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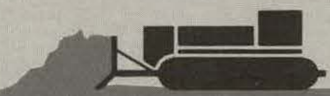

METHODS AND COSTS OF THIN-SEAM MINING

Final Report
Montana College of Mineral Science and Technology

February 1981

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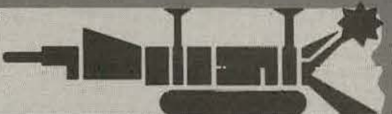

U. S. Department of Energy
Assistant Secretary for Fossil Energy
Office of Coal Mining

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METHODS AND COSTS OF THIN-SEAM MINING

FINAL REPORT

FOR THE PERIOD

25 SEPTEMBER 1977 - 24 JANUARY 1979

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

THOMAS E. FINCH
EDWARD L. FIDLER

MINING ENGINEERING DEPARTMENT

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PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
ASSISTANT SECRETARY FOR ENERGY TECHNOLOGY
OFFICE OF COAL MINING
UNDER CONTRACT DE-FG01-77 ET 12543

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ABSTRACT

This report defines the state of the art (circa 1978) in removing thin coal seams associated with vastly thicker seams found in the surface coal mines of the western United States. New techniques are evaluated and an innovative method and machine is proposed.

Western states resource recovery regulations are addressed and representative mining operations are examined. Thin seam recovery is investigated through its effect on 1) overburden removal, 2) conventional seam extraction methods and 3) innovative techniques. Equations and graphs are used to accomodate the variable stratigraphic positions in the mining sequence on which thin seams occur.

Industrial concern and agency regulations provided the impetus for this study of total resource recovery. The results are a compendium of thin seam removal methods and costs. The work explains how the mining industry recovers thin coal seams in western surface mines where extremely thick seams naturally hold the most attention. It explains what new developments imply and where to look for new improvements and their probable adpatability.

EXECUTIVE SUMMARY

This is the final report under DOE Contract No. ET-77-G-01-9083 entitled "Methods and Costs of Thin Seam Mining." The object of the report is to define the state of the art in removing thin coal seams associated with vastly thicker seams found in the surface coal mines of the western United States. New techniques are evaluated and an innovative method is proposed. All methods are explained, and the associated costs are shown.

The report is assembled in a straightforward manner. Initially, the topic is introduced, appropriate regulations addressed, and representative mining operations are detailed. Following the initial portion, thin seam mining is examined by (1) overburden removal methods; (2) conventional thin seam removal techniques; and (3) new and innovative thin seam removal methods. Since overburden handling and thin seam removal methods are a function of where in the geologic strata the thin seam appears, equations and graphs are developed to expedite costs calculations for any situation. Each section has a concluding table of typical costs. Derivations are shown in appendices at the end of the report.

This final report is therefore a detailed catalog and analysis of thin seam coal removal methods and costs. It is an encyclopedia of how the mining industry recovers thin coal seams in western surface mines, what new developments imply, and where to look for new improvements.

INTRODUCTION

Thin seam coal mining in the western United States nominally equates to recovery of stray seams associated with thicker, major seams. The thin or stray seams encountered are generally recovered, but not in all cases. The alternative to extraction is, of course, spoiling.

The majority of thin seams are encountered somewhere in the overburden above the major seam or in the parting between thick seams. Although some are true strays and appear anywhere in the geologic sequence, others might be classified as thin "rider" seams immediately above or below a thick seam and separated by some equally thin parting. For the purpose of this discussion, stray or thin seams are defined as those which are less than four feet thick or represent less than ten percent of the expected extractable coal. Figure 1 is a graphic representation of typical thin, stray, or rider seams which actually appear in a western operation.

Operationally, stray seams create irritating scheduling problems and require special handling techniques which do not always lead to efficient equipment utilization. Additionally, coal recovery from a thin seam is considerably less than the 95% usually recovered from thick seams. Higher recovery in thin seams leads to dilution problems which depreciates Btu quality and most western coals are not in a position to lose heating value. Thin western seams also undulate and pinch or swell more than thick seams, and this leads to more difficult recovery. Often they are associated with equally dark carbonaceous shales and visual selectivity is difficult at best during daylight hours.

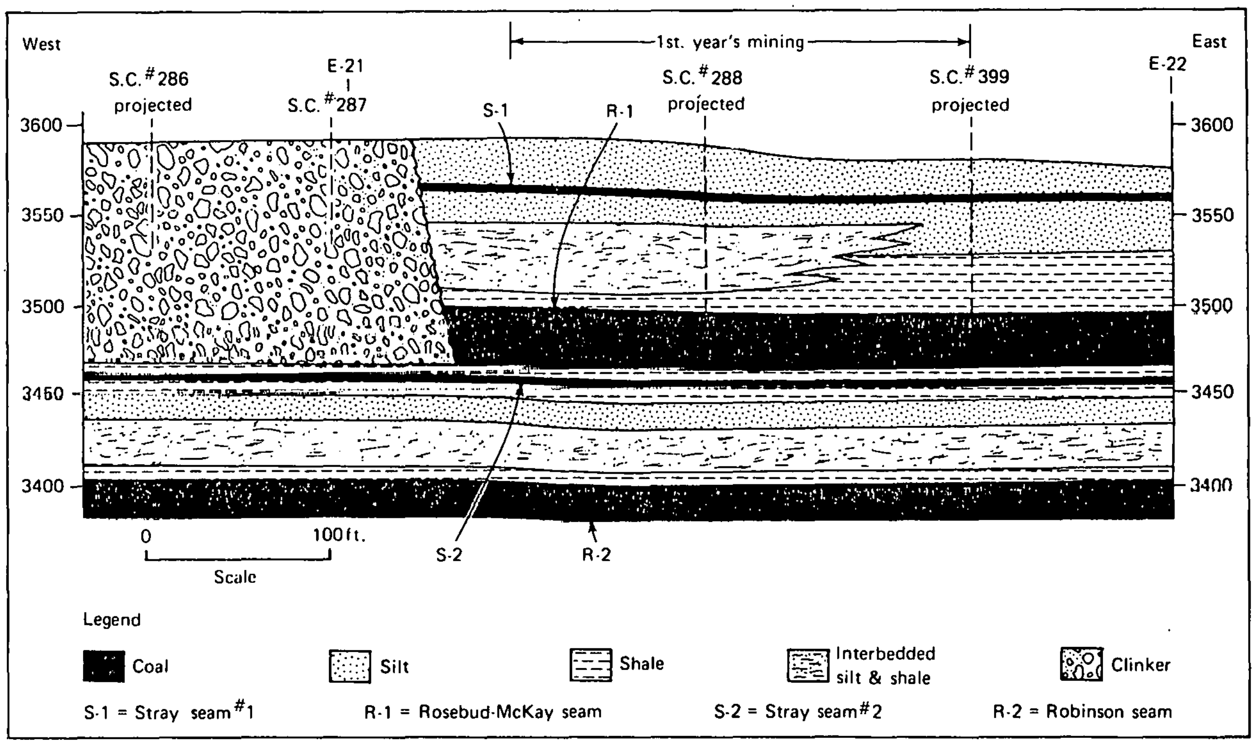


Figure 1. Typical Stray Seams

Surface mines with thin or stray seams have addressed their presence in various manners. Some mines ignore the resource and spoil the coal. Some operations recover thin seams as convenience allows and others have established methods of thin seam recovery. A thin seam is always a resource but economics often refute their existence as a viable reserve entity. Trends by federal and state regulatory agencies imply that stray seams will require economic justification if they are to be spoiled. The purpose of this investigation is to examine existing thin seam mining techniques and to attach a probable cost of extraction.

The results are reported as unit operations which examine 1) thin seam extraction and its effects and added costs on overburden handling, 2) conventional thin seam extractive methods, and 3) new or proposed methods of thin seam removal. Included within the report is a review of state and federal regulations and philosophies covering stray seam recovery. Another section reviews existing western surface mines which mine thin seams.

THIN SEAM RECOVERY REGULATIONS

Before reviewing methodologies associated with thin seam removal, an examination of federal and state regulatory policies is in order. It is the regulatory agencies which will undoubtedly force justification of operational plans which call for spoiling thin coal seams. Other interested parties are those private owners of coal who desire maximum return from their leases. Confrontations in the recent past have motivated this research to explain and clarify the methods, problems, and costs of thin seam coal recovery.

The appropriate federal agencies and those of the western coal producing states were polled to determine each department's regulations or philosophies on thin seam coal recovery.

It was found that only the state of Montana required that all mining operations within the state recover all economically mineable coal found in their mining areas. However, it was found that there are state and federal policies concerning the recovery of thin seams on state and federally owned lands. The following are the regulating governmental agencies and their polices:

Federal Government - Bureau of Land Management

Before the Bureau of Land Management will issue a coal mining lease on Federally owned land, the operator must show minimal land disturbance for maximum energy resource recovery.

Federal Government - Office of Surface Mining

The Surface Mining Control and Reclamation Act of 1977 states: "General performance standards shall...require the operation as a minimum to...conduct the surface coal mining operations so as to maximize the utilization and conservation of the solid fuel resource being recovered."

Montana - The Department of State Lands

The Department of State Lands requires that all mining operations conducted in the state recover all "economically recoverable and marketable" coal found in the mining area.

North Dakota - The State Land Department

The State Land Department requires that an operator mining on state lands must show in his mining plans that an "orderly development and maximum extraction of coal" will take place.

Wyoming - The Department of Environmental Quality

The State of Wyoming's statutes do not address the concept of maximum extraction of coal.

Utah - The Division of State Lands

The Division of State Lands requires that mining operations on state lands be conducted in a "prudent and good workmanlike manner for the conservation and efficient removal of the coal deposits."

The three states (Montana, North Dakota, and Utah) that have regulations or policies concerning thin-seam mining enforce them by using a permit system. The operator cannot mine without a permit, and to get a permit, the operator must submit a mining plan to the proper authorities for their approval. The permit will be approved only if the regulating agencies decide that the mining plan meets their regulations including those mentioned in this paper. Often the permits are for a short period, only 3-5 years. New mining plans must be submitted and approved for the next 3-5 year period before the previous permit expires if mining operations are to be continued.

Arizona - State Land Department

The State of Arizona has no existing or pending legislation dealing with the recovery of thin seam coal deposits. It was also noted that all the coal currently being mined in the state is on the Navajo and Hopi Indian Reservations. From personal communication with the firms which are currently operating on the Indian Reservations, there are no regulations dealing with total resource recovery.

Colorado - Department of Natural Resources

The State of Colorado does not have any existing or pending legislation that deals explicitly with thin seam coal removal. However, there is a 1973 Legislative Declaration which states:

> "The state policy shall be to encourage by every appropriate means, the full development of the state's natural resources to the benefit of all of the citizens of Colorado and shall include, but not be limited to, creation of a resource management plan to integrate the state's efforts to implement and encourage full utilization of each of the natural resources consistent with realistic principles."

This declaration is interpreted to mean that any given mining plan under consideration must adequately meet the 'full utilization' clause or be denied the necessary mining permit. This is, in essence, a means to insure acceptable recovery from all surface mines.

New Mexico - Bureau of Mines and Mineral Resources

The State of New Mexico does not have pending or existing legislation that covers the forced mining of thin coal beds or of rider seams.

Table I is a summary of the western coal producing states and their present regulations or philosophies concerning thin seam coal recovery. Federal agencies have not yet promulgated any regulations addressing this topic.

TABLE I

Resource Recovery Regulations in Western Coal Mining States

States	State Agency	Resource Recovery Regulation	Scope of Regulations	Legislation
Arizona	State Land Dept.	No	N.A.	N.A.
Colorado	Dept. of Natural Resources	Yes	All Lands	1973 Legislative Declaration: "The state policy shall be to encourage by every appropriate means, the full development of the state's natural resources to the benefit of all of the citizens of Colorado and shall include, but not be limited to, creation of a resource management plan to integrate the state's efforts to implement and encourage full utilization of each of the natural resources consistent with realistic principles."
Montana	Dept. of State Lands	Yes	All Lands	Strip Mined Coal Conservation Act: "An act providing for the conservation of strippable and marketable coal, and prohibiting the waste thereof."
New Mexico	Bureau of Mines & Mineral Resources	No	N.A.	N.A.
North Dakota	State Land Dept.	Yes	State Owned Lands Only	State Land Dept. Leasing Rules & Regulations require the submittal of a complete mining plan which demonstrates "orderly development & maximum extraction of coal."
Utah	Dept. of Natural Resources	No	N.A.	N.A.
Wyoming	Dept. of Environmental Quality	No	N.A.	N.A.

THIN SEAM MINING OPERATIONS

The basis for the methods, problems and costs presented in this study of thin seam coal recovery is built upon literature review and mine operation visits. Stray seams associated with major seams and thin seams mined alone were examined, the first to recognize the setting of the problem and the latter to fully investigate appropriate technologies which might be applied to stray seam extraction.

Mining operations recovering thin seams for the most part employ conventional multi-seam mining methods to recover both the thick and thin seams. This involves the use of draglines, scrapers, or trucks and shovels to remove overburden and parting and front-end loaders, shovels and trucks to load and remove the coal. However, it was found that a few operators are starting to use special equipment to recover the thin seams.

Montana

There are two major mines operating in the state of Montana that are practicing thin seam mining. One of these is the Absaloka Mine near Hardin, Montana. The operator is Westmoreland Resources. The mine began production in 1974 and it now produces approximately 5 million tons per year.

There are four coal seams that are encountered in this mining operation. Starting from the surface, the first seam is the 2-foot thick S-1 seam (Stray seam #1). The second seam down in the 30-35 foot thick Rosebud-McKay. Separating these two seams are 20-30 feet of silt and shale parting. The third seam is the 2-foot thick S-2 seam (Stray seam #2). It is found 5-10 feet below the base of the Rosebud-McKay. Below the S-2 seam is the fourth and last seam, the Robinson seam. The parting between it and the S-2 seam varies between 45-90 feet in thickness. The top seam, the S-1, has not been mined because the mining operation has been in the lower elevations where the S-1 seam, when present, has been of substandard quality. However, Westmoreland plans to recover this seam as the mining operation advances into the deeper overburden.

Until that time, the mining operation involves removing the overburden with a 75-cubic yard dragline to uncover the Rosebud-McKay seam. After this seam has been blasted and removed with front-end loaders and trucks, the parting over the S-2 seam is ripped and removed half the width of the pit with scrapers. The removed parting is placed on top of the undisturbed parting. The coal is then removed from that half of the pit and the parting, both disturbed and undisturbed, in the other half of the pit is removed with scrapers and placed in the first half of the pit where the coal has been removed. Then the last half of the S-2 seam is removed. Next the 75-cubic yard dragline, sitting on an extended bench made from the spoiled overburden, removes the rehandled S-2 parting and the remaining parting to expose the Robinson seam.

The other mine in Montana practicing thin-seam mining is the Decker Mine north of Sheridan, Wyoming. The Decker Coal Co. is a joint venture of Western Minerals, Inc., and Wytana, Inc. The Decker Mine began production in 1972 and is now producing approximately 10 million tons per year of coal.

There are two seams being mined. The main seam is the Dietz #1 seam. This seam lies flat and averages 52 feet in thickness. Directly above this seam and separated by two feet of shale parting is a two-foot thick stray seam.

The overburden, which averages about 80 feet, is removed with two draglines (45 cu. yds. and 70 cu. yds.) in two benches down to the stray seam. The top of this seam is then cleaned with scrapers. Originally the next operation was to rip the seam and then remove it with scrapers, but now this operation is performed with a CMI fine grader. This fine grader is modified with carbide tip teeth on the auger. With this machine, the operator can better control the shaving of the bottom coal from the parting and hence less coal is wasted. The fine grader windrows the coal and a self-loading scraper picks it up. The parting is then ripped with dozers and removed with scrapers. The Dietz #1 seam is then loaded out with trucks and shovels in two benches.

North Dakota

There are four major mines recovering North Dakota lignite that are practicing thin seam mining operations. The first that will be discussed is the Beulah Mine in Mercer and Oliver counties. It is operated by the Knife River Coal Mining Co. Production begain in 1963 and the mine is now producing approximately 1.5 million tons per year.

Three seams are mined. The first seam, which is found under an average 40 feet of overburden, is ten feet in thickness. Beneath this is a 35-foot parting over the second seam which is also ten feet in thickness. The third seam is 3 feet thick and is separated from the second seam by 10 feet of clay.

The mining operation begins by removing the overburden with either their 12- or 17-cubic yard dragline. The coal is then cleaned with scrapers, blasted and loaded out with trucks and shovels. This procedure is repeated to recover the other two seams, with the exception that the dragline operates from the spoil.

A second mine is the Glenharold Mine operated by Consolidation Coal Co. This mine began its operation in 1966 and now produces 3.8 million tons per year. Two and sometimes three coal seams are mined. The initial overburden ranges from 35-200 feet to the first seam which is 3-3.5 feet in thickness. Below that is 10-20 feet of parting and 4.5-5 feet of lignite. The third seam is found under another parting which varies from 6 to 25 feet in thickness. This third seam averages 8 feet in thickness.

Two draglines, a 33-cubic yard and a 60-cubic yard, are employed to remove the overburden and partings. When the initial overburden is removed, the dragline sits in the conventional manner above the coal. To remove the partings, the dragline operates from the spoil digging in a cross-pit manner. The lignite is cleaned, blasted, and removed with shovels and trucks.

A third mine is the Gascoyne Mine in Bowman County. It also is operated by the Knife River Coal Mining Co. The mine has been producing since 1952, but production was minimal until 1975 when production jumped from 200,000 to its present level of 3 million tons per year.

Three seams with a composite thickness of 30 feet are being recovered at this mine. The average overburden is 42 feet. The first parting is extremely variable and runs from a minimum of 2 to a maximum of 22 feet in thickness. The second parting is a consistent 2 feet thick.

The overburden and parting are removed using one 32-cubic yard dragline working in four pits. The dragline moves from pit to pit in sequential order to complete the circuit. Two methods are used to load out the lignite once it is uncovered. One is the conventional truck and shovel method. The other employs a prototype coal ripping and loading machine built by Huron Manufacturing Co. This machine rips the intact lignite and with a conveyor loads the lignite onto the haul truck. The machines's loading rate is 500 tons per hour.

The final North Dakota mine that will be discussed is the Falkirk Mine located in McLean County. This mine, operated by Falkirk Mining Co., is now under development and should begin producing in early 1978. Full production, 5.6 million tons per year, is expected by 1980. The operator will mine two seams. The first 8-foot seam is under approximately 90-100 feet of overburden. The second seam is 2-4 feet in thickness and separating the two seams is a parting which ranges from a few inches up to 40 feet.

This mining operation will employ two 105-cubic yard draglines to remove the overburden. The parting between the two seams will be removed with two crawler mounted 17-cubic yard draglines. The lignite will be loaded out using trucks and shovels.

Wyoming

Two mines were found to be mining thin seams in conjunction with thicker seams in Wyoming. The first is Arch Mineral's Medicine Bow Mine located near Hanna, Wyoming. The mine began production in 1975 and produces 3 million tons per year.

This operation is mining five seams simultaneously. A typical stratigraphic section is as follows:

30' overburden

7' coal

30' parting

4.5' coal

20' parting

6' coal

35' parting

5' coal

8-40' parting

8' coal

A 78-cubic yard dragline is used to handle the overburden and first parting. If spoil room is available, it will also remove the second parting. The dragline is always in the conventional position, sitting directly above the coal and spoiling into the previous cut. The remainder of the parting is removed using trucks and shovels. This material is hauled out of the pit or a haulback method is employed. The coal is blasted and loaded out with trucks and shovels.

The second and final to be discussed is the Jacobs Ranch Mine operated by Kerr-McGee near Gillette, Wyoming. The mine begins production of coal in early 1978. The first year's production should be 3 million tons per year and by mid-1980 production should peak out at 14.5 million tons per year.

The uppermost seam averages 8 feet in thickness and is found under an average of 120 feet of overburden. The second seam averages 43 feet in thickness and ranges between 1.5-45 feet below the base of the first seam. The third seam averages 5.5 feet in thickness and is separated from the second by 1-6 feet of shale.

The company will operate two pits at this mine. One 25-cubic yard shovel and four 170-ton trucks per pit will remove the overburden. The coal will be loaded using 30-35 yard shovels and front-end loaders. The overburden will be hauled directly from the face to the backfill area. The haul to the backfill area is at the same elevation as the face and dump. As the pit approaches property lines, the mining direction reverses 180° adjacent and parallel to the previously mined pit.

Utah

In the state of Utah there are no surface coal mines being operated at this time.

The abundance of multiple coal seams in the southwestern U.S. makes the study of some of the operating mines very informative. Most of the larger operations in Arizona and New Mexico have been in operation for a long time and, thus, have had a great deal of experience in handling thin coal seams. The mines currently operating with thin seams will now be discussed by state.

Arizona

There are two mines in Arizona that deal with thin seam removal, the Black Mesa Mine and the Kayenta Mine (formerly known as the Black Mesa No. 2). Both operations are located on the Navajo Indian Reservation and owned and operated by the Peabody Coal Company.

The two mines have similar operations which utilize conventional mining techniques. A dragline is used to remove the overburden and electric shovels are used to load the coal, which ranges in thickness from 5 to 28 feet.

The current literature was unfortunately vague on the methods and sequences used to remove both the partings and thinner coal seams. It is known that these mines are currently expanding their operations and are planning on mining deeper thin seams.

New Mexico

The major producer in New Mexico, as well as the entire southwest, is Utah International's Navajo Mine near Farmington, New Mexico. Currently the operation is mining three seams of coal. The stratigraphic sequence from the surface down is: 90 feet of overburden, #8 coal seam (16 feet of coal), 22 feet of parting, #7 coal seam (5 feet of coal), 8 feet of parting, and #6 coal seam (7 feet of coal). At one end of the pit the #7 coal seam splits into an upper split of 4 feet and a lower split of 1 foot. An illustration of the following narrative is found in Figure 2.

The mining sequence at the mine begins with the removal of the top 90' of overburden down to the #8 seam with a 55 yd^3 dragline. Due to the rolling surface topography, Utah International employs an unusual technique by which the dragline digs all the overburden above a set machine elevation using an overhand cut. In the overhand cut the machine is digging material higher than its own elevation up to 40 feet. This technique does away with most of the rehandle involved with leveling the surface topography for the dragline to operate on.

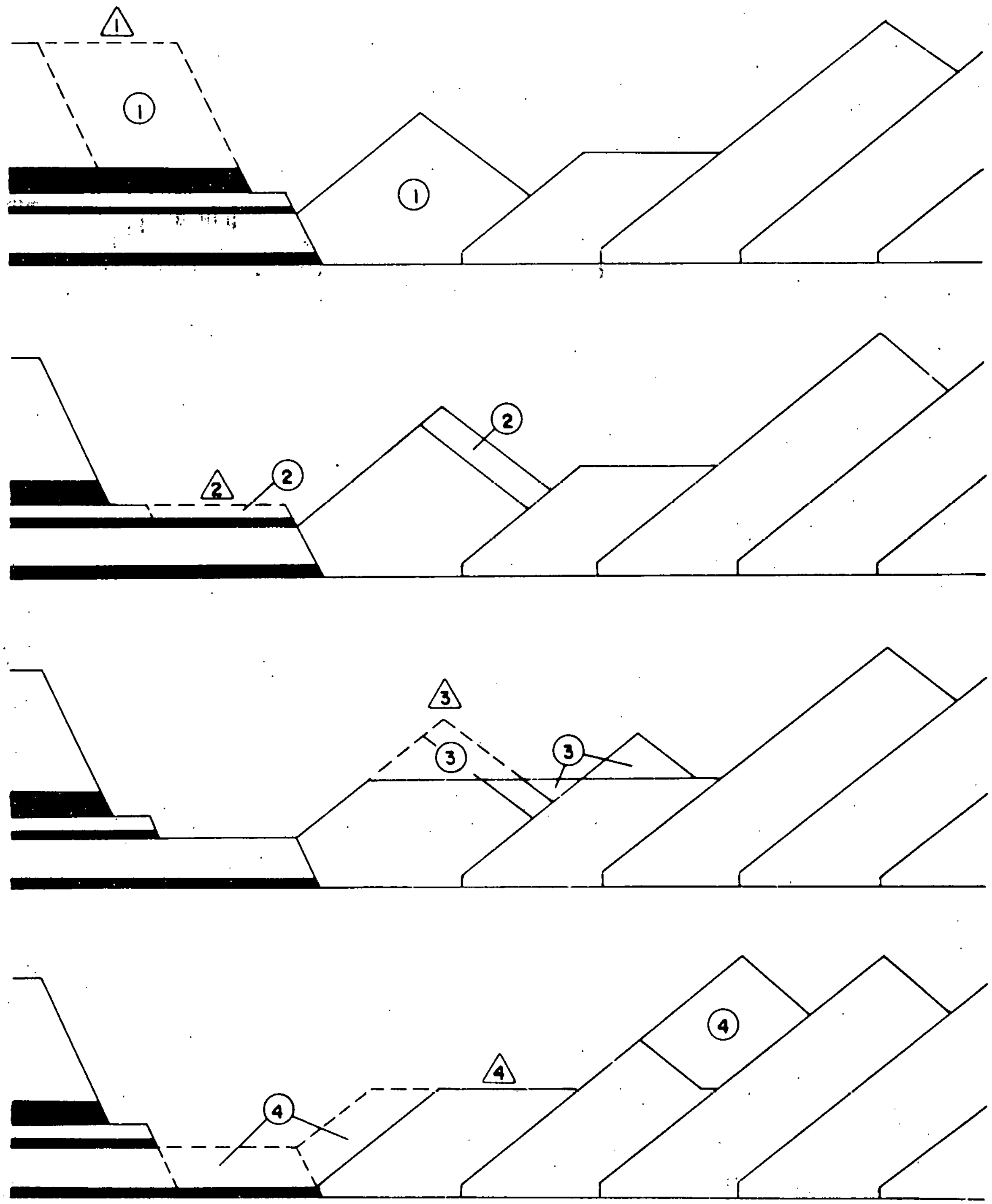
After the top overburden is removed, the #8 seam is drilled, blasted, and loaded into 120-ton bottom-dump coal haulers with 24 yd^3 front end loaders. The dragline then sits on the parting between the #8 and #7 seams and casts it over onto the spoil pile. Because the parting is so thin (11 feet), after it is removed the dragline moves over and flattens a bench down the spoil pile on the opposite side of the cut thus allowing time for the coal to be removed.

After the coal from the #7 seam is removed, the dragline begins removing the parting between #7 and #6 seam by sitting on the spoil bench it previously flattened and cross-chopping the parting. The coal in #6 seam is then removed using end-loaders and coal-hauler trucks.

While sitting on the spoil side and cross-chopping the #7 - #6 parting, the dragline productivity drops due to an increase in swing angle from 90° to 135°. This method of mining also involves a significant amount of material rehandle, about 25%. It should also be noted that the lower split of the #7 seam is spoiled. It is Utah International's current policy to spoil those thin seams under 3 feet.

The future mining plans at the Navajo Mine include a seven-seam operation in the near future. The seven-seam plans call for a similar operation as is currently in use for three seams. Because of their future plans and their long experience with alternate thin seam methodology, this mine will receive further investigation.

Another significant thin seam producer in New Mexico is McKinley Mine near Gallup. The McKinley Mine is owned and operated by the Pittsburg and Midway Coal Company, which is a wholly owned subsidiary of Gulf Oil Corporation.



△ Dragline Position ○ Material Position

Figure 2. Navaho Mining Sequence

The mine is currently expanding to mine three to four coal seams. The expansion includes the purchase of four 55 yd^3 draglines with 320 foot booms. This expansion is intended to boost production to 5,000,000 tons/year by 1980.

The four coal seams range from a few inches to 15 feet with an overall average of 5 ft. The plans call for mining all seams over 18 inches in thickness. The top seam, called the Yellow Seam, is a true rider seam that constitutes less than 10% of the total production.

The mining plan calls for mining the seams in a conventional manner using the dragline on the highwall side digging to a depth of up to 150 feet. The coal will be loaded out with front-end loaders into 100-ton rear-dump trucks.

Colorado

The northwestern section of Colorado is the site of several new multiple thin-seam mines. Mines are being planned and/or under construction by Peabody Coal Company, Utah International, and W. R. Grace's Colorado Coal Company.

The Trapper Mine

The Trapper Mine is owned and operated by Utah International Inc., a wholly owned subsidiary of General Electric Company. The Trapper Mine is located six miles south of Craig, Colorado. Production from the mine commenced in May of 1977 and will produce 2.1 million tons per year to power Colorado Ute Electric Association's Yampa Project power plant. The Yampa Project is a mine mouth power plant and is located 2-1/2 miles northeast of the mine. The power plant was scheduled for completion in 1977 but construction delays have set the completion date back to late 1978. Until the power plant is completed, coal from the Trapper Mine is being stockpiled in one of two large stockpiles and a small amount is being shipped to midwestern utilities.

Presently there are three pits in operation at the Trapper Mine. Two Page 752 draglines equipped with 30-cubic yard buckets and 305-foot booms remove the overburden and interburden. One of these machines operates in two of the pits and the other machine operates in the remaining pit. A third dragline identical to the first two machines is being erected at the mine. Upon completion, it will be used to open up the mine's fourth pit.

There are several coal seams that will be recovered by the mining operation and often more than one seam will be recovered from a pit. For example, in the first pit a five-foot seam of coal is found under 40 feet of overburden. A second seam is found forty feet below the five-foot seam and averages 10 feet in thickness. In the first pit, both of these seams will be recovered simultaneously.

The coal seams dip approximately 10° in this area. The pits are located on a large hillside where the topography slopes in approximately the same direction and amount as the coal seams. Because of this, the depth to coal remains relatively uniform. The length of the pits run up and down the hillside and the pits are advanced across the hillside.

The draglines remove overburden and interburden. They begin at the end of the pit near the top of the hill and work down the slope. When they reach the end of the pit near the bottom of the hill, the draglines deadhead up the hill to the beginning end of the pit and begin the next cut.

Pads are required to provide a level area for the draglines to dig from. These are constructed in advance of the machines as they work their way down the hillside with two Caterpillar D9H dozers and one Fiat-Allis 31 dozer.

Overburden, interburden, and the thicker coal seams are drilled and blasted with ANFO. The thin coal seams are ripped with a Fiat-Allis 31 dozer equipped with a single-shank ripper. A Demag H-111 backhoe is used to load out the coal. Once the power plant begins producing electricity, the coal will be hauled to the plant for processing and consumption. The life of the mine is estimated at 35 years.

The Edna Mine

The Edna Mine is located south of Steamboat Springs, Colorado, near the town of Oak Creek, Colorado. The mine has been in production since before World War II and was purchased in 1961 by Pittsburg & Midway Coal Mining Company. In 1963, Pittsburg & Midway became a wholly owned subsidiary of Gulf Oil Corporation.

Three coal seams are recovered at the Edna mine. The top seam is the Lennox seam. The next seam is the Wadge seam and under this seam is the Lower Wadge. The Lennox and Wadge seams average from 5 to 6 feet in thickness. The Lower Wadge averages 30 inches in thickness. All three seams dip at approximately 10%. Therefore, most of the mining is performed on a hillside where the slope is in the same direction as the dip of the coal seams. Because of this unique situation, the overburden is relatively uniform.

The length of the pit runs across the hillside and the pit is advanced up the hill. A B-E 1260-W dragline with a 40-cubic yard bucket is used to remove overburden and the interburden above the Wadge seam. The dragline operates from a bench created by the removal of the top coal seam, the Lennox seam. From this position the dragline operates in an overhand chopping manner to remove the overburden above the Lennox coal that will be removed in the next cut. Also from this same position, the dragline removes the interburden above the Wadge seam to expose that coal. All interburden is drilled and blasted. Overburden is drilled and blasted in areas where it is required.

The Lennox and Wadge coal seams are drilled and shot. A Demag H-111 backhoe is used to load the coal into 57-ton Mack trucks. These trucks transport the coal up steep grades to the top of the hill where the hopper is located.

The interburden above the Lower Wadge is removed in a haulback operation. A Demag H-111 backhoe is employed to excavate the blasted interburden and load it into one of the two 50-ton International rock trucks. The trucks transport the material a few hundred feet down the pit to an area where the Lower Wadge has been removed. There the material is dumped.

This same backhoe and the two trucks are used to load out the Lower Wadge coal after it has been ripped.

Once the coal is dumped into the hopper, it is transported by a 2900-foot belt conveyor to the processing plant which is located 800 feet below the hopper at the bottom of the hill. There the coal is crushed, screened, and sized. The coal is then loaded onto rail cars. The Mine ships its coal via the Denver & Rio Grande Western Railroad to its customers. Most of the coal is sold to the City of Colorado Springs, Ideal Cement, and Great Western Sugar. The Edna mine produces approximately 1.2 million tons of coal per year.

The Energy Fuels #1 Mine

The Energy Fuels Corporation of Denver, Colorado, is a privately owned company that operates three surface coal mines in northwestern Colorado. The three mines, Energy Fuels #1, #2, and #3, are located twenty-five miles south of Steamboat Springs, Colorado.

Energy Fuels Corporation was founded in 1961 for the purpose of developing its coal leases and properties in northwest Colorado. By 1962 stripping operations were underway at the Energy Fuels #1 mine and that year's production was 175,000 tons. A $20 million expansion program was implemented in 1973 to boost production to 2.5 million tons by 1975. Energy Fuels Corporation is now Colorado's largest coal producer and has been since 1975. The 1978 production from the three mines is expected to reach 4.2 million tons. Much of the land that the company mines is privately owned with the mineral rights held by the federal government.

At the Energy Fuels #1 mine there are two pits in operation and the Wadge coal seam is being recovered. The Wadge dips approximately 10^{o} at this mine. The pits are located on a large hillside and their length runs across the hillside in a manner similar to the Edna mine's pit. The Wadge seam dips at a greater angle that the slope of the hill, therefore the coal is shallowest at the top of the hill and increases in depth going down the hill.

Overburden from the one pit is stripped with a Marion 8050 dragline. This machine is equipped with 55-cubic yard bucket. The pit was started near the top of the hill and has advanced down the hill. The other pit was started at the bottom of the same hill and has advanced up the hill. Two draglines operate in this pit. A B-E 770 dragline equipped with a 21-cubic yard bucket and a Marion 7400 equipped with a 14-cubic yard bucket are used. The draglines strip the overburden in a conventional manner. The maximum depth of overburden is 120 feet.

Once the 96-inch Wadge seam is exposed, it is drilled on a 7 X 7 foot pattern and blasted using ANFO and dynamite. The company employs front-end loaders for loading the coal out of the pit. They have two Houghes, one Michigan and one LeTourneau L-800. The coal is hauled out of the pit using 50-ton Mack and International coal haulers. The company plans to replace some of its coal trucks with new 170-ton Euclid coal haulers in the near future.

The coal is transported to the two-stage crushing plant where it is crushed first to 8 inches and then to minus 2 inches. From the crusher the coal is conveyed to a 100,000-ton open stockpile. The coal is loaded into rail cars that pass underneath the stockpile. The coal can be loaded out at rates up to 2000 tons per hour.

The coal is shipped via the Denver & Rio Grande Western Railroad to its customers. Energy Fuels principal customer is the Public Service Company of Colorado. This utility buys approximately 2 million tons of coal per year from Energy Fuels. Energy Fuels also ships coal to midwestern utilities.

The Colowyo Mine

The Colowyo mine is owned and operated by Colowyo Coal Company, a joint venture of Hanna Mining Company and W.R. Grace and Company. The mine is located approximately 25 miles south of Craig, Colorado, near the town of Axial. Production from the mine commenced early in 1978.

The Colowyo mining operation recovers eight coal seams from its one pit. The coal seams range in thickness from 14 feet to slightly less than three feet. The combined average thickness of the eight seams is eight feet. The coal seams are flat lying and are of uniform quality so that blending is not required. A weighted average of the coal quality is: Btu - 10,728; ash - 5.06%; sulfur - 0.4%; moisture - 14.81%.

Presently, two draglines are being erected at the mine site. The larger machine is a new B-E 1300 and is equipped with a 38-cubic yard bucket. The second machine is a used B-E 800 and is equipped with a 26-cubic yard bucket. Until the dragline erection is completed, all overburden and interburden is removed with trucks and loaders. Four LeTourneau L-800 front-end loaders and a Marion 191 shovel are used for loading the rock and coal. The Marion shovel has a 12-cubic yard bucket and is used primarily for loading interburden. The LeTourneaus used for coal loading are equipped with 22-cubic yard buckets, and those used for loading interburden and overburden are equipped with 12-cubic yard buckets. The company employs eleven 120-ton Unit Rig Electra Haul trucks for hauling coal and rock. Two of the trucks are used for hauling coal and average 118-tons per load. The nine rock trucks average 90 tons per load.

Once the dragline erection is completed, the truck/shovel operation will be used to uncover the top two seams and the bottom seam. The two draglines will be used to expose the remaining five coal seams. The larger dragline will be used as the primary stripping machine, and the smaller dragline will operate as a pull-back machine to rehandle spoils that need to be placed back farther than the primary machine can reach.

Overburden, which averages about 60 feet in thickness, and interburden are drilled with one of the B-E 45R overburden drills and blasted with ANFO. The coal is also drilled with one of the company's coal drills and blasted. Colowyo is experimenting to determine the best pattern for blasting both coal and overburden.

Coal is being processed at a temporary processing plant near the mine. There the coal is crushed, screened, and oiled before it is loaded into one of the 30-ton highway trucks. The highway trucks transport the coal to Craig where loading onto rail cars takes place.

A rail spur is being constructed to link the mine to the Denver and Rio Grande Western Railroad that runs through Craig. A permanent processing plant is projected to be completed at the time of completion of the rail spur. At that time coal will be processed at a location near the mine. It will then be transported to loading facilities at the rail spur using highway trucks. The loading facilities will be located within a few thousand feet of the processing plant.

The mine is designed to produce 3 million tons of coal per year. Most of the coal is sold to the City of Colorado Springs.

CONVENTIONAL OVERBURDEN REMOVAL

METHODS AND COSTS

Introduction

The major operation in the recovery of any coal seam by surface mining methods is the removal of the overburden. There are several overburden removal methods that are being practiced in the western U.S. coal fields and many of these are adaptable to thin seam mining. This section examines conventional methods and techniques of overburden removal for recovery of thin coal seams. The overburden removal costs associated with the thin seam recovery are projected.

The determination of the overburden removal costs for a conventional single seam or multiseam operation may seem complex in practice but in theory is very straightforward. It is simply the accumulation of costs incurred to expose the coal seam or seams. This is not the case, however, for a thin seam mining operation if the recovery of the thin coal seam is to be evaluated as an economic entity.

An operator mining in an area where a thin seam is found above the main production seam has two alternatives. Either the thin seam coal is spoiled or it is recovered. The proper method of evaluating the alternatives on a purely economic basis is to assign only the additional overburden removal costs incurred by the thin seam coal recovery to that coal. All other overburden removal costs should be assigned to the major seam coal since these costs would be realized regardless of whether the thin seam was recovered or lost.

The "additional costs" are the overburden removal costs that result from extra input required to recover the thin seam. The costs can result from extra material that must be excavated, increased cycle times, decreased equipment utilization, extra moving, additional equipment and other operations. Only when these costs are isolated and applied to the thin seam coal in addition to normal mining costs that result from the recovery of the thin coal seam such as loading, transporting, and processing can the economic feasibility of recovering the thin seam be determined. Most western U.S. coal mining operations employ one of three methods to remove overburden: scrapers, trucks/shovels, or draglines.

Scrapers and Trucks/Shovels

Scraper and truck/shovel methods are very similar in that relatively small and highly mobile equipment is used to excavate and remove the overburden in large, rectangular shaped pits. The overburden is removed from one of a series of benches or terraces that make up the highwall and backfilling on a similar horizon around the pit. Because of this configuration, the method is called a terrace pit system of mining. The system involves excavating the highwall terraces to advance the highwall into the virgin land and exposing the coal. The excavated material is transported, using mobile equipment, to the rear of the pit for back-filling. As the coal is exposed, it is removed by one of several methods that are discussed later in this report.

Because of the great mobility and versatility of the equipment used to remove the overburden, the recovery of a thin coal seam does not greatly affect the overall operation of a terraced pit system. It is seldom that "additional overburden removal costs" are realized using this method. At most, they are due to an additional bench which might be realized.

Bench heights must be designed to allow one of the benches to coincide with the elevation of the thin coal seam if it is to be recovered. For this reason, bench heights are governed by the overburden and interburden thicknesses, as well as the digging height limitations of the excavating equipment. In the most extreme case, the location of the thin seam in the stratigraphic sequence is such that an additional bench is required because of the previous parameters governing bench heights. An additional bench would increase the width of the pit by one bench width thus increasing the haul distance by the same amount. The increase in hauling distance is an additional cost. The drilling and blasting of an additional bench also adds costs. The cost increase is due to extra drill moving, extra labor to load, stem and connect the holes, plus additional trunk lines and detonators that are required. These hauling and drilling and blasting cost increases are related to the recovery of the thin seam and are "additional costs" which must be applied to the thin seam coal.

Scrapers do not have a limited digging height. For this reason, the bench heights can easily be adjusted in a scraper operation to eliminate the need of any additional benches. The excavating equipment in a truck/shovel operation does have a limited digging height and, therefore, bench heights are not as easily adjusted. Even with this limitation, however, by utilizing careful planning, pit design and proper equipment sizing, a truck/shovel operation is capable of recovering a thin seam without requiring an additional bench.

In summary, most scraper and truck/shovel operations can recover thin coal seams without an additional bench. As this is most often the case, extra overburden removal costs are very slight and are not considered.

Dragline Methods

The third method of removing overburden is to use a dragline. Dragline methods are not as flexible as truck/shovel or scraper methods. A dragline, because of its great size and mass, is a slow and cumbersome machine to move. Auxiliary equipment is required to maintain wide roads for moving and level pads for digging. Draglines are limited in spoiling distance and digging depth and therefore cannot mine as deep or spoil the overburden material as far as other methods. In spite of these and other disadvantages, draglines are still the principal equipment in surface coal mining because they excavate material more cheaply than other methods.

Substantial additional costs are incurred when a thin seam is recovered in a dragline operation because of this limited flexibility of the dragline. To best understand to what the additional overburden removal costs are due, the methods of recovering thin seams with a dragline are discussed first. When this is accomplished, the additional operations and resulting additional overburden removal costs are isolated and examined.

Although there are many variations, basically there are only four principal methods used in thin seam mining operations using a dragline. These methods are methods used in multiseam mining that have been adapted to thin seam mining.

Two of these methods involve benching on the highwall side of the pit. In both, the dragline's first digging position is on top of the highwall. From this position the dragline digs down to the top of the first seam. The overburden is removed from the digging face and spoiled into the previous cut. After the first seam has been uncovered, the dragline digs an inclined ramp from the top of the highwall to the top of the bench created by removing the first coal seam. This is called ramping. The machine then deadheads down the ramp to the bench and continues deadheading on the bench until it returns to the starting end of the pit. There the dragline is in position to uncover the second seam.

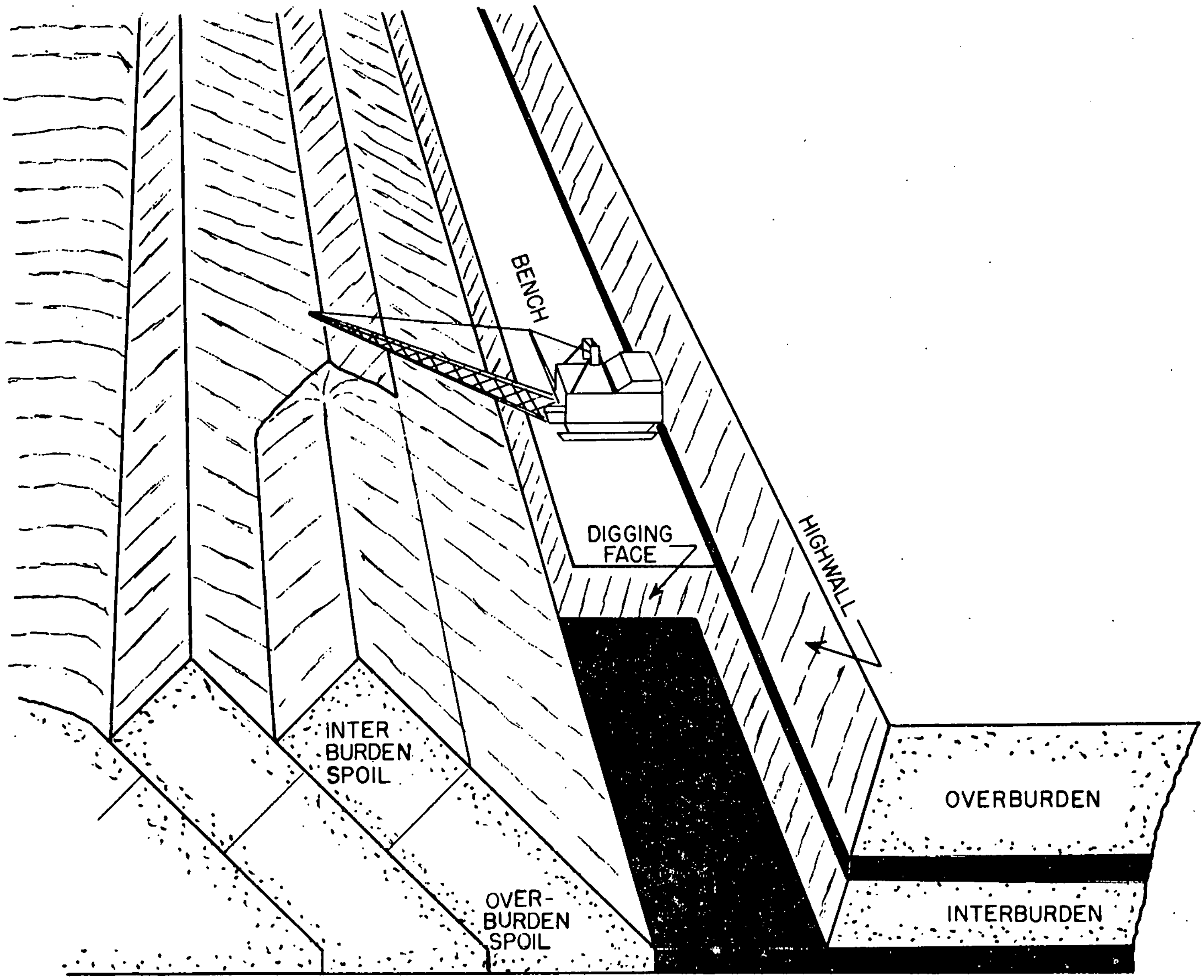
Here the two methods vary. In one, the dragline removes the interburden from the digging face and spoils it on top of the overburden spoil as shown in Figure 3. In the other, the machine spoils the interburden inside of and against the overburden spoil as shown in Figure 4. The dragline proceeds to uncover the second seam in one of these two manners until it has uncovered the coal the full length of the pit and has reached the ramped end of the pit. The dragline then deadheads up the ramp and back to the starting end of the pit via the highwall. There the machine begins the digging cycle over again.

The second method, placing the interburden spoil inside of the overburden spoil, initially was developed for a duo-dragline operation where the amount of interburden is considerably less than the overburden. By placing the interburden spoil inside of the overburden spoil, less reach is required for spoiling and a small dragline having a short reach can be used to remove the interburden.

The second method is advantageous if the interburden material is unsuitable for plant growth. Unlike other dragline methods, this method keeps the overburden spoil on top which makes a protective cover between the replaced topsoil and the interburden spoil, thus keeping the interburden spoil buried.

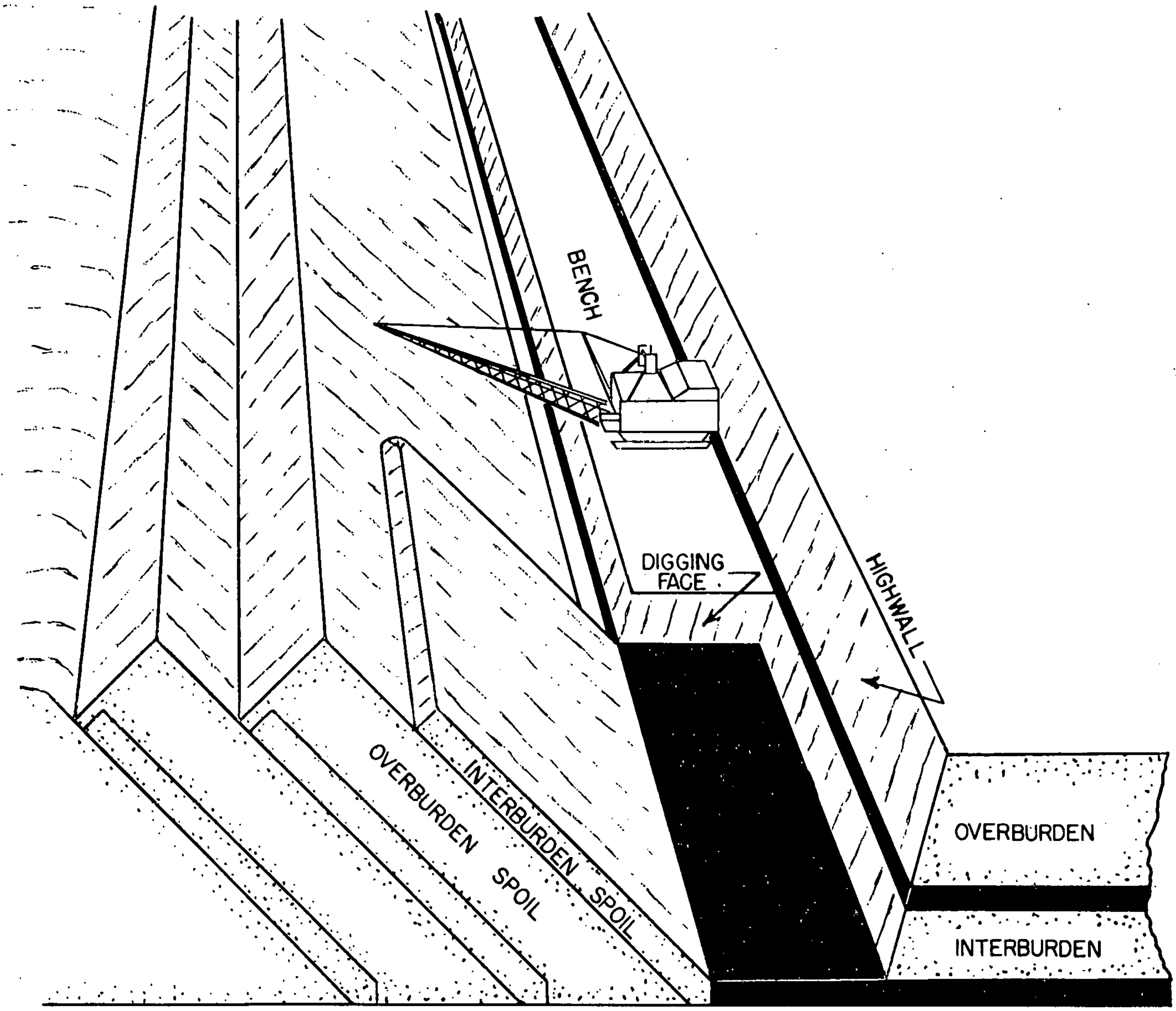
Extra care and time are required in placing the interburden spoil when employing this method, but usually the swing angle is less than 90° and the swing time is less. Therefore, the cycle time of this method is about the same as the cycle time of the first method where the interburden spoil is placed on top of the overburden spoil. An advantage of both of these two methods is that little or no rehandling is required.

A variation of thse two methods is the extended bench method. The extended bench method is used when the dragline does not have enough reach to spoil effectively from its position on the bench. The dragline uses part of the overburden material to extend the interburden bench out toward the spoilling area. The extension of the bench allows the dragline to position itself nearer to the spoiling area and the dragline can spoil more effectively. The



DRAGLINE UNCOVERING SECOND SEAM
FROM BENCH ON THE HIGHWALL SIDE
PLACING INTERBURDEN SPOIL ON TOP OF OVERBURDEN SPOIL

FIGURE 3.



DRAGLINE UNCOVERING SECOND SEAM
FROM BENCH ON THE HIGHWALL SIDE
PLACING INTERBURDEN SPOIL INSIDE OF OVERBURDEN SPOIL

FIGURE 4.

extended bench method does involve rehandling. The amount of rehandling is dependent upon the thickness of the interburden and the distance that the bench has to be extended.

The third principal method is the spoil-bench method. The top seam is uncovered in the same manner as the first two methods. The dragline then digs a ramp down to the bench and deadheads down the ramp and continues deadheading on the bench until it returns to the starting end of the pit. The machine then crosses over to a bench on the spoil that is made by leveling the top of the overburden spoil. From this position the dragline exposes the second seam by removing the interburden material and rehandling part of the overburden spoil as shown in Figure 5. The dragline digs this material in a cross-pit manner often referred to as "chopping." This is a term used to describe the situation where the dragline must fill the bucket without the aid of a highwall digging face. Chopping is a less efficient method of digging because without the aid of the highwall, it takes longer to fill the bucket and it doesn't fill as completely.

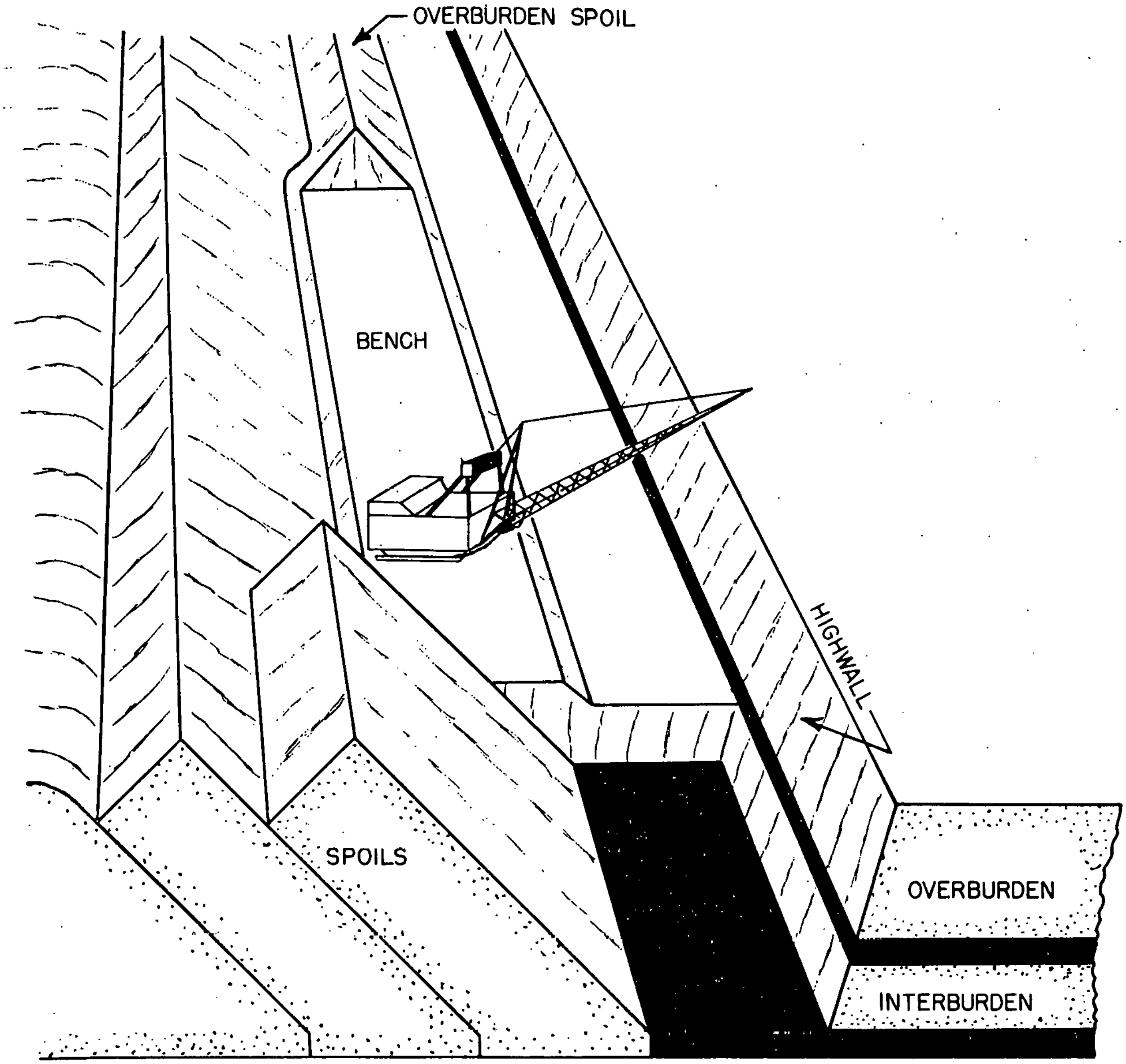
By the time the dragline completes uncovering the second seam, it has progressed back to the ramped end of the pit. From there it deadheads up the ramp and back to the starting end of the pit to begin the cycle over again.

A haulroad coming into the pit will interrupt the continuity of the spoil. When this occurs, the dragline must cross back to the interburden bench, proceed down the bench until it is beyond the haul road entrance, and then cross back to the spoil bench to continue digging.

The spoil bench is used when the dragline's reach is not enough to spoil from either a bench or an extended bench effectively. Normally in a two seam operation, the spoil bench is not used. Usually the dragline's reach is such that the more efficient bench or extended bench methods can be utilized. However, when three seams are mined, the spoiling distance is often so great that the spoil bench method is the only method that allows the dragline to spoil the interburden that is over the third seam.

This method of mining is not as efficient as the other three for several reasons. First, chopping, as stated before, is a less efficient method of digging. Second, the dragline must either make its own bench by leveling the overburden spoil or have it done with a bulldozer. Third, there is rehandling involved.

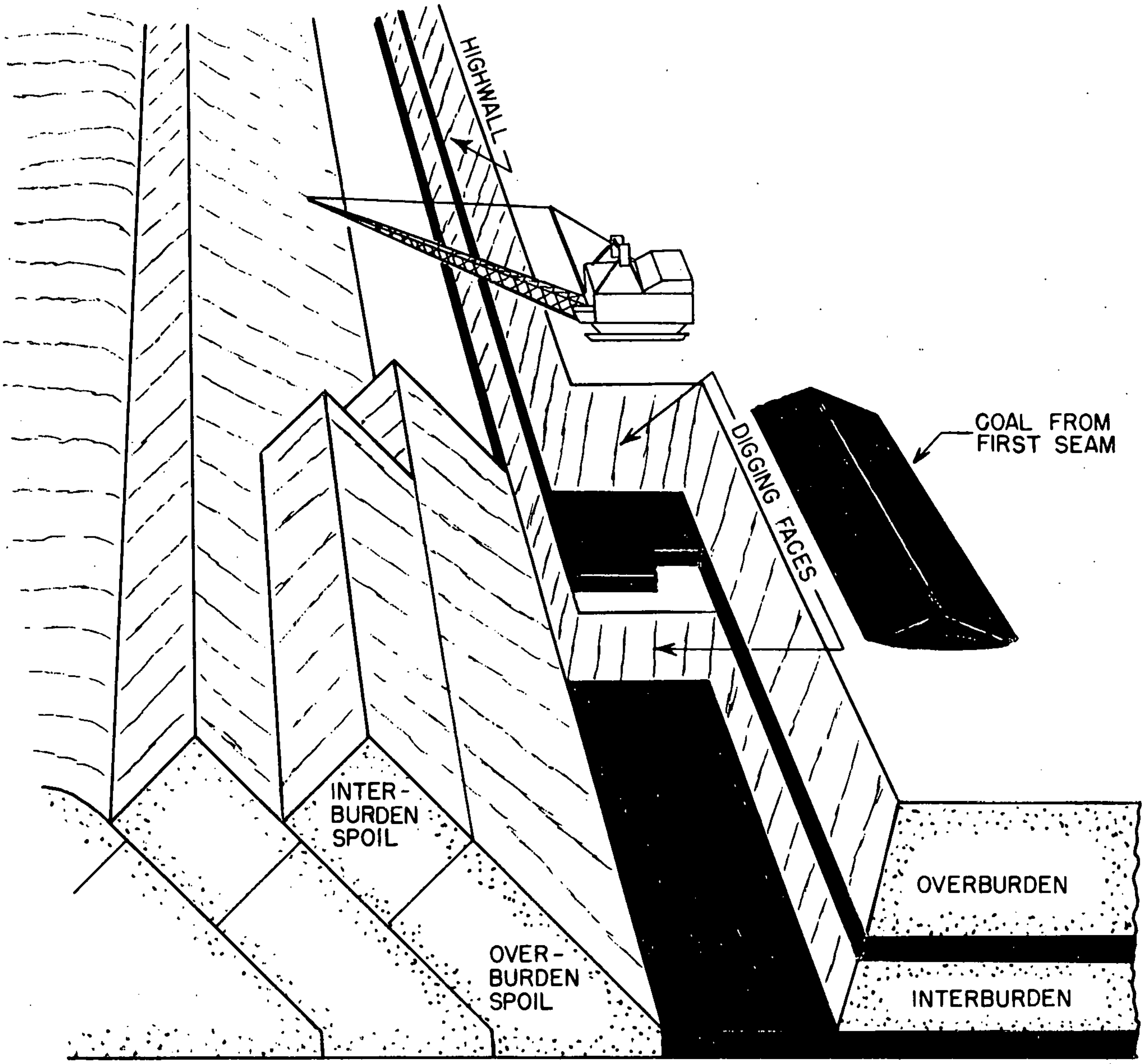
The fourth and final method of mining thin seams with a dragline is one in which the machine digs both the overburden and the coal. This is shown in Figure 6. First the overburden, thin seam and interburden are drilled and blasted in one sequence. Then the dragline is used to remove the overburden material to expose the top seam but only for a short distance. The overburden material is spoiled into the previous cut. The dragline then removes the exposed coal and places it either on top of the highwall (as shown in Figure 6) or casts it down on top of the second seam. The dragline then digs the interburden material directly below the coal that has just been removed and spoils it on top of the overburden spoil. The operation continues in this manner until the end of the pit is reached. The machine then deadheads back to the starting end of the pit and begins the cycle over



DRAGLINE UNCOVERING SECOND SEAM
FROM BENCH ON THE SPOIL SIDE

REMOVING THE INTERBURDEN AND
REHANDLING PART OF THE OVERBURDEN

FIGURE 5.



DRAGLINE UNCOVERING BOTH SEAMS FROM THE TOP OF THE HIGHWALL

PLACING THE COAL FROM THE FIRST SEAM ON TOP OF THE HIGHWALL AND CONTINUING DOWN TO THE SECOND SEAM

FIGURE 6.

again. One advantage of using this method is that the dragline does not have to dig a ramp down to the interburden bench. Also, haulroads giving access to the top of the bench are not required.

The coal on the highwall is collected by front-end loaders and trucks when enough coal accumulates or when the equipment is available. The thin coal quality suffers considerable contamination due to blasting through it and from the poor selectivity by the dragline bucket and operators' perception of the coal. If enough coal is available from the major seam to allow a satisfactory blending for a marketable product, dragline extraction of thin seams is the most economic and least disruptive method of recovering the resource. Percent extraction could be low, but this technique is better than spoiling the thin seam.

Dragline Costs

The additional costs that are encountered when a dragline is used for the exposure or recovery of a thin coal seam are due to six operations. The six operations are ramping, extra moving, rehandle, cross-pit digging, removing of the thin seam coal with the dragline, and drilling and blasting. The thin seam mining methods previously discussed encompass one or more of these six operations.

In the remainder of this section on overburden removal the six operations and the cost of each will be discussed. Then the operations will be grouped according to the thin seam mining method where they are used. The four thin seam mining overburden handling methods previously discussed can be evaluated on an economic basis.

<u>Ramping</u>

Ramping is the operation where the dragline, after uncovering the first coal seam, digs an inclined road from the top of the highwall to the top of a bench created by uncovering the first seam. The ramp provides an access for the machine to deadhead from its digging position on top of the highwall to a digging position on the bench. Ramps are required when the dragline must dig from a bench. Exceptions to this occur when the topography of the mining area is such that a natural access is provided. Ramps are usually dug at 6-7% grade, but since draglines are capable of climbing a 10% grade, 10% ramps are possible.

In a thin seam mining operation the dragline uncovers a section of the first coal seam and then ramps down to the bench created by uncovering the coal. The dragline then deadheads down the ramp to the other end of the section. There the first coal seam has been removed and the dragline can begin to uncover the second coal seam.

The dragline uncovers both seams of coal in sections until the full length of the pit has been mined. Operators favor mining both seams in sections because the electrical support system for the dragline (transformers, cable, etc.) doesn't have to be moved as often.

With the exception of the ramp at the end of the pit, the dragline removes the overburden that has to be removed eventually to expose the main coal seam when it digs a ramp. Therefore, the cost of these interior ramps cannot be charged off to the thin seam. However, the cost of the ramp that is dug at the end of the pit is a cost of recovering the thin seam since the excavation of this ramp does not remove overburden that has to be removed to expose the main coal seam. The only use of the end ramp is to enable the thin seam to be recovered and is a direct cost of thin seam recovery.

The cost of this ramp expressed in terms of cost per ton of thin seam coal recovered can be found by multiplying the volume of the end ramp (cu yds) by the dragline's owning and operating cost per cubic yard and dividing this figure by the number of tons of thin seam coal recovered. Equation (1) can be used to calculate the ramping cost (C_R).

$$C_R = \frac{0.456(d^2)\ (CPY)}{R(L)\ (G)t_1} \qquad (1)^*$$

where:

R = percent of thin seam coal recovered (decimal form)
d = depth of the ramp at its maximum point (ft)
CPY = dragline's owning and operating cost (\$/cubic yard)
L = total length of the pit (ft)
G = the percent grade of the ramp (decimal form)
t_1 = the thickness of the thin coal seam (ft)

By substituting in appropriate values for CPY, G, and R, that are discussed in Appendix B, equation (1) can be simplified to the following:

$$C_R = \frac{1.840\ d^2}{L(t_1)} \qquad (2)^*$$

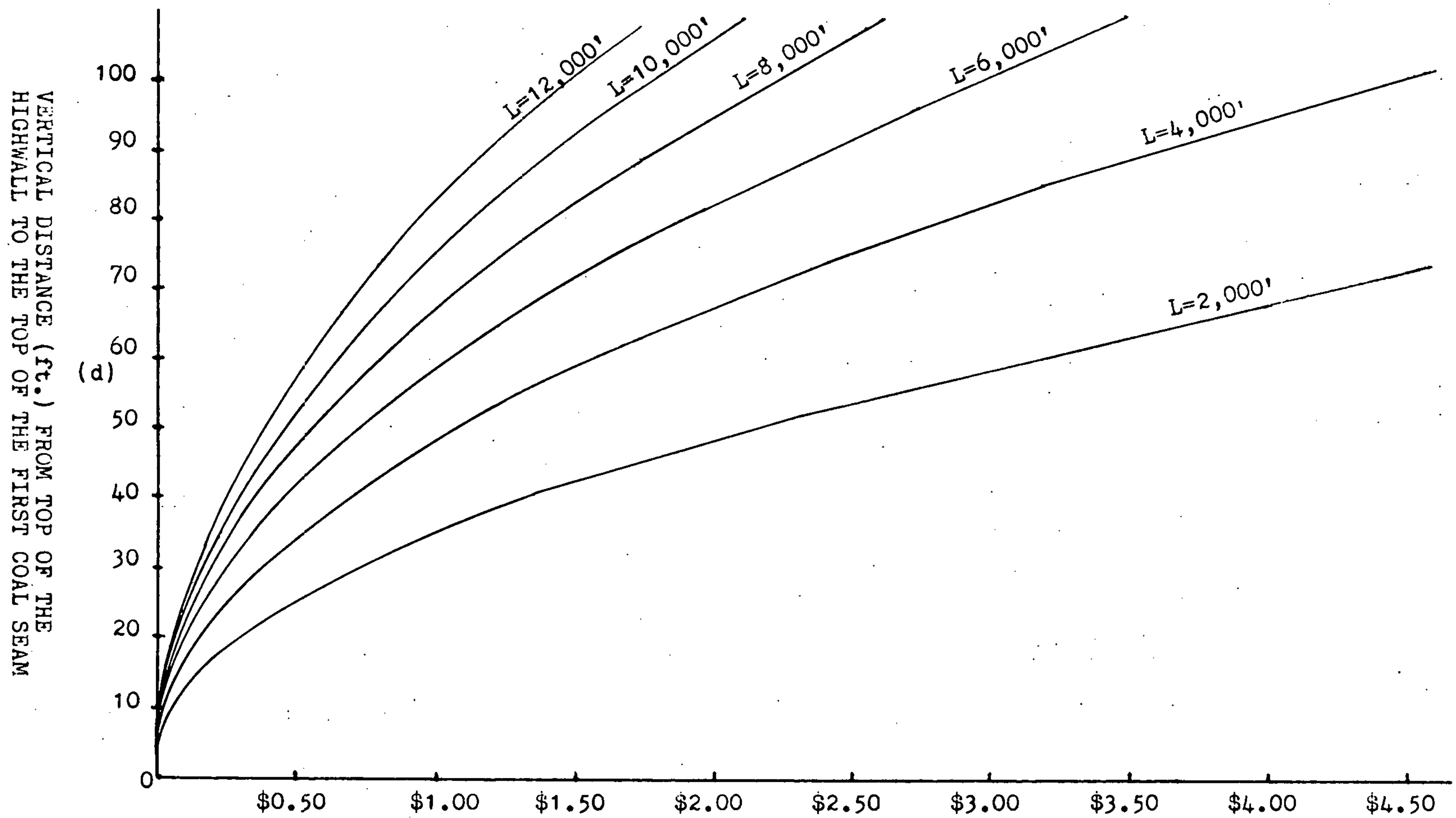
Figure 7 is a graphical representation of equation 2.

Moving

A thin seam mining operation where a bench method is used, increases the amount of time spent moving or deadheading the dragline. The increase in moving time is required so that the thin coal seam can be recovered and therefore, is a cost of recovering the thin seam.

Nominally, a thin seam mining operation, as stated before, is conducted in sections. The dragline first uncovers the top seam of coal. Next the machine is used to dig a ramp down to the bench created by uncovering the thin seam. When this is completed, the dragline is deadheaded down the ramp and along the bench until the beginning end of the section is reached. Once there, the machine uncovers the second seam as it progresses back to the ramped end of the section. When performing this sequence, the dragline deadheads a distance equal to the expression:

*For the derivation of equations 1 and 2, refer to Appendix B.



DRAGLINE RAMPING COST PER TON OF COAL PER FOOT OF THIN SEAM COAL RECOVERED

(for thin seam thickness greater than one foot, divide the above cost values by the seam thickness)

Figure 7.

$$L_B + 2L_R \qquad (3)$$

where:

L_B = the length of the section (ft)
L_R = the length of the ramp (ft)

The increase in moving time of the dragline in order that the thin seam coal be recovered is due to the dragline's having to traverse this distance. This distance is shown in Figure 8.

The cost of the increase in moving time (C_M) expressed in terms of cost per ton of thin seam coal recovered can be found from equation 4:

$$C_M = \frac{24.610(L_B+2\frac{d}{G}(1+G^2)^{\frac{1}{2}})(OP)}{R(L_B)(w)(t_1)s} \qquad (4)^*$$

where:

d = depth of the ramp at its maximum point (ft)
L_B = length of the section (ft)
G = percent grade of the ramp (decimal form)
OP = the dragline's hourly owning and operating cost ($/hr)
s = average walking speed of the dragline (ft/hr)
w = width of the pit (ft)
t_1 = thickness of the thin seam (ft)

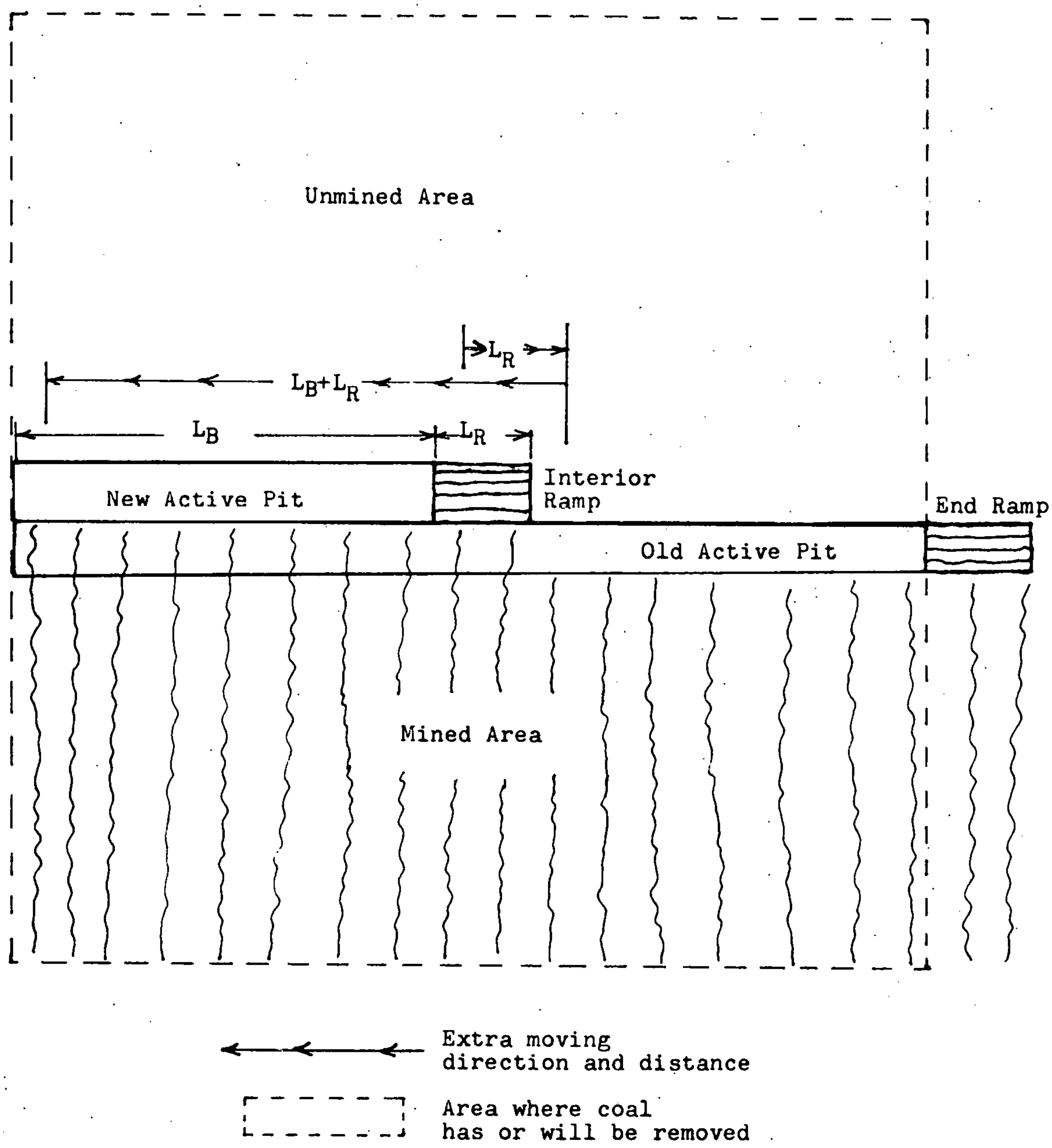
By substituting in appropriate values for L_B, G, w and OP, that are discussed in Appendix C, equation 4 can be simplified to the following:

$$C_M = \frac{(1.569 + 0.026\ d)B}{t_1\ s} \qquad (5)^*$$

where:

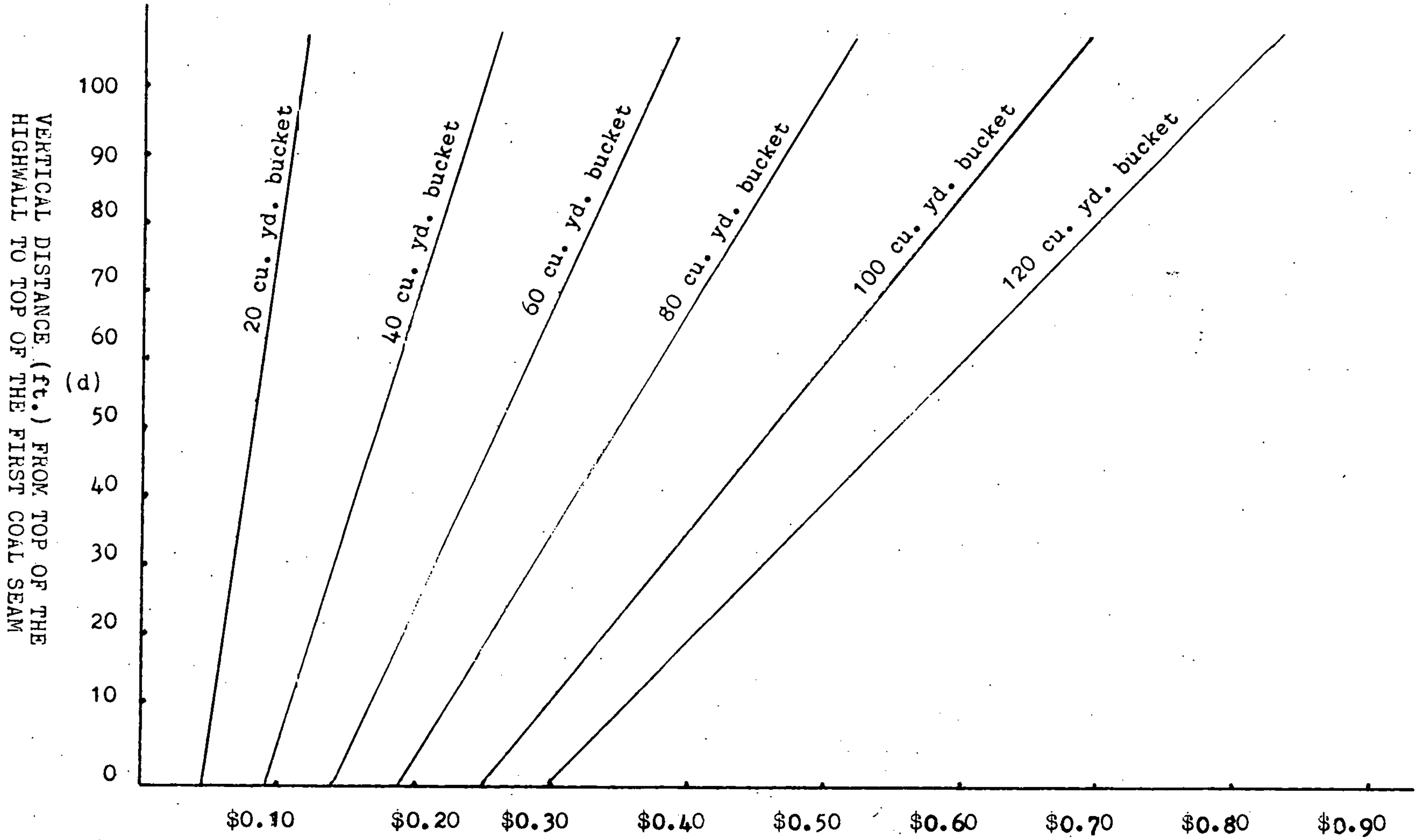
B = the dragline's bucket size (cu yds)

The graphical solution to equation 5 is shown in Figure 9.



SKETCH OF INTERIOR AND END RAMPS
and
EXTRA MOVING DISTANCE L_B+2L_R

FIGURE 8.



DRAGLINE MOVING COST PER TON OF COAL PER FOOT OF THIN SEAM COAL RECOVERED

(for thin seam thickness greater than one foot, divide the above cost values by the seam thickness)

FIGURE 9.

Rehandle

Rehandle is the term used to describe the overburden material that the dragline has to move more than once. Rehandle occurs when the dragline's reach (swing radius) is not long enough to allow the machine to spoil the material the required distance in one operation. In this case the dragline will spoil the material at some intermediate point, move to a location nearer to the desired spoiling location, and then transfer the material from the intermediate point to the spoiling location.

Rehandle also occurs when the dragline must construct a bench out of material to be spoiled. In this instance the machine uses some of the material it is excavating to construct a bench to dig from. Later, when the bench is no longer needed, it is removed with the dragline and spoiled. An example of this is an extended bench method of mining.

The factors that affect the amount of rehandle are numerous. Some of them are: dragline's reach, curvature of the pit, angle of repose and swell factor of the material being dug, width of the pit, overburden, interburden and coal thicknesses, etc.

Nominally, in a thin seam mining operation where only two seams are being mined, the dragline selected is one that can mine 80-90% of the coal field without having to rehandle any of the overburden or interburden. For the 10-20% of the coal field that cannot be mined without rehandle, dozers or scrapers are often used to move the extra material.

However, when three or more seams are being mined with a dragline, the total distance that material must be moved is often greater than any machine is capable of, and rehandling is required.

In a thin seam mining operation where rehandling is required to recover the thin seam, the cost of rehandling (C_H) expressed in terms of cost per ton of thin seam coal recovered is:

$$C_H = \frac{(\text{cu yd of rehandle})(\text{CPY})}{\text{tons of thin seam coal removed}} \qquad (6)$$

Most often the amount of rehandle is expressed as a percent of solid bank material. Expressing the amount of rehandle in this form and substituting in an appropriate value for CPY, equation 6 becomes:

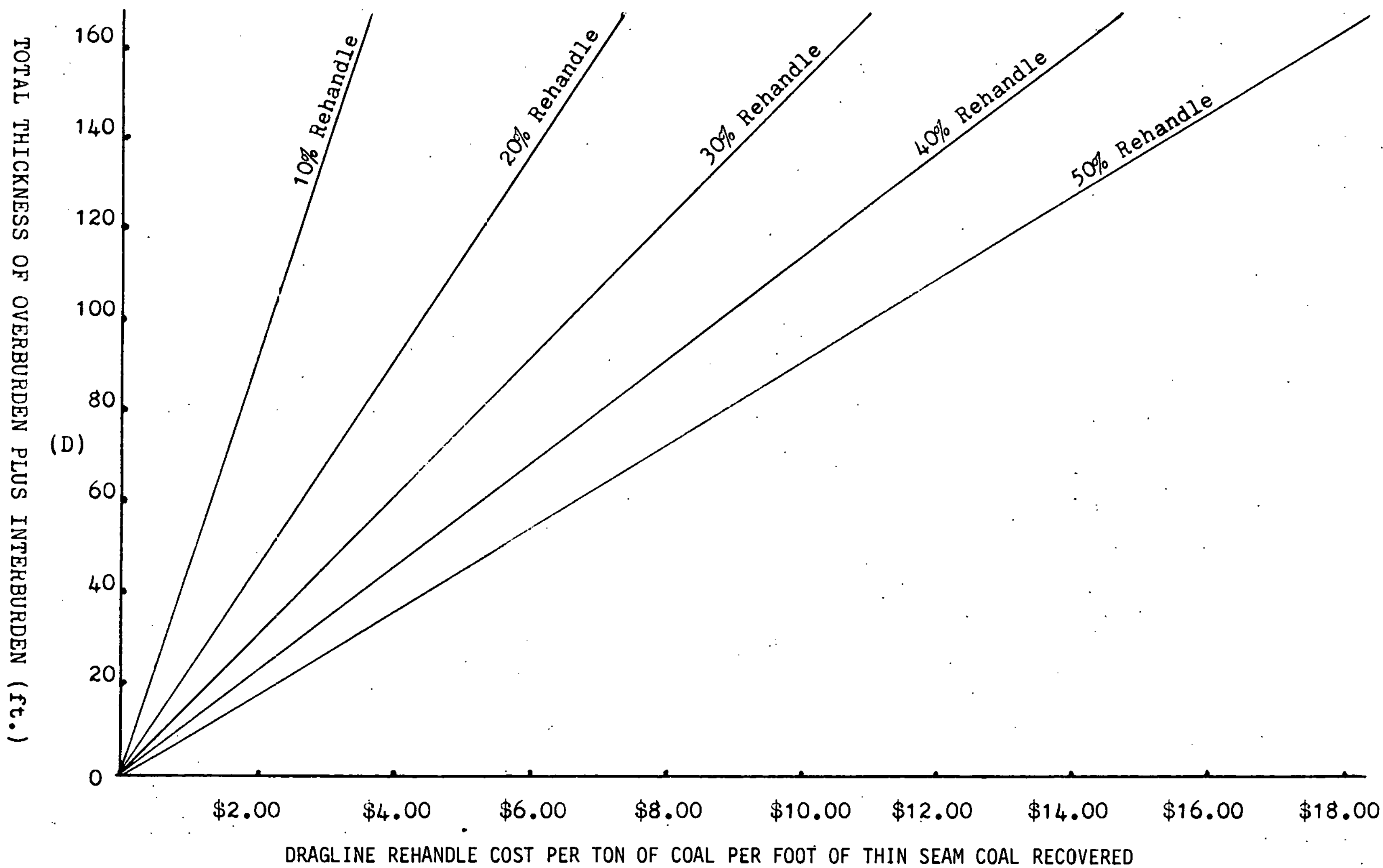
$$C_H = \frac{0.221(R_e)D}{t_1} \qquad (7)^*$$

where:

D = the thickness of the overburden plus interburden (ft)
R_e= the percent rehandle (decimal form)

Figure 10 is a graph of equation 7.

*The derivation of equation 7 is shown in Appendix D.



(for thin seam thickness greater than one foot,
divide the above cost values by the seam thickness)

Fig. 10

Because there are so many variables that dictate the amount of rehandle that is necessary, the individual mining operation has to be studied to determine the amount of rehandle required. This is done by constructing range diagrams, calculating the volume of material to be spoiled and the volume of spoil room available.

Cross-Pit Digging

Cross-pit digging, often referred to as "chopping," is a term used to describe the situation where the dragline's bucket is filled without the aid of a highwall.

A conventional operation consists of the dragline digging from a position on top of a highwall or bench and removing the material that makes up the highwall or bench. The bucket is filled as it is dragged up the digging face of the highwall or bench. The teeth on the bucket cut into the bank and the force of the bucket being dragged up the face plus gravity enable the bucket to be filled quickly and completely.

When the dragline is used in a cross-pit digging manner, there is no highwall. The dragline's bucket is filled by dragging it across the top of the material being excavated. The teeth of the bucket cut into the surface and the force of the bucket being dragged across the material fills the bucket. This method of filling the bucket takes longer because the bucket has to be dragged a considerable distance across the pit to fill it and then raised the required dumping height. Whereas in a conventional operation, the bucket is filled as it is being raised the dumping height. Also, in a cross-pit digging operation, the bucket usually doesn't fill as completely as in a conventional operation.

Cross-pit digging is employed when the dragline must operate from the spoil side of the pit. For the machine to operate from this side of the pit, a bench has to be made on the spoil so that the machine has a level area to dig from. This bench is made by knocking down the top of the spoil peak. This is shown in Figure 5. The spoil bench can be made by either a dozer or the dragline, but most often the dragline is employed to handle most of this work since it is already there and can move the material cheaply.

It has been found that when a dragline is employed in a cross-pit digging operation, it moves 30% less material than it would if operating in a conventional manner.[1] This is a 30% reduction in efficiency. When cross-pit digging must be employed to recover the thin coal seam, this 30% reduction in efficiency is a cost of recovering the thin seam coal. This cost (C_c) when expressed in terms of cost per ton of thin seam coal recovered is:

$$C_c = \frac{0.434\,(d_2)(CPY)}{t_1} \qquad (8)^*$$

*The derivation of equation 8 is shown in Appendix E.

By substituting in the appropriate value for CPY, the equation becomes:

$$C_c = \frac{0.095\ d_2}{t_1} \qquad (9)^*$$

where d_2 = the thickness of the interburden.

Figure 11 shows the graphical solution to equation 9.

Removing the Coal with the Dragline

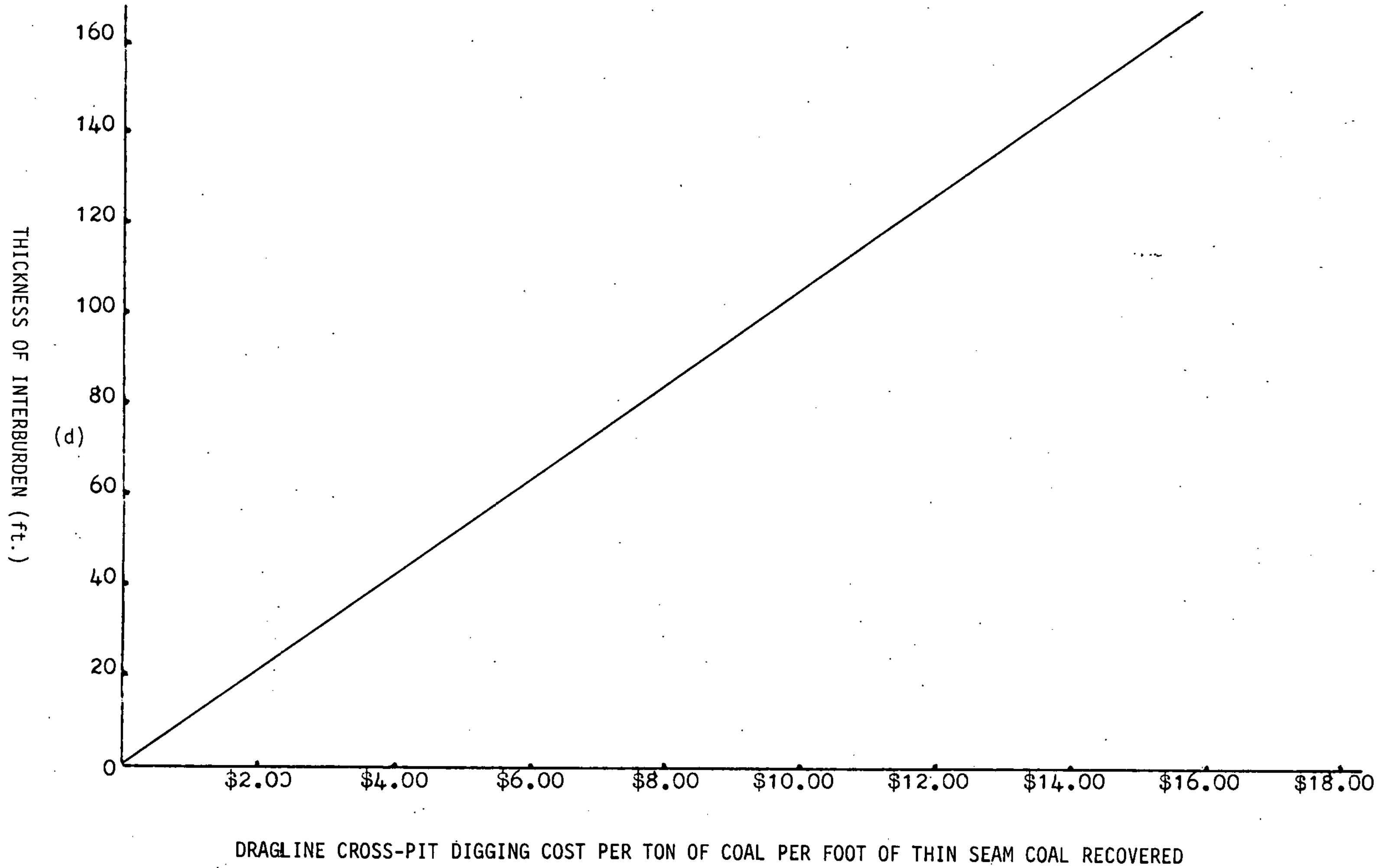
The dragline can be utilized to remove the thin seam coal as it digs down to expose the main seam. First the overburden, thin seam and interburden are all drilled and blasted in one sequence. The dragline then proceeds to uncover the main seam from a digging position on top of the highwall. When the thin seam coal is encountered in the bank, it is selectively removed and placed either on top of the highwall as shown in Figure 6 or cast down on top of the exposed main coal seam. Later it is loaded and transported to the processing plant with conventional equipment.

An apparent advantage to this method is that both seams of coal can be recovered without having to provide access to the thin seam coal bench for either the dragline or loading and hauling equipment.

There are two costs of employing this method that are due to recovering the thin seam coal. The first is decreased dragline productivity. However, this decrease is only during the thin seam coal removal sequence and is negligible since the time spent recovering thin coal is small compared to the time spent removing overburden and interburden.

The second cost is due to dilution. It is estimated by an operator employing this method that the thin seam coal is diluted 50%.(2) The actual cost of the 50% dilution of the thin seam coal is dependent upon the contract the operator has with the buyer. When 50% diluted thin seam coal is mixed with the main coal seam, the dilution of the total coal increases only slightly because the amount of thin seam coal is slight compared to the total. If the mixed coal is within the contract limits for ash and Btu even with the increased dilution, there is no dilution cost. However, if the increased dilution causes the total coal not to be within the contract's limits, the dilution cost is equal to the amount of money the operator loses by not being able to sell at the contract price. Nominally, the operator will employ another mining method than the one just described if this is the case.

*The derivation of equation 9 is shown in Appendix E.



(for thin seam thickness greater than one foot, divide the above cost values by the seam thickness)

Fig. 11

Drilling and Blasting

When a dragline is used to expose a thin seam, drilling and blasting is accomplished by individual benches. First the overburden is drilled and blasted, and after it and the thin seam have been removed, the interburden material which makes up the bench is drilled and blasted. Drilling and blasting the overburden, thin seam and interburden in one sequence is rarely done because of the mixing and dilution of the coal that would occur.

Bench methods employ costly loading and hauling equipment and techniques to recover the in-place coal. To justify the loading and hauling costs, it is important to minimize the dilution of the coal and no decrease its already marginal value.

After the upper overburden and thin seam have been removed, a second probably duplicative series of blast hole drilling and shooting is required before the bench or interburden material can be excavated. Scheduling the second drilling and blasting can be inconvenient, and cost increases occur. The increases are due to extra drill movement to repeat a pattern similar or identical to that drilled in the overburden; labor to load, stem, and connect the holes; and a second set of blasting trunk lines and detonators.

To determine the additional drilling and blasting cost, two sub-operations must be examined and their resulting costs determined. The first is extra drill movement. The extra movement includes moving the drill from the top of the highwall to the thin seam bench plus moving from hole to hole on the thin seam bench. An approximation of this cost is given by the following expression:

$$DMC = O\&O(1.05MT) \qquad (10)$$

where: DMC = Drill moving cost per blast hole
O&O = Drill owning and operating cost per hour
MT = Average time in hours it takes the drill to move from one hole to the next.

The other sub-operation is that of making up the blasting circuit. Materials, equipment, and labor are involved. The materials include additional detonators, detonation cord, delays, and trunk lines. An expression of this cost is as follows and is the sum of costs for the additional materials required to fragment the overburden and interburden in separate blasts.

$$BMC = (DET) + (TLC) + DEL) \qquad (11)$$

where: BMC = The cost per hole of additional blasting materials
DET = Cost per hole for detonators
TLC = Cost per hole for trunk lines
DEL = Cost per hole for delays

The other cost associated with blasting is that of the additional labor and equipment required to load, stem and connect the blast holes. This usually involves three men and two trucks. Two of the men and a 1 1/2 - 2 ton powder truck are required to load and stem the holes. A

The other cost associated with blasting is that of the additional labor and equipment required to load, stem and connect the blast holes. This usually involves three men and two trucks. Two of the men and a 1 1/2 - 2 ton powder truck are required to load and stem the holes. A third man and a pick-up truck are needed to connect the blasting circuit. At a particular mining operation, usually enough data is available to calculate this cost directly. For a general expression this cost can be approximated by assuming that it equals the drill cost due to the extra moving, DMC.

The total of these drilling and blasting costs per hole divided by the tons of thin-seam coal recovered yields the additional drilling and blasting cost per ton of thin-seam coal recovered. An expression for this cost is:

$$D\&B = \frac{2(DMC) + BMC}{(S_{p1} \times S_{p2})t_1} \quad 27.345 \qquad (12)$$

where: D&B - Drilling and Blasting cost per ton of thin-seam coal recovered
DMC = Drill moving cost per blast hole
BMC = The cost per hole of the additional blasting materials
$(S_{p1} \times S_{p2})$ = The blast hole spacing in feet
t_1 = The thickness of the thin coal seam in feet

(This expression assumes 1770 tons of coal per acre-foot and 90% recovery.)

The additional drilling and blasting cost associated with the recovery of a thin coal seam with a bench method range from $0.18 to $0.36 per ton. The drilling and blasting cost of recovering the thin seam can vary considerably depending upon local labor and material costs, blast hole spacings, and type of overburden drill used.

Dragline Methods and the Resulting Costs

With the additional operations and their costs to recover thin coal seams identified, these costs are combined to determine the total overburden removal cost associated with recovering thin seams. These costs are grouped according to the dragline mining methods, previously discussed. As the costs are discussed, it is important to keep certain points in mind. First, the costs discussed are overburden removal costs only. The total cost of recovering the thin seam coal includes these costs plus the cost of loading, hauling, preparation, etc. Second, the approach taken is as follows: the overburden removal costs are those due to any overburden removal operation that would not have been performed if the thin seam was spoiled. Hence, the removal of overburden and interburden that is over the main seam is a cost of recovering the main seam, while ramping, additional moving, rehandling, etc., are costs of recovering the thin seam. In the case of the thin seam being beneath the main seam, the removal of this interburden is a cost of recovering the thin seam.

employ three of the six operations that affect the cost of recovering the thin seam coal. The three are ramping, extra moving, and drilling and blasting. The cost of recovering the thin seam coal for either of the two highwall bench methods is determined by combining equations 2, 5, and 12. The resulting equation is:

$$C_{DH} = \frac{1.840d^2}{L(t_1)} + \frac{(1.569 + 0.026d)B}{t_1 S} + D\&B \qquad (13)$$

where C_{DH} equals the dragline cost of recovering the thin seam coal expressed in terms of cost per ton of thin seam coal recovered. Equation 13 assumes that there is no rehandle (which is most often the case in two seam operation) and that the thin seam is above the main seam. If rehandle is required, its cost can be found from equation 7 and added to equation 13.

Spoil Side Bench Method

The third principal method is the spoil side bench method. Not only does it employ the operations of ramping, extra moving, and drilling and blasting, it also employs rehandle and cross-pit digging. Combing these five dragline costs, the cost of this method (C_{DS}) is:

$$C_{DS} = \frac{1.840d^2}{L(t_1)} + \frac{(1.569 + 0.026d)B}{t_1 S} + \frac{0.221(R_e)D}{t_1} + \frac{0.095d_2}{t_1} + D\&B \qquad (14)$$

Equation 14 is the sum of equations 2, 5, 7, 9, and 12, and it also assumes that the thin seam is above the main seam.

Removing the Coal with the Dragline

Removing the coal with the dragline is the fourth and last principal dragline mining method. The cost of this method is not as straightforward as the other three. This is because the cost is dependent on the effect the dilution of the thin seam coal has on the total coal quality and its ability to meet the coal contract's specifications. Nominally, if the dilution of the thin seam coal affects the total coal quality so that it doesn't meet the contract specifications, this method of mining isn't used because the operator generally prefers not to jeopardize the contract.

However, if dilution does not affect the total quality enough to make it below contract specifications, the cost of recovering the thin seam coal is negligible as far as overburden removal costs are concerned.

Table II shows the additional costs incurred as a function of the method used to expose a thin coal seam for recovery. Each of the preceding equations is used where applicable. The table represents the results of substituting a typical mine geometry into the equations. The mine situation used follows: a dragline with a 50 cubic yard bucket, recovery at 90%, 6% ramp grades, 6000 foot pit length mined in 2000 foot sections, the depth from surface

Table II

TYPICAL OVERBURDEN REMOVAL COSTS PER TON

OF THIN SEAM COAL RECOVERED

Dragline Highwall Bench Methods

	Depth from Surface to Thin Seam				
	20'	40'	60'	80'	100'
Two foot thick thin seam	0.41	0.61	0.94	1.39	1.96
Four foot thick thin seam	0.34	0.44	0.60	0.83	1.11

Dragline Spoil Bench Method*

	Depth from Surface to Thin Seam				
	20'	40'	60'	80'	100'
Two foot thick thin seam	6.49	5.74	5.11	4.61	4.23
Four foot thick thin seam	3.38	3.00	2.69	2.44	2.25

Dragline Removing Thin Seam Coal

For the conditions previously discussed, the overburden removal costs are negligible.

Truck/Shovel and Scraper Operations

If the thin seam can be recovered without requiring an additional bench, the overburden removal costs are insignificant.

*Since this method involves rehandle, the rehandle is assumed to be 10% for all depths. Normally, rehandle varies as depth increases.

to major coal seam is 120 feet and additional drilling and blasting costs are $0.27 per ton.

Rider Seams

A discussion of overburden removal is not complete without some discussion of methods used to remove the parting between the rider seam and the major seam. Rider seams are thin coal seams appearing immediately above or below the major seam and separated from the major seam by a thin parting. The parting is from a few inches to a few feet in thickness and is often material that is tough and difficult to dig.

The parting, because it is thin, cannot justify the use of a dragline for removal considering both digging efficiency and the moving required. Therefore, auxiliary equipment is most often used to remove the parting. The parting is usually ripped with a dozer and removed with scrapers or front-end loaders and trucks. Backhoes loading into trucks are also an option. The backhoe is particularly useful in very tough partings because of its excellent break-out force. Some rotating rippers and bucket wheel loaders which have been used successfully in coal loading opera-operations have been tried in parting removal operations. They show promise in this endeavor but as yet a production model capable of excavating and loading both coal and the tougher parting has not been fully developed.

The rider seam appears immediately above or below the major seam, and for this reason in dragline pits it is advantageous to stow the parting within the pit. Some operators prefer to place the parting in piles on top of the lower coal seam. The piles are located such that later a dragline from a position on top of the highwall can removed the piled parting material and spoil it.

There are a great number of methods of removing the parting, and these methods and the resulting costs have been discussed in detail in another USBM project* and therefore will not be discussed in detail in this report. Nevertheless, it must be realized that the overburden removal cost of recovering thin coal seams is the difference between the cost of stripping through the thin seam and removing the parting with the prime stripping machine and the cost of removing the parting using auxiliary methods and equipment.

SUMMARY

The methods discussed are those presently being used in western U.S. coal fields and are effective in the recovery of thin coal seams. With the continued development of specialized mining equipment, other methods may soon be in use, particularly in parting removal. It was found that the method where the dragline, operating from on top of the highwall, removes the thin seam coal, is one of the most economical methods of recoverying thin coal seams. However, this method is only economical for the conditions discussed. Truck/shovel and scraper operations can most often recover thin coal seams without realizing significant overburden removal costs. Even so, draglines can remove overburden at a lesser cost and therefore, should probably be used at thin seam mining operations whenever applicable.

*USBM Contract No. G0264014, Limits and Cost Sensitivity of Alternate Parting Handling Methods, March 1977.

CONVENTIONAL THIN SEAM COAL REMOVAL METHODS AND COSTS

CONVENTIONAL THIN SEAM COAL REMOVAL

METHODS AND COSTS

Introduction

The most important criterion that must be met to promote thin coal seam removal is economic viability. The thin seam must be mined at a profit or at least a break-even point to justify its removal. The two major categories for determining its economic feasibility are: 1) the added stripping costs, and 2) the coal removal costs. The value of the coal obtained from the thin seam must be sufficient to pay for both of these costs.

The increased stripping costs for a thin seam were discussed in the previous section. The cost of the actual coal removal is discussed here. This section deals primarily with removal methods and costs utilizing existing conventional equipment. The two primary methods covered are a front-end loader-truck operation and a scraper operation. Use of the stripping dragline for thin seam removal is addressed, and in addition fragmenting and ramping for coal are discussed.

A very important additional factor in thin-seam removal is time. The thin seam must be removed quickly enough so there is no interference with interburden removal between the thin seam and lower seam. At the same time, the entire operation must advance at a pace that allows removal of the major seams to meet blending and production requirements.

The objective of this section is to describe the conventional methods and techniques used for removing thin coal seams. In addition, a comparison of techniques and methods will be made on the basis of cost per ton of thin seam coal mined. Therefore, representative production and cost estimates will be calculated for the various methods. It should be understood that these calculated production and cost figures are estimates and do not represent actual field observed quantities.

When possible, a general cost per ton of thin-seam coal is calculated using assumptions based on known fact or accepted engineering practice. An attempt is made to develop equations for determining production and costs that are not dependent upon the thickness of the thin seam or the parting However, for certain types of costs, i.e. ramping and haul cycle times, a standard pit cross-section of 40 feet of overburden, the thin seam, 40 feet of parting, and a lower major coal seam were used. In addition, it is assumed that the overburden would be removed by a dragline in 2000-foot passes. An important assumption is that the lower, major seam can be mined at a profit if the overburden is removed in one single pass that wastes the thin seam.

Fragmenting

Using conventional methods to load out coal requires that it be fragmented in some manner. Fragmentation is usually accomplished by either ripping or blasting the seam. During the course of this study, all of the mines visited had a cut-off limit of four feet for blasting coal. Below the 4-foot limit the coal was fragmented by ripping.

The reasons for not blasting the thinner seams are based on both economics and general scheduling problems. When drilling a thin seam, the coal drill must be moved off the main seam up to the thin seam. Once there, it usually spends more time moving between holes than it does drilling. Once the holes are drilled, there is the cost of the blasting. The major cost in blasting is the labor involved in setting the charges. This procedure normally involves a minimum of two laborers, plus a driver for the powder truck. In addition to the large labor cost, the cost of the blasting agents, except for Ammonium Nitrate, are essentially the same as for the thicker seams. These items include primacord, detonating primers, and delays. These costs, plus the problems of the new federal regulations and requirements for blasting, have made ripping the preferred method of thin-seam fragmentation.

Coal ripping is normally accomplished using 400-horsepower bulldozers equipped with single-shank rippers. A few producers are trying the new 500-horsepower dozers and double-shank rippers. One such mine that is using a larger dozer is the McKinley mine in New Mexico. They are using a Fiat-Allis 41B to rip their thin seams and claim good success.

To estimate the rippability of a material, it is standard practice within the industry to use its seismic velocity. The correlation is that the higher the seismic velocity, the harder the rock is to rip. Coal has a seismic velocity between 6000 and 9000 feet per second depending, of course, on the type of coal in question.[3] These velocities are all within the rippable ranges for a Caterpillar D9H dozer equipped with a single-shank ripper.[4]

Ripper production is dependent upon four factors: cycle time, volume ripped per cycle, availability, and efficiency. Cycle time is inversely proportional to the production. It is controlled by the speed of the dozer, the length of pass, and the fixed time allowed for raising the tooth, turning, and lowering the tooth. In order to obtain the most efficient cycle times the passes should be as long as possible, hence minimizing the amount of time spent turning around and resetting the ripper tooth. The speed of the dozer while ripping depends a great deal on the type of material being worked. While traveling at higher speeds may increase production in the short run, increased maintenance costs and downtime may become a significant factor after a period of time.

Directly related to the production rate is the volume of coal that is ripped during a given pass with the dozer. The volume per pass depends upon the spacing of the passes, the spacing of the ripper teeth if more than one tooth is used, and the depth of penetration of the ripper tooth. It is obvious that the cycle time is also dependent upon the number of teeth and the depth of penetration. More teeth and deeper penetration will require more power and thereby reduce the dozer speed, hence increasing the cycle time. Additional ripper teeth also increase the shock load on the dozer and adversely affect the availability and maintenance costs of the unit.

After calculating the optimum production, that figure must be discounted according to availability and efficiency. Availability is a measure of the time the machine will be working, or available to work, during a given scheduled hour. It reflects the unscheduled downtime that is required for repairs.

Efficiency is a discounting factor which accounts for many intangible factors. Among these are: operator competency, supervision, job conditions, machine performance, and general continuity of operation.

A final cost per ton of coal for ripping is arrived at by dividing the final production figure by the owning and operating cost of the dozer. When calculating the owning and operating cost of a dozer ripping coal, it is necessary to increase the 0 & 0 cost of the dozer being used by 30% to 40%. (4) This accounts for the added abuse given the dozer while ripping.

A formula for calculating ripping cost per ton of coal is:

$$\text{Dollars/ton} = \frac{0\ \&\ 0}{(\text{Den})\left(\dfrac{1.422 \times D \times P \times S_p \times N}{\dfrac{D}{88 \times S} + M}\right)} \qquad (15)$$

where:
- 0 & 0 = Owning and Operating cost ($/hour)
- D = distance per pass (feet)
- S_p = Spacing between passes (feet)
- P = Penetration of tooth (feet)
- S = Speed of dozer (mph)
- M = Fixed maneuver time at end of pass (min.)
- N = Number of ripper teeth
- Den = Density of coal (tons/Bank cubic yard)

This formula assumes an availability and efficiency of 80%. The 0 & 0 cost of the standard dozer should also be increased by 30% to 40% prior to using the formula. Derivation of the formula is described in Appendix G.

The cost per ton of coal for ripping a thin coal seam was calculated using the following data:

1) 300 feet passes,
2) 3 feet between passes,
3) single shank ripper on a D9H,
4) 80% availability and efficiency,
5) 1.1 tons per bank cubic yard,
6) average dozer speed of 1 mph, and
7) a fixed maneuver time of 0.25 minutes.

The ripping cost per ton of coal was found to be $0.09/ton with a production capacity of 700 bank cubic yards per hour. The calculations are outlined in Appendix G.

The major disadvantages of ripping thin seam coal is the dilution it causes. Because the seams are not flat-bottomed, rippers tend to tear into the parting beneath the seam, mixing it with the coal. This has caused some mining operations to rip coal only during daylight hours. Other mines have changed to different methods of fragmentation such as the Huron Easi-Miner, and CMI's Fine-Grader. Both of these are discussed in later sections.

Front-end Loaders and Trucks

One of the most common methods currently used for the removal of thin seams at operating western surface mines is by front-end loaders and trucks. Front-end loaders are used instead of shovels because of their greater mobility and versatility.

During the thin seam removal operation, the coal is first drilled and blasted or ripped. As previously discussed, ripping is the prevalent method of fragmentation. After ripping, it is either loaded directly from the ripped seam into the haul trucks with the loader, or it is pushed into piles by dozers from which the loader loads the trucks.

By loading from dozer piles, the cycle time of the loader is reduced. The loader is not required to break out coal from the seam; instead it loads from a high, loose coal pile. Since it does not have to chase after the seam to get a full bucket, lower travel distances also reduced overall cycle time. This type of loading also provides lower operating costs because of reduced wear and tear on the machine. On the other hand, there is the additional cost of piling the coal with the dozer. Depending on the thickness of the coal seam and the rippability of the coal, normally the same dozer that does the ripping will pile the coal.

To determine dozer production, the most widely used technique is to use a maximum production figure quoted by the manufacturer of a given machine and apply appropriate correction factors. The correction factors should take into account the given job characteristics, which effectively reduce the maximum production rate to a realistic estimate.

An equation can be developed for calculating dozer production, and in turn, dozing cost in dollars per ton of coal. The following equation for dozer production can be utilized to determine dozer production:

$$TPH = (MAXLCY)\ (DEN)\ (CF) \qquad (16)$$

where:
- TPH = Production in tons per hour
- MAXLCY = Maximum production in loose cubic yards as obtained from manufacturer specifications
- DEN = Density in tons per loose cubic yard
- CF = Sum of correction factors in decimal form

The term MAXLCY is obtained from the manufacturers' production specifications for each given type of machine. Once this figure is arrived at for a given machine with a certain blade, it is reduced using the correction factor, CF. The correction factor is the sum of many factors, including material type, efficiency, availability, dozing technique, etc., that would increase or decrease productivity. This production volume is then converted to 'tons per hour' using the density factor.

The cost per ton of coal is then calculated using:

$$\$/ton = \frac{O\&O}{TPH} \qquad (17)$$

where: \$/ton = Cost per ton of coal
O&O = Owning and operating costs in dollars per hour
TPH = Production in tons per hour.

To obtain a working cost per ton of coal for comparison of the different loading methods, the dozer production was calculated for a Caterpillar D9H dozer with a U-blade. The maximum production and assorted correction factors were obtained from the Caterpillar Performance Handbook. (4) The actual calculations and correction factors are indicated in Appendix G. Production for a single D9H, dozing ripped coal into piles, is estimated at 583 tons per hour at a cost of \$0.08 per ton coal.

It should be noted that actual production for the dozer should be close to the calculated production of 583 tons per hour but will vary according to how well the coal is ripped, the skill of the operator, condition of the machine, and the driftability of the fragmented coal. These and other intangible conditions can change the actual production figures by several percent.

To calculate front-end loader production, the following equation was used:

$$TPH = \frac{(60)\ (BCAP)\ (BFF)\ (EFF)\ (AVAIL)\ (DEN)}{CT} \qquad (18)$$

where: TPH = Production in tons per hour
BCAP = Capacity of bucket in loose cubic yards
BFF = Bucket fill factor in decimal form
EFF = Efficiency in decimal form
AVAIL = Availability in decimal form
DEN = Density in tons per loose cubic yards
CT = Cycle time per bucketfull in minutes

In the preceeding equation cycle time, CT, is the sum of the time required to fill the bucket, move to the truck, raise the bucket, move to the pile, and lower the bucket. The bucket fill factor, also known as the carry factor, is the amount of struck volume capacity the bucket will normally hold for each cycle. The bucket fill factor for the coal is generally considered to be 0.8 (5). The cost per ton of coal is calculated by using the previously described formula of owning and operating cost divided by the production.

When calculating loader production, it can be assumed that there is a consistent operation with an average cycle time for the loader. The cycle time varies depending on whether the coal is ripped in place or piled. The average cycle times were 0.7 minutes for loading from a dozer pile and 1.15 minutes for digging the ripped coal directly from the thin seam. (6) The production estimates using a Letourneau L-800 with a 23-yard coal bucket and the previous cycle times were: 833 tons per hour with a dozer pile and 475 tons per hour with direct loading from the seam. The cost per ton for loading is then $0.15 per ton for the dozer-pile and $0.25 per ton for direct loading from the thin seam. The cost per ton for chasing the coal includes a 20% increase in the owning and operating cost of the loader. This additional cost is due to increased maintenance from the loader's having to break out some of the coal with additional tire spinning.

To make an accurate cost comparison between the two types of loading methods, the cost of the dozer must be added to the dozer-piled loader cost. This results in a figure of $0.23 per ton, which shows a savings of about 9% over chasing the coal with the loader. These findings were substantiated by the mine engineers at several western operations where front-end loaders are used to mine thin seams. At most of these operations, the coal was piled before being loaded.

For purposes of a general cost comparison, it is assumed that the coal will be loaded into small off-highway end-dump coal haulers, such as the Wabco 75B. End-dump trucks have the advantage of being capable of climbing steeper ramps thus minimizing ramping costs.

To calculate the haulage cost of the thin seam, the maximum truck speeds were calculated using the following formulas:[7]

Loaded

$$S = 42.5077 - 7.65\ G + 0.55489\ G^2 - 0.01412\ G^3 \quad (19)$$

Empty

$$S = 34.342 - 0.37379\ G - 0.123396\ G^2 \quad (20)$$

where: G = Percent grade
S = Maximum speed.

All negative grades were assumed to be maximum. All maximum speeds were then adjusted for vehicle acceleration, deceleration, and momentum using the graphs shown in Appendix H.

Once the maximum speeds have been determined, the total cycle time is calculated to include travel time, load time, and dump and maneuver time. Truck production can then be obtained using the following formula:

$$TPH = \frac{(60)\ (EFF)\ (AVAIL)\ (TCAP)\ (DEN)}{CT} \quad (21)$$

where: TPH = Production in tons per hour
EFF = Efficiency in decimal form
AVAIL = Availability in decimal form
TCAP = Truck capacity in loose cubic yards
DEN = Density of coal in tons per loose cubic yard
CT = Cycle time in minutes.

The haulage cost is then obtained by dividing the vehicle owning and operating cost by the truck production as previously described.

The cost of hauling the thin seam down to the main using a Wabco 75B with a coal box would be $0.16 per ton. Two trucks would be required to keep up with the loader production and insure a constant operation.

To remove the thin seam by a front-end loader-truck combination, the total cost for loading from dozer piles and hauling would be $0.39 per ton. If the loader were chasing the coal, the cost would be $0.41 per ton. Figure 12 is a schematic of a front-end loader-truck operation.

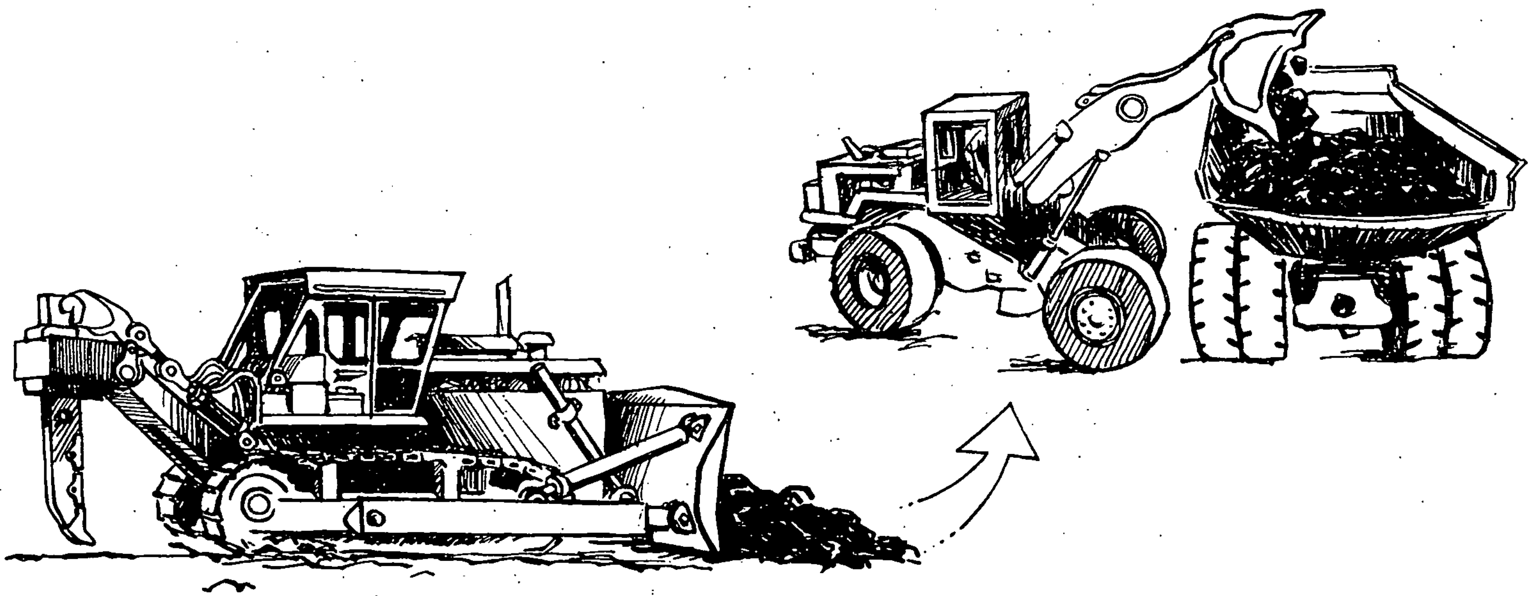


Figure 12. Schematic of a Front-End Loader-Truck Combination

Scrapers

The scraper has been widely accepted at surface mining operations throughout the country. They have proved to be extremely versatile pieces of equipment. Currently in the west most scrapers are used primarily for topsoil removal and reclamation work. They are finding additional utilization for haul road construction, some stripping, especially when topographic variations must be leveled in front of the dragline, and for thin seam removal.

The scraper is both a loading and hauling unit in one. Although, in many cases, scrapers have a higher cost per yard than other combinations of loading and hauling equipment, their low capital cost and extreme flexibility make them desirable. They are essentially a short haul machine as indicated by their poor gross weight to tare weight ratio.[8] Studies have indicated that for haul distances up to about 4000 feet one way, scrapers are more economical to operate than bottom dump coal haulers and end loaders. Studies also indicate that they begin economic operation at haul distances as short as 300 to 400 feet. Figure 13 shows a comparison, cost vs. distance, for dozers, front-end loaders, and scrapers.

Scrapers have a distinct advantage over other haulage units in terms of gradability. Most scrapers have the ability to negotiate steep adverse grades while loaded. They are also capable of descending steep grades safely while loaded. This allows the construction of steep ramps which minimize haul road distances.

There are several types of scrapers available on the market from several different manufacturers. Among the different types, two are particularly suited for thin-seam removal and have found the greatest acceptance in western operations. These are the single-engine elevating scraper and the tandem-powered elevating scraper. They have a distinct advantage over the open-bowl scrapers in that they use a revolving paddlewheel assembly to shovel material into the scraper bowl. An open-bowl scraper, in order to load, must shove the material into the bowl. Fragmented coal is a dead, uncohesive material that tends to push out ahead and around the bowl of an open-bowl scraper resulting in longer loading times and smaller loads.

The single-engine elevating scraper is used at surface mines throughout the west. This type of scraper works best in unconsolidated material; hence, coal must be ripped prior to being loaded and hauled. Scrapers are short-haul machines, and therefore the coal is usually moved from the thin seam to a convenient transfer point. The location of this transfer point varies upon the position of the coal seams, topography, pit ramps, and type of major coal loading machine.

If the thin seam is located near the surface, the coal would probably be hauled to the surface, dumped at a transfer station, then rehandled into coal haulers for the trip to the preparation plant. This type of hauling would also be the case if the topography or location of existing haul road ramps made hauling to the surface economically viable.

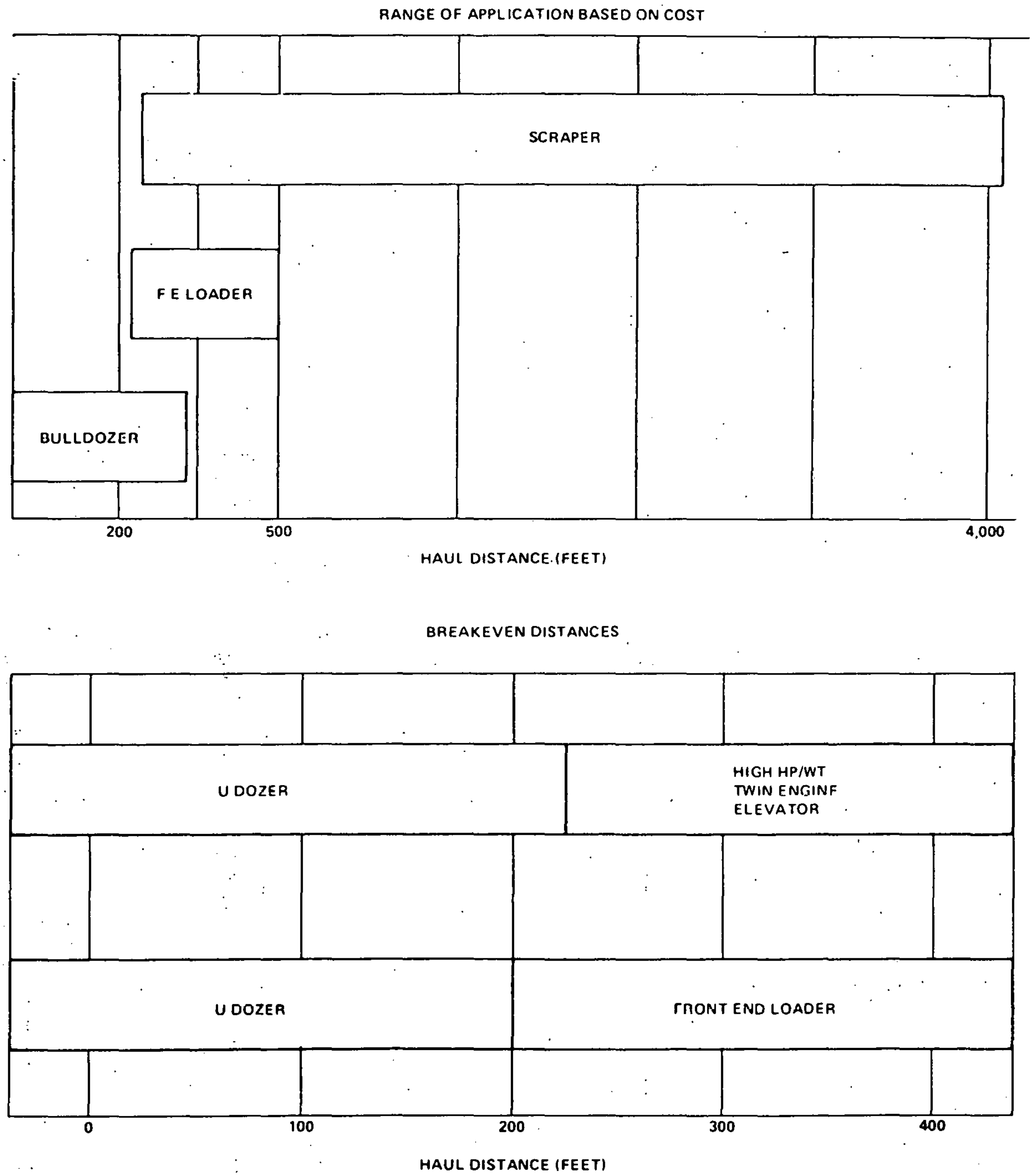


Figure 13--Economic Application Distances for Dozers, Front-end Loaders, and Scrapers.[9]

In many cases, such as the Decker mine, the thin seam is located very close to the main seam. The economic alternative is to haul the coal down, dump it on the main seam, and load it into coal haulers using the main coal loading machines, either a shovel or a front-end loader. Using the scraper to haul to the lower seam is also advantageous because removing the material for the ramp down can be accomplished with the dragline at a very low cost. This cost does not have to be added to the thin seam removal cost because the stripping required for the ramp construction also uncovers the lower coal seam. An additional advantage of hauling down to the lower seam is reduced cycle time and shorter ramps. The units would be loaded going downgrade, thus allowing higher speeds. The grade of the ramps would be determined by the static and dynamic braking systems of the hauling units.

A standard Caterpillar 633D elevating scraper with a full 37.5 ton payload can go down a 20% grade with 5% rolling resistance at 17 miles per hour utilizing only the engine retarder. In comparison, going up the same grade with the same payload, the maximum speed the machine could attain would be 2.5 miles per hour. This does not make a large variation in cycle time since with the poor gross weight to tare weight ratio the maximum speed attained going up grade empty would be 4 miles per hour. The retarding speed for the empty scraper going down grade would equal the loaded retarding speed of 17 mph. The difference in cycle time for a 500-foot grade would be 51 seconds.

The cost of loading and hauling the thin coal seam with scrapers varies with several factors, most notably cycle time and load size. It is possible to modify most scraper bowls so that the rated tonnage of coal can be hauled. For example, the Cat 633D has a standard rated capacity of 34 loose cubic yards with a payload of 37.5 tons but could be modified with side boards and elevator extensions to haul up to approximately 45 loose cubic yards of coal. By increasing the payload, the production increases thus decreasing the cost per ton of coal.

The cost of loading and hauling coal with scrapers is going to vary with each separate operation. It is largely dependent upon cycle time which in turn depends directly upon grades, haul distances, type of fragmentation, and many other variables. For purposes of comparing thin-seam removal techniques, a single engine Caterpillar 633D elevating scraper was used to determine scraper production and costs. The production and costs were calculated for both a standard 633D with a 34-cubic yard bowl, hauling a 28-ton payload of coal, and for a modified 45 cubic yard with a 37.5-ton payload.

In determining the production of the scrapers in tons per hour, the following equation was utilized:

$$TPH = \frac{(60)(CAP)(AVAIL)(EFF)}{CT} \qquad (22)$$

where: TPH = Production on tons per hour
CT = Cycle time in minutes
EFF = Efficiency in decimal form
AVAIL = Availability in decimal form
CAP = Scraper capacity in tons

The cycle time includes the haul, return, load, dump, and maneuver times. These times must be calculated separately for each machine being utilized using its performance specifications. In order to obtain the cost per ton of coal, the following equation was utilized:

$$\$/\text{ton} = \frac{\text{O\&O}}{\text{TPH}} \qquad (17)$$

where: $/ton = cost in dollars per ton
O&O = Owning and Operating cost in dollars per hour
TPH = Production in tons per hour

The job conditions and calculations are described in Appendix G.

The standard 633D scraper has a production capacity of 258 tons per hour at a cost of $0.24 per ton of thin seam coal. The modified machine could produce 345 tons per hour at a cost of $0.18 per ton of thin seam coal.

Assuming a production of about 250 tons per hour, two standard single-engine elevating scrapers could keep up with the ripper production capabilities of one D9H dozer. In fact, if a property was producing 5,000,000 tons of coal a year with 10% as a thin seam, the two scrapers could remove that coal in only 125 shifts. For a one-shift per day, five days a week coal loading operation, the required production could be achieved in 25 weeks. Thus, a single standard elevating scraper could move all of the required production in only 50 weeks per year.

The actual cost per ton of thin seam for a single engine scraper must include the cost of ripping to make an accurate comparison. Since the cost of ripping was previously calculated at approximately $0.09 per ton, the standard single-engine scraper cost would be $0.33 per ton. If a modified bowl was used on the scraper, the cost could be as low as $0.27 per ton.

The use of twin-engined elevating scrapers enable operation in more difficult conditions because of the added horsepower and 4-wheel drive. To remove the ripped coal with a twin-engined elevating scraper such as the Wabco 333FT would cost $0.24 per ton. When the ripper cost is included, the resulting cost is $0.33 per ton. This calculation assumes a partially modified bowl carrying 38 ton or 45 cubic yards. The production for this machine would be approximately 390 tons/hour.

Even though the twin-engined scraper is faster as indicated by higher production capabilities, the cost per ton of coal is significantly greater than comparably sized single-engine machine. This cost increase is caused by the additional purchase cost and greater maintenance cost of the twin-engine machine. These additional costs increase the owning and operating cost of the twin-engine machine by almost 50% over the costs of the single-engine machine.

A relatively new concept in coal loading and hauling has recently received attention. This concept utilizes twin-engine elevating scrapers such as the Wabco 333FT to rip, load, and haul the coal. Ripping the coal directly with the scraper would mean that the entire thin-seam removal could be accomplished with a single machine. Not requiring the purchase of an additional dozer to rip the coal effectively reduces the capital outlay of the thin-seam removal.

This method of thin-seam removal has been tested by the Wabco Construction and Mining Equipment Company at several mines including Peabody's Black Mesa mine in Arizona.(9) According to Wabco, this method is economically viable but does have some problems that need to be resolved for total success. The problems quoted by Wabco were: 1) coal retention in the scraper bowl, 2) dust generated by the elevator and tires, and 3) breaking ripper teeth. They felt that problems one and two could be easily solved by: 1) installing baffles in the bowl to keep the broken coal from sloughing out, and 2) either by pre-watering the coal or by installing a dust collection system on each scraper. The problem with ripper teeth strength is currently being studied with some new, stronger teeth being developed.

For a comparative cost of this method of coal removal, the production of a Wabco 333FT scraper was calculated using the same pit design as used for the single-engine elevating scraper. The actual calculations are found in Appendix G. The production capabilities were calculated for a standard scraper with the addition of sideboards and elevator extensions that would require no major body modifications. Wabco states that with these modifications the capacity can be increased from 34 cubic yards to 46 cubic yards thus allowing a payload of 38 tons of coal. The calculated production was 375 tons per hour at a cost of $0.36 per ton of coal. It should be noted that this cost was based on an owning and operating cost that was increased by 40% for increased maintenance costs and lower machine life. This was the same percentage increase that was calculated for a Caterpillar D9H ripping coal.

Assuming that no modifications were made to the scraper, it would be capable of carrying 28 tons of coal per trip. While not providing significant speed increases, the production of the machine would drop to about 285 tons per hour at a cost of approximately $0.47 per ton of thin-seam coal. This figure shows the advantage of modification to the scraper bowl thus making better utilization of the machine capabilities.

The twin-engine elevating scraper does have some definite advantages over its single-engine counterpart even if it does not rip the coal. These advantages stem mainly from its high horsepower-to-weight ratio and 4-wheel drive traction. In poor underfoot conditions and on steep grades, these factors allow it to produce where single-engine scrapers or end-loader truck combinations would be down. These factors could ultimately play a significant role in the decision whether or not to utilize a twin-engine or a single-engine machine.

Ramping

Removing the thin seam requires that a haul road be built either to the surface or down to the lower seam. The decision regarding where to build the ramp depends upon the factors previously discussed with loading and hauling. An additional factor that must be discussed is the type of overburden stripping equipment utilized at the property. If the mine is a truck-shovel stripping operation, the coal will most likely be moved directly to the surface and preparation plant since overburden haul road ramps are an integral part of the pit design. Hence, they require no additional overburden removal or rehandle for extra coal handling ramps.

If a dragline is the prime stripping machine, and depending upon the thickness of the seam and its location in the overburden, the coal may or may not be hauled directly to the surface. After visiting several western stripping operations it appears that thin seams approximately two feet thick were hauled down to the main seam and later rehandled. However, seams approximately four feet thick were normally loaded out and hauled directly to the preparation plant.

Building an in-pit ramp down to the main seam has several advantages. The cycle times are faster for loaded units hauling down-grade rather than up-grade. Also, if the coal is dumped on the main seam for later rehandle, as is often the case with scrapers, the loading equipment need not be moved to perform the coal rehandle task.

The major benefit of building in-pit haul roads down to the lower seam is that the material for the ramp can be economically removed by the dragline. The cost of digging an in-pit ramp would not be charged against the thin seam because it is uncovering the lower seam. Also, because these are temporary ramps that will be removed during the next dragline pass, there would not be a maximum grade restraint imposed by state and federal strip mine laws. In this way, steep ramps greater than 8% for scrapers or end-dump coal haulers could be utilized.

The only ramping cost that would be charged out against the thin seam would be the first ramp at the beginning of a new pit. The dragline would first work a section uncovering only the thin seam; because the lower seam is still covered with parting, the thin seam would have to be removed and stockpiled allowing the dragline to move back and uncover the lower seam.

In most cases the thin seam would be moved down to the haul road elevation. To move the coal directly to the surface would require a haul road ramp up the highwall of the pit. A highwall ramp, if constructed using the dragline, would add a sizable cost to the thin coal. The cost relationship for building a highwall coal removal ramp can be computed using the same equation utilized for the dragline ramp previously discussed. The cost per ton of coal for different length pits and overburden thicknesses is shown in Figure 14. Note that the graph in Figure 12 is calculated for a 10% ramp. To obtain a cost per ton of thin seam coal for other ramp grades, divide the indicated cost per ton by the ratio of the desired ramp grade over given ramp grade. In addition to the initial digging cost the ramp material would have to be re-

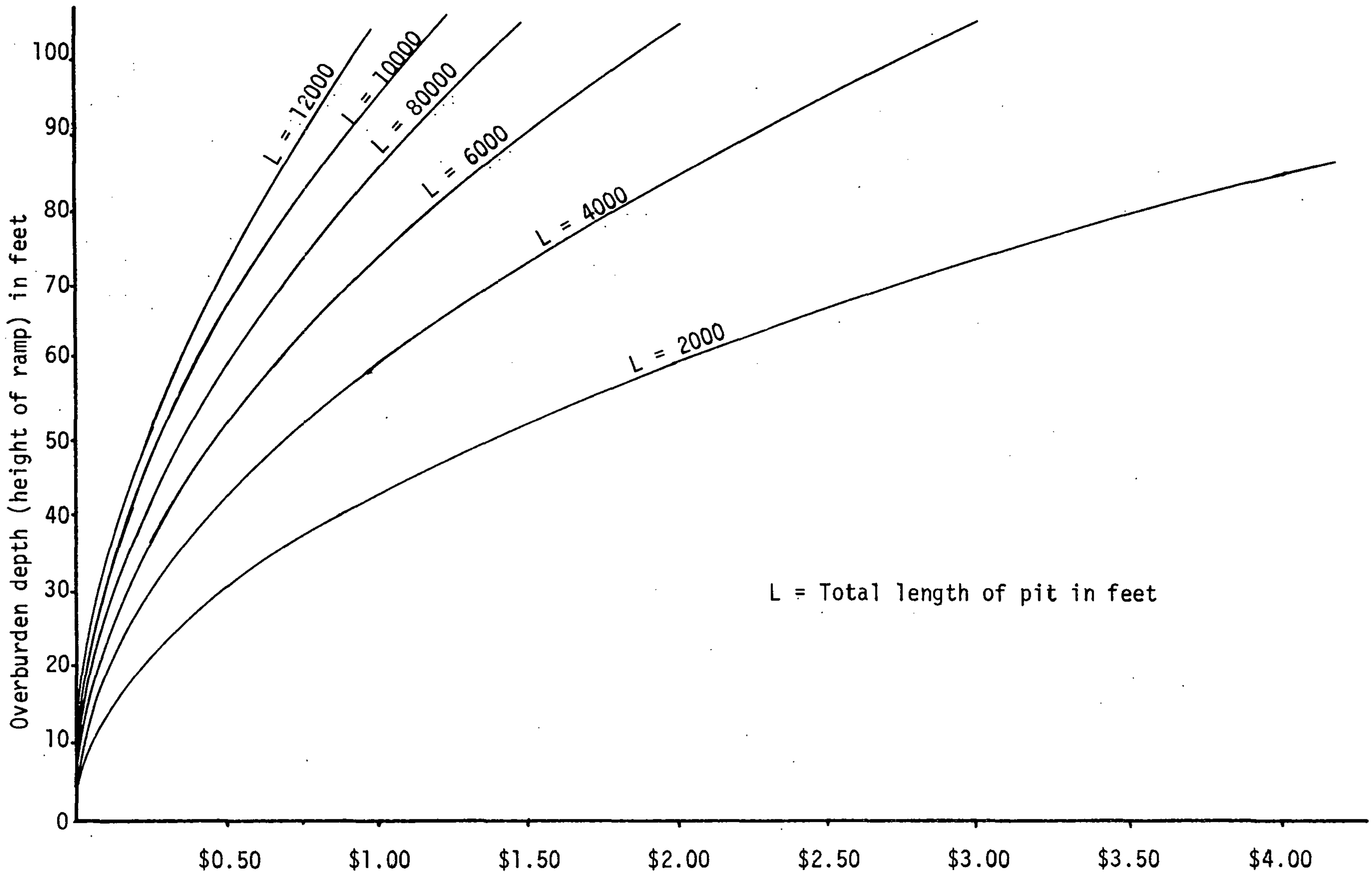


Figure 14--Cost Curve for a 10% Highwall Ramp for Cost Removal of a 1-foot Thin Coal Seam

handled later. The rehandle cost is discussed later in this section.

Besides the high cost, the highwall side ramp method of removing the coal poses additional problems. One of these problems is that coal piled on the highwall side of the pit is not readily accessible to the main spoil-side haul roads. This means additional haulage cost for transfer to the preparation plant.

When moving the coal down to the haul road elevation, the down ramp can be easily and economically constructed. The dragline builds the ramp by dumping spoil material in the proper location while uncovering the thin seam. Since the dragline is effectively stripping for the lower seam, the cost of moving the ramp material would not be assessed against the thin seam. However, after the thin coal is removed, the ramp must be rehandled to expose the lower seam. The amount of rehandle depends upon the grade of the ramp and the thickness of the parting.

The percentage of rehandle can be computed by using 'the average end method'[10] for computing the volume of the ramp, then dividing the volume by the combined volume of the overburden and parting. This percentage figure can be used in the previously discussed formula for dragline rehandle costs to obtain a cost per ton of thin seam coal.

As an example, ramping down at 20% from a 1-foot thin seam covered with 40 feet of overburden and 40 feet of parting between it and the lower seam would require a 0.29% rehandle with a cost of $0.05/ton of thin seam coal. Note that for thicker seams this amount would be reduced. Refer to Appendix G for an outline of the calculations.

Coal ramping costs are relatively small when compared to the total cost of handling and hauling. Since only the cost of the first ramp is assessed against the thin seam, the ramping cost can be reduced by building steep ramps, thus minimizing the amount of rehandle required. The ramping cost per ton of thin seam coal is inversely proportional to the grade of the ramp. Hence, if the grade is doubled, the cost is halved.

The ramping cost per ton of coal is therefore inversely proportional to the coal depth and the grade of the ramp. This partially explains why, at various western operations, the thinner seams are hauled down to the lower seam and rehandled. At the same time, the ramping costs for the thicker stray seams are reduced such that they may economically be removed directly from the pit.

The Hydraulic Excavator/Backhoe

With the recent development of the large hydraulic excavator, commonly called a backhoe, the machine has gained popularity as a coal loading machine. The new large machines have proven to be very versatile and are capable of handling tonnages that rival many front-end loaders. The backhoe, like the front-end loader, is usually employed in coal seams that are less than ten feet thick, while large coal loading shovels are usually employed in the thicker seams.

The backhoe is sometimes selected over the front-end loader when the operator wants to take advantage of: 1) the backhoe's greater breakout force allowing it to dig tougher material, 2) the backhoe's ability to selectively excavate allowing it to recover a coal seam while spoiling a thin parting within the coal seam, 3) the backhoe's ability, because it is track mounted, to operate in areas where tire wear and maintenance are excessive.

Two coal mining operations were visited that employed backhoes to excavate and load coal. At one end of the operations, the backhoe was selected because some of the coal seams had a thin parting within the coal seam. The backhoe is used to excavate and load the coal while separating out the impure parting and spoiling it in the pit. The coal seams are 5-6 feet in thickness and the parting within the coal seam is only a few inches thick. The backhoe had enough reach to stow the small volume of parting material within the pit without the aid of auxiliary equipment.

The other operation observed selected a backhoe to excavate and load a thin coal seam and then to excavate and load a very tough interburden material. This is loaded into trucks for stowing within the pit. The interburden was approximately ten feet thick. The machine was capable of performing both operations satisfactorily.

In both operations the coal was fragmented before it was loaded out. One employed ripping as the coal seam was thin (three feet thick), and the other operation lightly shot or "bumped" the coal. However, it is felt that some coals could be loaded out without fragmentation.

An equation can be developed to determine the cost per ton of coal being loaded with a backhoe. The following equation can be utilized to determine backhoe production:

$$TPH = (MAXLCY)(DEN)(CF) \qquad (16)$$

where: TPH = Production in tons per hour
MAXLCY = Maximum production as obtained from the manufacturer
DEN = Coal denstiy in tons per loose cubic yard
CF = Sum of correction factors in decimal form

The value of MAXLCY can be obtained from the manufacturer's production specifications for each type of machine. Once this figure is obtained, it is reduced using the correction factor, CF. The correction factor is the sum of many factors including material type, efficiency, availability, loading technique, etc., that would increase or decrease productivity. This production volume is then converted to "tons per hour" using the density factor.

The cost per ton of coal is then calculated using:

$$\$/\text{ton} = \frac{O\&O}{TPH} \qquad (17)$$

where: $/ton = cost per ton of coal
O&O = Owning and Operating cost in dollars per hour
TPH = Production in tons per hour

To obtain a working cost per ton of coal for comparison of the different loading methods, the backhoe production was obtained from an operation using a Demag H-111 backhoe to excavate and load coal. Using this information, it is estimated that a Demag H-111 can load 1250 tons of fragmented coal per hour at a cost of $0.07 per ton. The same machine in unfragmented coal produces only 940 tons of coal per hour at a cost of $0.09 per ton.

Dragline Removing Coal

This method, advantages, and disadvantages of removing the thin seam coal with a dragline have been discussed in previous sections, and therefore need not be discussed here. However, it is appropriate at this time to examine the cost of employing this coal loading method.

When a dragline is used to selectively remove the thin seam coal and place it for later recovery, the productivity of the dragline during this operation is decreased an estimated 75%. To determine the dragline cost per ton of thin seam coal recovered, the following expression is used.

$$CRCY = \frac{\frac{O\&O}{(CYH)}}{0.75\ (DEN)} \qquad (23)$$

where: CRCY = The dragline cost per ton of coal recovered
O&O = The dragline owning and operating cost per hour
CYH = The dragline's average production in overburden in cubic yards per hour
DEN = Coal density in tons per cubic yard

Using average dragline costs discussed in previous sections, it is found that a dragline can remove coal and place it on the highwall at $0.27 per ton. When the cost of loading the coal onto a truck with a front-end loader is added, it appears that this is an expensive method of recovering thin coal seams.

As before, however, the cost of recovering the thin seam must be the additional cost incurred because it is recovered and not spoiled. The critical part of understanding the problem is to determine this difference between the dragline spoiling the coal and the dragline selectively removing the coal and placing it for later recovery. The added cost of the dragline recovering the thin seam coal is $0.07 per ton as shown in Appendix G. This cost, plus the front-end loader cost of loading the coal into trucks, is $0.22 per ton. Figure 15 is a sketch of this operation.

Coal Removal Results

The simplest method of evaluating the various thin-seam removal techniques is by comparing their cost per ton for the coal recovered. Table III shows a breakdown of conventional coal removal methods and their associated costs. The most cost effective method for thin-seam removal is utilizing the dragline to recover the thin seam. However, this method can only be used if the dilution of the thin-seam coal is tolerable. This method has a total cost of $0.22 per ton. The next most cost effective methods are the modified single-engine elevating scraper and the backhoe loading unshot coal. Both of these methods have a total cost per ton of $0.30. A scraper method has an additional advantage besides cost in that most mines have an existing fleet of these machines. They could be modified and used for thin seam removal thereby eliminating any additional capital expense. If a capital outlay was required, they would have the lowest purchase cost of any of the conventional equipment. They could also provide numerous other duties at the

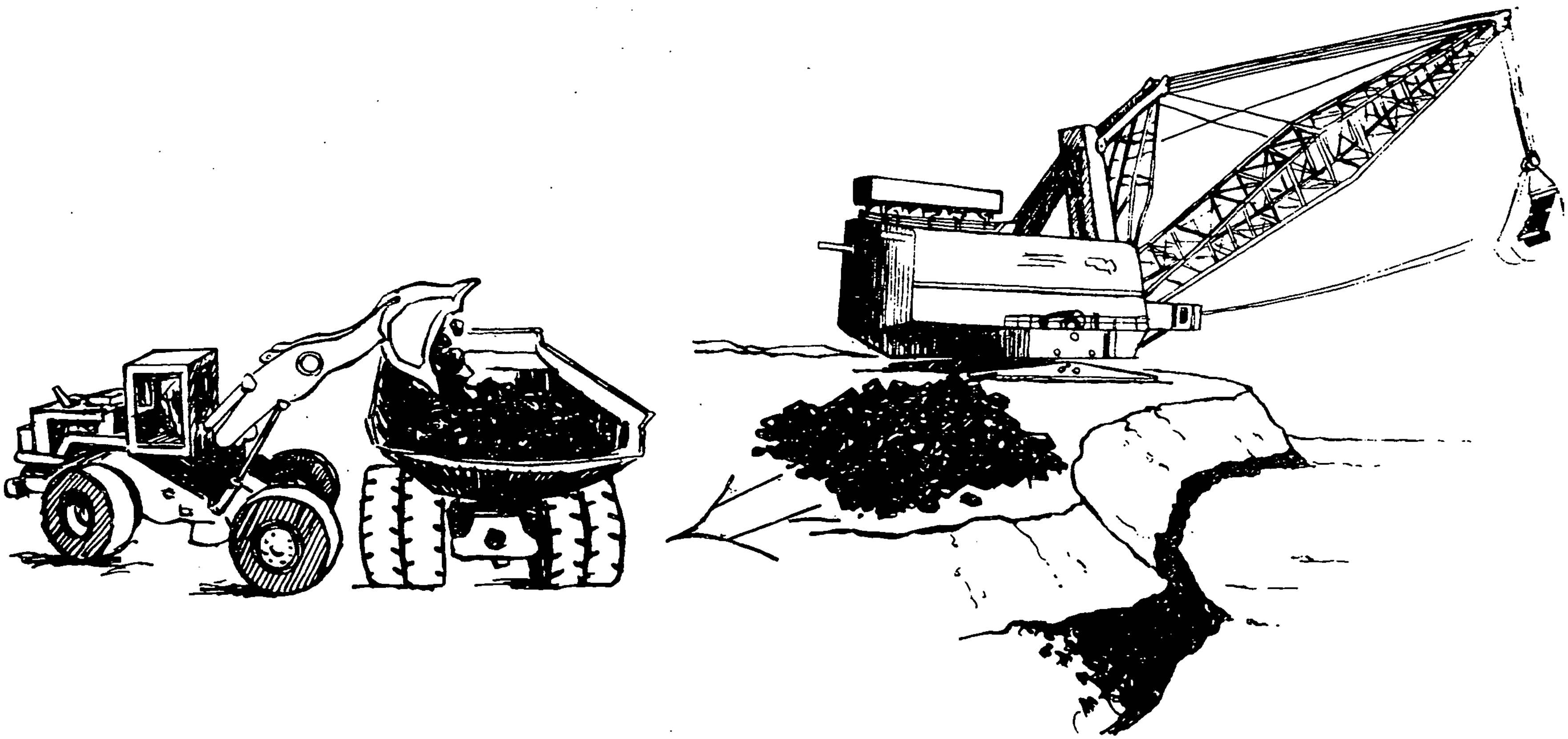


Figure 15. Dragline Removing the Thin Seam Coal to be Loaded Later onto Trucks with a Front-End Loader

<table>
<tr><th colspan="2">Method</th><th>Fragmenting</th><th>Piling</th><th>Loading</th><th>Hauling</th><th>Ramping*</th><th>Total</th></tr>
<tr><td rowspan="2">Front-End Loader & Trucks</td><td>Dozer Piles</td><td>0.09</td><td>0.08</td><td>0.15</td><td>0.16</td><td>0.05</td><td>0.53</td></tr>
<tr><td>Direct from Seam</td><td>0.09</td><td colspan="2">0.25</td><td>0.16</td><td>0.05</td><td>0.55</td></tr>
<tr><td rowspan="4">Elevating Scrapers</td><td>Standard Single-Engine</td><td>0.09</td><td colspan="3">0.24</td><td>0.03</td><td>0.36</td></tr>
<tr><td>Modified Single-Engine</td><td>0.09</td><td colspan="3">0.18</td><td>0.03</td><td>0.30</td></tr>
<tr><td>Twin Engine Loading & Hauling</td><td>0.09</td><td colspan="3">0.24</td><td>0.03</td><td>0.36</td></tr>
<tr><td>Twin Engine Ripping Loading & Hauling</td><td colspan="4">0.36</td><td>0.03</td><td>0.39</td></tr>
<tr><td rowspan="2">Backhoe</td><td>Loading "Bumped" Coal</td><td>0.18</td><td colspan="2">0.07</td><td>0.16</td><td>0.05</td><td>0.46</td></tr>
<tr><td>Loading Unshot Coal</td><td colspan="3">0.09</td><td>0.16</td><td>0.05</td><td>0.30</td></tr>
<tr><td>Drag-Line</td><td>Recovering Thin-Seam Coal</td><td>0.07</td><td colspan="2">0.15</td><td colspan="2">--</td><td>0.22</td></tr>
</table>

Mean = $0.39

Table III -- Removal Costs for Coal in Thin Seams Expressed in Dollars per Ton of Thin Seam Coal

*Ramping cost assumes a 2-foot coal seam in a 10,000 feet long pit. Ramp height equals 40 feet with 10% grade for trucks and 20% for scrapers.

mine thus providing maximum machine utilization.

The twin-engined elevating scraper also has a total cost per ton of $0.36 when loading and hauling ripped coal. Given difficult underfoot conditions, this would provide a workable answer for thin seam removal. They would also be capable of performing numerous other functions at the mine and have a reasonably low capital cost.

Ripping the coal with the twin-engined elevating scraper also appears to be economically feasible with a cost of $0.39 per ton. This method would eliminate the cost and scheduling problems of ripping the coal with a dozer. The entire process would be accomplished using a single machine. This technique appears to have a definite advantage when the time factor is included. Scheduling problems would be minimized because only one machine is concerned; plus, there would not be a time delay between uncovering the seam and its actual removal. This machine would enable the thin-seam removal to stay right up with the stripping operation.

The calculations performed in this report indicate that the front-end loader and truck method of coal removal is the least cost effective. The cost of loading from dozer piles is $0.53 per ton, and direct loading costs $0.55 per ton. These high costs are a result of longer loading times and the high capital cost of the equipment. These findings generally agree with other studies that indicate front-end loader-truck combinations are more expensive to operate than scrapers when short haul distances are involved.

The capital costs of the truck-loader method are also the highest of the conventional methods studied. If all new equipment were to be purchased, three pieces of equipment would be involved, two trucks and one loader. The capital outlay for this equipment could easily exceed one million dollars. This is almost triple the outlay required to purchase a twin-engined elevating scraper. The front-end loader-truck method would also provide the largest scheduling problems for the thin-seam removal because of the amount of equipment involved.

In addition to the stated costs of removing the thin seam, one additional cost must be considered. This is the rehandle cost for transfer from the main seam to preparation plant. This cost varies greatly according to the type of coal handling equipment utilized on the major seam and the haul road distance to the preparation plant. The cost is generally considered to range from $0.20 to $0.40 per ton, depending on the preceding factors.

Using the average price for the thin-seam removal costs, $0.39 per ton, the total coal removal cost would range from $0.59 to $0.79 per ton of thin seam. This cost, when added to stripping and preparation cost, must provide a profit to make thin-seam removal attractive to mine operators.

NEW AND INNOVATIVE COAL REMOVAL METHODS

NEW AND INNOVATIVE COAL REMOVAL METHODS

Introduction

Presently several western coal operators are testing new and innovative methods of coal removal utilizing special mining equipment. Much of the special mining equipment consists of machines capable of continuously excavating and loading coal directly into haul trucks. These machines have several advantages when used to recover a thin seam: 1) Because they operate continuously, they are capable of removing the thin seam quickly. 2) They are very mobile and can be moved easily and quickly from one mining area to another. 3) They excavate and load unshot, unripped coal and thus this additional operation and cost are eliminated.

Although there are several different types and designs, these special mining machines can be categorized into two groups, the bucket wheel excavator and the continuous excavator-loader.

The Continuous Excavator-Loader

The continuous excavator-loader utilizes a large rotating ripper head to fracture and loosen inplace coal. The ripper design augers the loosened coal to the center of the machine. The coal is then either windrowed and left on the ground or picked up by the machine's conveyor system which transports the coal to the rear of the machine for dumping into a haulage truck.

Two models of the continuous excavator-loader were observed in operation. The following is a discussion of the two models.

The CMI Finegrader

The CMI finegrader is a continuous excavator-loader which has been adapted for use as a surface-mining machine. The machine is capable of excavating unshot, inplace coal and loading it into haul trucks in a continuous operation. The finegrader which is manufactured by the CMI Corp. of Oklahoma City, Oklahoma, was originally designed for use by the construction industry. However, the machine has proven to be effective in coal removal as well as earth excavation.

The finegrader is mounted on three tracks and requires only one operator. The cutter assembly is mounted behind the front track and is hydrostatically driven. The cutter head is comprised of an auger with carbide tipped teeth mounted on it. The teeth cut and break out the coal allowing the auger to move the broken coal to the center of the machine. There the coal is pulled onto a conveyor which moves the coal to the rear of the machine. The coal is then either dumped on an 180° swing arc loading conveyor for loading haul trucks or windrowed behind the machine for pickup by front-end loaders or scrapers.

The finegrader has a variable speed auger-cutter which allows the coal to be broken in the desired size. This eliminates the need for a primary crusher. The machine is equipped with controls that allow the cutting depth to be maintained either manually or automatically. The automatically maintained cutting depth is accurate to 1/8 inch.

The first finegrader ever used for coal removal was the CMI, Model TR-225. It was employed at a small coal mining operation in north central Oklahoma. The operator elected to use the finegrader in order to eliminate the need of a crusher. The machine proved successful at that operation and has since been employed at other coal mining operations, including the Decker mine which uses the machine to recover its thin coal seam.

At the Decker mine there is a two-foot thick seam of coal separated from the 52-foot thick main coal seam by two feet of shale parting. Originally the thin coal seam was ripped by a dozer and removed with scrapers. However, this method was not satisfactory. The undulating parting made it difficult to rip the coal without getting into the parting. This caused dilution of the thin seam coal. To overcome this problem, the finegrader was employed. It is able to breakout the coal without cutting into the parting.

The machine is a Model PR-375 which is similar to the model used at the Oklahoma mine. The PR-375 makes a 9-foot wide cut with a depth of cut which can be varied from 0 to 6 inches. The machine at Decker does not load the coal but instead windrows the coal so that it can later be picked up with elevating scrapers. Loading time is considerably less when the scrapers pick up the windrowed coal rather than using the finegrader to load trucks. The scrapers haul the coal to the major seam where it is dumped.

This system requires rehandle of the thin seam coal and as will be seen, is rather expensive. Minimal equipment tie-up is involved since the windrowed coal may be picked up as the scrpaer is available. Since the thin seam represents only 4% of the total mine production, the low productivity rate of the PR-375 is acceptable. Direct truck loading requires continuous attendance of extra labor and equipment.

The windrowing and pickup concept is similar to that used with continuous miners in underground mines. The coal is dumped to allow continuous extraction and hence optimal use of the miner. Pickup and loading is rapid thus optimizing use of the loading and hauling machine. Unfortunately, optimizing each machine use need not optimize (minimize) costs.

The machine performs well at this thin seam removal operation. The availability of the machine is adequate and maneuverability is good. Dust is not a problem since the top of the coal is normally sprayed with water to keep truck haulage dust down. The personnel at Decker feel that a drawback to the machine is its low productivity rate and the fact that the machine must make four passes to remove the two-foot coal seam. They rate the machine at approximately 300 TPH.

Another mining operation employing the CMI finegrader is the Dundee Coal Reclaimers, Ltd., of Natal, South Africa. The company is using a TR-225M to reclaim anthracite fusion dust. The machine was selected because of its ability to accurately control its cutting depth. The anthracite coal found at the mine is in seams of about 7 feet in thickness. Within the seams are thin layers of carbonaceous shale. Because the finegrader's cutting depth can be accurately controlled, it can extract the coal without cutting into the carbonaceous shale. This prevents dilution of the high quality coal.

The machine removes the coal in eight-inch lifts except when the cut is above a shale layer. Then the cut is reduced to within 1/2 inch of the shale layer. The shale layers are also removed with the finegrader. The machine is used both to excavate the material and to load it into trucks. The machine has been averaging over 200 TPH and the coal recovery has been excellent.

Dundee, which is small mining company, is pleased with the operation of the CMI finegrader. Since it went into operation, they no longer need to crush or wash their coal. They state that in the type of operation where the seams are thin or a layer of impurities exist in the seam, the finegrader is the ideal machine for coal removal.

The Easi-Miner

The Easi-Miner is an all-hydraulic continuous surface mining machine. The machine is designed to rip inplace coal and load it directly into haul trucks. The machine is manufactured by the Huron Manufacturing Corp. of Huron, South Dakota. The company has considerable experience in designing continuous slip-form paving machines and continuous grade excavators used in the construction industry.

The company has designed various sizes of the Easi-Miner. The smallest is its prototype machine which is in operation at a North Dakota lignite mine. The mine operator there reports that the average production of this machine is 500 TPH. The largest machine is the Easi-Miner Model 1224. It is rated at 1800 TPH by the manufacturer. Huron also advertizes that it can design and build machines capable of producing 10,000 TPH or more if a buyer desires such a machine.

Basically, the Easi-Miner is a machine equipped with a rotating cutter head that breaks up the coal and a conveyor system that transports the coal from the cutter head and loads it directly into a trailing haul truck. The cutter head is equipped with replaceable, tungsten carbide tipped teeth which are mounted on long steel shanks. The machine can cut coal to a desired size by varying the operating speed of the machine. This eliminates the need of a primary crusher. The Easi-Miner is crawler mounted and requires only one operator.

The machine nominally does not remove the total coal seam thickness in one pass since the maximum cutting depth of the machine is usually less than the seam thickness. Instead, the coal seam is removed in lifts. Typically, the Easi-Miner will make a cut of a given length in a section of the pit and then turn around and make another cut parallel and adjacent to the first cut. The width and depth of the cut depends on the design characteristics of the particular model being used. A haul truck will parallel the Easi-Miner so that the coal being removed is conveyed into the haul truck. The operation will proceed in this manner until the first lift has been removed the full width of the pit. The second and remaining lifts will be removed in the same manner as the first lift until the total seam of coal has been removed.

Observation of the prototype Easi-Miner in operation was made at Knife River Coal Mining Co.'s Gascoyne mine located near Bowman, North Dakota. The Easi-Miner Model 916 at the Gascoyne mine makes approximately a nine-foot wide cut that varies from 0 to 18 inches deep. The machine produces an average of 500 TPH.

The mine personnel are generally pleased with the operation of their machine. According to them, the maintenance of the machine has been no worse than any of their other hydraulic machines. The machine, like most prototypes, has a few "bugs" but these have been worked out, and since then, the availability of the machine has been good. Dust, which often is a major problem with continuous coal mining machines, is not a problem at the Gascoyne mine. The lignite there is very wet (it averages 42% in moisture) and somewhat sticky and thus very little dust is generated. The only fault the mine personnel found with the Easi-Miner is its lack of mobility. The turning radius of the machine is such that the machine must be jockeyed back and forth several times to turn it around in the 120-150 foot wide pits.

The Easi-Miner at Gascoyne is used for a variety of operations besides excavating and loading lignite. The machine is used at times for topsoil removal. Two years ago, it was used to remove frozen topsoil and the machine worked fine. However, last winter there was a lot of water in the topsoil before it froze, and the machine was not able to excavate this frozen material. The machine has also been used for ditching, building and maintaining haul roads, parting removal, and leveling spoil peaks. It performed well in all of these operations.

Because of the success of the Easi-Miner at Gascoyne, another Easi-Miner has been tried at an operating coal mine. Wyodak Resources, Inc., operated an Easi-Miner at its Wyodak mine near Gillette, Wyoming for several months.

At the Wyodak mine, the 80-foot thick sub-bituminous Smith seam is being mined. As is the case at the Rawhide mine which is mining the same seam, the recovery of the bottom two feet of the Smith seam is a problem. The material under the coal seam is unusually soft, wet clay. Because of this, the bottom two feet of coal is left to provide a firm surface for the traditional loaders and coal haulers.

The Rawhide mine uses a dragline to recover the bottom two feet of coal after it is no longer needed to support coal haulage. The dragline is positioned on solid coal and casts out its bucket to recover the coal. This method is costly since the capital investment required to purchase a dragline is very high. The Rawhide mine can economically recover the coal using this method only because it already had a dragline at the mine for utility work. At the Wyodak mine the bottom two feet of the coal seam is left in the pit because the coal could not be economically recovered using conventional mining methods.

However, in November of 1977, Wyodak initiated a three-month pilot project to evaluate the feasibility of using an Easi-Miner to recover the bottom two feet of the coal seam. The machine used was a Model TE-475. This particular machine makes a 10-foot wide cut and can vary the depth of cut from 0-16 inches. The low bearing pressure exerted by the machine allowed it to recover the bottom coal without becoming stuck in the soft clay underlying the seam. The Easi-Miner excavated the coal and loaded it into haul trucks which were kept on the two feet of coal adjacent to the Easi-Miner's cut. The machine was used to recover 110,000 tons of the bottom coal. Records kept during the operation showed that the machine averaged 577 tons per hour at a cost of $0.077 per ton. The availability of the machine was over 90%.

The success of the pilot project prompted Wyodak to order a large production machine from Huron. The machine will primarily be used for bottom coal recovery. The machine ordered is the Easi-Miner Model 1224. This model makes a 12-foot cut that varies in depth from 0-24 inches and will produce 1800 TPH of coal. The mine received delivery of the machine in September of 1978. Production of 3000 TPH has been attained.

It should be noted that the same Easi-Miner Model TE475 that proved successful at the Wyodak mine was tested at a mine in Eastern Montana. The coal at that mine, which is also sub-bituminous, proved too hard for the machine to operate effectively.

The Bucket Wheel Excavator

The bucket wheel excavator (BWE) has been part of the U.S. mining industry since 1944 when the Kolbe wheel was put into operation at United Electric's No. 9 mine near Cuba, Illinois. Since that time, large scale application of BWE's in the U.S. has been limited to stripping unconsolidated overburden in central and southern Illinois. Recently, however, a great deal of attention has been focused on the BWE and its ability to excavate and load unshot coal continuously. Presently there are several companies that are in the process of developing a BWE capable of continuously excavating and loading unshot coal.

The Barber-Green WL-50

One such company is the Barber-Greene Company of Aurora, Illinois. The company has been involved with the development of a BWE for several years. As early as 1967, they tested one of their machines at Utah International's Navaho mine near Farmington, New Mexico. There the machine successfully excavated a 10-foot thick seam of unshot, sub-bituminous coal and loaded it into 120-ton haul trucks. During the test, the machine produced at rates up to 1700 tons per hour.

The Barber-Greene BWE has been used successfully on numerous dam and road construction projects. In fact, the machine was initially designed for use on large earth moving, construction projects. However, the success of the BWE at the Navaho mine encouraged Barber-Greene to continue the development of a coal excavating and loading machine.

Barber-Greene makes only one model of BWE. This machine is the Model WL-50 Excavator. This machine's mechanically driven digging wheel is 16 feet in diameter and is 10 feet wide. The digging wheel is mounted on the right side of the machine. There are 12 equally spaced buckets bolted onto the digging wheel. The one-cubic yard buckets have replaceable teeth and a high-strength steel cutting lip. The digging wheel rotates "backwards" so that the buckets cut the bank on an upward rotation. The wheel operates at 5.8 to 6.8 RPM's and makes a maximum cut of 13 feet deep and 10 feet wide.

As a full bucket rotates on the digging wheel, coal falls from the bucket onto a 54-inch internal conveyor. The internal conveyor deposits the coal onto a 60-inch stacker conveyor. The 31-foot stacker conveyor carries the coal up and away from the machine where it falls off the conveyor into haul trucks. The BWE is mounted on three crawlers and has two angling scraper blades, one in front of the forward crawler and one directly behind the forward crawler, that clean the pit floor and direct the loose coal into the path of the digging wheel.

A WL-50 Excavator was demonstrated at North American Coal Corporation's Indian Head mine near Beulah, North Dakota. The machine was being tested in both coal and overburden removal operations. The machine averaged 3500 tons per hour excavating overburden and could load a 120-ton haul truck with coal in 4 1/2 minutes.

<u>The Unit Rig Unimatic</u>

Another of the BWE's being developed for continuous excavation and loading of unshot coal is Unit Rig and Equipment Company's Unimatic. This machine is similar to the Barber-Greene machine in that it is a "backward" rotating BWE. It is a much more versatile machine than the Barber-Green BWE, however. This is because the digging wheel is mounted directly on the front of the machine, and the wheel makes a cut as wide as the width of the machine. This allows the BWE to cut into or out of coal at will without the aid of auxiliary equipment. Also, the loading conveyor is not fixed but can be rotated 120° either side of the machine's center line.

The Unimatic's digging wheel consists of four units each of which is 12' 6" in diameter and 36 inches in width. The total width of the digging wheel is 15 feet. The wheel can be hydraulically raised as much as 2 feet and lowered as much as one foot. The wheel can also be hydraulically rolled up to 5° to either side. This allows the machine to follow the pitch and roll of the coal seam. The optimum cutting depth is approximately 6 feet but depths greater than this can be made.

A moldboard cleans the floor in front of the front wheels and directs the loose material to where it can be picked up by the digging wheel. Two wingboards are located under the machine with one on each side of the moldboard. These can be independently deployed to clean a 3 1/2 foot wide path at the side of the machine. These wingboards direct the loose material into the path of the moldboard which directs the coal to where the digging wheel can pick it up.

There are five conveyors on the Unimatic. Two 42-inch cross conveyors collect the coal at the digging wheel and dump the coal onto the 60-inch main conveyor. The main conveyor transports the coal to the rear of the machine and unloads it onto the 60-inch loading conveyor. The loading conveyor carries the coal to the stinger conveyor which can be raised or lowered to the desired dumping height. From the stinger conveyor the coal is loaded into haul units.

The Unimatic was field tested at the Navaho mine also. The machine's overall performance was good; however, the results of the test have not yet been released by Unit Rig.

The Foster-Miller Forward Rotating BWE

Foster-Miller Associates, Inc., have undertaken a research project sponsored by the U.S.B.M. to design, erect and field test a full scale "forward" rotating BWE. The project is part of a program that the USBM is conducting on methods of improving the productivity of surface mines while reducing capital investments costs.

A "forward" rotating BWE is one where the buckets cut into the bank on a downward rotation. The buckets are reversed on the digging wheel and the wheel rotates opposite that of a conventional or "backward" rotating BWE. The concept of a "forward" rotating BWE is to reduce the large weight and power requirements of conventional BWE's. This is accomplished with a "forward" rotating digging wheel with a curved blade mounted underneath it. As the forward rotating buckets dig into the bank, they pull the machine forward into the bank. Hence less power is required for crowding the machine into the bank. The forward force of the buckets also force the curved blade underneath the digging wheel into the bank. The blade then exerts a "hold down" force and thus reduces the weight required to keep the machine from lifting itself out of the bank. The curved blade also breaks up some of the solid bank.

Foster-Miller Associates, Inc., designed the machine to furnish data on the performance of a "forward" rotating BWE and not as a prototype production machine. Hence the machine was of a simplistic and economcal design. Many systems that would be required on a production machine were not incorporated into the machine's design. The machine basically consisted of a rented tractor, an additional power source, digging wheel and conveyor system. The digging wheel and conveyor system are mounted onto the front of the tractor via a "gooseneck" like structure. The additional power source is mounted at the rear of the tractor.

The BWE was field tested at the Navaho mine. The conclusions drawn from the data that was collected during the field test are encouraging. As expected, the machine could excavate unshot coal and load it into haul units with no tractive effort required to force the machine into the bank.

New and Innovative Equipment Summary

The bucket wheel excavators and the larger versions of the continuous excavator/loaders are capable of production rates more than a typical thin seam would require. They may, therefore, be most useful when the thin seam appears as a rider, and the machines are used to remove both the thin seam and the major seam. As discussed previously, many of these machines have been succesfully used in overburden and parting removal operations and thus would be capable of this.

Table IV is a summary of the estimated production and cost of the three BWE's discussed. The second table, Table V, compares the cost per ton of recovering a thin coal seam with conventional and new, innovative mining equipment. The costs shown are only the costs of excavating the coal and loading it into a truck. They do not reflect haulage, ramping, or other such costs.

TABLE IV

BWE PRODUCTION
and
COST PER TON

Factors:

Bucket Fill Factor - 65%

Availability - 56%

Utilization - 6.5 HR/8 HR Shift

Coal Density - 1.1 Ton/Cu Yd

	Barber-Greene WL-50	Unit Rig Unimatic	Forward Rotating BWE
No. Buckets	12	4 x 12	3 x 15
Vol. Buckets (cu.yd.)	1.0	0.28	0.266
RPM Range	5.8-6.8	7.5-10	0-13
Ave Oper. RPM	6.2	8.2	6.0
Estimated Hourly Production*	1450	2150	1400
Estimated Hourly Owning & Operating Cost	$110.78	$132.07	$84.55
Estimated Owning & Operating Cost Per Ton**	$0.076	$0.061	$0.060

* Hourly Production = (No. Buckets)(Vol Buckets)(Ave Oper RPM)(60 Min/Hr)

x (Coal Density)(Bucket Fill Factor)(Availability)(Utilization)

$$\text{** Cost Per Ton} = \frac{\text{(Hourly Owning \& Operating Cost)}}{\text{(Hourly Production)}}$$

TABLE V.

Typical Thin Seam Coal Loading Costs

Method	Operation	Cost/ton	Description of Method	Total Cost Per Ton
Dragline	Dragline Front-end Loader	$0.07 $0.15	The dragline recovers the thin seam coal and places it on the highway; later it is loaded into trucks with F.E.L.s.	$0.22
Front-End Loader	Dozer-Ripper F.E.L.	$0.09 $0.25	The thin seam coal is ripped and loaded out with F.E.L.	$0.34
Front-End Loader from Dozer Piles	Ripping Pushing into Piles F.E.L.	$0.09 $0.08 $0.15	The thin seam coal is ripped and pushed into piles with a dozer. The coal is loaded out with a front-end loader.	$0.32
Scraper in Ripped Coal	Ripper Scraper Loader	$0.09 $0.24 $0.10	The thin seam coal is ripped then picked up by scraper and placed where the loader is removing the main coal seam.	$0.43
Scraper in Unripped Coal	Scraper Loader	$0.36 $0.10	Unripped coal is removed by scraper and placed where the main seam loader is working.	$0.46
Backhoe in Unshot Coal	--	$0.09	The backhoe loads unshot coal directly into trucks.	$0.46
Backhoe in "Bumped" Coal	"Bumping" Coal Backhoe	$0.18 $0.07	The thin seam coal is lightly blasted, "Bumped". The backhoe loads this coal directly into trucks.	$0.25
Rotating Ripper Miners	--	$0.07	The rotating ripper miner excavates and loads directly into trucks.	$0.07
Rotating Ripper Miner Windrowing Coal	Thin seam Miner Scraper Loader	$0.07 $0.20 $0.10	The rotating ripper miner excavates and windrows the coal. It is pickcd up by scrapers that take the coal where the main seam is being loaded out.	$0.37
Barber Greene WL-50	--	$0.08	The wheel loader excavates the coal and loads it into trucks.	$0.08
Unit Rig Unimatic	--	$0.06		$0.06
FWD Rotating BWE	--	$0.06		$0.06

EXOTIC EQUIPMENT FOR THIN SEAM COAL REMOVAL

EXOTIC EQUIPMENT FOR THIN SEAM COAL REMOVAL

During the investigation of coal removal methods, it was found that scrapers possessed several advantages in the recovery of a thin coal seam. They are very maneuverable and are capable of traversing steep ramps. They have a low capital cost. They eliminate the need for trucks for input haulage from the thin seam bench to the major seam. Another machine that was quite effective in thin seam recovery was the continuous excavator-loader. This machine was impressive because it eliminated ripping or shooting the coal, demonstrated good productivitly, and operated at a low cost per ton of coal recovered.

It is conceivable that a machine combining the advantages of the scraper and the continuous excavator-loader can be a very useful machine in the recovery of thin coal seams. An artist's conception of this combination is shown if Figure 16. This machine is referred to as a self-excavating/loading scraper or simply a SEL scraper. It is in fact a true self-loading scraper capable of operating in unshot or unripped, competent material.

The concept of this machine came about after observing the method used at the Decker mine to recover their thin seam coal. Their method involves using a Finegrader to cut the coal and windrow it so that a self-loading scraper can pick up the coal and transport it a short distance to where the main coal seam is being loaded out. There the thin seam coal is loaded out with the main seam coal. The thin seam coal is recovered in six-inch lifts. Easi-Miners have also been used at other mines in operations similar to this.

A SEL scraper would eliminate the need for cutting or ripping machines such as the dozer-ripper, Finegrader or Easi-Miner. This is because A SEL scraper is capable of cutting coal and loading itself without the aid of auxiliary machines. Besides eliminating the costs of owning and operating these auxiliary machines, efficiency in recovering the thin seam coal is gained since fewer men and machines are involved.

Basically, a SEL scraper consists of a twin engine, self-loading scraper with a rotating cutter head mounted on it. The cutter head is located directly in front of the scraper's bowl and behind the front drive wheels. The cutter head is like the type used on the Easi-Miner. This type of cutter head resembles a large rototiller in that it is comprised of many long, curved steel shanks.

The cutter head is hydrostatically driven by one of the machine's twin engines. The cutter head breaks up the solid coal and the elevating assembly picks up this loose coal and top loads it into the bowl. The elevating assembly is similar to that on a conventional self-loading scraper. Once the bowl is full, the self-excavating/loading scraper transports the thin seam coal a few hundred feet down the pit to where the main seam is being loaded out. There the thin seam coal is left to be loaded out with the main seam coal and the machine returns to the thin seam removal area to begin the cycle over.

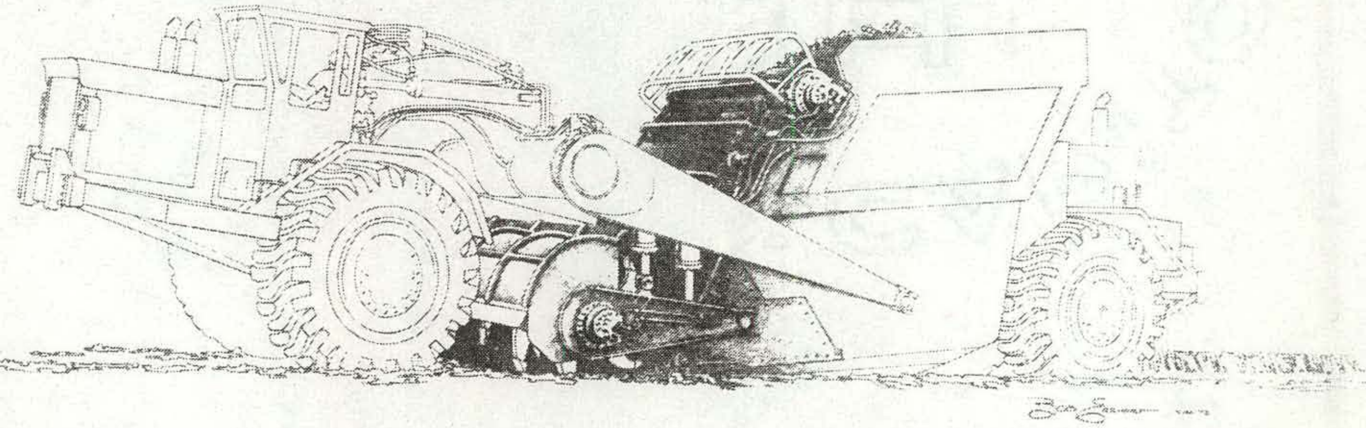


Figure 16. Artist's Conception of a Self-Excavating/Loading Scraper

Power requirements for a self-excavating/loading scraper should not be much greater than that of a conventional twin engine scraper. This is for two reasons. First, the power required for crowding the machine into the solid seam is not great since the cutter head is "forward" rotating which tends to pull the machine into the solid bank. Second, the cutter head breaks up the coal and the elevating assembly removes it from the face and loads it into the bowl instead of the conventional method of using the machine's brute force to break out the material and force it into the scraper's bowl; thus, less power is required for loading.

The availability of such a machine should be relatively good. It is reasonable to assume that the availability of this machine would be somewhat less than that of a conventional self-loading scraper because of the extra moving parts required for the operation of the rotating cutter head. However, the digging wheel or cutter head should affect the availability of the machine very little.

Production from a SEL scraper is governed by several factors including: loading speed, haul distance and grade, and the size of the machine's bowl. Since the same factors also govern the productivity of a conventional self-loading scraper, it is reasonable to assume that the exotic machine would produce more than a conventional self-loading scraper of the same size and under the same conditions. The reason the SEL scraper is expected to produce more is because of the faster loading rate made possible by the action of the cutter head feeding the coal into the machine.

The capital cost of such a machine should not be significantly greater than for a standard twin-engine elevating scraper. The actual machine construction would entail lengthening an existing scraper and adding a rotating cutting head. Since the technology is available for both the scraper and the rotating cutting head, it would simply be a matter of combining two available components into a single unit. Total capital purchase price would be expected to be about $450,000 ($350,000 for the scraper and $100,000 for the cutting head).

It should be noted that the actual feasibility of such a machine would be dependent upon detailed engineering studies. Such an examination is beyond the scope of this report but would certainly be an interesting concept. The engineering concepts are rather straightforward, but applications and market demand should be examined further.

APPENDIX A

DRAGLINE OWNING AND OPERATING COSTS

APPENDIX A

Dragline Owning and Operating Costs

Dragline Production

(Bucket size)(Fill factor)(No. cycles/min)(60 min/hr)(Availability)
(Utilization) = (Cubic yards/hr)

Assume:

Bucket fill factor - 0.81

No. sec/cycle - 60 sec implies 1 cycle/min

Availability - 80%

Utilization - 6.5 hr/8 hr shift

(Bucket size)(0.81)(1)(60)(o.80)(6.5/8.0) = 31.59(Bucket size)
= (Cubic yards/hr)

B.E. Machines

Model	Bucket Size (CuYd)	Production (CuYd/Hr)	Own. & Oper. Cost/Hr	Cost Per Cu Yd
480W	15	474	$112.16	$0.237
800W	22	695	185.42	
1260W	32	1011	215.08	0.213
1300W	37	1169	256.90	0.220
1350W	43	1358	307.86	0.227
1360W	50	1580	336.01	0.213
1370W	57	1801	359.82	0.200
1570W	69	2180	420.74	
2570W	104	3285	712.01	0.217
			Average	$0.218

The average cost per cubic yard was determined by throwing out the maximum and minimum value and averaging the remaining.

The average cost, $0.218/cu yd, is used as the dragline owning and operating cost per cubic yard for this report.

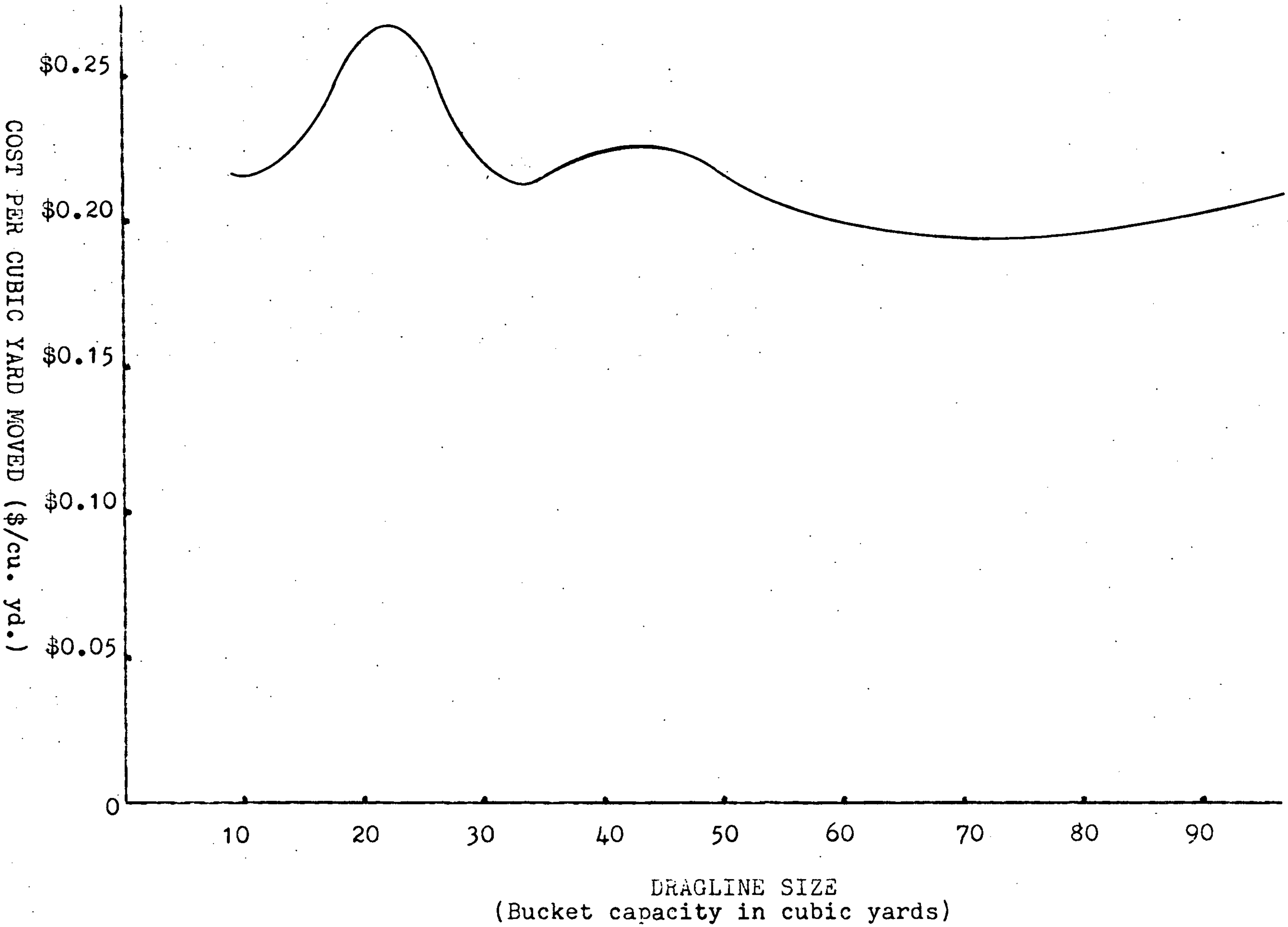

COST PER CUBIC YARD MOVED ($/cu. yd.)
$0.25
$0.20
$0.15
$0.10
$0.05
0
10
20
30
40
50
60
70
80
90
DRAGLINE SIZE
(Bucket capacity in cubic yards)

Fig. 17

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 480-W

OWNERSHIP COST

1. Depreciation

Weight and Price	1,300,000 #	$2,925,260
Extras Transformers, cables, etc.	#	292,526
Erection	#	292,526
Freight 1,300,000 # @ $3.20 /cwt.		41,600
Total Delivered Price		$3,551,912
Less Original Tires		NA
Amount to be Salvaged		3,551,912
Less Salvage or Resale @ 10 %		355,191
Total Amount to be Depreciated		$3,196,721
Useful Life: 20 yrs. @ 8320 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		1,953,552
Hourly Depreciation Cost		19.21/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr 32.87/hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 52.08/hr

OPERATING COST

3. Fuel or Power Cost
(Est. Consumption: 458 /hr) @ ($ 0.015/unit) 6.87/hr

4. Tire Replacement and Repair
($ / hrs) + (% for Repairs) . . . . NA /hr

5. Lubricants, Filters, & Grease
Est. at 125 % of Fuel cost 8.59/hr

6. Repairs, Maintenance, and Supplies
Est. at 130 % of Hourly Depreciation Cost 8.93/hr

7. Wages and Fringe Benefits

a) Operator: $9.41 /hr + 35 % for Fringe Benefits 12.70/hr

b) Oiler: $ 8.66/hr + 35 % for Fringe Benefits 11.69/hr

c) Groundman: $8.37 /hr + 35 % for Fringe Benefits 11.30/hr

TOTAL HOURLY OPERATING COST . . . . $ 60.08/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 112.16/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 800-W

OWNERSHIP COST

1. Depreciation

Weight and Price	2,350,000 #	$6,010,500
Extras Transformers, Cables, etc.	#	601,050
Erection	#	1,212,100
Freight 2,350,000 # @ $3.20 /cwt.		75,200
Total Delivered Price		$7,888,850
Less Original Tires		NA
Amount to be Salvaged		7,888,850
Less Salvage or Resale @ 10 %		788,885
Total Amount to be Depreciated		$7,099,965

Useful Life: 20 yrs.

@ 8320 hrs/yr

Average Investment (Del. Price + Salvage) / 2	4,338,868
Hourly Depreciation Cost	42.67/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14% x Average investment / hrs/yr 73.01/hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 115.68/hr

OPERATING COST

3. Fuel or Power Cost
(Est. Consumption: 639 /hr) @ ($0.015/unit) 9.59/hr

4. Tire Replacement and Repair
($ / hrs) + (___ % for Repairs) . . . . . . NA /hr

5. Lubricants, Filters, & Grease
Est. at 125% of Fuel cost 11.99/hr

6. Repairs, Maintenance, and Supplies
Est. at 130 % of Hourly Depreciation Cost 12.47/hr

7. Wages and Fringe Benefits

a) Operator: $9.41 /hr + 35 % for Fringe Benefits 12.70/hr

b) Oiler: $ 8.66 /hr + 35 % for Fringe Benefits 11.69/hr

c) Groundman: $8.37 /hr + 35 % for Fringe Benefits 11.30/hr

TOTAL HOURLY OPERATING COST . . . . $ 69.74/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 185.42/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 1260-W

OWNERSHIP COST

1. Depreciation

Weight and Price	3,315,000 #	$ 6,632,400
Extras Transformers, Cable, Etc.	#	663,240
Erection	#	1,326,480
Freight 3,315,000 # @ $3.20 /cwt.		106,080
Total Delivered Price		$ 8,728,200
Less Original Tires		NA
Amount to be Salvaged		8,728,200
Less Salvage or Resale @ 10 %		872,820
Total Amount to be Depreciated		$ 7,855,380

Useful Life: 20 yrs.

@ 8320 hrs/yr

Average Investment $\left(\frac{\text{Del. Price + Salvage}}{2}\right)$ 4,800,510

Hourly Depreciation Cost 47.21/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

$\frac{\text{Total 14 \% x Average investment}}{\text{hrs/yr}}$ 80.78/hr

TOTAL HOURLY OWNERSHIP COST .... $ 127.99/hr

OPERATING COST

3. Fuel or Power Cost
   (Est. Consumption: 926 KW /hr) @ ($0.015 /unit) 14.48/hr
4. Tire Replacement and Repair
   $\left(\frac{\$\_\_\_\_}{\text{hrs}}\right)$ + (____ % for Repairs) .... NA /hr
5. Lubricants, Filters, & Grease
   Est. at 125 % of Fuel cost 18.10/hr
6. Repairs, Maintenance, and Supplies
   Est. at 130 % of Hourly Depreciation Cost 18.82/hr
7. Wages and Fringe Benefits
   a) Operator: $ 9.41/hr + 35 % for Fringe Benefits 12.70/hr
   b) Oiler: $ 8.66 /hr + 35 % for Fringe Benefits 11.69/hr
   c) Groundman: $ 8.37/hr + 35 % for Fringe Benefits 11.30/hr

TOTAL HOURLY OPERATING COST .... $ 87.09/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST .... $ 215.08/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 1300-W

OWNERSHIP COST

1. Depreciation

Weight and Price 3,615,000 #	$8,070,000
Extras Transformers, Cable, Etc. #	807,000
Erection #	1,614,000
Freight 3,615,000 # @ $3.20 /cwt.	115,680
Total Delivered Price	$10,606,680
Less Original Tires	NA
Amount to be Salvaged	10,686,680
Less Salvage or Resale @ 10 %	1,060,668
Total Amount to be Depreciated	$9,546,012
Useful Life: 20 yrs. @ 8320 hrs/yr	
Average Investment (Del. Price + Salvage) / 2	5,833,674
Hourly Depreciation Cost	57.37/hr

2. Interest, Taxes, and Insurance

Interest 10%, Taxes 2 %, & Insurance 2 %	
Total 14 % x Average investment / hrs/yr	98.16/hr

TOTAL HOURLY OWNERSHIP COST	$ 155.53/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 1233KW /hr) @ ($0.015/unit)	18.50/hr
4. Tire Replacement and Repair ($ / hrs) + (% for Repairs)	NA /hr
5. Lubricants, Filters, & Grease Est. at 125 % of Fuel cost	23.13/hr
6. Repairs, Maintenance, and Supplies Est. at 130 % of Hourly Depreciation Cost	24.05/hr
7. Wages and Fringe Benefits	
a) Operator: $9.41 /hr + 35 % for Fringe Benefits	12.70/hr
b) Oiler: $ 8.66 /hr + 35 % for Fringe Benefits	11.69/hr
c) Groundman: $8.37 /hr + 35 % for Fringe Benefits	11.30/hr
TOTAL HOURLY OPERATING COST	$ 101.37/hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 256.90/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 1350-W

OWNERSHIP COST

1. Depreciation

Weight and Price	4,895,000 #	$10,197,500
Extras Transformers, Cable, Etc.	#	1,019,750
Erection	#	2,039,500
Freight 4,895,000 # @ $3.20 /cwt.	. . . .	156,640
Total Delivered Price	. . . .	$13,413,390
Less Original Tires	. . . .	NA
Amount to be Salvaged	. . . .	13,413,390
Less Salvage or Resale @ 10 %	. . . .	1,341,339
Total Amount to be Depreciated	. . . .	$12,072,051

Useful Life: 20 yrs.
@ 8320 hrs/yr

Average Investment (Del. Price + Salvage) / 2		7,377,365
Hourly Depreciation Cost	. . . .	72.55/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr	. . . .	124.14/hr
TOTAL HOURLY OWNERSHIP COST	. . . .	$ 196.69/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 1417KW /hr) @ ($0.015 /unit)		21.26/hr
4. Tire Replacement and Repair ($ / hrs) + (% for Repairs)	. . . . . .	NA /hr
5. Lubricants, Filters, & Grease Est. at 125 % of Fuel cost		26.58/hr
6. Repairs, Maintenance, and Supplies Est. at 130 % of Hourly Depreciation Cost		27.64/hr
7. Wages and Fringe Benefits		
a) Operator: $ 9.41/hr + 35 % for Fringe Benefits		12.70/hr
b) Oiler: $ 8.66 /hr + 35 % for Fringe Benefits		11.69/hr
c) Groundman: $ 8.37/hr + 35 % for Fringe Benefits		11.30/hr
TOTAL HOURLY OPERATING COST	. . . .	$ 111.17/hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	. . . .	$ 307.86/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 1360-W

OWNERSHIP COST

1. Depreciation

Weight and Price 5,057,000 #	$11,020,300
Extras Transformers, Cable, Etc. #	1,102,030
Erection #	2,204,060
Freight 5,057,000 # @ $3.20 /cwt.	161,824
Total Delivered Price	$14,488,214
Less Original Tires	NA
Amount to be Salvaged	14,488,214
Less Salvage or Resale @ 10 %	1,448,821
Total Amount to be Depreciated	$13,039,393
Useful Life: 20 yrs. @ 8320 hrs/yr	
Average Investment $\left(\frac{\text{Del. Price + Salvage}}{2}\right)$	7,968,518
Hourly Depreciation Cost	78.36/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %	
$\frac{\text{Total 14 \% x Average investment}}{\text{hrs/yr}}$	134.09/hr
TOTAL HOURLY OWNERSHIP COST	$ 212.45/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 1650KW /hr) @ ($ 0.015/unit)	24.75/hr
4. Tire Replacement and Repair $\left(\frac{\$}{\text{hrs}}\right)$ + (% for Repairs)	NA /hr
5. Lubricants, Filters, & Grease Est. at 125 % of Fuel cost	30.94/hr
6. Repairs, Maintenance, and Supplies Est. at 130 % of Hourly Depreciation Cost	32.18/hr
7. Wages and Fringe Benefits	
a) Operator: $ 9.41/hr + 35 % for Fringe Benefits	12.70/hr
b) Oiler: $ 8.66/hr + 35 % for Fringe Benefits	11.69/hr
c) Groundman: $ 8.37/hr + 35 % for Fringe Benefits	11.30/hr
TOTAL HOURLY OPERATING COST	$ 123.56/hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 336.01/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 1370-W

OWNERSHIP COST

1. Depreciation

Weight and Price 5,705,000 #	$11,602,100
Extras Transformers, Cable, Etc. #	1,160,210
Erection #	2,320,420
Freight 5,705,000 # @ $3.20 /cwt.	182,560
Total Delivered Price	$15,265,290
Less Original Tires	NA
Amount to be Salvaged	15,265,290
Less Salvage or Resale @ 10 %	1,526,529
Total Amount to be Depreciated	$13,738,761
Useful Life: 20 yrs.	
@ 8320 hrs/yr	
Average Investment (Del. Price + Salvage) / 2	8,395,910
Hourly Depreciation Cost	82.56/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %	
Total 14 % x Average investment / hrs/yr	141.28/hr

TOTAL HOURLY OWNERSHIP COST	$ 223.84/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 1883 /hr) @ ($ 0.015 /unit)	28.25/hr
4. Tire Replacement and Repair ($ ___ / hrs) + (___ % for Repairs)	NA /hr
5. Lubricants, Filters, & Grease Est. at 125 % of Fuel cost	35.31/hr
6. Repairs, Maintenance, and Supplies Est. at 130 % of Hourly Depreciation Cost	36.73/hr
7. Wages and Fringe Benefits	
a) Operator: $ 9.41/hr + 35 % for Fringe Benefits	12.70/hr
b) Oiler: $ 8.66 /hr + 35 % for Fringe Benefits	11.69/hr
c) Groundman: $ 8.37/hr + 35 % for Fringe Benefits	11.30/hr
TOTAL HOURLY OPERATING COST	$ 135.98/hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 359.82/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 1570-W

OWNERSHIP COST

1. Depreciation

Weight and Price 5,795,000 #	$13,413,700
Extras Transformers, Cable, Etc. #	1,314,370
Erection #	2,682,740
Freight 5,795,000 # @ $3.20 /cwt.	185,440
Total Delivered Price	$17,623,250
Less Original Tires	NA
Amount to be Salvaged	17,623,250
Less Salvage or Resale @ 10 %	1,762,325
Total Amount to be Depreciated	$15,860,925
Useful Life: 20 yrs. @ 8320 hrs/yr	
Average Investment (Del. Price + Salvage) / 2	9,692,788
Hourly Depreciation Cost	95.32/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %	
Total 14% x Average investment / hrs/yr	163.10/hr
TOTAL HOURLY OWNERSHIP COST	$ 258.42/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 2378KW /hr) @ ($0.015/unit)	35.67/hr
4. Tire Replacement and Repair ($ / hrs) + (% for Repairs)	NA /hr
5. Lubricants, Filters, & Grease Est. at 125 % of Fuel cost	44.59/hr
6. Repairs, Maintenance, and Supplies Est. at 130 % of Hourly Depreciation Cost	46.37/hr
7. Wages and Fringe Benefits	
a) Operator: $ 9.41/hr + 35 % for Fringe Benefits	12.70/hr
b) Oiler: $ 8.66 /hr + 35 % for Fringe Benefits	11.69/hr
c) Groundman: $ 8.37/hr + 35 % for Fringe Benefits	11.30/hr
TOTAL HOURLY OPERATING COST	$ 162.32/hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 420.74/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: 2570-W

OWNERSHIP COST

1. Depreciation

Weight and Price	10,670,000 #	$24,741,000
Extras	Transformers, Cables, Etc. #	2,373,100
	Erection #	4,948,200
Freight 10,670,000# @ $3.20/cwt.		341,400
Total Delivered Price		$32,504,700
Less Original Tires		NA
Amount to be Salvaged		32,504,700
Less Salvage or Resale @ 10 %		3,250,470
Total Amount to be Depreciated		$29,254,230

Useful Life: 20 yrs.

@ 8320 hrs/yr

Average Investment $\left(\frac{\text{Del. Price + Salvage}}{2}\right)$ 17,877,585

Hourly Depreciation Cost 175.81/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

$\frac{\text{Total 14 \% x Average investment}}{\text{hrs/yr}}$ 300.82/hr

TOTAL HOURLY OWNERSHIP COST .... $ 476.63/hr

OPERATING COST

3. Fuel or Power Cost
   (Est. Consumption: 3750KW /hr) @ ($0.015 /unit) 56.25/hr
4. Tire Replacement and Repair
   $\left(\frac{\$\ \_\_\_}{\text{hrs}}\right)$ + (___ % for Repairs) .... NA /hr
5. Lubricants, Filters, & Grease
   Est. at 125 % of Fuel cost 70.31/hr
6. Repairs, Maintenance, and Supplies
   Est. at 130 % of Hourly Depreciation Cost 73.13/hr
7. Wages and Fringe Benefits
   a) Operator: $ 9.41/hr + 35 % for Fringe Benefits 12.70/hr
   b) Oiler: $ 8.66/hr + 35% for Fringe Benefits 11.69/hr
   c) Groundman: $ 8.37/hr + 35 % for Fringe Benefits 11.30/hr

TOTAL HOURLY OPERATING COST .... $ 235.38/hr

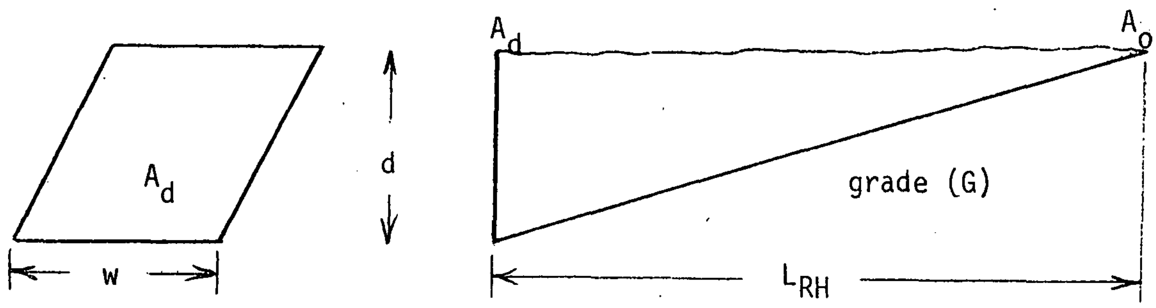
TOTAL HOURLY OWNERSHIP & OPERATING COST .... $ 712.01/hr

APPENDIX B

DRAGLINE RAMPING COSTS

APPENDIX B

Ramping



Ramp Volume

w = width of pit = width of ramp (ft)
d = the depth of the ramp at its maximum point (ft)
G = the percent grade of the ramp expressed in decimal form
L_{RH} = the horizontal length of the ramp = $\frac{d}{G}$
A_d = area of the ramp at the bottom end of the ramp = wd
A_o = area of the ramp at the top end of the ramp = 0

Using the average end area method, the volume (V) is:

$$V = \left(\frac{A_d + A_o}{2}\right) l_R = \left(\frac{1}{27}\right) \frac{wd}{2} \left(\frac{d}{G}\right) = \frac{wd^2}{54G}$$

Thin Seam Coal Tonnage (T)

L = total length of the pit (ft)
R = percent recovery of the thin seam coal in decimal form
t_1 = thickness of the thin coal seam (ft)

Assuming 1770 tons of coal per acre-ft, the recovered tonnage per pit length (L) is:

$$T = \frac{1770RLwt_1}{43{,}560 \text{ sq ft/Ac}} = 0.0406RLwt_1$$

Ramp Cost per Ton of Thin Seam Coal Recovered (C_R)

(CPY) = the owning and operating cost of the dragline ($/cu yd)

The cost is the volume (V) times (CPY) and this expression divided by the tonnage recovered (T)

$$C_R = \frac{V(CPY)}{T} = \frac{\frac{wd^2}{54G}(CPY)}{0.0406RLwt_1} = \frac{0.456d^2(CPY)}{RLGt_1}$$

The expression for C_R can be simplified by substituting appropriate values for (CPY), R, and G. In Appendix A, CPY was found to be \$0.218/cu yd. When investigating mining operations being conducted in the western U.S., it was found that ramps are usually constructed on a 6% grade. R is assumed at 90%. This is a figure often assumed when calculating coal reserves. Using these values, the expression becomes:

$$C_R = \frac{1.840\ d^2}{(L\ t_1)}$$

for: (CPY) = \$0.218
R = 90%
G = 6%

APPENDIX C

DRAGLINE MOVING COSTS

APPENDIX C

Moving

Distance Traversed (D)

$$D = L_B + 2L_R = L_B + 2\frac{d}{G}(1 + G^2)^{\frac{1}{2}}$$

where L_B = the length of the section (ft)

L_R = the inclined length of the ramp (ft) = $\frac{d}{G}(1 + G^2)^{\frac{1}{2}}$

Time (T_M) Spent Moving

$$T_M = \frac{L_B + 2L_R}{S} = \frac{L_B + 2\frac{d}{G}(1 + G^2)^{\frac{1}{2}}}{S}$$

where S = the average walking speed of the dragline.

Cost

The moving cost per ton of thin seam coal recovered (C_M) is determined by multiplying the time (T_M) spent moving by the hourly dragline owning and operating cost (OP) and dividing this by the tons recovered (T).

$$C_M = \frac{(T_M)(OP)}{T} = \frac{\left[L_B + 2\frac{d}{G}(1 + G^2)^{\frac{1}{2}}\right](OP)}{0.0406\ RLwt_1S}$$

but L in this case = L_B, therefore, the expression becomes:

$$C_M = \frac{\left[L_B + 2\frac{d}{G}(1 + G^2)^{\frac{1}{2}}\right](OP)}{0.0406\ R(L_B)(w)(t_1)S} = \frac{24.610\left[L_B + 2\frac{d}{G}(1 + G^2)^{\frac{1}{2}}\right](OP)}{R(L_B)(w)(t_1)S}$$

The owning and operating cost (OP) equals the cost per cubic yard (CPY) times the dragline's hourly production. From Appendix A, it was found that 31.59 (B) where (B) equals the dragline's bucket size is the hourly production.

$$(OP) = 31.59(B)(CPY)$$

The length of the section is approximately 2,000 feet. This is a reasonable distance since it allows enough coal to be uncovered to make it worth while to bring in the loading equipment, yet it is short enough that excessive trailing cable or moving the transformer is not required to excavate the section (L_B). Therefore (L_B) is assumed to be 2,000 feet. Also, most western mining operations design their pits to be 120 feet wide. Therefore (w) is assumed to be 120 feet.

Substituting the values discussed for (OP), (L_B), and (w) just discussed and the values used in Appendix B for (CPY), (R), and (G), into the expression for (C_M), this expression becomes:

$$C_M = \frac{(1.569 + 0.026\ d)B}{t_1 S}$$

for:
$$\begin{aligned} OP &= 31.59(B)(CPY) \\ L_B &= 2000 \text{ feet} \\ w &= 120 \text{ feet} \\ CPY &= \$.218/\text{cu yd} \\ R &= 90\% \\ G &= 6\% \end{aligned}$$

For a particular dragline of bucket size (B), the average walking speed (S) is known (from either the manufacturer's specification sheet for that model or by field measurement). On the next page is a list of the average walking speed for various Bucyrus-Erie draglines. The average walking speed is assumed to be 80% of the maximum walking speed specified by B-E.

B-E Draglines[11]

Model	Bucket Size (cu yds)	Max.Walking Speed (MPH)	Ave. Walking Speed (ft/hr)
800-W	22	0.17	718
1260-W	32	0.17	718
1300-W	37	0.17	718
1350-W	43	0.16	676
1370-W	57	0.16	676
1500-W	60	0.16	676
2450-W	75	0.16	676
2560-W	86	0.15	634
2570-W	104	0.15	634

The values from this table and the equation $C_M = \frac{(1.569 + 0.026\ d)B}{t_1 S}$ were used to constract the graph in Figure 8.

APPENDIX D

DRAGLINE REHANDLING COSTS

APPENDIX D

Rehandle

The cost of rehandle per ton of thin seam coal recovered (C_H) is:

$$C_H = \frac{\text{(cu yds of rehandle)(CPY)}}{\text{tons of thin seam coal recovered}}$$

Rehandle is most often expressed as a percent of the solid bank. Therefore instead of cubic yards of rehandle, the amount of rehandle is a percent of the bank. The rehandle for a pit length and width (L) and (W) respectively is Rehandle = $(R_e)(L)(w)D$, where D is the thickness of the overburden plus interburden and R_e is the percent of rehandle required. The rehandle divided by the number of tons of thin seam coal recovered in a pit of length and width (L) and (w) and times the cost per cubic yard (CPY) gives the cost of the dragline rehandling in terms of cost per ton of thin seam coal recovered (C_H). This expression is:

$$C_H = \frac{\left[(R_e)(L)(w)(D)/27\right](CPY)}{0.0406\ RLwt_1} = \frac{0.912\ (R_e)(D)(CPY)}{(R)t_1}$$

Substituting the values previously discussed for (CPY) and (R), the expression becomes:

$$C_H = \frac{0.221\ (R_e)D}{t_1}$$

for: CPY = \$0.218
R = 90%

APPENDIX E

DRAGLINE CROSS-PIT DIGGING COSTS

APPENDIX E

Cross-Pit Digging

The use of a cross-pit digging method reduces the efficiency of the dragline by 30%. A 30% decrease in efficiency implies that the production of the machine decreases 30% and therefore the cost per cubic yard of material moved with the dragline increases. The following derivation determines this amount.

$$(CPY) = \frac{(OP)}{P}$$

where:

(CPY) = dragline's owning and operating cost (\$/cu yd)
(OP) = dragline's owning and operating cost (\$/hr)
P = the dragline's hourly production when digging in a conventional manner (cu yds/hr)

For a machine working in a cross-pit digging manner the production (P) decreases by 30% (production equals 70% of the original). If (P) decreases by 30% then from the above equation it can be seen that the new cost per cubic yard $(CPY)^1$ equals (CPY/0.70).

The difference in (CPY) and $(CPY)^1$ is the cost of recovering the thin seam coal. This difference can be expressed as CPY(1/.70 -1) or 0.4286(CPY). This difference times the number of cubic yards of material removed in a cross-pit manner and then divided by the tons of thin seam coal recovered is the cross-pit digging cost (C_c) expressed in terms of cost per ton of thin seam coal recovered. This expression for a pit of length and width (L) and (w) and excavating interburden of (d_2) thickness in a cross-pit manner is:

$$C_c = \frac{0.434(d_2)(CPY)}{t_1}$$

where d_2 = the thickness of the interburden being dug in a cross-pit manner.

Substituting the value \$0.218/cu yd for CPY, the expression becomes:

$$C_c = \frac{0.095\ d_2}{t_1}.$$

APPENDIX F

CONVENTIONAL COAL LOADING EQUIPMENT

OWNING AND OPERATING COSTS

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: D9H Caterpillar Bulldozer w/ripper

OWNERSHIP COST

1. Depreciation

Weight and Price ____ ____ #	$____
Extras Delivered: Billings, Montana #	____
#	250,000
Freight ____ # @ ____ /cwt.	N/A
Total Delivered Price	$ 250,000
Less Original Tires	N/A
Amount to be Salvaged	250,000
Less Salvage or Resale @ 20 %	50,000
Total Amount to be Depreciated	$ 200,000
Useful Life: 5 yrs. @ 3,750 hrs/yr	
Average Investment (Del. Price + Salvage) / 2	150,000
Hourly Depreciation Cost	8.00 /hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %	
Total 14 % x Average investment / hrs/yr	5.60 /hr
TOTAL HOURLY OWNERSHIP COST	$ 13.60 /hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 24 /hr) @ ($ 0.40 /unit)	9.60 /hr
4. Tire Replacement and Repair ($ ____ / hrs) + (____ % for Repairs)	N/A /hr
5. Lubricants, Filters, & Grease Est. at 10 % of Fuel cost	0.96 /hr
6. Repairs, Maintenance, and Supplies Est. at 150 % of Hourly Depreciation Cost	12.00 /hr
7. Wages and Fringe Benefits	
a) Operator: $9.10 /hr + 35 % for Fringe Benefits	12.28 /hr
b) Oiler: $____ /hr + ____ % for Fringe Benefits	N/A /hr
c) Groundman: $____ /hr + ____ % for Fringe Benefits	N/A /hr
TOTAL HOURLY OPERATING COST	$ 34.84 /hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 48.44 /hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: Letourneau L-800 23 cu. yd. (Coal) Front End Loader

OWNERSHIP COST

1. Depreciation

Weight and Price ____ ______ #		$______
Extras ______ #		______
Delivered & Erected, Eastern Montana #		540,000
Freight ______ # @ ______/cwt.		N.A.
Total Delivered Price		$ 540,000
Less Original Tires		32,200
Amount to be Salvaged		507,800
Less Salvage or Resale @ 10 %		50,780
Total Amount to be Depreciated		$ 457,020
Useful Life: 3 yrs. @ 3750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		295,390
Hourly Depreciation Cost		40.62/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %	
Total 14 % x Average investment / hrs/yr	11.03/hr

TOTAL HOURLY OWNERSHIP COST	$ 51.65/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 29 gal /hr) @ ($ 0.40 /unit)	11.60/hr
4. Tire Replacement and Repair ($ 26,800) / (3,000 hrs) + (15 % for Repairs)	10.27/hr
5. Lubricants, Filters, & Grease Est. at 10 % of Fuel cost	1.16/hr
6. Repairs, Maintenance, and Supplies Est. at 100 % of Hourly Depreciation Cost	33.86/hr
7. Wages and Fringe Benefits	
a) Operator: $ 9.10/hr + 35 % for Fringe Benefits	12.28/hr
b) Oiler: $____/hr + ____% for Fringe Benefits	N.A. /hr
c) Groundman: $____/hr + ____% for Fringe Benefits	N.A. /hr
TOTAL HOURLY OPERATING COST	$ 69.17/hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 120.82/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: WABCO 75B Haulpak Rear Dump Truck

OWNERSHIP COST

1. Depreciation

Weight and Price	91,500 #	$ 252,890
Extras	#	
	#	
Freight 91,500 # @ $3.20 /cwt.		2,928
Total Delivered Price		$ 255,818
Less Original Tires		46,836
Amount to be Salvaged		208,982
Less Salvage or Resale @ 10 %		20,898
Total Amount to be Depreciated		$ 188,084
Useful Life: 5 yrs. @ 3750 hrs/yr		
Average Investment $\left(\frac{\text{Del. Price + Salvage}}{2}\right)$		138,358
Hourly Depreciation Cost		10.03/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

$\frac{\text{Total 14 \% x Average investment}}{\text{hrs/yr}}$ 5.17/hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 15.20/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 24 gal /hr) @ ($ 0.40 /unit)	9.60/hr
4. Tire Replacement and Repair $\left(\frac{\$48,836}{3,000 \text{ hrs}}\right)$ + (15 % for Repairs)	18.72/hr
5. Lubricants, Filters, & Grease Est. at 20 % of Fuel cost	1.92/hr
6. Repairs, Maintenance, and Supplies Est. at 100 % of Hourly Depreciation Cost	10.03/hr
7. Wages and Fringe Benefits	
a) Operator: $ 8.76/hr + 35 % for Fringe Benefits	11.83/hr
b) Oiler: $ ____/hr + ____% for Fringe Benefits	N.A. /hr
c) Groundman: $ ____/hr + ____% for Fringe Benefits	N.A. /hr

TOTAL HOURLY OPERATING COST . . . . $ 52.10/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 67.30/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: CAT 633D Elevating Scraper

OWNERSHIP COST

1. Depreciation

Weight and Price	175,680 #	$
Extras	#	
Delivered Price: Billings, Montana #		240,000
Freight # @ /cwt.		N.A.
Total Delivered Price		$ 240,000
Less Original Tires		15,000
Amount to be Salvaged		225,000
Less Salvage or Resale @ 25 %		56,520
Total Amount to be Depreciated		$ 168,750
Useful Life: 3 yrs. @ 3750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		148,125
Hourly Depreciation Cost		15.00/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr 5.53/hr

TOTAL HOURLY OWNERSHIP COST .... $ 20.53/hr

OPERATING COST

3. Fuel or Power Cost
   (Est. Consumption: 16.0 gal /hr) @ ($ 0.40 /unit) 6.40/hr

4. Tire Replacement and Repair
   ($ 15,000 / 3000 hrs) + (15 % for Repairs) 5.75/hr

5. Lubricants, Filters, & Grease
   Est. at 20 % of Fuel cost 1.28/hr

6. Repairs, Maintenance, and Supplies
   Est. at 110 % of Hourly Depreciation Cost 16.50/hr

7. Wages and Fringe Benefits
   a) Operator: $9.10 /hr + 35 % for Fringe Benefits 12.29/hr
   b) Oiler: $ /hr + % for Fringe Benefits .... N.A./hr
   c) Groundman: $ /hr + % for Fringe Benefits .... N.A./hr

TOTAL HOURLY OPERATING COST .... $ 40.91/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST .... $ 62.75/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: Wabco FT333 Twin-Engine Scraper

OWNERSHIP COST

1. Depreciation

Weight and Price	#	$
Extras	#	
Delivered	#	$350,000
Freight ____ # @ ____ /cwt.		N.A.
Total Delivered Price		$350,000
Less Original Tires		15,000
Amount to be Salvaged		335,000
Less Salvage or Resale @ 25 %		83,750
Total Amount to be Depreciated		$251,250
Useful Life: 3 yrs. @ 3750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		216,875
Hourly Depreciation Cost		22.31 /hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr . . . . 8.10 /hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 30.41 /hr

OPERATING COST

3. Fuel or Power Cost
(Est. Consumption: 33.0 gal /hr) @ ($ 0.40 /unit) — 13.20 /hr

4. Tire Replacement and Repair
($15,000 / 2500 hrs) + (15 % for Repairs) . . . . 6.90 /hr

5. Lubricants, Filters, & Grease
Est. at 25 % of Fuel cost — 3.39 /hr

6. Repairs, Maintenance, and Supplies
Est. at 130 % of Hourly Depreciation Cost — 29.00 /hr

7. Wages and Fringe Benefits
a) Operator: $ 9.10/hr + 35 % for Fringe Benefits — 12.29 /hr
b) Oiler: $____/hr + ____% for Fringe Benefits — N.A. /hr
c) Groundman: $____/hr + ____% for Fringe Benefits — N.A. /hr

TOTAL HOURLY OPERATING COST . . . . $ 64.69 /hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 95.10 /hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: DEMAG H-111
Hydraulic Excavator

OWNERSHIP COST

1. Depreciation

Weight and Price	240,300 #	$ 700,000
Extras	#	
	#	
Freight 240,300 # @ $3.20/cwt.		7,690
Total Delivered Price		$ 707,690
Less Original Tires		N.A.
Amount to be Salvaged		707,690
Less Salvage or Resale @ 20 %		141,540
Total Amount to be Depreciated		$ 566,150
Useful Life: 5 yrs. @ 3750 hrs/yr		
Average Investment $\left(\frac{\text{Del. Price + Salvage}}{2}\right)$		424,615
Hourly Depreciation Cost		30.19 /hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %	
Total $\frac{14\% \text{ x Average investment}}{\text{hrs/yr}}$	15.85 /hr
TOTAL HOURLY OWNERSHIP COST	$ 46.04 /hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 25 gal. /hr) @ ($ 0.40 /unit)	10.00 /hr
4. Tire Replacement and Repair $\left(\frac{\$}{\text{hrs}}\right)$ + (___ % for Repairs)	N.A. /hr
5. Lubricants, Filters, & Grease Est. at 50 % of Fuel cost	5.00 /hr
6. Repairs, Maintenance, and Supplies Est. at 33 % of Hourly Depreciation Cost	10.00 /hr
7. Wages and Fringe Benefits	
a) Operator: $ 8.66 /hr + 35 % for Fringe Benefits	11.69 /hr
b) Oiler: $ ___ /hr + ___ % for Fringe Benefits	N.A. /hr
c) Groundman: $ ___ /hr + ___ % for Fringe Benefits	N.A. /hr
TOTAL HOURLY OPERATING COST	$ 36.69 /hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 82.73 /hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: BE 195-B Coal Loading Shovel

OWNERSHIP COST

1. Depreciation

Weight and Price	637,000 #	$1,570,000.00
Extras	#	
	Erection at 10% #	157,000.00
Freight 637,000 # @ $3.20/cwt.		20,380.00
Total Delivered Price		$1,747,380.00
Less Original Tires		N.A.
Amount to be Salvaged		1,747,380.00
Less Salvage or Resale @ 10 %		174,740.00
Total Amount to be Depreciated		$1,572,640.00
Useful Life: 20 yrs. @ 3,750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		961,060.00
Hourly Depreciation Cost		20.97/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr 35.88/hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 56.85/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 596 KW /hr) @ ($ 0.015/unit) . . . 8.94/hr

4. Tire Replacement and Repair ($ / hrs) + (% for Repairs) . . . . N.A. /hr

5. Lubricants, Filters, & Grease Est. at 100 % of Fuel cost . . . 8.94/hr

6. Repairs, Maintenance, and Supplies Est. at 140 % of Hourly Depreciation Cost . . . 29.36/hr

7. Wages and Fringe Benefits
   a) Operator: $ 9.41 /hr + 35 % for Fringe Benefits . . . 12.70/hr
   b) Oiler: $ 8.66 /hr + 35 % for Fringe Benefits . . . 11.69/hr
   c) Groundman: $ /hr + % for Fringe Benefits . . . - /hr

TOTAL HOURLY OPERATING COST . . . . $ 71.63/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 128.48/hr

APPENDIX G

CONVENTIONAL COAL LOADING EQUIPMENT PRODUCTION AND COST CALCULATIONS

RIPPER PRODUCTION

Ripper Production Formula

$$TPH = \frac{60}{\left(\frac{D \times S}{88}\right) + M} \times \frac{(D)(N)(SP)(P)}{27} \times AVAIL \times EFF \times DEN$$

$$TPH = \frac{(1.422)(D)(P)(SP)(N)(DEN)}{\frac{D}{S \times 88} + M}$$

Assuming availability and efficiency both equal 80%.

where:
- TPH = Production in tons per hour
- D = Distance of path in feet
- SP = Spacing between passes in feet
- P = Penetration of ripper tooth in feet
- S = Speed of dozer in miles per hour
- M = Maneuver time in minutes
- N = Number of ripper teeth
- AVAIL = Availability in decimals
- EFF = Efficiency in decimals
- DEN = Density of coal in tons per bank cubic yard

Ripping Cost Formula

$$\$/ton = \frac{O\&O}{TPH}$$

where:
- \$/ton = Ripper cost per ton of thin seam coal
- O&O = Owning and operating cost in \$/hr
- TPH = Ripper production per hour in tons/hr

Estimated cost for a D9H dozer

Assume:
1) Single shank ripper on D9H,
2) 3 feet between passes,
3) 300 feet passes,
4) 80% availability and efficiency,
5) 1.1 tons per bank cubic yard,
6) Average dozer speed of 1.0 mph,
7) A fixed maneuver time of 0.25 minutes, and
8) 2 foot ripper penetration

$$TPH = \frac{(1.422)(300)(2)(3)(1)(1.1)}{\frac{300}{1x88} + 0.25}$$

TPH = 769 tons per hour

BCY/hr = 700 bcy per hour

$$\$/ton = \frac{O\&O}{TPH}$$

$$\$/ton = \frac{48.44 + (40\% \times 48.44)}{769}$$

$/ton = $0.09/ton coal

DOZER PRODUCTION

Dozer Production Formula

TPH = (MAXLCY)(DEN)(CF)

where: TPH = Production in tons per hour
MAXLCY = Maximum production in loose cubic yards obtained from manufacturer specifications
DEN = Density in ton per loose cubic yards
CF = Product of correction factors in decimal form

Dozer Cost Formula

$$\$/\text{ton} = \frac{\text{O\&O}}{\text{TPH}}$$

where: \$/ton = cost per ton coal
O&O = Owning and Operating cost in dollars per hour
TPH = Production in tons per hour

Estimated Production for Caterpillar D9H

Machine = D9H with U-Blade
Push distance = 150 feet

Maximum Production from Cat Performance Handbook, No. 7 =

1000 loose cubic yards per hour

Correction Factors:

Operator Average = 0.75
Material Hard to Drift = 0.80
Side-by-side Dozing = 1.20
Light Material with U-Blade = 1.20
Weight Correction = 1.39
Availability = 85%
Efficiency = 85%

CF = 0.75 x 0.80 x 1.20 x 1.20 x 1.39 x 0.85 x 0.80 = 0.817

TPH = (MAXLCY)(DEN)(CF)
TPH = (1000)(0.825)(0.817)
TPH = 674

$$\$/\text{ton} = \frac{\text{O\&O}}{\text{TPH}}$$

O&O for D9H = 48.44 dollars/hr

$$\$/\text{ton} = \frac{48.44}{674}, \quad \$/\text{ton} = 0.07$$

Dozer cost = \$0.07/ton

SCRAPER PRODUCTION

Scraper Production Formula

Cycle Time = Haul Time + Return Time + Load Time + Dump Time + Maneuver Time

$$TPH = \frac{60}{CT} \times CAP \times AVAIL \times EFF$$

$$TPH = \frac{(60)(CAP)(AVAIL)(EFF)}{CT}$$

where: TPH = Scraper production in tons per hour
CAP = Scraper capacity in tons
AVAIL = Availability in decimals
EFF = Efficiency in decimals
CT = Total cycle time in minutes

Scraper Cost Formula

$$\$/ton = \frac{O\&O}{TPH}$$

where: \$/ton = Scraper cost per ton coal
O&O = Owning and operating cost in \$/hr
TPH = Production in tons/hr

Estimated Scraper Costs:

Caterpillar 633D elevating scraper

Cycle Time

	Distance (feet)	GR	RR	Max.Speed (mph)	Correction Factor	Av.Speed (mph)	Time (min)
Loaded	2000	--	6%	24	0.93	22.32	1.02
	200	-20%	6%	17	0.75	12.75	0.18
Empty	200	+20%	6%	4	1.5	6	0.38
	2000	--	6%	25	0.93	23.29	0.98

Caterpillar 633D elevating scraper, continued

Fixed time = Load time + Dump time + Maneuver time

Fixed time = 1.6 min.

Travel time = 1.02 + 0.18 + 0.38 + 0.98 = 2.56 min.

Total cycle time = Travel time + Fixed time

CT = 2.56 + 1.6

CT = 4.16 min.

<u>Standard Scraper (Cap = 28 ton)</u>

$$TPH = \frac{(60)(CA)(AVAIL)(EFF)}{CT}$$

$$TPH = \frac{(60)(28)(0.80)(0.80)}{4.16}$$

TPH = 258 tons/hr

$$\$/ton = \frac{O\&O}{TPH}$$

$$\$/ton = \frac{\$62.75}{258}$$

$/ton = $0.24/ton

<u>Modified Scraper (Cap = 37.5 tons)</u>

TPH = 345 tons/hour

$/ton = $0.18/ton

Wabco 333FT twin-engined elevating scraper (Cap = 38 tons)

Loading and Hauling Ripped Coal

	Distance (feet)	GR(%)	RR(%)	Max.Speed (mph)	Correction Factor	Av.Speed (mph)	Time (min)
Loaded	2000	--	6%	22	0.93	20.5	1.11
	200	-20%	6%	22	0.75	16.5	0.14
Empty	2000	--	6%	34	0.93	3.16	0.72
	200	+20%	6%	8.5	12.75	12.75	0.18

Travel time = 1.11 + 0.14 + 0.72 + 0.18 = 2.15 min.

Fixed time = 1.6 min.

Cycle time = 2.15 + 1.6 = 3.75 min.

$$TPH = \frac{(60)(CAP)(AVAIL)(DEN)}{CT}$$

$$TPH = \frac{(60)(38)(0.80)(0.80)}{3.75}$$

TPH = 390 tons/hour

$$\$/ton = \frac{O\&O}{TPH}$$

$$\$/ton = \frac{95.10}{390}$$

$/ton = $0.24/ton

Ripping, loading, and hauling coal

Travel time equals Travel Time for loading and hauling

Travel time = 2.15 min.

Fixed time = 1.75 min.

Cycle Time = 2.15 + 1.75 = 3.90 min.

$$TPH = \frac{(60)(38)(0.80)(0.80)}{3.90}$$

TPH = 375 tons/hour

$$\$/ton = \frac{O\&O}{TPH}$$

$$\$/ton = \frac{95.10 + 40\%(95.10)}{375}$$

$$\$/ton - \frac{\$133.14}{375}$$

$/ton = $0.36/ton

Windrowed Coal

Travel Time = 2.15 min.

Fixed Time = 1.00 min.

Cycle Time = 2.15 + 1.00 = 3.15

TPH = 463

$$\$/Ton = \frac{O\&O}{TPH}$$

$$\$/Ton = \frac{95.10}{463} = \$0.20/T$$

LOADER PRODUCTION

Loader Production Formula

$$TPH = \frac{(60)(BCAP)(BFF)(EFF)(AVAIL)(DEN)}{CT}$$

where: TPH = Production in tons per hour
BCAP = Capacity of bucket in loose cubic yard
BFF = Bucket fill factor in decimal form
EFF = Efficiency in decimal form
AVAIL = Availability in decimal form
DEN = Density in tons per loose cubic yard
CT = Cycle time per bucketful in minutes

Loader Cost Formula

$$\$/ton = \frac{O\&O}{TPH}$$

where: \$/ton = Cost per ton coal
O&O = Owning and operating cost in dollars per hour
TPH = Production in tons per hour

Estimated Production and Cost for Letourneau L800 (23 yd^3 bucket)

Loading from dozer piles

Cycle Time = 0.70 min.
Bucket Fill Factor = 0.80

$$TPH = \frac{(60)(BCAP)(BFF)(EFF)(AVAIL)(DEN)}{CT}$$

$$TPH = \frac{(60)(23)(0.80)(0.80)(0.80)(0.825)}{0.70}$$

TPH = 833 tons/hour

O&O for a Letourneau L800 is \$120.82/hr

$$\$/ton = \frac{O\&O}{TPH}$$

$$\$/ton = \frac{120.82}{833}$$

\$/ton = \$0.15/ton

Loading directly from thin seam

Cycle Time = 1.00 min.
Bucket Fill Factor = 0.80

$$TPH = \frac{(60)(BCAP)(BFF)(EFF)(AVAIL)(DEN)}{CT}$$

$$TPH = \frac{(60)(23)(0.80)(0.80)(0.80)(0.825)}{1.15}$$

$$TPH = 583 \text{ tons/hr.}$$

$$\$/ton = \frac{O\&O}{TPH}$$

$$\$/ton = \frac{120.82 + 20\%(120.82)}{583}$$

$$\$/ton = \$0.25/ton$$

Note: O&O was increased by 20% for additional maintenance costs.

TRUCK PRODUCTION

Maximum Speed Formulas(7)

Loaded

$$S = 42.5077 - 7.65\,G + 0.55489\,G^2 - 0.01412\,G^3$$

Empty

$$S = 34.342 - 0.37379\,G - 0.123396\,G^2$$

where: S = Maximum vehicle speed in miles per hour
G = Section grade in percent

Downhill speeds are assumed to be maximum.

Truck Production Formula

$$TPH = \frac{(60)(TCAP)(DEN)(EFF)(AVAIL)}{CT}$$

where: TPH = Production in tons per hour
TCAP = Truck capacity in loose cubic yards
DEN = Density in tons per loose cubic yard
EFF = Efficiency in decimal form
AVAIL = Availability in decimal form
CT = Cycle time in minutes

Cycle time = Load time + Loaded travel time + Dump time + + Empty travel time + maneuver time

Note that if the truck is hauling a known tons of material, the equation can be reduced to:

$$TPH = \frac{(60)(TCAP)(DEN)(EFF)(AVAIL)}{CT}$$

where: TCAP = truck capacity in tons.

Truck Cost Formula

$$\$/ton = \frac{O\&O}{TPH}$$

where: \$/ton = Cost in dollars per ton coal
O&O = Owning and operating cost in dollars per hour
TPH = Production in tons per hour

Production and cost estimate for Wabco 75B (Cap. = 75 tons)

	Distance (feet)	G.R.(%)	R.R.(%)	Max.Speed (mph)	Correction Factor	Av.Speed (mph)	Time (min)
Loaded	2000	--	6%	13.53	0.93	12.6	1.80
	400	-10%	6%	13.53	0.75	10.2	0.45
Empty	2000	--	6%	27.66	0.93	25.7	0.88
	400	+10%	6%	12	1.3	15.6	0.29

Cycle Time = Travel time + Load time + Dump time

Cycle Time = (1.80 + 0.45 + 0.88 + 0.29) + 3.50 + 1.00

Cycle Time = 7.92

$$TPH = \frac{(60)(TCAP)(EFF)(AVAIL)}{CT}$$

$$TPH = \frac{(60)(75)(0.80)(0.90)}{7.92}$$

TPH = 409 ton/hour

Owning and Operating cost for a Wabco 75B equals $67.30/hr

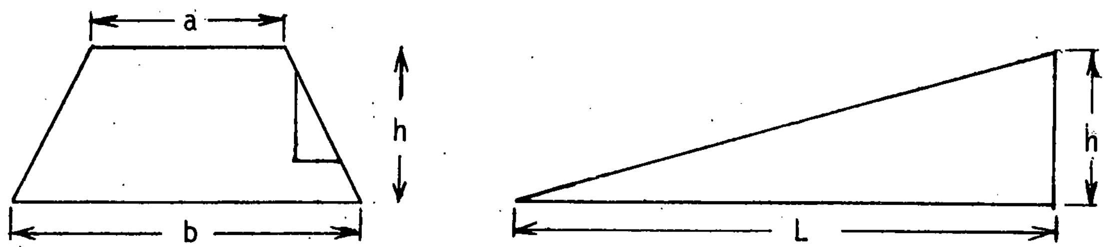
$$\$/ton = \frac{O\&O}{TPH}$$

$$\$/ton = \frac{67.30}{409}$$

$/ton = $0.16

COAL RAMPING COSTS

Average End Area for Ramp Volume



$$A = 1/2\,(a + b)h$$

where:
- A = Area of a trapezoidal cross-section in square feet
- a = width of haul road in feet
- b = Width at base of fill in feet
- h = height of ramp in feet

$$b = \frac{2h}{S} + a$$

where: S = grade (rise:run) of the slope

$$V_R = \frac{L(A_1 + A_2)}{(2)(27)}$$

where:
- V_R = Volume of the ramp by the average end area in cubic yards
- A_1 = Area at the bottom of the ramp in square feet
- A_2 = Area at the top of the ramp in square feet
- L = Horizontal length of the ramp in feet (height divided by grade in decimal form)

Coal Ramping Cost Formula (See Appendix B)

$$C_R = \frac{0.456d^2(CPY)}{R\,L_p\,G\,t_1}$$

where:
- C_R = Ramping cost in dollars per ton of thin seam
- d = Depth of the ramp in feet
- G = Grade of the ramp in decimal form
- L_p = Total length of the pit in feet
- R = Percent recovery of the thin seam in decimal form
- t_1 = Thickness of the thin seam
- CPY = Owning and operating cost of dragline in \$/cu.yd.

Ramp Rehandle Cost Formula (See Appendix D)

$$C_H = \frac{0.221(R_e)(D)}{t_1}$$

where: C_H = Cost of rehandle per ton of thin seam
R_e = Percent rehandle required in decimal form
D = Total thickness of overburden and parting in feet
t_1 = Thickness of thin coal seam in feet

Assumes: CPY = \$0.218/cu.yd.
R = 90%

Estimated Rehandle Cost of 40 Foot High 20% Ramp

Assume: 20 foot roadway
20% Ramp grade
0.8 to 1 slope
40 foot high ramp
12,000 foot pit
1 foot seam of coal
100 foot wide pit
80 feet of overburden and parting

$$V_R = \frac{L(A_1 + A_2)}{(2)(27)}$$

$$A_1 = 0$$

$$A_2 = 1/2\ (a + b)h$$

$$A_2 = 1/2\ (a + \frac{2h}{S} + a))h$$

$$A_2 = 1/2\ (20 + \frac{2(40)}{0.8} + 20))40$$

$$A_2 = 2800\ ft^2$$

$$V_R = \frac{(\frac{40}{.2})(0 + 2800)}{(2)(27)} = 10,370\ yd^3$$

$$\%\ Rehandle = \frac{V_R}{V_P}(100) = \frac{10,370}{(100)(80)(12,000)(1/27)}(100)$$

$$\%\ Rehandle = 0.29\%$$

$$C_H = \frac{0.221(R_e)(D)}{t_1},\ C_H = \frac{0.221(0.29\%)(80)}{100}$$

C_H = \$0.05/ton coal for a 1-foot seam

For a 2-foot seam C_H = \$0.025/ton, For a 4-foot seam C_H = \$0.013/ton

HYDRAULIC EXCAVATOR

Estimated Production:

Shot Coal - 1250 TPH

Unshot Coal - 940 TPH

$$\$/T = \frac{O \& O}{TPH}$$

$$\text{Shot Coal} - \$/T = \frac{82.73}{1250} = \$0.07/T$$

$$\text{Unshot Coal} - \$/T = \frac{82.73}{940} = \$0.09/T$$

DRAGLINE REMOVING COAL

Ave. Cost/cu yd = $0.218 per cu yd moved

Coal - 1.1 T/cu yd

Since the dragline is loading coal, the production will be only 75% that of when removing overburden.

$$\text{Cost/cu yd} = \frac{\text{Owning \& Operating Cost/hr}}{\text{Cu yds/hr}}$$

and the cu yds/hr decreases by 75%

$$\text{Cost/cu yd in coal} = \frac{0.218}{.75} = \$0.291/\text{cu yd}$$

$$\text{Cost/ton} = \frac{(\$0.291/\text{cu yd})}{1.1\ \text{T/cu yd}} = \$0.265/\text{T}$$

But if dragline didn't get the thin seam coal, it would have to be spoiled and so the difference between spoiling and recovering would be the cost.

Difference

$$\$0.291/\text{cu yd} - \$0.218/\text{cu yd} = \$0.073/\text{cu yd}$$

$$\frac{\$0.073/\text{cu yd}}{1.1\ \text{T/cu yd}} = \$0.07/\text{T}$$

B-E 195 B COAL LOADING SHOVEL

Standard Bucket - 20 cu yd

Production:

Assumptions

Coal - 1.1 T/cu yd

Bucket Fill Factor - 75%

Availability - 80%

Utilization - 6.5 hr/8 hr shift = 81.25%

Average Cycle Time - 30 sec.

TPH = (20 cu yd/cycle)(2 cycles/min)(60 min/hr)(1.1 Ton/cu yd)(.75)(.80)(.8125)

= 1287 Tons/hr

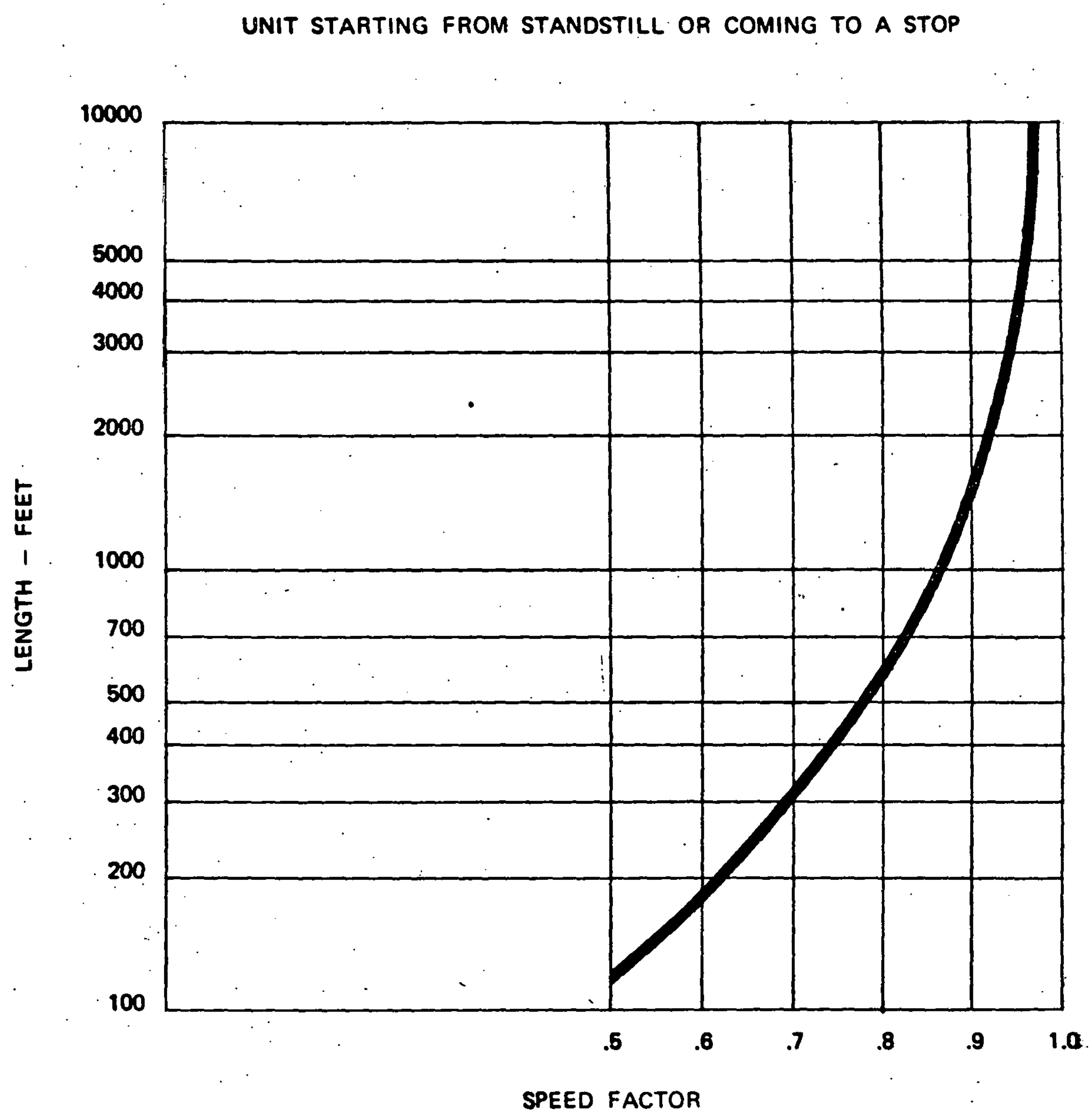
$$\$/T = \frac{O\&O}{TPH}$$

$$\$/T = \frac{\$128.48}{1287\ TPH} = \$0.10/T$$

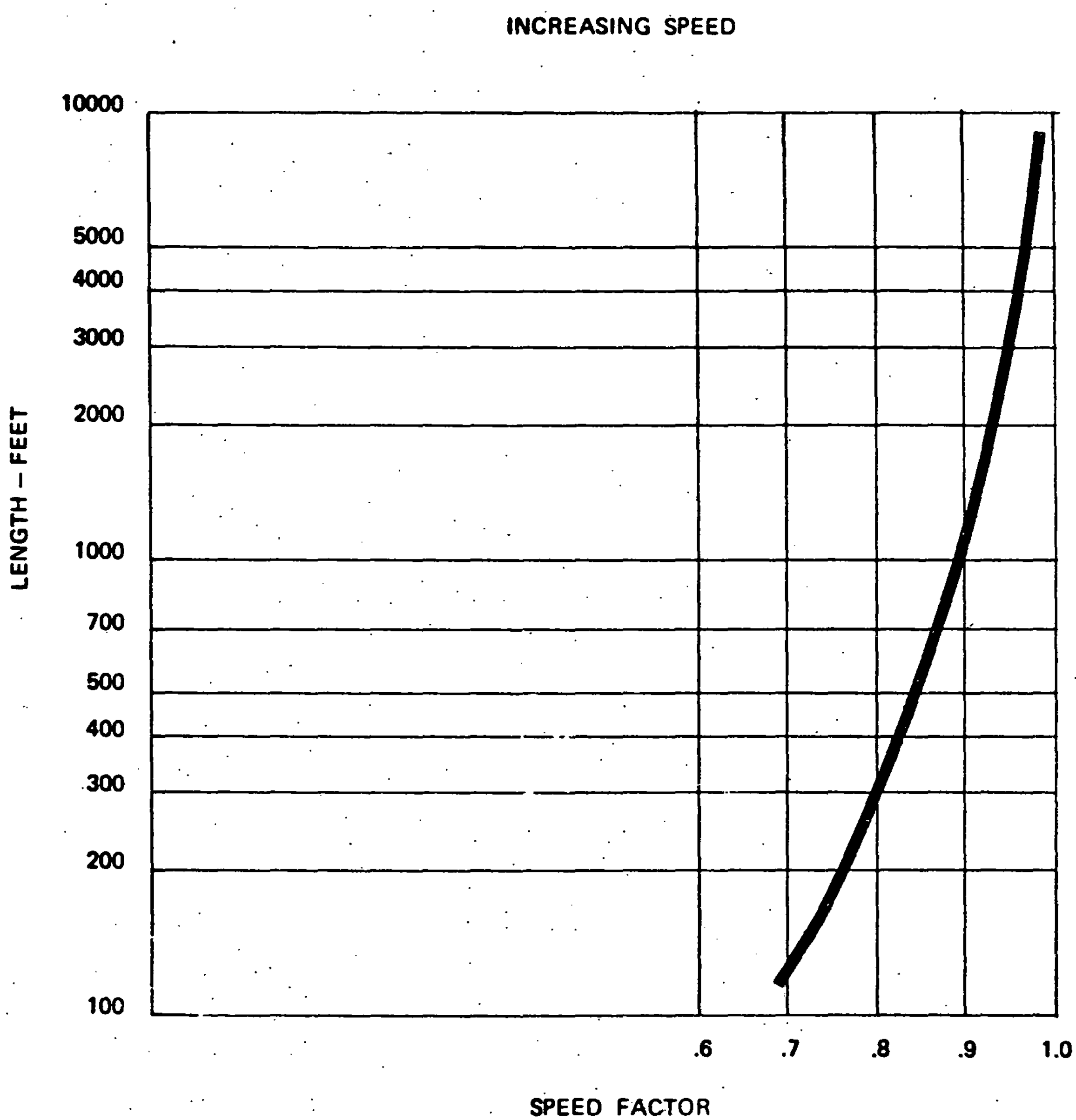
APPENDIX H

VEHICLE SPEED CORRECTION CURVES

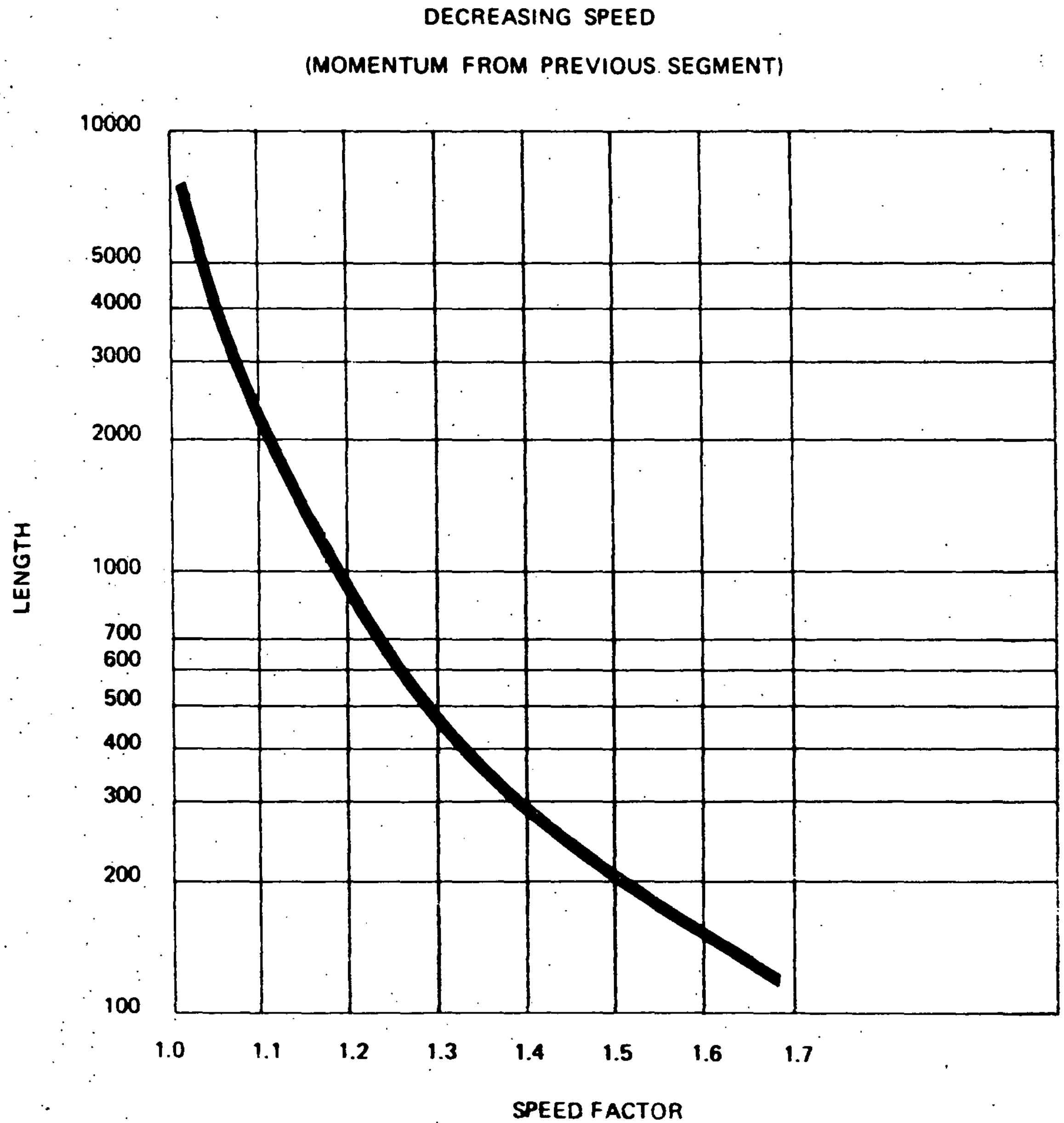
The following speed correction curves were adapted from <u>Production and Cost Estimating of Material Movement with Earthmoving Equipment</u> by Terex G.M. (General Motors Corporation, 1970), revised Nov. 1974, p. 24.


UNIT STARTING FROM STANDSTILL OR COMING TO A STOP
LENGTH – FEET
10000
5000
4000
3000
2000
1000
700
500
400
300
200
100
.5
.6
.7
.8
.9
1.0
SPEED FACTOR

UNIT IN MOTION



UNIT IN MOTION



APPENDIX I

OWNING AND OPERATING COST

NEW THIN SEAM MACHINES

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: Easi-Miner Model 1224

OWNERSHIP COST

1. Depreciation

Weight and Price	150,000 #	$ 567,000
Extras	#	
	#	
Freight # @ /cwt.		6,500
Total Delivered Price		$ 573,500
Less Original Tires		
Amount to be Salvaged		573,500
Less Salvage or Resale @ 0 %		0
Total Amount to be Depreciated		$ 573,500

Useful Life: 5 yrs.

@ 3750 hrs/yr

Average Investment $\left(\frac{\text{Del. Price + Salvage}}{2}\right)$ 286,750

Hourly Depreciation Cost . . . . 30.59 /hr

2. Interest, Taxes, and Insurance

Interest 10%, Taxes 2 %, & Insurance 2 %

$\frac{\text{Total 14\% x Average investment}}{\text{hrs/yr}}$ . . . . 10.71 /hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 41.30 /hr

OPERATING COST

3. Fuel or Power Cost
(Est. Consumption: 56 gal /hr) @ ($ 0.43 /unit) 24.08 /hr

4. Tire Replacement and Repair
$\left(\frac{\$ \quad}{\text{hrs}}\right)$ + (____ % for Repairs) . . . . . . N.A. /hr

5. Lubricants, Filters, & Grease
Est. at 20 % of Fuel cost 4.82 /hr

6. Repairs, Maintenance, and Supplies
Est. at 125 % of Hourly Depreciation Cost 38.24 /hr

7. Wages and Fringe Benefits
   a) Operator: $ 8.66 /hr + 35 % for Fringe Benefits 11.69 /hr
   b) Oiler: $ ____ /hr + ____ % for Fringe Benefits N.A. /hr
   c) Groundman: $ ____ /hr + ____ % for Fringe Benefits N.A. /hr

TOTAL HOURLY OPERATING COST . . . . $ 78.83 /hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 120.13 /hr

@ 1800 TPH = $0.067/ton

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: Easi-Miner Model TE-475

OWNERSHIP COST

1. Depreciation

Weight and Price	52,000 #	$ 265,000
Extras	#	
	#	
Freight ______ # @ ______ /cwt.		5,000
Total Delivered Price		$ 270,000
Less Original Tires		N.A.
Amount to be Salvaged		270,000
Less Salvage or Resale @ 0 %		0
Total Amount to be Depreciated		$ 270,000
Useful Life: 5 yrs. @ 3750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		135,000
Hourly Depreciation Cost		14.40 /hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %	
Total 14 % x Average investment / hrs/yr	5.04 /hr

TOTAL HOURLY OWNERSHIP COST	$ 19.44 /hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 10 gal /hr) @ ($ 0.43/unit)	4.30 /hr
4. Tire Replacement and Repair ($ ____ / hrs) + (____ % for Repairs)	N.A. /hr
5. Lubricants, Filters, & Grease Est. at 20 % of Fuel cost	0.86 /hr
6. Repairs, Maintenance, and Supplies Est. at 125 % of Hourly Depreciation Cost	18.00 /hr
7. Wages and Fringe Benefits	
a) Operator: $ 8.66 /hr + 35 % for Fringe Benefits	11.69 /hr
b) Oiler: $ ____ /hr + ____ % for Fringe Benefits	N.A. /hr
c) Groundman: $ ____ /hr + ____ % for Fringe Benefits	N.A. /hr
TOTAL HOURLY OPERATING COST	$ 34.85 /hr
TOTAL HOURLY OWNERSHIP & OPERATING COST	$ 54.29 /hr

@ 500 TPH = $0.108/ton

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: Barber-Greene BWE Model WL-50

OWNERSHIP COST

1. Depreciation

Weight and Price	200,000 #	$1,000,000
Extras	Erection and Misc. #	10,000
	#	
Freight 200,000 # @ 3.20 /cwt.		6,400
Total Delivered Price		$1,016,400
Less Original Tires		N.A.
Amount to be Salvaged		1,016,400
Less Salvage or Resale @ 0 %		0
Total Amount to be Depreciated		$1,016,400
Useful Life: 10 yrs. @ 3750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		508,200
Hourly Depreciation Cost		27.10/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr 18.97/hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 46.07/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 35.6 gal /hr) @ ($0.43 /unit)	15.31/hr
4. Tire Replacement and Repair ($ ___ / hrs) + (___ % for Repairs)	N.A. /hr
5. Lubricants, Filters, & Grease Est. at 25 % of Fuel cost	3.83/hr
6. Repairs, Maintenance, and Supplies Est. at 125 % of Hourly Depreciation Cost	33.88/hr
7. Wages and Fringe Benefits	
a) Operator: $8.66/hr + 35 % for Fringe Benefits	11.69/hr
b) Oiler: $___/hr + ___% for Fringe Benefits	N.A. /hr
c) Groundman: $___/hr + ___% for Fringe Benefits	N.A. /hr

TOTAL HOURLY OPERATING COST . . . . $ 64.71/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 110.78/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: Unit Rig Unimatic BWE

OWNERSHIP COST

1. Depreciation

Weight and Price	200,000 #	$1,038,000
Extras	Erection and Misc. #	10,000
	#	
Freight 200,000 # @ 3.20 /cwt.		6,400
Total Delivered Price		$1,054,400
Less Original Tires		20,000
Amount to be Salvaged		1,034,400
Less Salvage or Resale @ 0 %		0
Total Amount to be Depreciated		$1,034,400
Useful Life: 10 yrs. @ 3750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		527,200
Hourly Depreciation Cost		27.58/hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr 19.68/hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 47.26/hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 65.5 gal /hr) @ ($0.43 /unit)	28.17/hr
4. Tire Replacement and Repair ($ 20,000 / 7000 hrs) + (20 % for Repairs)	3.43/hr
5. Lubricants, Filters, & Grease Est. at 25 % of Fuel cost	7.04/hr
6. Repairs, Maintenance, and Supplies Est. at 125 % of Hourly Depreciation Cost	34.48/hr
7. Wages and Fringe Benefits	
a) Operator: $8.66 /hr + 35 % for Fringe Benefits	11.69/hr
b) Oiler: $____/hr + ____% for Fringe Benefits	N.A. /hr
c) Groundman: $____/hr + ____% for Fringe Benefits	N.A. /hr

TOTAL HOURLY OPERATING COST . . . . $ 84.81/hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 132.07/hr

ESTIMATED HOURLY OWNERSHIP AND OPERATING COST

Machine: Production Model Forward Rotating BWE

OWNERSHIP COST

1. Depreciation

Weight and Price	150,000 #	$ 485,000
Extras	Erection and Misc. #	5,000
	#	
Freight 150,000 # @ 3.20 /cwt.		4,800
Total Delivered Price		$ 494,800
Less Original Tires		N.A.
Amount to be Salvaged		494,800
Less Salvage or Resale @ 0 %		0
Total Amount to be Depreciated		$ 494,800
Useful Life: 10 yrs. @ 3750 hrs/yr		
Average Investment (Del. Price + Salvage) / 2		247,400
Hourly Depreciation Cost		13.19 /hr

2. Interest, Taxes, and Insurance

Interest 10 %, Taxes 2 %, & Insurance 2 %

Total 14 % x Average investment / hrs/yr . . . . 9.24 /hr

TOTAL HOURLY OWNERSHIP COST . . . . $ 22.43 /hr

OPERATING COST

3. Fuel or Power Cost (Est. Consumption: 57 gal /hr) @ ($ 0.43 /unit)	24.51 /hr
4. Tire Replacement and Repair ($ ____ / hrs) + (____ % for Repairs)	N.A. /hr
5. Lubricants, Filters, & Grease Est. at 25 % of Fuel cost	6.13 /hr
6. Repairs, Maintenance, and Supplies Est. at 150 % of Hourly Depreciation Cost	19.79 /hr
7. Wages and Fringe Benefits	
a) Operator: $ 8.66/hr + 35 % for Fringe Benefits	11.69 /hr
b) Oiler: $ ____ /hr + ____ % for Fringe Benefits	N.A. /hr
c) Groundman: $ ____ /hr + ____ % for Fringe Benefits	N.A. /hr

TOTAL HOURLY OPERATING COST . . . . $ 62.12 /hr

TOTAL HOURLY OWNERSHIP & OPERATING COST . . . . $ 84.55 /hr

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