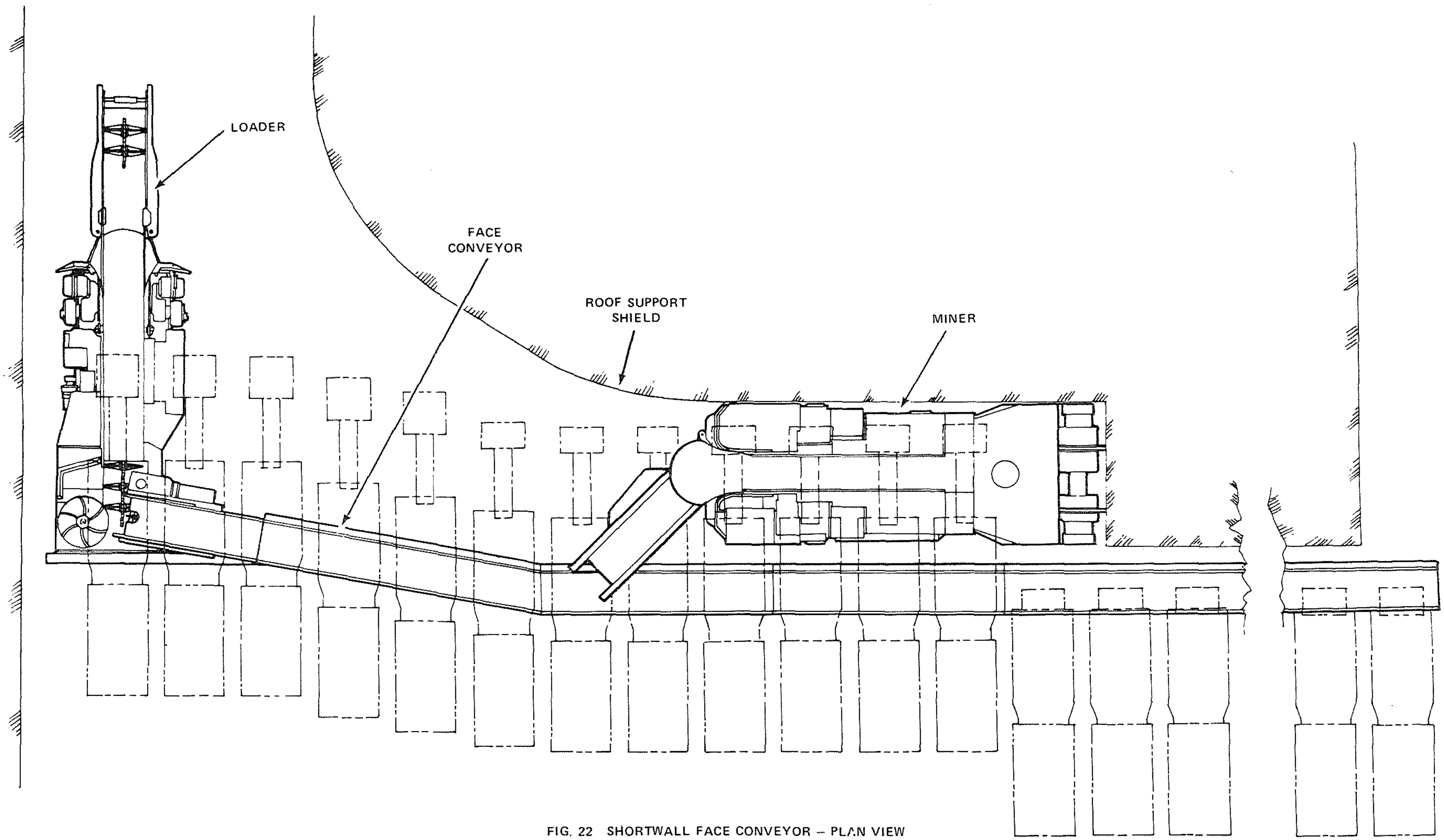


FIG. 22 SHORTWALL FACE CONVEYOR – PLAN VIEW

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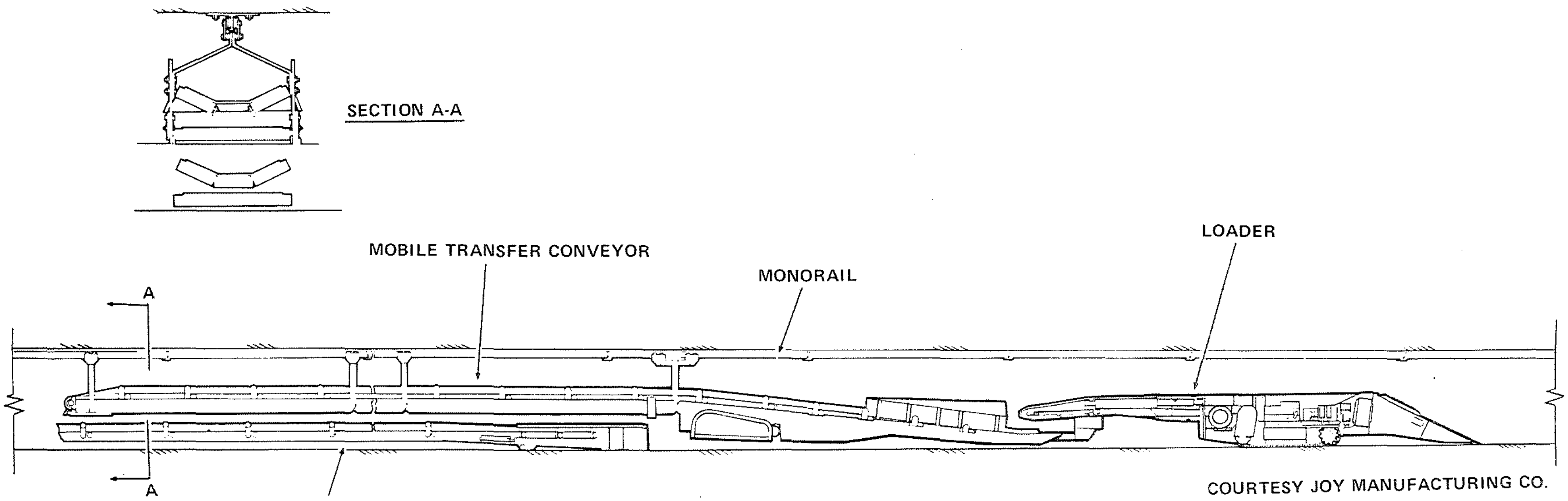

FIG. 23 SHORTWALL FACE CONVEYOR SYSTEM
SIDE VIEW

SAFETY ASPECTS OF CONTINUOUS FACE HAULAGE SYSTEMS

Previous sections of this report have indicated that the reasons for widespread interest in continuous face haulage include, in addition to the search for increased productivity, a search for safer mining methods.

The most common method for face haulage of coal in U. S. underground coal mines today is to use shuttle cars or scoops and tractors to carry coal from the loader or the continuous miner to the secondary haulage system, which is generally a belt conveyor. Accidents related to these haulage vehicles, primarily when they are moving through the mine, are a source of concern to everyone connected with the mining industry.

Statistics relating to such accidents are available from several sources, the principle source being the reports prepared by the Bureau of Mines. Unfortunately the use of continuous face haulage systems in any quantity has occurred just in the last few years, and we find no data related to any accident statistic record for these newer systems. There is a belief, however, that continuous face haulage systems have inherent safety advantages over shuttle car and scoop and tractor haulage. The primary reason for this would appear to be that the most promising systems use conveyor belts for moving the coal, so that the supporting machinery mass is relatively slow moving compared to shuttle cars and scoops.

Among the manufacturers and users of modern continuous face haulage systems interviewed during this study, there was no knowledge of a fatal accident involving these systems.

The best way to analyze the safety aspects of continuous face haulage systems, in the absence of historical data, would appear to be to consider the accident data related to shuttle cars and scoops and tractors and determine in what ways the use of continuous haulage systems could improve the safety performance of the more conventional systems.

This kind of analysis must be tempered by considering that the safety performance of shuttle cars and scoops and tractors is certain to be improved, perhaps dramatically, by the addition of effective protective canopies and by improved mine illumination standards. Other ongoing improvements in current haulage machinery, such as improved brake systems and improved operating controls should also affect the safety statistics of existing designs in the immediate future.

To place the accident subject in perspective, the Bureau of Mines report for Injury Experience in Coal Mining, 1970, shows that 205 fatal injuries and 8738 non-fatal injuries occurred during that year in underground bituminous coal mines in the United States. Shuttle cars and mobile electric trucks accounted for 24 fatal accidents and 709 non-fatal accidents out of the above totals, or 11.7% and 8.1% respectively.

Two reports have been studied relating to this phase of the continuous face haulage study that give some detailed information about face haulage accidents. They are:

1. Analysis of Fatalities Related to Scoops and Tractors in Underground Bituminous Coal Mines, 1971-1973. This is a Mesa Information Report, 1975, number IR 1016.

2. Accident Analysis by Functional Classifications for Bituminous Coal Mines in 4-foot to 8-foot Seam Heights. This is a report by the FMC Corporation, and is part of USBM Contract HO 111670.

The report on scoops and tractors indicates the following:

a. During the years 1971 through 1973, a total of 33 persons were killed while operating scoops and tractors in underground bituminous coal mines, primarily in coal seams ranging from 27 to 48 inches in thickness.

b. Seventy-four percent of the fatal injuries involved crushing of the head, neck, or chest while tramming in areas of restricted clearance and poor visibility.

c. The most frequent type of accident involved the operator being crushed between the roof or roof support and the vehicle.

d. Forty-two percent of the accidents involved operators who were not classified as scoop or tractor operators.

The FMC report is interesting in that it relates entirely to operations from the face to the point of first transfer of the coal, which is precisely the part of the mining operation covered by continuous face haulage. Also, the accident data is related to mining function being performed, and one such functional classification, Move and Load Coal (by shuttle car), gives data that is pertinent to this discussion.

The FMC report indicates the following:

a. Over a five-year period, 1966 through 1970, out of 283 fatal face-area accidents among the mines covered by this study, 38 accidents, or 13% occurred during the shuttle car haulage part of the cycle.

b. The shuttle car haulage function ranked fourth in number of fatal accidents, following:

   1. Support Roof (roof bolter) 50 accidents
   2. Load Coal (loader) 47 accidents
   3. Extract Coal (continuous miner) 43 accidents

c. Over a five-year period, out of 11, 170 non-fatal face-area accidents among the mines covered by this study, 1119 accidents, or 10%, occurred during the shuttle car haulage part of the cycle.

d. The shuttle car haulage function ranked second in number of non-fatal accidents, with the top four functions being:

   1. Support Roof (roof bolter) 2735 accidents
   2. Move and Load Coal (shuttle car) 1119 accidents
   3. Extract Coal (continuous miner) 1118 accidents
   4. Load Coal (loader) 966 accidents

e. Shuttle car accidents involved the worker at the controls 82% of the time, and a worker in a supporting role 18% of the time.

f. 82% of the shuttle car accidents occurred when the car was moving through the mine, and 71% of the accidents occurred during the hauling part of the shuttle car cycle, as opposed to the tramming part of the cycle during which the shuttle car returns to the face unloaded.

The Department of the Interior, orginally through the Bureau of Mines, and more recently through the Mining Enforcement and Safety Administration, publishes detailed reports on fatal coal mine accidents. Eighteen such reports covering fatal shuttle car accidents have been studied relative to this project. The period covered by these reports is January 10, 1967 through January 7, 1975.

The fatality reports were reviewed to determine the following information:

1. Was the shuttle car in motion at the time of the accident?

2. Was the shuttle car operated by a classified shuttle car operator at the time of the accident?

3. What was the seam height of the coal where the accident occurred?

4. What was the experience record of the operator, in years of mining experience, and years of operator experience on shuttle cars?

5. What contributing factors appeared throughout the reports?

The reports yielded the following answers to the questions listed above:

1. The shuttle car was in motion in every instance.

2. The operator of the shuttle car was not classified as a shuttle car operator in 7 of the 18 fatal accidents.

3. Seam heights ranged from 37" to 87", with 13 out of 18 accidents occurring in seam heights below 60", and 9 out of 18 accidents occurring in seam heights below 48".

4. Mining experience of the car operator ranged from 35 years to 9 months, and averaged 15 years.

   Shuttle car operating experience of the person driving the car at the time of the accident ranged from 20 years to zero, and averaged 4-1/2 years.

5. Contributing factors that appeared throughout these reports included:

   a. Dangers associated with brattice cloths and curtains, including hindering visibility and snagging the operator and the controls, contributed to 6 of the 18 fatal accidents.

   b. Protrusions from the roof and ribs, including roof supports and poorly trimmed roof and rib surfaces, contributed to 9 out of 18 accidents.

   c. Mechanical problems with the cars, including poorly maintained brakes, poorly designed brake systems, poorly maintained steering systems, poorly maintained or inadequate lighting systems, and poorly maintained tramming controls, contributed to 8 out of 18 accidents.

   d. In at least 8 instances out of 18, it appeared that an adequate canopy installation would have prevented the fatality.

When all of the above information is considered relative to the safety advantages of continuous face haulage systems, it would appear that the most common continuous systems, as represented by the bridge carrier systems and the flexible conveyor belt systems, hold the promise of reducing accidents because they move slower through the mine. There is still a danger with any of these systems of crushing a machine operator or a supporting worker while maneuvering the equipment, but this danger should be much less than with the faster moving shuttle car and tractors and scoops.

Conveyor devices have their own built-in hazards, with belt speeds of several hundred feet per minute, so a longer period of use will be required before the safety aspects of continuous haulage systems can be well defined.

Throughout this study it was apparent that the continuous face haulage systems currently in use are predominantly in low coal, in seams below 60 inches in height. This statement applies to the bridge-carrier, bridge-conveyor type of system, which is the most prevalent.

The Bureau of Mines information circulars entitled Injury Experience in Coal Mining, for the years 1967 through 1970; yield the information shown on Figures 24 and 25. These tables relate accident frequency rates to mine seam thicknesses, and it is obvious that both fatal and non-fatal accidents increase in the thinner coal seams. What an analysis of these figures show is that there are twice as many fatal accidents in the low coal (25 to 60 inches) as there are in the high coal (61 to 96 inches), and that there are approximately 50% more non-fatal accidents in the low coal than in the high coal.

The reason that the coal mining companies are using continuous face haulage systems in the lower coal seams would appear to be related primarily to increased productivity, rather than safety, since shuttle car efficiency as a haulage system drops off in the very low seams. Any safety advantage that may evolve over the next few years in favor of continuous face haulage systems, however, should be more noticeable in the relatively low coal seams because of the greater hazards that exist there.

Figure 24. Accident frequency rates for United States underground bituminous coal mines, by thickness of bed or vein.

year	Thickness, inches	Fatal	Fatal Av.	Non-fatal	Non-fatal Av.
		Accident frequency rates Per million man-hours			
1970	25 to 36	4.62)		65.72)	
	37 to 48	1.14)	2.32	64.19)	63.0
	49 to 60	1.20)		59.09)	
	61 to 72	.36)		50.65)	
	73 to 84	.64)	.56	26.52)	38.6
	85 to 96	.74)		28.74)	
1969	25 to 36	1.45)		49.83)	
	37 to 48	1.01)	1.12	59.47)	55.9
	49 to 60	.91)		58.40)	
	61 to 72	1.09)		41.09)	
	73 to 84	.53)	.70	34.93)	35.6
	85 to 96	.49)		30.83)	
1968	25 to 36	1.74)		53.62)	
	37 to 48	1.25)	1.39	51.94)	54.6
	49 to 60	1.19)		58.28)	
	61 to 72	1.08)		42.24)	
	73 to 84	1.03)	1.00	33.94)	37.5
	85 to 96	.90)		36.35)	
1967	25 to 36	1.27)		52.52)	
	37 to 48	1.24)	1.20	51.92)	55.6
	49 to 60	1.10)		62.23)	
	61 to 72	.86)		40.80)	
	73 to 84	.44)	.83	32.10)	35.1
	85 to 96	1.18)		32.25)	

Figure 25. Ratio of accident frequency rates, given as accidents per million man-hours, for thick seam (61 to 96 inches) and thin seam (25 to 60 inches) underground bituminous coal mines in the United States.

Thick seam to thin seam ratios

year	Fatal Accidents	Non-Fatal Accidents
1970	$\frac{2.32}{.56} = 4.14$	$\frac{63.0}{38.6} = 1.63$
1969	$\frac{1.12}{.70} = 1.60$	$\frac{55.9}{35.6} = 1.57$
1968	$\frac{1.39}{1.00} = 1.39$	$\frac{54.6}{37.5} = 1.46$
1967	$\frac{1.20}{.83} = 1.45$	$\frac{55.6}{35.1} = 1.58$
ratio averages	2.15	1.56

ECONOMIC ASPECTS OF CONTINUOUS FACE HAULAGE SYSTEMS

Among the most promising continuous face haulage systems covered in this study, which includes mobile bridge carrier systems and flexible belt systems, the system capital costs range from (approximately) $115,000 to $450,000, depending on the type of system and the length of the system that is installed.

If we take a typical shuttle car haulage system, the equipment required to move the coal from the face to the panel conveyor generally consists of the following:

(2) shuttle cars @ $65,000 (approx.)	=	$130,000
(1) feeder breaker unit (approx.)	=	$ 40,000
Total		$170,000

Typical mobile bridge carrier system components are estimated to run as follows:

a. 3-entry system, consisting of (1) mobile bridge carrier, (2) bridge conveyors, and a room conveyor, giving a flexible reach of approximately 130 feet:

belt type	$115,000
chain type	$166,000

b. 5-entry system, consisting of (2) mobile bridge carriers, (3) bridge conveyors, and a room conveyor, giving a flexible reach of approximately 200 feet:

belt type	$180,000
chain type	$260,000

For the flexible belt systems, a Joy Serpentix system, giving a flexible reach of approximately 400 feet, runs to approximately $410,000. This includes:

a. 400 feet of 40 inch wide conveyor belt reach.
b. 20 foot long, 36 inch wide belt bridge conveyor.
c. Transfer conveyor 36" wide to discharge to panel belt.
d. Tram car, crawler mounted, with lump breaker.
e. Monorail-mounted controller unit.
f. Monorail system, 2500 feet long, with switch units.

The Joy Flexible Conveyor Train, in a monorail-mounted version, was quoted at 1974 prices at a system cost of approximately $450,000. This system would have a flexible reach of 400 feet, and would consist of the following:

a. Outby terminal.
b. Inby terminal.
c. Conveyor car train.
d. Miscellaneous parts.
e. 800 feet of Serpentine belt.
f. Monorail system 3000 feet long, with switch units.
g. Bridge conveyor.
h. Electric cable.
j. Tram car, with lump breaker.

From the above capital costs it can be seen that the shuttle car system cost of about $170,000 falls somewhere within the continuous face haulage system range of costs, which go from approximately $115,000 to $450,000, depending on the type of system chosen and the reach capability that is desired.

Operating costs with any of these systems vary widely depending on mining practices at specific mines, since such factors as manpower assignments, maintenance practices, length of haul, and mining procedures will differ. Some generalizations may be made in this area from observations made during this study.

Comparing a continuous miner section using shuttle cars for haulage to one using a mobile bridge carrier haulage system, the number of men required per section would appear to be about the same, ranging from six to nine men plus a section foreman, depending on local mining practice. The average size would appear to be seven men. The Joy Serpentix system, by comparison, or a monorail mounted FCT, would appear to require an average of nine men on a section, with the additional men being required to install and take down the monorail track.

On the subject of maintenance, one mine manager with considerable experience with continuous face haulage systems indicated that he has found the electrical systems and hydraulic systems on bridge carriers and bridge conveyors to be simpler than those systems on shuttle cars, and consequently they are simpler and easier to maintain, which reduces maintenance costs.

Probably the greatest influence on reduced operating costs of continuous face haulage over shuttle car haulage is the greater output anticipated from continuous face haulage. This output has not always been achieved in the past, but in mines where continuous face haulage has been successful, outputs 20% to 40% better than with shuttle car haulage are not uncommon.

If we assume that face haulage costs for shuttle car haulage and mobile bridge carrier haulage run about the same on a given section, and that the mobile bridge carrier system results in a 20% greater production, we can make an approximation of the savings that are achieved. The analysis shown below is similar to one shown in a paper presented at the American Mining Congress on May 7, 1975, in Pittsburgh, Pa. The paper was presented by Arthur E. Belton of the John T. Boyd Company, and was entitled Evaluation of Underground Coal Haulage Systems.

	Range	
Total mine cost per ton (1974):	\$ 10.00	\$ 20.00
Face Haulage cost per ton at 10% of above:	\$ 1.00	\$ 2.00
Face Haulage cost per ton w/20% greater production, assuming overall face haulage cost remains the same:	\$ .83	\$ 1.66
Savings per ton:	\$ .17	\$ .34
Annual savings at 1.0 million tons:	\$170,000	\$340,000
Total savings w/25 year mine life (\$ million)	\$ 4.25	\$ 8.50

While this analysis is over-simplified, it demonstrates that large savings can be realized by face haulage systems that increase production, and that these savings can justify increased investments on face haulage equipment.

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