DRAGLINE PRODUCTION RATES USING DATA RECORDERS

by

Victor Abiad

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Mining Engineering).

Golden, Colorado

Date 14 May 1993

Signed: Victor Abiad
Victor Abiad

Approved: Matthew J. Hrebar
Dr. Matthew J. Hrebar
Thesis Advisor

Golden, Colorado

Date 5/14/93

Donald W. Gentry
Dr. Donald W. Gentry
Department Head
Mining Engineering

ABSTRACT

The increasing importance of walking draglines for overburden removal at Western U.S. surface coal mines has led to the focusing of attention on their activities. With the advent of electronic data collectors installed on draglines a large amount of production related data has become available regarding dragline operations under varying conditions. This study aims to present a method that identifies the factors of the dragline's operating environment that influence their performance, and incorporate these factors in the measurement of their production rates.

Data was collected from two operating draglines in North Dakota and was analyzed using linear regression and analysis of variance techniques. A copy of the data used in the study is included in the Colorado School of Mines - Mining Department's copy of this thesis.

The influential variables in the specific operation studied were identified to be the machine in use, the dig mode employed, the material being excavated, the swing angle and the hoist distance. Bucket type and weather were initially thought to be influential but were found not to be. Production rate functions were derived which took

these variables into consideration. The use of the production rate functions is twofold. Firstly, they can be used as a performance gauge to quantify productivity or to measure impacts of changes. And secondly, they can be used as a tool for predicting production under future conditions.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

ACKNOWLEDGMENTS

The author wishes to thank Dr. Matthew J. Hrebar, Thesis Advisor, for his extensive support and direction of this study. Gratitude is also expressed to Dr. Kadri Dagdelen and Dr. Rod Eggert for their interest and suggestions.

Thanks also to the engineers of the North Dakota property whose input was very valuable to this study. Special thanks to the Disciple Nathaniel, for his wisdom and great interest in the project. Gratitude is also extended to the management of the North Dakota property for allowing this study to be undertaken.

The author also wishes to thank the people of Integrated Systems, Incorporated of Sanford, Florida. Their help and knowledge were indispensible to this study.

Thanks are also extended to the Mining Engineering Department for providing the teaching assistantship that made the pursuit of a masters degree feasible.

And finally, the author wishes to express his deepest gratitude to his wife and best friend, Patricia, for her faith, sacrifice, and strength.

DEDICATION

Para kay Patricia.

CHAPTER 1

INTRODUCTION

In the past few decades walking draglines have gained prominence as the choice of equipment for overburden removal in Western U.S. surface coal mines (1,2). The large capacity, low unit operating cost, and high availability of these machines has made them very attractive for this purpose.

Many operations depend on a few of these machines to handle the majority of their stripping requirements. One such example is a coal mine in North Dakota which employs two walking draglines, an electric shovel, a front end loader, and a fleet of trucks for their stripping needs. Of this equipment, the two walking draglines move approximately 78% of the overburden. Due to this great dependence upon draglines, attention has been focused upon their activities because changes in their performance have an impact on the over-all productivity of the mine.

An understanding of dragline production rates and the factors that control these rates are important because rates are often used for evaluation and planning purposes. The impact of changes in mining methods and the effectiveness of new mining equipment are often gauged by comparisons of production rates before and after the changes are made. Operator proficiency is sometimes graded by direct comparisons between their production rates. Clearly, misunderstanding or misuse of production rate measurement may lead to incorrect decisions. Production rates can also be utilized as an accurate production forecasting tool when future operating conditions are known or can be predicted.

In the past, production and productivity functions have been formulated for draglines, but these tended to be of a general nature and were meant mainly for estimation purposes (1,3). These earlier estimators neglected operation factors such as the digging modes, the type of material, the weather, and the specific equipment used. These factors are thought to greatly influence the productivity of a machine.

With the advent of electronic data collectors installed on draglines, a large amount of production related data has become available regarding their operations under varying conditions. This study aims to present a method that takes these influential factors into account and formulate production functions for applications under specific conditions.

Chapter 1 gives a general overview of the work done in this study. It includes a description of how the data was acquired, and the procedure for analysis. The scope of the thesis and its limitations are also discussed.

Chapter 2 describes the production cycle of the dragline and how the data recorders function. It includes descriptions of the information gathered and how the information is treated.

Chapter 3 reviews the different factors that determine dragline production and includes a discussion of how the differences in the operating environment are expected to affect them. This chapter also presents the general dragline production function which shall be used in the later parts of the thesis.

Chapter 4 covers the statistical analysis of the operating data. It describes the statistical processes used in the determination of which factors of the operating environment are influential on production. These important components are those that shall be accounted for in the production function.

Chapter 5 summarizes the results of the data analysis and discusses applications of these results to real world problems. It includes application of the production function as a performance gauge, and as a predictor of future production.

Chapter 6 deals with the conclusions of the study and gives recommendations for further work.

1.1 Scope of Thesis

Dragline production rates are dependent upon the conditions under which they are operated. Comparison between this week's production, for example, and last week's production cannot be done directly because conditions may not have been the same. Among other factors that must be taken into account are the dig mode employed, the material type being excavated, and the particular equipment in use.

Information from data recorders on two operating draglines in the western U.S. was analyzed and important variables were identified and isolated. Production functions were then formulated for different conditions using statistical and linear regression techniques. The use of this function can be twofold. First, the equation can be utilized to gauge the performance of existing operations. Second, it can be used to forecast production under future conditions.

This study presents a model of how to use the data available from data recorders installed on many draglines.

1.2 Thesis Data Acquisition

Operating data were acquired from two similar machines working in the western U.S. These draglines had identical data recorders installed on them in 1990. The recorders are produced by Integrated Systems, Incorporated (ISI) of Sanford, Florida. The data recorders continuously document the performance of the draglines and the conditions under which they operate. The information recorded by these recorders includes dig mode employed, swing time, dump time, loading time, swing angle, hoist distance, number of dumps, cubic yards moved, delay times, and others. The data is recorded on magnetic tape and then downloaded onto a DBASE III-Plus (a Borland software product) database.

The data is kept in 4 data files. The "DIG" data file contains operational data (swing time, load time, number of dumps, cubic yards moved, etc.). The "DTR" data file has records on delays (reason for delay, down time, etc.). The "SHF" file has shift data such as kilowatt hours used and regenerated, and maximum electrical demand. The "SWG" data file contains production data (number of dumps, tons, number of swings, etc.). The data is classified according to the swing angle used. For example, an entry lists the number of swings between 50 and 60 degrees, and tons of material moved at this angle. A complete description of the data files, sample data, and a flowchart of the data recorder are presented in appendix A.

The data used in this study was from the "DIG" data file and covered the period from January to October 1992. The "DIG" file was edited to discard unnecessary data and prepare the needed data for analysis. The data in the "DIG" file is cumulative, for example the entry under swing time gives the total number of seconds that the dragline was swinging. To get the average swing time, the total swing time was divided by the number of dumps. Table 1 contains a description and sample of the data sets used in the study.

The data used in the analysis was comprised of 3479 data sets. A data set includes the operating conditions (e.g., dig mode, and material type) and the record of the performance (e.g., number of dumps, swing time, and tons) of the dragline under those conditions. When there is a change in operating conditions the recording of a new data set begins. Each shift is represented by one or more data sets depending on the working conditions.

1.3 Procedure For Analysis

The first step in the analysis was to identify which factors could be influential on the production of a drag-

Table 1
Data Set Description and Sample

Fields and Descriptions:

Date - year,month,day of operation
- used for classification for weather and bucket type

avg_swg - average swing angle in degrees
avg_hst - average hoist distance in feet
swg_ti - average swing time in seconds
dump_ti - average dump time in seconds
load_ti - average load time in seconds
ratio - ratio of average swing to average hoist
- for classification of dig as hoist limited or swing limited

yds/dump - measure of bucket load in lcy
dtyp - dig mode in use (10 = double dig, 41 = chopcut, 42 = frontcut)
matl - material type being excavated (1 = gray clay, 0 = sandy till)
bucket - classification of bucket (1 = high capacity, 0 = regular)
weather - classification of weather (1 = above freezing, 0 = below freezing)
machine - classification of machine (1 = D901, 0 = D902)
group - data group identification number

Sample Data:

ROW	date	avg_swg	avg_hst	swg_ti	dump_ti	load_ti	ratio
1	19920402	140.167	120.358	52.5000	12.8333	31.667	0.85868
2	19920402	89.707	118.578	35.0303	9.6667	27.343	1.32183
3	19920404	64.632	125.487	27.9474	7.4737	20.368	1.94157
4	19920404	60.050	109.780	26.1000	13.1000	25.150	1.82814

ROW	yds/dump	dtyp	matl	bucket	weather	machine	group
1	60.167	10	0	1	0	1	1
2	97.960	10	0	1	0	1	1
3	107.158	10	0	1	0	1	1
4	103.400	10	0	1	0	1	1

line. This was done through discussions with the mining engineers at the property being studied. The factors identified as potentially influential are listed below:

1. dig mode employed
2. material type excavated
3. bucket type used
4. particular machine
5. time of year/weather

The data was sorted on the database according to these five different potentially influential factors. Once sorted, the data was input into MINITAB (a statistical software package from Minitab, Inc.) which is available on the Colorado School of Mines' VAX mainframe computer. MINITAB was used for analysis of variance, establishment of general statistical relations, and for linear regression analysis.

An analysis of variance study was done to identify which of the potentially influential factors were really important. Production functions were then formulated under each set of conditions which incorporated these influential factors.

The production functions are dependent upon the conditions which the dragline operates (i.e., the swing angle, the hoist distance, the material). Therefore it can be used as a performance gauge if the conditions are known, and can also be used as a forecasting tool if swing angles, hoist distances, and other operating conditions can be predicted. A relation for forecasting swing angle and hoist distance from overburden depth is also presented.

1.4 Thesis Limitations

This study was performed on a set of machines working in nearly identical situations. The functions derived are applicable only for those machines working under those conditions and are not valid under any other set of conditions. This study does not aim to formulate a universal productivity function for all operating draglines. It is intended to serve only as a model for the future analysis of information from dragline data recorders and for the future formulation and use of productivity functions for each operation.

Only monthly average overburden data was available, as compared to detailed shift data for swing angle and hoist distance. This was found to be unsatisfactory for establishing the relationships between depth of overburden and swing angle, and depth of overburden and hoist distance. As a substitute, cut diagrams in plan view and cross-section were used to demonstrate the theoretical relation.

This study did not take into account differences between the different operators at the mine.

CHAPTER 2

DRAGLINE PRODUCTION DATA RECORDING

Electronic data collectors for dragline operations appeared on the market in the early 1980's and since then have become common in the coal mining industry (4). These data collectors chronicle the performance of the dragline and take note of the operating conditions for long periods of time. This has made a large amount of production related data available for study, which should lead to a greater understanding of the operations of draglines. This chapter describes the operation of draglines and how the ISI data recorders treat the different information.

2.1 Digging Cycle

The concept behind the operation of a dragline is a simple one. Explaining it in a non-complicated manner: the dragline moves overburden by first, dragging its bucket through the dirt. Second, picking the bucket up and swinging it over to the dumping area. Third, dumping the dirt out of the bucket. Fourth, swinging back to refill the bucket. No matter how complicated a dragline operation becomes, these four basic steps are followed. The four components taken together are called a cycle.

The full description of a dragline cycle starts at the point when the bucket is positioned and ready to be filled. The bucket is dragged through the material thus loading it. The bucket fills up to approximately a third of its capacity for every length of bucket that it is dragged. Therefore, it is dragged approximately three times its length in order to fill up to capacity (2).

Once the bucket is filled, it is hoisted out of the pit and swung in the direction of dumping. During this operation, the hoist ropes are reeled in and drag ropes are payed out simultaneously until the bucket is balanced in a stable carry position.

The dragline continues to swing and hoist the bucket until the proper dumping position is approached. As the dumping position nears, the swinging motion is decelerated and the drag rope is payed out. This causes the material to be dumped out of the bucket into an empty pit where the material collects into spoil piles and forms spoil peaks. The location of the spoil peaks are a function of depth and digging mode employed. Hoist distances are approximately 20 to 30 ft. above the spoil peak where dumping occurs.

In the middle of the dump cycle, swing controls are reversed to slow the swing motion and prepare for the swing back. Because of inertia, the draglines continue to swing in the original direction before reversing. As a result, the dumps are not performed at a single spot but occur over an arc as the dragline is still in motion while dumping.

During the return swing, the bucket is lowered and the drag ropes are reeled in to put the bucket back into a digging position. As the digging area is approached, the swing controls are reversed to slow the swing and are then put in neutral when the digging area is reached. The bucket is lowered into the dirt and is positioned for the next dig which starts the cycle over again.

2.2 Cycle Time

The total time required to complete the cycle is called the cycle time. The time it takes to complete each task is influenced by a large number of factors, including the swing angles, the hoist distance, the material being moved, the digging conditions and the particular equipment installed on the dragline in use. This is where the data recorders become important because they are able to record the time necessary to perform the dig and the conditions under which the dig occurs. Since the recorders are automated they are able to collect data over long periods.

The data recorders installed on the draglines note the swing time, the dump time, and the load time. Cycle time can be acquired as the sum of these three components. The data recorders also track delays and delay time. Delays are signaled and identified by the operators. Cycle time, on the other hand, is not. The data recorders are automated and time the three different cycle segments (swing, dump, and load) continuously while the draglines are in operation. The running time is recorded and assigned to one of the three different segments. The segments are identified in the following manner:

1. Swing Time: Recorded time during which the dragline is swinging its boom. Direction of swing is not recorded, only the total angle traversed between dumps and loads.

2. Dump Time: Starts when the swinging motion slows in preparation for the dump and terminates when the swing direction reverses and reaches a given speed. In some cases when swing motions do not slow down or reverse, dump time recording initiates when the drag drum starts to pay out rope and terminates when the drag drum reverses direction which signifies that a dump has been made.

3. Load Time: Starts when the swinging motion slows after a dump has been made in preparation for loading and terminates when the swing starts in the reverse direction. Thus, the time spent for positioning the bucket for digging

at the start of the loading cycle is included in this category.

Delays which are not recorded as such, are recorded either as dump time or load time. For example, if an operator stops the operating cycle for personal reasons (e.g., to remove his jacket), he positions the bucket and sets it down on the dirt. With the dragline stationary, he is free to release the controls and perform personal functions. Once ready, he can proceed with loading the bucket. This type of minor delay is often not recorded as a delay, but the elapsed time is credited to the load time segment.

2.3 Positioning - Swing, Hoist, and Drag

Positioning, as noted by the data recorders, refers to the position of the dragline in relation to where the dig is occurring. There are three entries under positioning:

1. Pu_swing : This refers to the swing angles that the dragline goes through from the end of the load to the dumping point. It is measured in degrees.
2. Pu_hoist : The figure recorded is the number of times a particular hoist gear rotates. Converting with the appropriate gear ratios gives the number of rotations of the hoist drum. Since the drum diameter is known, the amount of hoist rope that comes on and off the drum can be

calculated. This amount of rope is a direct measure of the distance the bucket is hoisted and lowered. Dividing by two gives the average hoist distance.

3. Pu_Drag : This number is similar to the Pu_hoist number in manner of measurement and significance except that it refers to drag distance as opposed to hoist distance. This number was meant to give a measurement of the displacement of the dragline from the point of digging by measuring the amount of drag rope payed out and reeled in. However, the data was not meaningful because, unlike the hoist ropes, the drag ropes often have a lot of slack and therefore cannot be used as a measure of drag distance.

All the positioning data is cumulative. The average swing angle, average hoist distance, and average drag distance is found by dividing the respective positioning data by the number of dumps in that data set.

2.4 Tonnage and Yardage

The data on amount of material moved is based on a measurement of the electrical current being used by the hoist motors. The data recorder continuously monitors the hoist motor during the hoist stage with a current transducer. A possible problem here is that hoist power required at different points is different (5). This is illustrated in

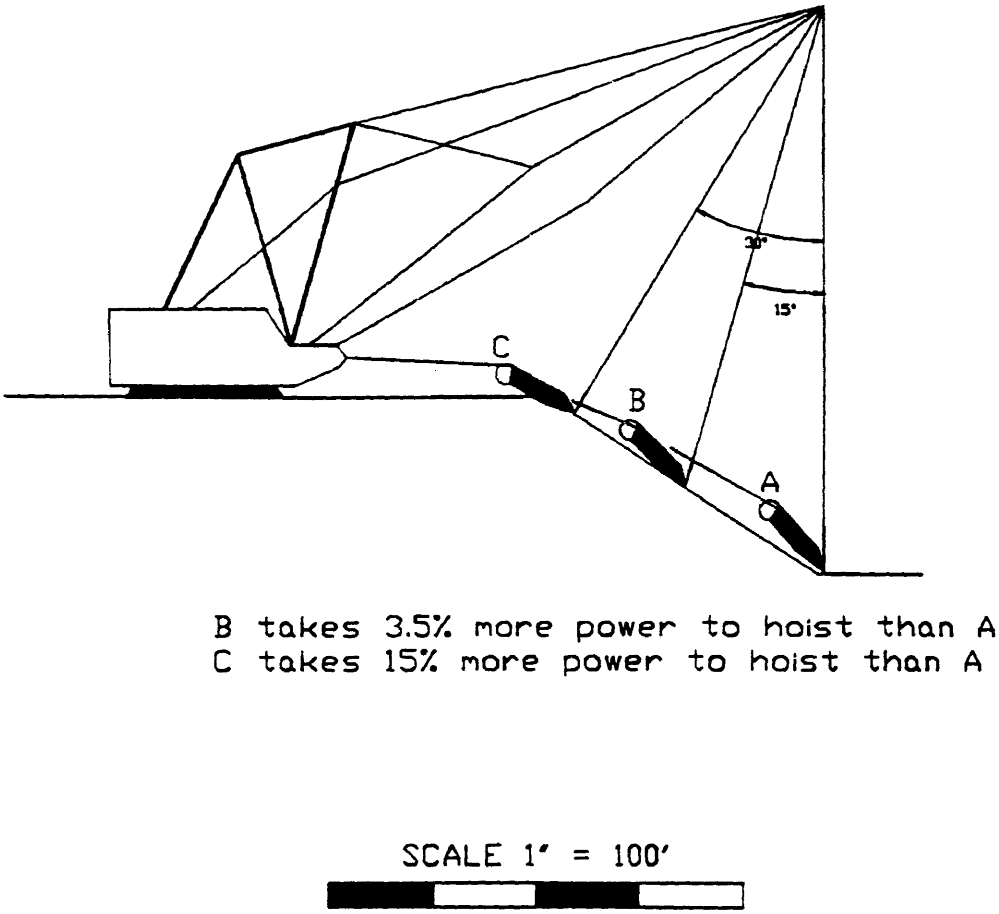
Figure 2.1.

To avoid this problem of varying hoist power requirements, the hoist current is monitored repeatedly (up to 30 times a second) during the hoist and only the final 6 seconds of readings before the actual dump are considered. These final readings are averaged and used for the tonnage calculation. A current versus load curve (Figure 2.2) is used for the conversion of current into tons. The relation between the current flow to the hoist motors and the tonnage of the material in the bucket was established from the curve, and takes into account bucket weight, material type, and digging practice among others. The weighing process was later calibrated with surveying data from the mine.

The tonnage can be converted to cubic yards with the use of the proper density or tonnage factor for the particular material being moved. When a bucket change occurs, the empty bucket is weighed and recorded as a reference for succeeding dumps.

2.5 Material Type, and Other Manually Entered Data

Some data is entered manually into the data recorders. This data includes: the material type, the shift, the crew, the operator, the scheduled hours, the date, the pit, the pass (i.e., upper or lower), and the dig mode.



B takes 3.5% more power to hoist than A
C takes 15% more power to hoist than A

SCALE 1' = 100'

Figure 2.1
Frontcut - Varying Hoist Power Requirements

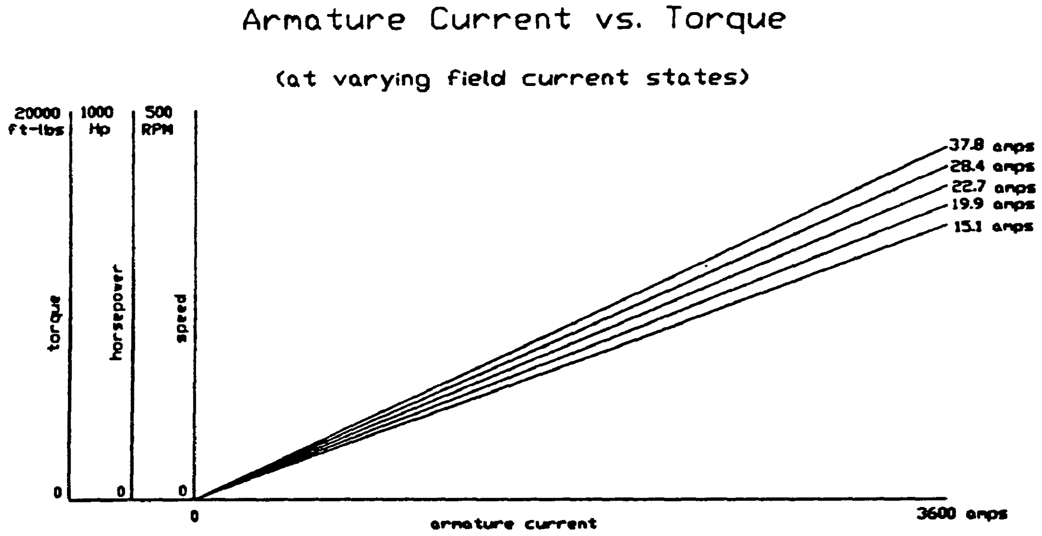


Figure 2.2
Current vs. Load Curve

Of the manually entered data, the most important information are the material type being excavated, the date, and the dig mode employed. The date was used for determining the prevalent weather pattern, and the bucket type.

2.6 Digging Modes

Though draglines are very common in coal mines, these machines rarely are used in the mining of the coal itself. The role of the dragline is to remove the overburden and uncover the coal. The coal is mined with other equipment, usually loaders and trucks.

Draglines, in general, work in a series of narrow (e.g., 100 to 200 ft.) pits. The pits run parallel to each other across the property, and progress over the property as each successive pit is mined out (Figure 2.3). The dragline digs the overburden in the current pit and dumps the material into the adjacent pit where coal has been removed.

The manner in which the dragline removes this overburden is referred to as the "dig mode". The dig mode is dependent on a number of factors such as the depth of the overburden and limitations of the dragline (i.e., reach and operating radius). For each given set of conditions, there often is a limited choice of dig modes, or combinations of

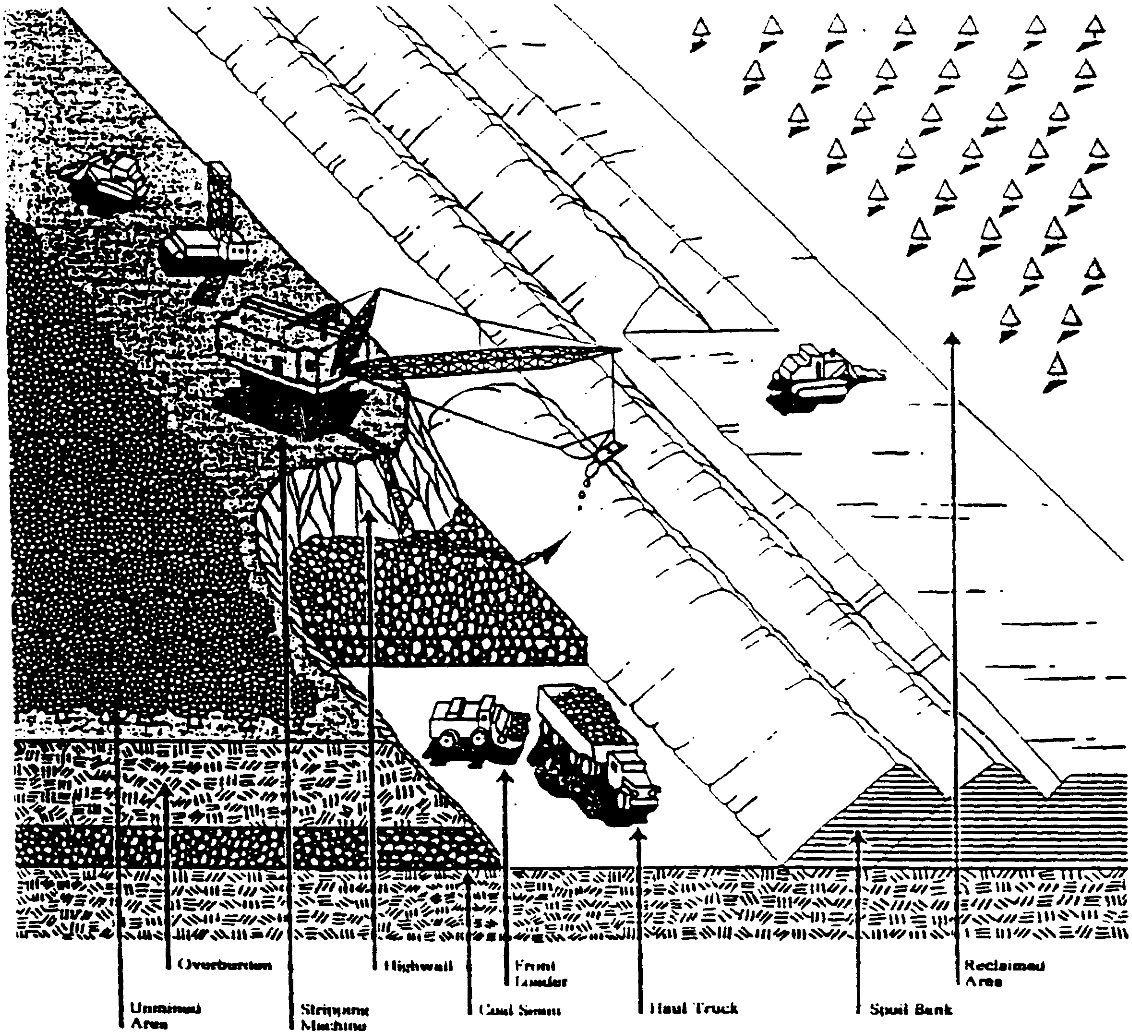


Figure 2.3
Dragline Stripping Operation

them, that can be employed.

It is important to understand which dig modes are used under given conditions because the dig mode affects the production of the machine. In the operation studied there were three dig modes in use:

1. sidecasting - front cut
2. sidecasting - chop cut
3. double dig

The most common dig mode is sidecasting-front cut. In this mode the dragline removes material in front of it and below its working level (Figures 2.1 and 2.4). The dragline drags its bucket up and across the digging face and swings 60 to 90 degrees to cast the material into the adjacent empty pit.

In this dig mode the dragline sits in four digging positions. In the first position, the machine is set off the key line by half the width of its bucket (about 10 ft.). In this position it digs the key cut (area 1) and is able to shape the new highwall without putting excessive lateral stress on the boom. It stays in this position and digs the key cut down as much as possible. After finishing the first lift of the key cut, the dragline then walks to position 2 from which it excavates the material beside the key cut in area 2.

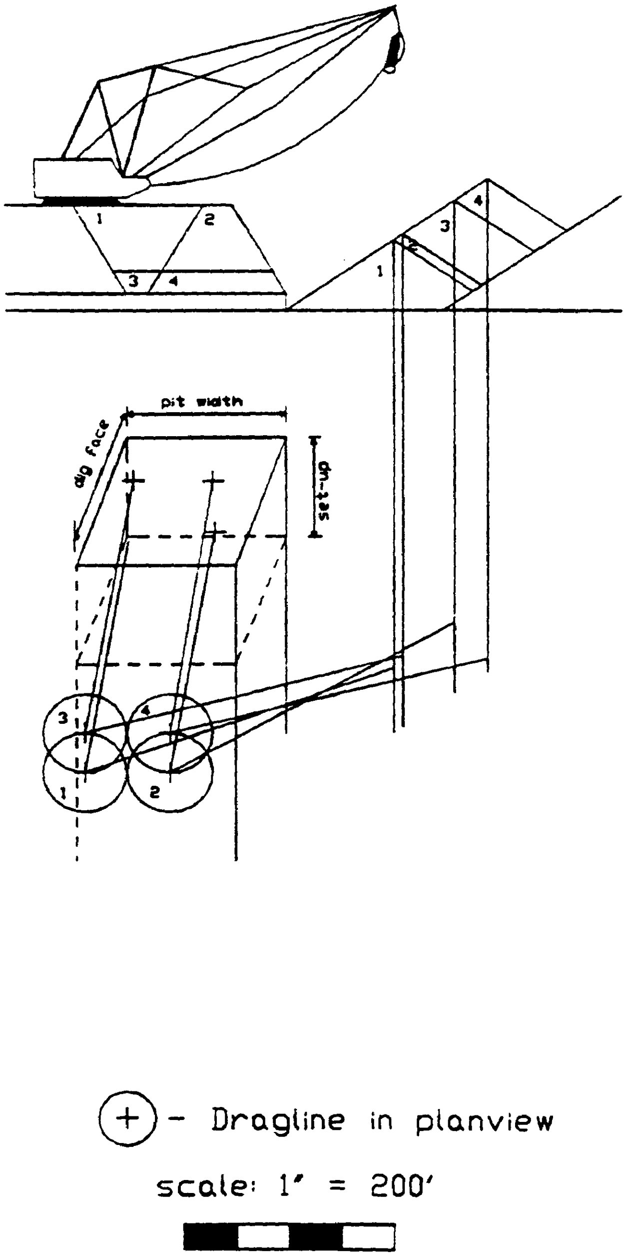


Figure 2.4
Sidecasting - Frontcut

When the first lift has been removed (areas 1 and 2),the dragline moves closer to the edge of the new working face and takes positions 3 and 4 to excavate the second lift (areas 3 and 4) in the same fashion as the first lift. In shallower overburdens (50 feet and below) only the first two positions are necessary as all of the material can be excavated in a single lift.

A less often-used dig mode is the sidecasting-chop cut mode (Figures 2.5a and 2.5b). This dig mode is similar to the previously discussed dig mode in that the dragline swings 60 to 90 degrees to spoil the material in the adjacent empty pit. The main difference is that the material being excavated lies above the working level of the dragline. Instead of the bucket being dragged up and across the digging face to pick up material, it is dragged down the digging face. In the frontcut mode,the material tends to flow into the upward moving bucket. In the chopcut mode, the material tends to flow out of the downward moving bucket. This results in lower bucket loads, longer load times and therefore lower production (1). There is also increased wear on the ropes and rigging as they are frequently dragged through the dirt.

This dig mode is rarely used and constituted only 3.1% of the digs in this study. The chopcuts are usually accom-

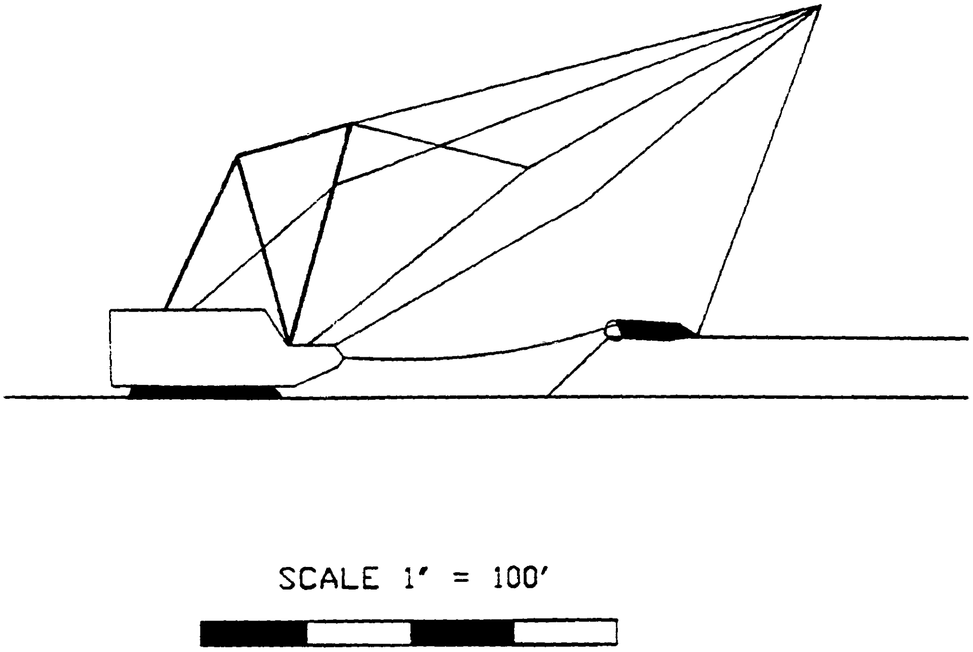


Figure 2.5a
Sidecasting - Chopcut (side view)

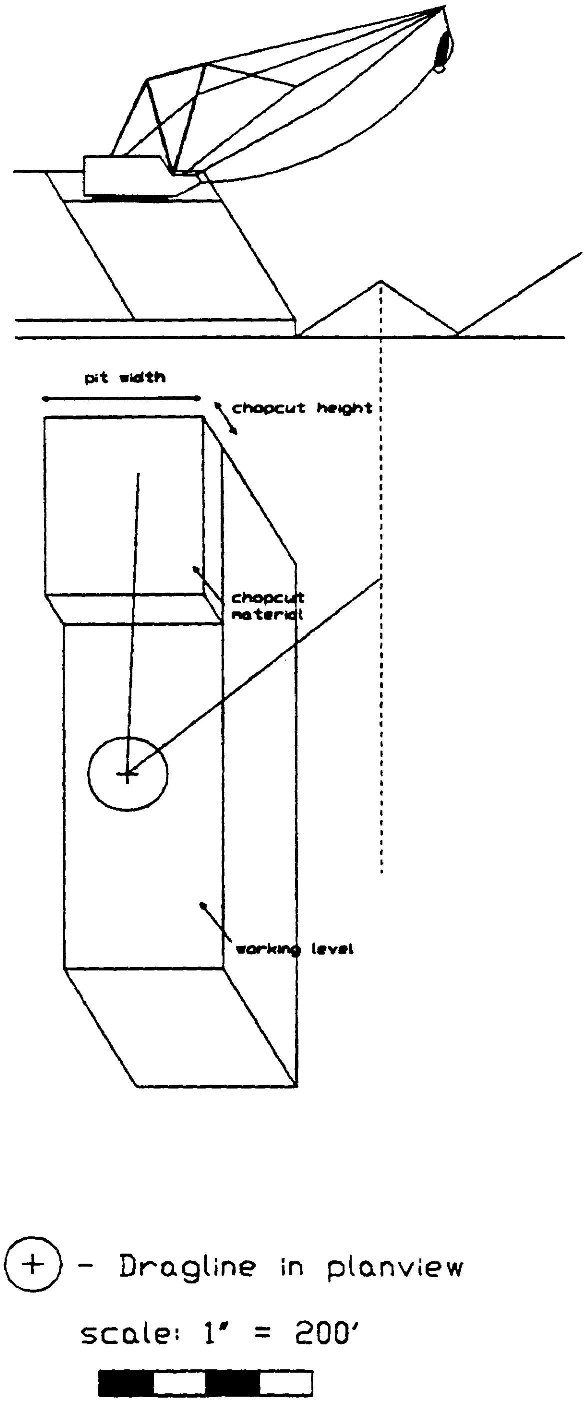


Figure 2.5b
Sidecasting - Chopcut (plan view)

plished in the double dig mode which shall be discussed later. Sidecasting chopcut is used only where the pit geometry makes it unsuitable to use the double dig mode.

The third digging mode studied is called the double-dig mode (Figure 2.6a). In this mode the dragline starts off with a front-cut similar to the one described earlier. It then starts to swing toward the empty pit and then, without slowing down, dumps into the empty pit. It continues swinging in its original direction and ends in a new digging position to take a chopcut. Once loaded at the chopcut, the dragline swings back toward the empty pit, where it dumps the material "on the fly", and swings on to the front cut dig position where it originally started. This dig mode is used when high overburden depths makes it necessary to employ the chopcut to lower the bench in the next pit and effectively increase the dragline reach. Double-dig is only used for the first 20 to 30 feet of lift. Once the chopcut has been completed, operators switch to the sidecasting-front cut dig mode for the excavation of the remainder of the bench.

Double-dig is also used when digging on the spoil side when excavating the extended bench (Figure 2.6b). This case is different because it digs from frontcuts on both sides of the swing. In this area the dragline is excavat-

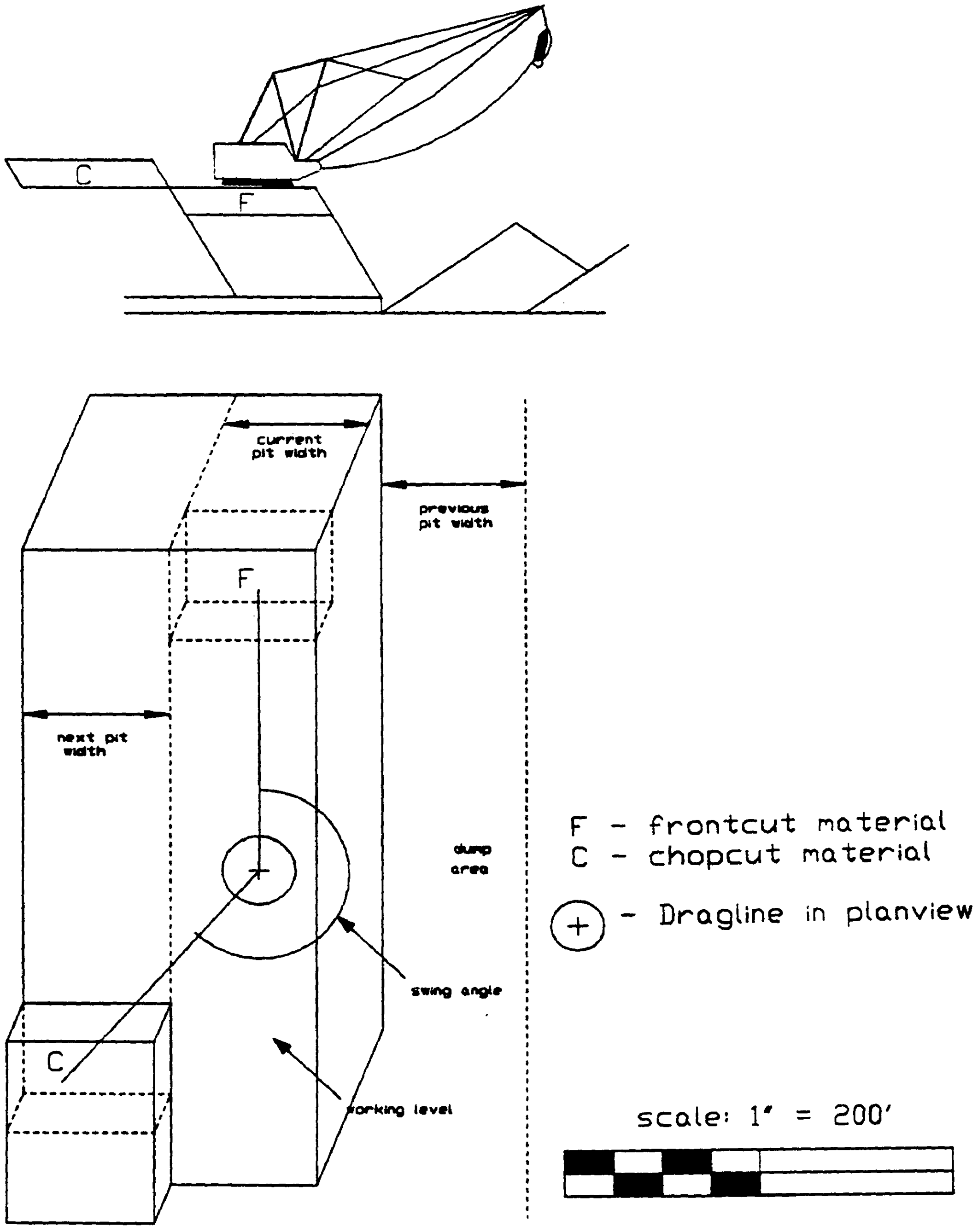


Figure 2.6a
Double Dig Mode
Frontcut to Chopcut

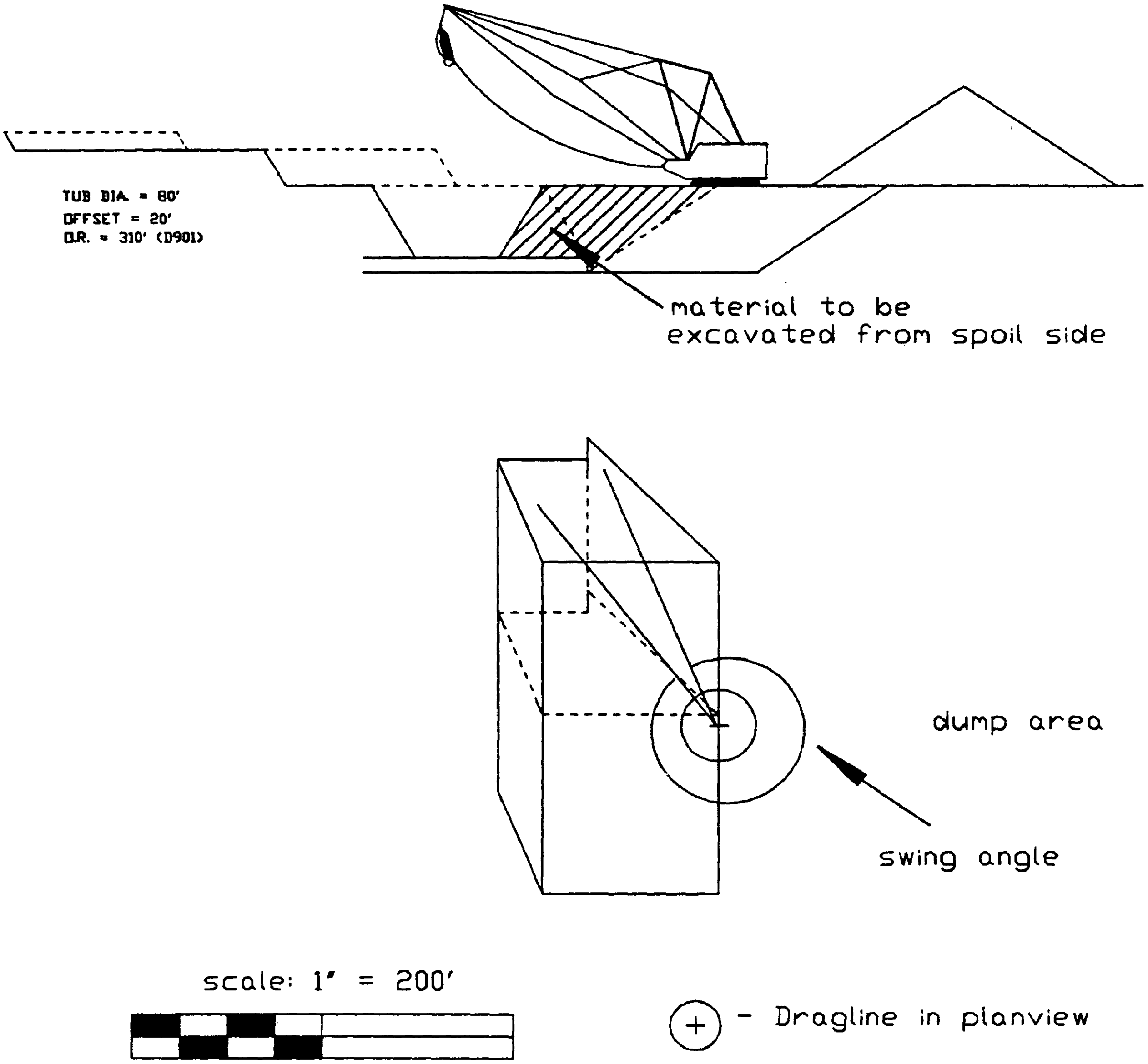


Figure 2.6b
Double Dig Mode
Frontcut to Frontcut on the Spoil Side

ing a mixture of virgin material and rehandle (material that has already been moved previously). The dumping occurs in the same manner.

CHAPTER 3

DRAGLINE PRODUCTION RATE

When considering production rates of any cyclic excavator there are two primary questions that need to be answered: 1.) How many cycles can the machine go through in a given period? and 2.) How much material is moved each cycle? The results of these two questions, when multiplied, give the production rate of the machine in question. The following formulas (Equations 1, 2 and 3) are the functions to be used for measuring cycle time and production rate in the various operating conditions. They were taken from a 1990 article by James Humphrey (6) and slightly modified.

$$\text{CYC\_TI} = \text{SWG\_TI} + \text{DUMP\_TI} + \text{LOAD\_TI} \qquad \text{(Eq. 1)}$$

where:

CYC_TI = average cycle time (secs.)
SWG_TI = average swing time (secs.)
DUMP_TI = average dump time (secs.)
LOAD_TI = average load time (secs.)

$$C = \frac{Hs \times Am \times JF\ I \times JF\ II \times 3600}{CYC\_TI} \qquad \text{(Eq. 2)}$$

where:

C = # of cycles per period
Hs = scheduled hours (hrs./period)
Am = machine availability factor (%)
JF I = job factor type I (%)
JF II = job factor type II (%)

$$P = \frac{C \times B \times F}{S}$$

$$= \frac{Hs \times Am \times JF\ I \times JF\ II \times 3600 \times B \times F}{CYC\_TI \times (1+S)} \qquad \text{(Eq. 3)}$$

where:

P = production rate (bcy/period)
B = rated bucket capacity (lcy/cycle)
F = fill factor
S = swell factor (%)

The definitions of the factors in the production function and the effect of the operating environment on them are discussed in this chapter.

3.1 Time Periods

The period refers to the time frame used when measuring production rates. The length of the period depends on intended use but is most often expressed in hours. The following list defines the terms used in this study.

1. Scheduled hours - This refers to the number of hours

that the dragline is expected to be operational. At the mine studied, there are usually 8 scheduled hours per shift, 3 shifts per day, and 365 working days per year. The scheduled hours decreases to account for scheduled delays such as holidays. It is also adjusted for delays which are not related to the machine in question, for example work stoppages due to labor disputes.

2. Available hours - This refers to the number of hours during which the dragline is physically available for digging. It is a subset of the scheduled hours and is defined as the scheduled hours minus mechanical and electrical delays. Following is a list of mechanical and electrical delays as identified in the data base.

Mechanical and Electrical Delays:

Daily Preventive Maintenance
Grease Bucket
Wire Rope
Bucket and Rigging
Lube/ Air System
Drag / Crowd Equipment
Hoist Equipment
Swing Equipment
Propel Equipment
Boom/Mast/A-frame
Fairleads/Pointsheave
Shoes/Crawlers
Scheduled Preventive Maintenance
Pit Power Distribution Equipment
Generators and Control (Drag/Crowd)
Generators and Control (Hoist)
Generators and Control (Propel)
Generators and Control (Swing)

Exciter Set
M.G. Sets
High Voltage Equipment
Auxiliary Electrical Equipment
Other

3. Digging Hours - This refers to the time spent by the machine excavating material. It is a subset of available hours and is defined as the available hours minus operating delays.

There are two types of operating delays used in this study. Type I operating delays are not related to the dig mode in use. These delays occur regardless of how the dragline is being utilized or the dig mode used. They are related to the machine in use, the crews that regularly operate them, the working conditions and practices at the particular mine, and the overall mine plan. Following is a list of Type I operating delays.

Type I Operating Delays (Non-dig mode related):

Shift Change
Training
Meeting
Tours
Load/Unload Supplies
Weather
Power Cable Moves
Deadheading
Blasting In Pit
Pit Clean Up
Clean Bucket

Type II delays are related to the dig mode in use. These delays reflect the fact that draglines operate differently in each dig mode and that some dig modes are more productive than others. For example if a certain dig mode requires frequent re-positioning of the machine, the production rate in that dig mode can be expected to decrease. Following is a list of Type II operating delays.

Type II Operating Delays (Dig mode related):

Maneuvering (Positioning)
Leveling Machine
Dozer Work
Inside Swing Radius

3.2 Availability Factors

The ratio of the available hours to the scheduled hours gives us the mechanical availability factor. The ratio of the digging hours to the available hours gives us the two types of job factors. Availability factors can be determined with historical data from each machine using the following equations.

$$Am = \frac{Hs - Dm}{Hs} \times 100 \qquad \text{(Eq. 4)}$$

where:

Am = mechanical availability factor (%)
Hs = scheduled hours
Dm = mechanical/electrical delays (hours)

$$JF\ I = \frac{Hs - Dm - Dnd}{Hs - Dm} \times 100 \qquad \text{(Eq. 5)}$$

$$JF\ II = \frac{Hs - Dm - Dnd - Ddr}{Hs - Dm - Dnd} \times 100 \qquad \text{(Eq. 6)}$$

where:

JF I = Job Factor Type I (%)
JF II = Job Factor Type II (%)
Dnd = Type I (non-dig mode related) operating delays (hrs.)
Ddr = Type II (dig mode related) operating delays (hrs.)

Availability factors are convenient ways of recognizing the fact that people and machines are not perfect, that they spend some time in delays, and do not work 100% of the time.

Mechanical Availability is expected to be constant for each machine considered. It is dependent on factors such as the age of the machine, the quality of maintenance, and the skill level of the operators. Job Factor Type I is non-dig mode related and is also expected to be constant per machine. It is dependent upon the behavior of operators and the labor practice of the mine. Job Factor Type II is dig mode related and is expected to vary with dig mode and specific machine in use.

3.3 Cycle Time

Cycle time, as defined earlier, is the time required for the dragline to complete a digging cycle. It is the sum of the swing time, dump time, and load time. Each of these time segments are affected by other factors and shall be considered individually.

3.3.1 Swing Time

Swing time is the time needed to get the loaded bucket into dumping position and return the empty bucket to the digging position. The buckets undergo two general motions in this stage. A swinging motion (loaded and return swings) and a vertical motion (hoisting and lowering).

The dragline can swing, hoist the bucket, and lower the bucket at a certain speed. These speeds are dependent upon the swing machinery and hoist machinery installed on the dragline. Given the equipment installed on a dragline the swing speeds, hoist speeds, and lowering speeds can be calculated.

For the loaded swing of each cycle, the positions in space at which the loading of the bucket ends and the dumping of the bucket begins can be described. The spatial distance between these two points must be traversed by the bucket through a certain swing angle and a certain hoist distance. The time needed to swing the required angle and the time needed to hoist the required distance can be found since the swing speed and the hoist speeds of the machines are known. In most cases, one shall take longer than the other. Therefore any given digging geometry can be described as being either swing-limited or hoist-limited.

For example, if the required swing angle is small and the hoist distance large, then the dragline would be able to swing the bucket over in a short period of time but would not be able to dump the load until the bucket was hoisted the proper hoist distance. This case would be called hoist limited because the swing is already completed but the hoist is not. The hoist speed is the limiting factor and the determinant for the swing time. The reverse case (i.e., large swing angle with low hoist distances) would be referred to as swing limited.

A line (Figure 3.1) with slope equal to the ratio of the rated hoist speed and the swing speed of a particular machine defines a line in space at which the hoist times and swing times are coincidental. Points with a hoist distance to swing ratio less than the slope of the coincidental line lie below the line. These points represent swing limited digs. All points above the line would represent hoist limited digs. In this study the swing speed of the machine was 2.63 degrees/second, and the rated hoist speed was 7.66 feet/sec. The coincidental line has a slope of 2.91 and passes through the origin.

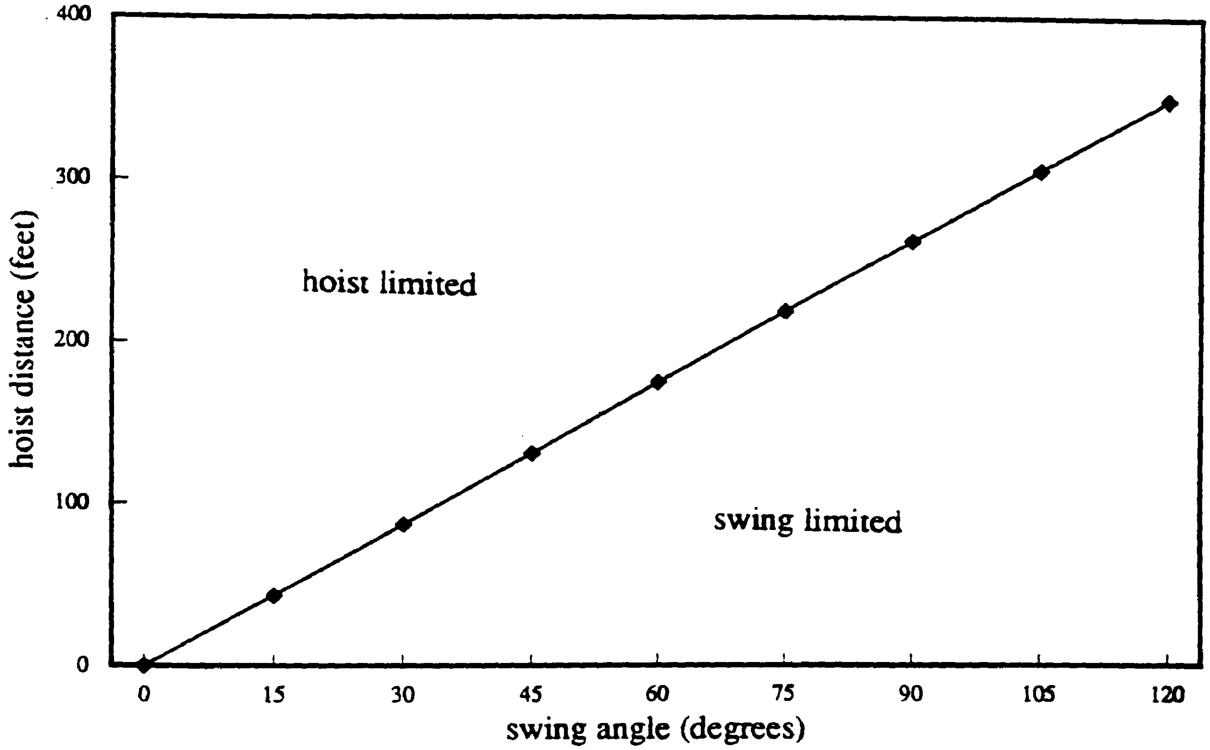


Figure 3.1
Hoist Distance vs. Swing Angle
Loaded Swing

Similarly, in the return segment of the swing, the bucket lowering speed and the swing speed are compared to determine which is the limiting factor in the determination of the swing time. In this segment of the swing, the empty bucket is being lowered rapidly (i.e., rated pay out speed of 17.55 feet per second) and the swing time becomes swing angle dependent again in the vast majority of cases. This is illustrated in Figure 3.2. The coincidental line in the curve for the return swing has a slope of 6.67 and passes through the origin. A review of the data shows that very few of the digs had geometries that made them hoist limited in the return swing.

The relationship between swing angle, hoist distance, and swing time was calculated and is tabulated in Table 3.1 and plotted in Figures 3.3a and 3.3b. Swing time in swing limited digs are dependent only upon the swing angle, on the other hand, swing time in hoist limited digs are dependent on both hoist distance and swing angle.

The reason that hoist limited digs are dependent upon both the swing angle and the hoist distance is they are hoist limited only during the loaded segment of the swing, when the loaded bucket is being lifted upwards. In the return segment, the swing becomes dependent on the swing angle once again.

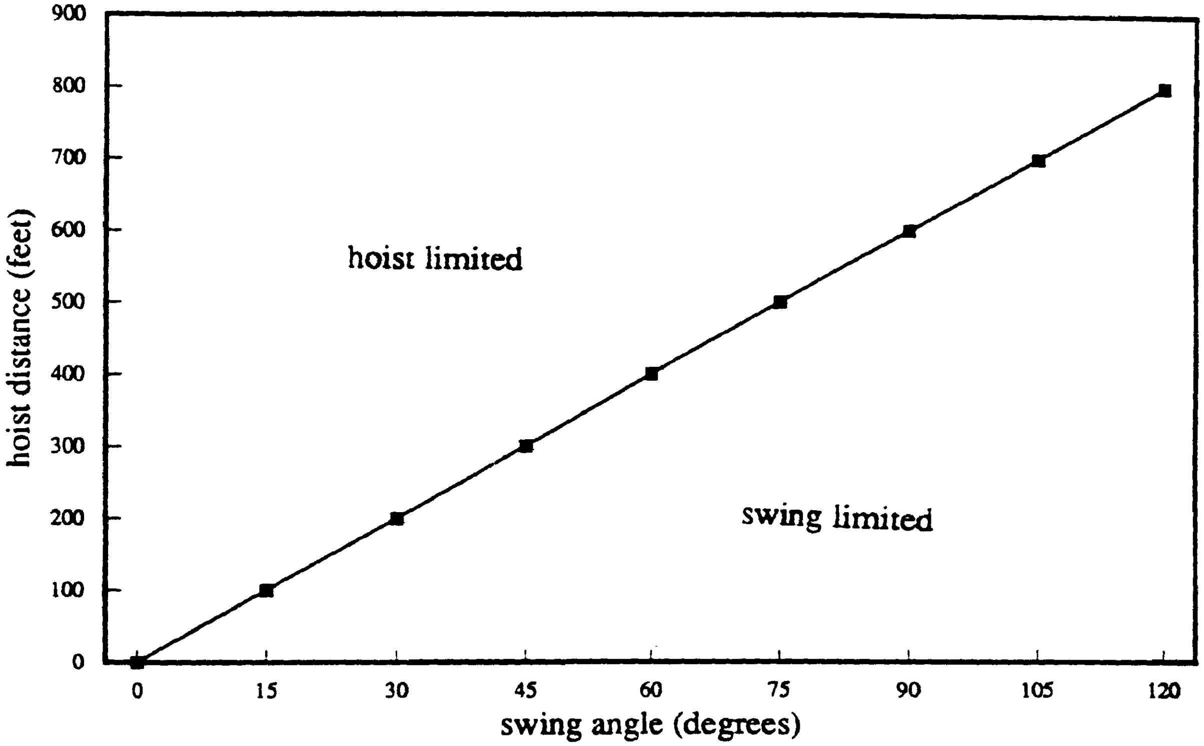


Figure 3.2
Hoist Distance vs. Swing Angle
Return Swing

Table 3.1
Theoretical Total Swing Times (secs.)
(Loaded and Return Swings)

HOIST DISTANCE IN FEET	SWING ANGLE (DEGREES)											
	60	65	70	75	80	85	90	95	100	105	110	115
100	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
110	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
120	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
130	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
140	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
150	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
160	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
170	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
180	46.3	49.4	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
190	47.6	49.5	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
200	48.9	50.8	53.2	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
210	50.2	52.1	54.0	57.0	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
220	51.5	53.4	55.3	57.2	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
230	52.8	54.7	56.6	58.5	60.8	64.6	68.4	72.2	76.0	79.8	83.7	87.5
240	54.1	56.0	57.9	59.8	61.7	64.6	68.4	72.2	76.0	79.8	83.7	87.5
250	55.5	57.4	59.3	61.2	63.1	65.0	68.4	72.2	76.0	79.8	83.7	87.5
260	56.8	58.7	60.6	62.5	64.4	66.3	68.4	72.2	76.0	79.8	83.7	87.5
270	58.1	60.0	61.9	63.8	65.7	67.6	69.5	72.2	76.0	79.8	83.7	87.5
280	59.4	61.3	63.2	65.1	67.0	68.9	70.8	72.7	76.0	79.8	83.7	87.5
290	60.7	62.6	64.5	66.4	68.3	70.2	72.1	74.0	76.0	79.8	83.7	87.5
300	62.0	63.9	65.8	67.7	69.6	71.5	73.4	75.3	77.2	79.8	83.7	87.5
310	63.3	65.2	67.1	69.0	70.9	72.8	74.7	76.6	78.5	80.4	83.7	87.5

hoist limited | swing limited

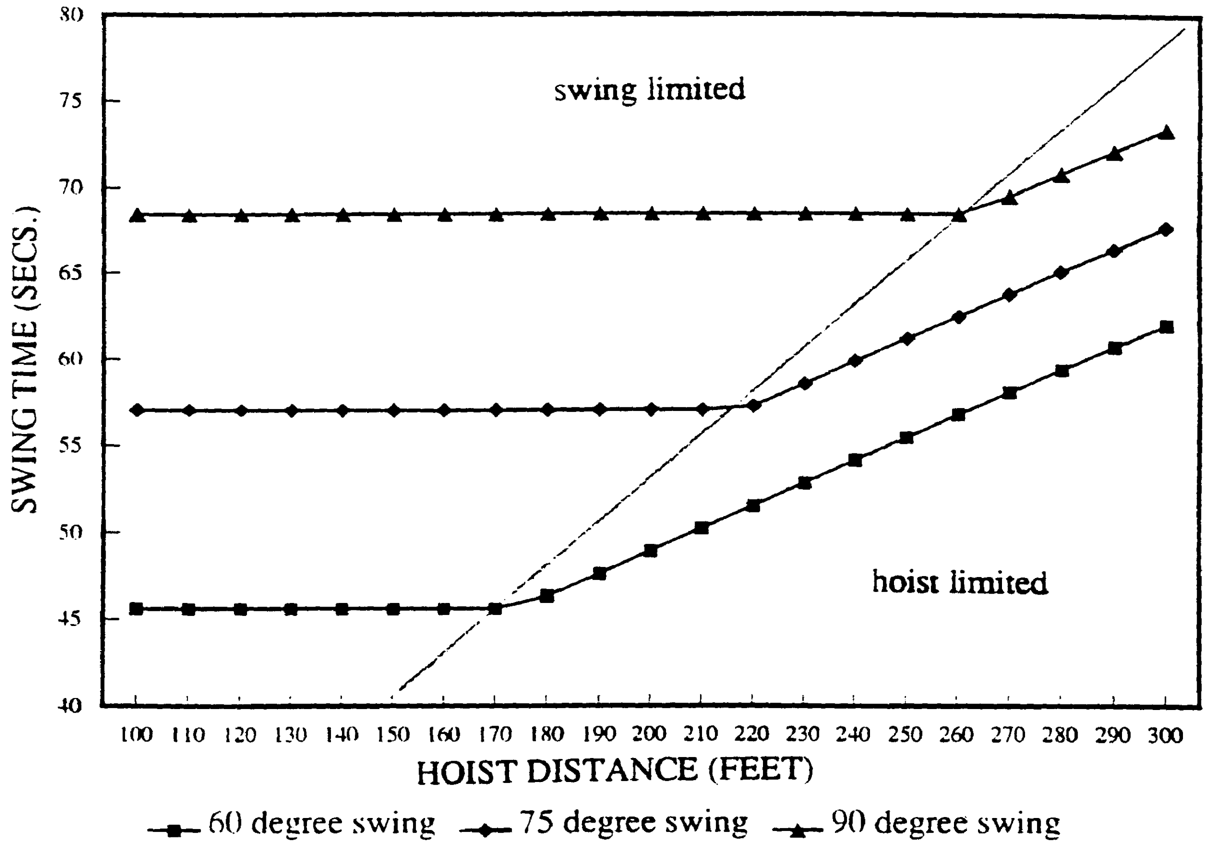


Figure 3.3a
Swing Time vs. Hoist Distance

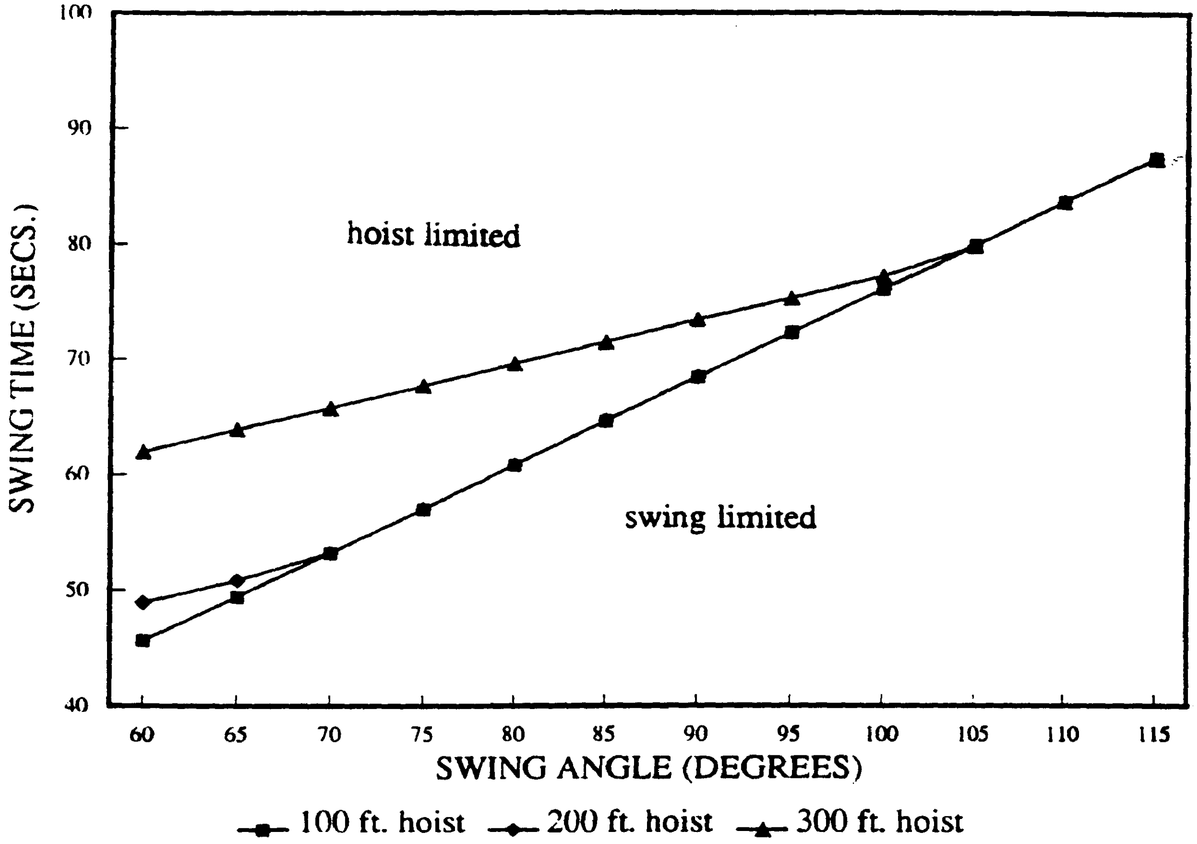


Figure 3.3b
Swing Time vs. Swing Angle

Because swing angle is one of the controlling factors in swing time, and because swing angles vary with different dig modes, a difference in the swing times in the different dig modes can be expected. A glance at Figures 2.4, 2.5, and 2.6 in the previous chapter shows that the swing angle in the double dig mode is greater than the swing angle in the sidecasting dig modes. Therefore, double dig can be expected to have a much greater swing time.

3.2.2 Load Time

Load times vary with the different dig modes used. For example when chopcutting, loading times are expected to take longer because the bucket is dragged down the face rather than up and across it. Dragging the bucket downward means less material in the bucket per length dragged because gravity causes the material to flow out of, rather than into, the bucket. This results in the buckets being dragged further in order to fill them up, and leads to a longer loading time.

The material type being excavated also is expected to impact loading time as different materials tend to handle easier than others (5). Other factors that may affect loading time are the bucket type used and the weather. Different bucket types may result in different loading times due to differences in design and bucket weight. Weather may affect the behavior of the different materials and thus affect the loading time.

3.3.3 Dump Time

Dump times are expected to vary with dig mode. When dumping in the sidecasting dig modes, for example, the dragline must slow its swinging motion until it stops, and then swing back in the opposite direction. In the double dig mode, the dragline dumps "on the fly", and does not need to change direction. This results in a shorter dump time for the double dig mode. Variations in dump time may also be attributed to differences in the flow of different materials, behavior of different bucket types, and differences in weather.

3.4 Bucket Load

The common units used in western U.S. coal mines to express volume are the bank cubic yard (bcy) and loose cubic yard (lcy). Bank cubic yards refer to in-situ or undisturbed material, loose cubic yards refer to material which has been disturbed (i.e., excavated and dumped). The ratio of loose to bank volumes of material of equal weight is referred to as the swell factor and is dependent upon the material being moved. The swell factor at the mine studied was estimated to be 20%.

Bucket loads per cycle are expressed in terms of loose cubic yards per cycle. They are dependent upon several factors such as dig mode, material being moved, and bucket type used.

Dig mode affects the load per bucket because of the nature of their operations. In chopcuts for example, draglines are expected to have a harder time filling up a bucket and are expected to have lower loads per bucket.

The type of material being moved also affects the load per bucket as different materials handle differently (5). Some materials, like light moist loam, flow easily into a dragging bucket, and others such as sticky clay do not flow as easily.

Different bucket types are also expected to carry different loads. New lighter buckets have been designed such that they require less metal in their construction. The result of this is that they are lighter, and, thus for a given suspended load capacity, more dirt can be carried per cycle.

CHAPTER 4

DATA ANALYSIS

The first step in the analysis was to identify potentially influential factors in the operating environment. The data was sorted into groups based upon these potentially influential factors and then statistically examined.

4.1 Data Sorting

To measure the impact of the different variables, the data was sorted into groups based upon dig mode, material excavated, machine, bucket type, and weather.

Under dig mode there were three possibilities: sidecasting frontcut, sidecasting chopcut, and double dig. These dig modes were described in Section 2.6. Differences in swing time, loading time, dumping time and digging availability were expected between the different dig modes.

There were two types of material excavated during the period of this study: Gray Clay (GC) and Sandy Till (ST). The Gray Clay is almost pure clay with a silty sand component. It has a low moisture content, and a density of 130 pounds/cubic foot. The Sandy Till generally overlies the Gray Clay. It is a glacial till with brown silty to sandy clay. It also contains gravel, and pebbles. The Sandy Till has a density of 123 pounds/cubic foot and a high moisture content. Figure 4.1 contains a sample geological cross section.

Differences in the loading time, dumping time, and bucket load were expected between the two materials as the sandy till was expected to handle better than the gray clay because of its lower clay content.

There were two machines studied, D901 and D902. The draglines were from the same manufacturer (Bucyrus-Erie) and were the same model (2570-W). The machinery installed on the draglines were similar. One major difference was that D901 had a 335 foot boom, set at an angle of 35 degrees and D902 had a 340 foot boom, set at 31 degrees. The machines were rated with a maximum suspended load of 550,000 pound for D901 and 525,000 pounds for D902.

The machines, even though similar, may show differences in terms of mechanical/electrical availability. Differences in type I job factor (non-dig mode related) availability may also be expected because each machine was assumed to have its own crew which behaves according to its own patterns.

There were two bucket types used, regular and high capacity. Differences were expected in the amount of

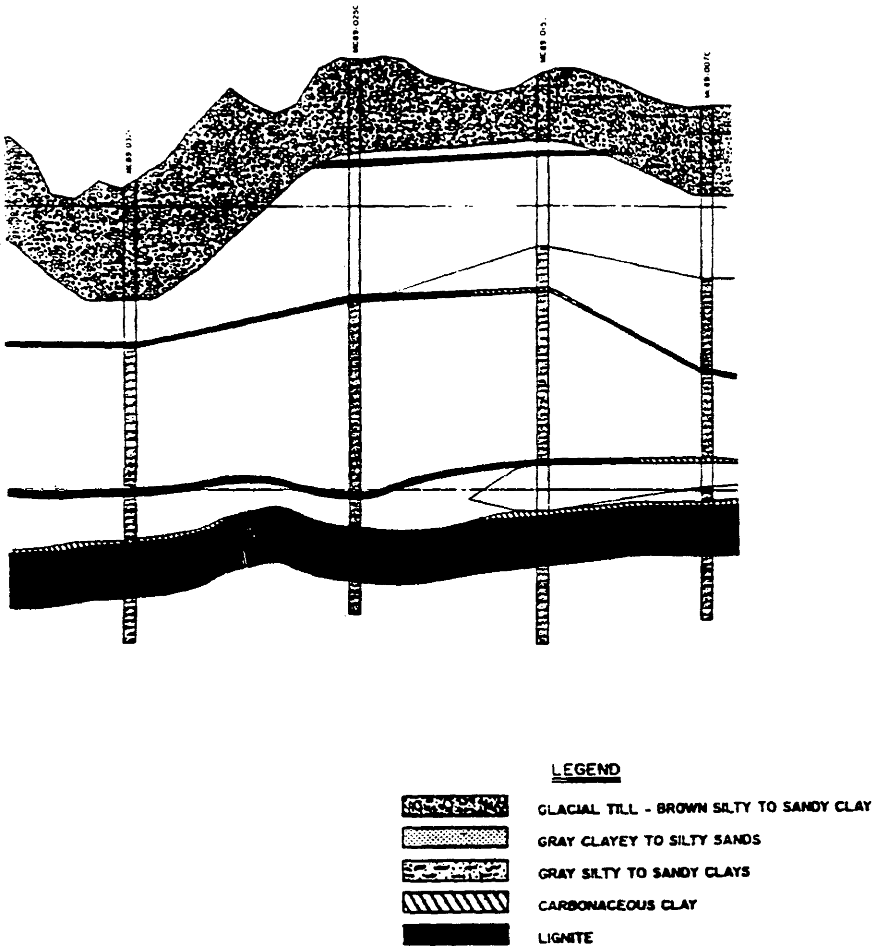


Figure 4.1
Sample Geological Cross Section

material loaded per bucket. The regular buckets weighed 242,270 lbs. and were rated at 105 cubic yards. The newer high capacity buckets weighed 198,400 lbs. and were rated at 120 cubic yards.

The data was collected over one year and was divided into two groups based upon the daily average temperature. One group included operating data from the period when the average temperature was below freezing. A second group was for data collected when the average temperature was above freezing. Climatological data collected at Garrison, North Dakota, the closest weather station, was used (7). Mean monthly temperatures from the past 30 years were utilized, and specific dates for the weather change were approximated by linear interpolation. The "below freezing" period was set between October 28 and April 1, and the "above freezing" period was set during the rest of the year.

4.2 Statistical Procedures

Once the data was sorted, statistical studies were performed with each data group considered independently. The general linear model was used for regression and analysis of variance purposes.

4.2.1 Linear Regression

Swing time was expected to vary linearly with swing angle and hoist distance. Linear regression was used to formulate a best fit equation for the prediction of swing time.

A measure for describing the usefulness of a regression equation is the R-square (R-sq) value, or the coefficient of determination, which is expressed in percent. The R-sq value indicates the proportionate reduction of total variation associated with the use of the predictor variable or variables (8). The R-sq value ranges between 0 and 100%. A high R-square value indicates a more useful or successful regression. An R-sq value of 100 % indicates a perfect fit which means all the data points coincide with the predicted line.

The acceptable R-square value depends on the field of science where the linear regression is applied. In most fields, regression equations with R-sq values of 70% and greater, indicate a considerable degree of linear association between the predictor and dependent variables in the observed sample. This means that the regression equation may be considered useful.

To judge whether a specific predictor variable in the regression function has a linear relation with the dependent variable or not, a test is done to determine whether or not the coefficient (B) of the predictor variable is significantly different from zero. The alternatives being tested are:

null hypothesis (Ho): $B = 0$

alternate hypothesis (Ha): $B \neq 0$

The test utilizes the t-distribution at a chosen level of significance α. The level of significance α is the probability of rejecting the null hypothesis when it is true. For this study α was controlled at .05.

The test statistic is:

$$t^* = \frac{B}{s\{B\}}$$

and the decision rule is:

If $|t^*| < t(1 - \alpha/2, n - 2)$, then conclude Ho

If $|t^*| > t(1 - \alpha/2, n - 2)$, then conclude Ha

Another option is to utilize the p-value. The p-value is the probability that the decision rule will lead to the conclusion Ha, or $P\{ t(n-2) > t^* \}$. If the p-value is less than the specified level of significance α, then Ha can be concluded directly. The p-value and the test statistic (t^*) are often reported together as this allows the test to be conducted at any desired level of significance α by comparing the p-value with the specified level α (8,9).

4.2.2 Analysis of Variance

The general linear regression model can also be used for analysis of variance purposes. This is done when the sample sizes are not equal for all treatments and when the dependent variables have predictors which are not quantitative but are qualitative. For example, variance in load time may depend on several qualitative factors such as bucket type (regular or high capacity), material type (ST or GC), or dig mode. The general linear test is used to identify which of the possible predictors the dependent variable varies with.

The first step is to assign dummy variables to the factors (for example: ST = 1 and GC = 0 for material type). Dummy variables are also known as indicator variables or binary variables. The second step is to fit the full model, which contains all the possible predictor variables, and calculate the error sum of squares SSE(F). The third step is to construct a reduced model, the full model with a predictor removed, and perform the same regression procedure. The error sum of squares SSE(R) for the reduced model is also calculated. A comparison of the error sum of squares of the full model SSE(F) and of the reduced model SSE(R) gives an indication of the whether or not the dependent variable varies with the predictor being tested.

The test statistic, called a partial F-test, is:

$$F^* = \frac{SSE(R) - SSE(F)}{df_R - df_F} \div \frac{SSE(F)}{df_F}$$

where:

$SSE(R)$ = error sum of squares of the reduced model
$SSE(F)$ = error sum of squares of the full model
df_R = degrees of freedom of the reduced model
df_F = degrees of freedom of the full model

the alternatives being tested are:

null hypothesis (Ho): dependent variable does not vary with the predictor removed for the reduced model

alternate hypothesis (Ha) : dependent variable varies with the predictor removed for the reduced model

The decision rule at a level of significance α is,

If $F^* < F(1-\alpha, df_R - df_F, df_F)$, then conclude Ho

If $F^* > F(1-\alpha, df_R - df_F, df_F)$, then conclude Ha

P-values can also be used to conclude the correct hypothesis. The p-value in this case is the probability $P\{ F(df_R - df_F, df_F) > F^* \}$. If the p-value is less than the specified level α then conclude Ha.

4.3 Data Relationships

The data groups were analyzed using the statistical procedures described in the preceding section. Each component of the production rate function (Equations 1, 2,and 3) was examined separately.

4.3.1 Swing Time

Swing times are dictated by swing angles and hoist distances, depending on whether the digs are swing limited or hoist limited. As indicated earlier, the relationship of the swing time to these two variables was thought to be linear.

The swing time functions are dependent upon the swing machinery and the hoist machinery installed on a particular dragline, and therefore the functions are thought to be constant for each machine. Two swing time functions were derived for each machine: a swing limited function and a hoist limited function. As discussed in Section 3.3.1, the dig can be classified as swing limited or hoist limited based upon the ratio of the hoist distance to swing angle. The swing limited functions have the swing time varying with only the swing angle. A linear regression analysis was performed on the data from each machine, and the following functions were derived:

For dragline D901: (n = 1559 data points)

$$SWG\_TI = 8.36 + .30\ SWING \qquad (R\text{-}sq = 85.4\%)$$

t-ratio	25.7	95.3
p-value	.00	.00

and for dragline D902: (n = 1558 data points)

SWG_TI = 11.7 + .25 SWING (R-sq = 77.2%)

t-ratio	32.4	72.6
p-value	.00	.00

where:

SWG_TI = swing time (secs.)
SWING = swing angle (degrees)

The R-sq values indicate that a high percentage of the variation in swing time of each machine can be explained by the functions. The p-value (p = 0.00) for the swing angle for both functions indicate that the swing angle is a good predictor for swing time.

When the swing is hoist limited, the swing time is thought to be dependent upon both the swing angle and the hoist distances. Again, a linear regression analysis was performed on the data from each machine and the following functions were derived:

For dragline D901: (n = 115 data points)

SWG_TI = 1.26 + .37 SWING + .01 HOIST (R-sq = 85.7%)

t-ratio	1.46	14.9	.98
p-value	.15	.00	.32

and for dragline D902: (n = 251 data points)

SWG_TI = 14.1 + .44 SWING - .09 HOIST (R-sq = 70.0%)

t-ratio	35.3	23.5	-19.6
p-value	.00	.00	.00

where:

SWG_TI = swing time (secs.)
SWING = swing angle (degrees)
HOIST = hoist distance (feet)

Again, the R-sq values indicate that the functions explain a large percentage of the variation in swing time. The p-values indicate that the constant terms of the equations are not significantly different from zero and are therefore not significant, but there is statistically significant evidence that the coefficient of the swing angle is not equal to zero indicating a relation between swing angle and swing time. For hoist distance the results are not good. For D901 the p-value indicates that the coefficient of the hoist distance is not significantly different from zero, but for D902 the p-value indicates that the coefficient is significantly different from zero but is of the wrong sign. An examination of the swing functions shows that the magnitudes of the constant and the coefficient of hoist distance are quite small and will not have a great impact on the swing time component of the cycle time. This is contrary to the expected result as both predictors theoretically have an effect on the swing time when in a hoist limited situation.

A reason for this discrepancy may be that the digs were classified as swing or hoist limited based on the rated hoist speed of the dragline. This may not be accurate as the machine may not have been working at 100% capacity, or because draglines may normally work at speeds which are less than their rated speed. Another possible cause is that the mine studied was working in overburden that was not at maximum depth. The depth ranged from 68 feet to 135 feet, over the period of the study, and averaged 104 feet.

The data was re-regressed to find the best fit equation and the predicted relationship between swing angle, hoist distance, and swing time is tabulated in Tables 4.1a and 4.1b for the two machines studied. A comparison between these tables and the table of theoretical swing times (Table 3.1) show the same trends but also show some discrepancies.

The reason for the discrepancies may be the manner in which the data recorders identify swing time. The swing time, as noted by the data recorders, terminates when a dump is recorded. But, as mentioned in section 2.1, the dragline continues to swing while dumping. This angular motion is recorded as swing angle, but the time is not recorded as swing time and is credited to dump time. A second reason may be that the classification of swings is based upon the rated hoist speed and, as mentioned earlier, this may not be accurate.

Table 4.1a
Predicted Total Swing Times
Dragline D901

	SWING ANGLE										
HOIST DISTANCE	70	75	80	85	90	95	100	105	110	115	120
120	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
130	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
140	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
150	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
160	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
170	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
180	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
190	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
200	58.72	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
210	59.50	61.72	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
220	59.50	63.50	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
230	59.50	63.50	64.72	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
240	59.50	63.50	67.50	67.72	70.72	73.72	76.72	79.72	82.72	85.72	88.72
250	59.50	63.50	67.50	71.50	70.72	73.72	76.72	79.72	82.72	85.72	88.72
260	59.50	63.50	67.50	71.50	70.72	73.72	76.72	79.72	82.72	85.72	88.72
270	59.50	63.50	67.50	71.50	75.50	73.72	76.72	79.72	82.72	85.72	88.72
280	59.50	63.50	67.50	71.50	75.50	79.50	76.72	79.72	82.72	85.72	88.72
290	59.50	63.50	67.50	71.50	75.50	79.50	76.72	79.72	82.72	85.72	88.72
300	59.50	63.50	67.50	71.50	75.50	79.50	83.50	79.72	82.72	85.72	88.72
310	59.50	63.50	67.50	71.50	75.50	79.50	83.50	87.50	82.72	85.72	88.72
320	59.50	63.50	67.50	71.50	75.50	79.50	83.50	87.50	82.72	85.72	88.72

hoist limited | swing limited

Table 4.1b
Predicted Total Swing Times
Dragline D902

	SWING ANGLE IN DEGREES											
HOIST DISTANCE IN FEET	65	70	75	80	85	90	95	100	105	110	115	120
100	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
110	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
120	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
130	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
140	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
150	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
160	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
170	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
180	55.9	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
190	57.2	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
200	57.2	58.4	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
210	57.2	61.6	60.9	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
220	57.2	61.6	66.0	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
230	57.2	61.6	66.0	63.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
240	57.2	61.6	66.0	70.4	65.9	68.4	70.9	73.4	75.9	78.4	80.9	83.4
250	57.2	61.6	66.0	70.4	74.8	68.4	70.9	73.4	75.9	78.4	80.9	83.4
260	57.2	61.6	66.0	70.4	74.8	68.4	70.9	73.4	75.9	78.4	80.9	83.4
270	57.2	61.6	66.0	70.4	74.8	79.2	70.9	73.4	75.9	78.4	80.9	83.4
280	57.2	61.6	66.0	70.4	74.8	79.2	83.6	73.4	75.9	78.4	80.9	83.4
290	57.2	61.6	66.0	70.4	74.8	79.2	83.6	73.4	75.9	78.4	80.9	83.4
300	57.2	61.6	66.0	70.4	74.8	79.2	83.6	88.0	75.9	78.4	80.9	83.4
310	57.2	61.6	66.0	70.4	74.8	79.2	83.6	88.0	92.4	78.4	80.9	83.4

hoist limited | swing limited

4.3.2 Dump Time

The dump time segment of the cycle time is expected to vary with dig mode, machine in use, material type, and possibly with weather and bucket type. Dump times were not expected to vary linearly as swing times, but were expected to have an average value for each set of conditions. The mean dump times under various conditions are tabulated in tables 4.2a and 4.2b. An analysis of variance study was performed to determine which of the factors in the operating environment were influential.

It was determined that there was a difference in the way the machines operated (F = 4.32) and that the prevalent weather did not have a significant impact (F = 1.06 and p = .304). The results also showed that the dumping time varied significantly between the different dig modes (F = 422.77). The double digging mode had significantly lower dumping times than the two sidecasting modes. This is expected because of the way the machine operates in that mode, it dumps "on the fly" without changing direction of swing.

Further, the analysis of variance also indicated that the dump time did not vary with bucket type (F = 0.11 and p = 0.741). As for the effect of the material type, the results showed that it had a significant impact upon the

Table 4.2a
Dragline 901 Mean Dump Times
(secs.)

dig mode	material	weather	bucket type	average dump time	standard deviation	count
Double Dig	Sandy Till	below freezing	high capacity	9.4	2.7	72
			regular	8.2	3.2	81
		above freezing	high capacity	8.8	4.4	101
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	8.1	3.8	54
			regular	8.1	4.1	249
		above freezing	high capacity	9.4	3.6	55
			regular	no data	–	0
Chop Cut	Sandy Till	below freezing	high capacity	13.7	2.3	15
			regular	14.1	3.6	13
		above freezing	high capacity	13.9	2.8	10
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	15.2	0.5	2
			regular	14.0	2.6	24
		above freezing	high capacity	15.8	2.0	2
			regular	no data	–	0
Front Cut	Sandy Till	below freezing	high capacity	12.5	3.6	126
			regular	11.5	3.0	118
		above freezing	high capacity	13.6	4.3	162
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	12.7	3.9	136
			regular	12.0	3.9	369
		above freezing	high capacity	12.5	3.0	85
			regular	no data	–	0

Table 4.2b
Dragline D902 Mean Dump Times (secs.)

dig mode	material	weather	bucket type	average dump time	standard deviation	count
Double Dig	Sandy Till	below freezing	high capacity	8.9	3.7	113
			regular	9.4	2.8	62
		above freezing	high capacity	8.9	3.9	27
			regular	7.1	3.5	4
	Gray Clay	below freezing	high capacity	7.5	0.6	57
			regular	9.3	2.3	25
		above freezing	high capacity	6.7	3.3	137
			regular	7.1	2.9	83
Chop Cut	Sandy Till	below freezing	high capacity	14.4	3.8	13
			regular	15.3	3.4	14
		above freezing	high capacity	11.7	2.9	2
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	13.0	0.4	2
			regular	11.1	3.8	5
		above freezing	high capacity	11.0	1.2	3
			regular	7.3	4.7	2
Front Cut	Sandy Till	below freezing	high capacity	12.4	4.0	419
			regular	13.1	4.4	143
		above freezing	high capacity	11.9	3.5	36
			regular	12.9	2.8	7
	Gray Clay	below freezing	high capacity	11.8	3.6	106
			regular	12.3	3.0	199
		above freezing	high capacity	11.1	3.4	224
			regular	12.4	3.0	122

dump time (F = 26.44).

With the influential factors identified the data was re-sorted and the mean dump times with the 95% confidence intervals were calculated. The results are tabulated in Table 4.3.

4.2.3 Load Time

The load time segment of the cycle time is expected to vary with dig mode, machine in use, material type and possibly with weather and bucket type. As with dump times, loading times were not expected to vary linearly but were expected to have an average value for each set of conditions. These values were calculated for each set of conditions and are tabulated in Tables 4.4a and 4.4b. An analysis of variance study was performed to identify which of the factors in the operating environment were influential on the loading time.

The results showed that the loading times vary between different machines (F = 4.29), different digging modes (F = 176.77), and different material types (F = 31.21).

As expected, sidecasting-chopcut showed the longest mean loading times. A surprising result was that double-digging mode, even though it has a chop-cut component, showed the lowest mean loading times among the three dig

Table 4.3
Mean Dump Times With
95% Confidence Intervals (secs.)

Machine	Material	Dig Mode	number of samples	average dump time:	standard deviation	95% confidence interval --------+---------+---------+------- 9.0 12.0 15.0
D901	sandy till	double dig	254	8.8	3.6	(*-)
		chopcut	38	13.9	2.9	(---*---)
		frontcut	406	12.7	3.8	(*-)
	gray clay	double dig	358	8.3	4.0	(-*)
		chopcut	28	14.2	2.5	(---*----)
		frontcut	590	12.2	3.8	(*)
D902	sandy till	double dig	206	9.0	3.5	(-*)
		chopcut	29	14.6	3.6	(----*---)
		frontcut	605	12.6	4.0	(*)
	gray clay	double dig	302	7.2	3.5	(*)
		chopcut	12	10.8	3.3	(------*------)
		frontcut	651	11.8	3.3	(*)

POOLED STANDARD DEVIATION = 3.7

note: confidence intervals for mean based on pooled standard deviation

Table 4.4a
Dragline 901 Mean Loading Times
(secs.)

dig mode	material	weather	bucket type	average loading time	standard deviation	count
Double Dig	Sandy Till	below freezing	high capacity	26.9	14.7	72
			regular	24.0	6.3	81
		above freezing	high capacity	23.1	5.7	101
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	22.4	5.6	54
			regular	22.1	5.5	249
		above freezing	high capacity	20.9	3.9	55
			regular	no data	–	0
Chop Cut	Sandy Till	below freezing	high capacity	31.0	2.8	15
			regular	32.0	4.5	13
		above freezing	high capacity	30.8	2.0	10
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	29.7	1.8	2
			regular	29.5	1.9	24
		above freezing	high capacity	29.7	2.6	2
			regular	no data	–	0
Front Cut	Sandy Till	below freezing	high capacity	28.4	5.5	126
			regular	27.2	6.1	118
		above freezing	high capacity	28.0	5.8	162
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	27.2	6.0	136
			regular	26.3	5.5	369
		above freezing	high capacity	27.2	7.2	85
			regular	no data	–	0

Table 4.4b
Dragline 902 Mean Loading Times (secs.)

dig mode	material	weather	bucket type	average loading time	standard deviation	count
Double Dig	Sandy Till	below freezing	high capacity	24.3	3.7	113
			regular	23.4	4.4	62
		above freezing	high capacity	25.9	4.9	27
			regular	20.6	2.7	4
	Gray Clay	below freezing	high capacity	21.1	0.8	57
			regular	23.3	3.5	25
		above freezing	high capacity	20.7	6.5	137
			regular	20.1	3.5	83
Chop Cut	Sandy Till	below freezing	high capacity	30.8	3.0	13
			regular	33.0	6.8	14
		above freezing	high capacity	27.8	0.2	2
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	27.9	2.1	2
			regular	42.2	17.5	5
		above freezing	high capacity	26.6	0.7	3
			regular	31.0	4.2	2
Front Cut	Sandy Till	below freezing	high capacity	27.1	6.0	419
			regular	27.0	5.6	143
		above freezing	high capacity	27.1	5.8	36
			regular	25.4	4.2	7
	Gray Clay	below freezing	high capacity	26.4	6.6	106
			regular	26.4	4.0	199
		above freezing	high capacity	25.8	12.4	224
			regular	27.2	3.8	122

modes. The reason for this may be that this dig mode is done at shallow depths and the operators need to spend less time positioning the bucket in preparation for the next dig. As mentioned in section 2.2, time spent in positioning the bucket is credited to load time. The statistics also showed that more time was spent loading the sandy till as compared to loading the gray clay.

From the analysis of variance study, it was also concluded that neither the bucket type ($F = 0.63$ and $p = .428$) nor the weather ($F = 3.32$ and $p = .069$) had a significant effect on loading time.

The mean loading times were re-calculated for the different data sets taking into account the variables identified as influential. The results are tabulated in Table 4.5.

4.2.4 Bucket Loads

Many mines express the amount of material moved per cycle as the rated bucket capacity multiplied by a bucket fill factor. A fill factor of one means that the bucket is full to capacity. Fill factors less than one indicate a less than full bucket and greater than one indicate a heaped bucket. The fill factor has to be estimated for each set of conditions.

Table 4.5
Mean Loading Times With 95% Confidence Intervals (secs.)

Machine	Material	Dig Mode	number of samples	average loading time	standard deviation	95% confidence interval ---------+---------+---------+----- 25.0 30.0 35.0
D901	sandy till	double dig	254	24.5	9.4	(-*-)
		chopcut	38	31.3	3.3	(----*---)
		frontcut	406	27.9	5.8	(-*)
	gray clay	double dig	358	21.9	5.3	(-*)
		chopcut	28	29.5	1.9	(----*----)
		frontcut	590	26.7	5.9	(*)
D902	sandy till	double dig	206	24.2	6.3	(-*)
		chopcut	29	31.7	5.3	(----*----)
		frontcut	605	27.1	5.9	(*)
	gray clay	double dig	302	20.8	5.5	(-*)
		chopcut	12	34.0	12.9	(-------*-------
		frontcut	651	26.3	8.2	(*)

POOLED STANDARD DEVIATION = 6.6

note: confidence intervals for mean based on pooled standard deviation

As explained in section 2.4, the data recorders measure and chronicle the amount of material moved in tons. The tonnage can then be converted into a volume if the density of the material is known. This eliminates the need for using estimated fill factors as bucket loads are available directly from the data recorders. The bucket load is recorded in loose cubic yards per cycle (lcy/cycle).

The bucket load per cycle is expected to vary with dig mode, material type, machine, bucket type, and possibly the weather. As with dump times and loading times, bucket loads were not expected to vary linearly but were expected to have an average value for each set of conditions. The mean bucket loads were taken for each data set and the results are tabulated in Tables 4.6a and 4.6b. An analysis of variance study was performed to identify which of the factors in the operating environment were influential on the bucket loads.

A surprising result was that the bucket type was shown not to have a significant effect on the load per bucket ($F = 0.35$ and $p = .554$). This meant that the lighter high-capacity buckets were not performing as expected. A glance at table 4.6b shows that in some cases the high capacity buckets performed better (machine D902, sidecast-frontcut, Sandy Till, below freezing) in other cases the regular

Table 4.6a
Dragline 901 Mean Bucket Loads
(loose cubic yards/cycle)

dig mode	material	weather	bucket type	average bucket load	standard deviation	count
Double Dig	Sandy Till	below freezing	high capacity	109.8	12.0	72
			regular	112.8	12.4	81
		above freezing	high capacity	113.6	14.6	101
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	108.1	12.9	54
			regular	108.6	10.8	249
		above freezing	high capacity	115.7	8.7	55
			regular	no data	–	0
Chop Cut	Sandy Till	below freezing	high capacity	101.9	10.6	15
			regular	105.2	10.9	13
		above freezing	high capacity	100.4	9.9	10
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	86.6	4.4	2
			regular	102.4	11.0	24
		above freezing	high capacity	119.8	6.2	2
			regular	no data	–	0
Front Cut	Sandy Till	below freezing	high capacity	102.0	10.3	126
			regular	106.0	12.7	118
		above freezing	high capacity	107.1	12.1	162
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	96.9	12.2	136
			regular	102.0	11.0	369
		above freezing	high capacity	105.9	13.3	85
			regular	no data	–	0

Table 4.6b
Dragline 902 Mean Bucket Loads
(loose cubic yards/cycle)

dig mode	material	weather	bucket type	average bucket load	standard deviation	count
Double Dig	Sandy Till	below freezing	high capacity	113.5	17.8	113
			regular	112.8	16.0	62
		above freezing	high capacity	100.0	16.9	27
			regular	100.7	41.3	4
	Gray Clay	below freezing	high capacity	112.1	1.8	57
			regular	115.1	10.6	25
		above freezing	high capacity	111.1	13.3	137
			regular	110.2	12.5	83
Chop Cut	Sandy Till	below freezing	high capacity	98.2	16.8	13
			regular	96.7	13.5	14
		above freezing	high capacity	112.8	16.0	2
			regular	no data	–	0
	Gray Clay	below freezing	high capacity	106.5	6.6	2
			regular	98.4	13.9	5
		above freezing	high capacity	97.1	4.2	3
			regular	99.3	9.5	2
Front Cut	Sandy Till	below freezing	high capacity	115.0	13.8	419
			regular	113.1	12.3	143
		above freezing	high capacity	104.8	10.2	36
			regular	112.6	2.3	7
	Gray Clay	below freezing	high capacity	110.0	9.9	106
			regular	110.1	3.0	199
		above freezing	high capacity	108.8	11.1	224
			regular	109.3	9.7	122

buckets performed better (machine D902, sidecast-frontcut, Sandy Till, above freezing). Overall, both types of buckets performed evenly.

The reason for this may be that the lower weight of the bucket prevented it from digging into the bank and utilizing its full capacity. The lighter weight of the high capacity buckets are a handicap as weight is one of the key factors that affect the initial penetration of the bucket teeth into the bank (10).

The results of the study also showed that bucket load varied significantly with the material type excavated (F = 52.58). This was expected and is due to the behavior of the materials, the sandy till (ST) loads or flows easier than the gray clay.

Average bucket load also varied between different digging modes (F = 52.54). Sidecasting-chopcut was shown to have the lowest mean bucket load in almost all cases. This was the expected result. Double dig mode had the highest load per bucket and this was surprising because this dig mode has a chop-cut component. This may be explained by easier loading conditions at shallower depths or better loading when digging rehandle material on the spoil side.

The analysis of variance also showed that load per bucket varied significantly with the particular machine involved (F = 155.96) but not with the weather (F = .26 and p = .611)

With the influential factors identified, the mean bucket loads per cycle were re-calculated for the different data groups and the results are tabulated in Table 4.7.

4.3 Availabilities

There were three availability factors derived: the machine availability factor (Am), job factor type I (JF I), and type II (JF II). The factors were calculated using equations 4, 5, and 6 with historical data from each machine.

The Am and JF I were assumed to be constant for each machine. Am accounts for delays due to the particular equipment installed on the dragline. JF I accounts for the behavioral delays of the particular crews assigned to that dragline. The average availabilities calculated are shown in Table 4.8 and from it can be seen differences in availabilities between the dig modes. The lower JF II value for sidecasting shows there are more delays such as repositioning the dragline and dozer work in this dig mode rather than in the double dig mode. A possible explanation for this is that sidecasting requires more set up positions than double dig.

Table 4.7
Mean Bucket Loads With 95% Confidence Intervals (loose cubic yards/cycle)

Machine	Material	Dig Mode	number of samples	average bucket load	standard deviation	95% confidence interval ---------+-----------+-----------+-------- 98.0 105.0 112.0
D901	sandy till	double dig	254	112.3	13.2	(-*--)
		chopcut	38	102.6	10.42	(-----*----)
		frontcut	406	105.2	12.0	(*-)
	gray clay	double dig	358	109.6	11.1	(-*)
		chopcut	28	102.5	12.1	(-----*------)
		frontcut	590	101.4	12.0	(-*)
D902	sandy till	double dig	206	111.3	18.2	(--*-)
		chopcut	29	98.5	15.2	(------*-----)
		frontcut	605	113.9	13.4	(-*)
	gray clay	double dig	302	111.4	12.8	(-*-)
		chopcut	12	99.6	9.8	(---------*--------)
		frontcut	651	109.5	10.5	(*-)

POOLED STANDARD DEVIATION = 12.5

note: confidence intervals for mean based on pooled standard deviation

Table 4.8
Average Availability Factors

Machine	Mechanical Availability (Am)	Job Factor Type I (JF I) non-dig mode related	Job Factor Type II (JF II) dig mode related	
			double dig	sidecasting
D901	78.6%	96.0%	92.6%	89.7%
D902	80.9%	95.2%	95.8%	92.9%

4.4 Comparison of Production Rates

The swing time for each data set was calculated by substituting the recorded swing angle into the derived swing time functions. Dump time, load time, bucket load, and availabilities were found based on the recorded conditions of the dig. The production rate for each data set was then calculated using Equations 1 and 3. Bucket loads were recorded in loose cubic yards per cycle and this term was used in place of the rated bucket capacity times the fill factor (B x F). The production rate is expressed as bank cubic yards per scheduled hour. This unit is useful because bank cubic yards relate directly to the amount of material that has to be moved. The computed production rates were grouped according to the identified influential factors and their means calculated. The results with the projected confidence intervals are shown in Table 4.9a and 4.9b.

The table shows that sidecasting-chopcut has the lowest production rate in all cases. It also has the widest confidence intervals because of the small number of samples. A comparison of the double dig mode and the sidecasting-frontcut mode reveals mixed results. For D901 the double dig mode tended to produce at higher rates, but for D902 this is not true. A comparison of the two ma-

Table 4.9a
Dragline 901 Mean Production Rates With 95% Confidence Intervals (bank cubic yards/scheduled hr.)

Material	Dig Mode	Swing Angle (degrees)	number of samples	average production rate	standard deviation	95% confidence interval ----+---------+---------+---------+- 2400 3000 3600 4200
sandy till	double dig	0–100	81	3774.7	360.8	(*)
		100–140	70	2962.9	119.8	(*)
		140–up	103	2672.9	130.3	(*)
	chopcut	0–60	10	3083.9	182.6	(-*--)
		60–90	13	2753.2	81.4	(-*-)
		90–up	15	2390.6	142.3	(-*-)
	frontcut	0–60	96	3372.8	200.2	(*)
		60–90	173	3006.8	116.1	(*)
		90–up	137	2555.8	206.3	(*)
gray clay	double dig	0–100	111	3700.7	485.8	(*)
		100–140	166	3102.0	137.1	(*)
		140–up	81	2707.7	96.1	(*)
	chopcut	0–60	14	3190.6	284.0	(-*-)
		60–90	9	2795.4	77.5	(--*-)
		90–up	5	2397.5	151.1	(--*--)
	frontcut	0–60	153	3445.6	288.3	(*)
		60–90	257	2966.1	115.5	(*)
		90–up	180	2562.6	147.9	(*)

Table 4.9b
Dragline 902 Mean Production Rates With 95% Confidence Intervals (bank cubic yards/scheduled hr.)

Material	Dig Mode	Swing Angle (degrees)	number of samples	average production rate	standard deviation	95% confidence interval ----+---------+---------+---------+- 2400 3000 3600 4200
sandy till	double dig	0–100	55	3735.1	264.5	(*)
		100–140	88	3316.6	126.7	(*)
		140–up	63	2876.3	158.4	(*)
	chopcut	0–60	8	3038.9	100.6	(--*-)
		60–90	14	2728.5	66.0	(-*--)
		90–up	7	2482.1	80.1	(--*--)
	frontcut	0–60	231	3975.1	292.3	(*)
		60–90	213	3512.6	115.8	(*)
		90–up	161	3025.6	274.9	(*)
gray clay	double dig	0–100	76	4349.5	727.5	(--*
		100–140	84	3538.9	159.1	(*)
		140–up	142	3097.3	185.4	(*)
	chopcut	0–60	4	3109.8	129.4	(---*---)
		60–90	1	2893.2	0.0	(------*-------)
		90–up	7	2420.6	268.7	(--*--)
	frontcut	0–60	180	3896.9	240.1	(*)
		60–90	342	3460.7	133.4	(*)
		90–up	129	2970.6	246.8	(*)

chines, shows that machine D902 tends to have higher production rates than D901. This is due to the higher availability factors for D902. Another reason for this is that the larger operating radius of D902 allows it to dump at smaller swing angles.

CHAPTER 5

RESULTS

The analysis of operational data has indicated that production rates of draglines are affected by the conditions under which the machine operates. The influential factors for the specific operation studied are listed below:

1. the machine in use
2. the dig mode employed
3. the material type being excavated
4. the swing angle
5. the hoist distance

Bucket type, and weather were initially thought to be influential, but the statistics showed otherwise.

Mechanical availability (Am), and type I job factors (JF I) were assumed to be constant for each machine. It was also assumed that they were independent of the material in the bucket and the dig mode in use. Swing time was thought to vary with either swing angle and/or hoist distance depending on whether the dig was swing dependent or hoist dependent, but hoist distance was found not to be a good predictor of swing time. Swing time functions were assumed to be constant per machine.

Dump time, load time, digging availability, and average bucket load were found to vary with machine, dig mode, and material being excavated. Type II job factors (JF II) vary with machine and dig mode used. The results are summarized in Tables 5.1a and 5.1b for dragline D901 and dragline D902 in their respective "production factor" tables.

5.1 Application Of The Dragline Production Rate Function

The production rate function can be used in two ways. First, the equation can be utilized to gauge the performance of existing operations or to measure impact of changes. And second, the function can be used to forecast production rates under future conditions.

5.1.1 Performance Gauge

To illustrate the use of the production rate function as a gauge of performance, consider an example from the mine analyzed in this study.

In a particular 72 hour period, machine D901 was operating with an average swing angle of 106 degrees and an average hoist distance of 139 feet. The material being moved was gray-clay and the dig mode in use was predominantly sidecasting-frontcut.

To find the expected production rate under a given

Table 5.1a
D901 Production Factor Table

Swing Time Functions :

Swing Limited: Swing Time = 8.36 + .3 Swing
Hoist Limited: Swing Time = 1.75 + .4 Swing

where: Swing Time = secs.
Swing = swing angle (degrees)

Mechanical Availability (Am): 78.6%
Job Factor Type I (JF I): 96.0%

Dig Mode	Double Dig		Sidecast Chopcut		Sidecast Frontcut	
Material	Sandy Till	Gray Clay	Sandy Till	Gray Clay	Sandy Till	Gray Clay
Dump Time (secs.)	8.8	8.3	13.9	14.2	12.7	12.2
Load Time (secs.)	24.5	21.9	31.3	29.5	27.9	26.7
Bucket Load (lcy/cycle)	112.3	109.6	102.6	102.5	105.2	101.4
Job Factor Type II (JF II)	92.6%	92.6%	89.7%	89.7%	89.7%	89.7%

Table 5.1b
D902 Production Factor Table

Swing Time Functions:

Swing Limited: Swing Time = 11.7 + .25 Swing
Hoist Limited: Swing Time = .44 Swing

where: Swing Time = secs.
Swing = swing angle (degrees)

Mechanical Availability (Am): 80.9%
Job Factor Type I (JF I): 95.2%

Dig Mode	Double Dig		Sidecast Chopcut		Sidecast Frontcut	
Material	Sandy Till	Gray Clay	Sandy Till	Gray Clay	Sandy Till	Gray Clay
Dump Time (secs.)	9.0	7.2	14.6	10.8	12.6	11.8
Load Time (secs.)	24.2	20.8	31.7	34.0	27.1	26.3
Bucket Load (lcy/cycle)	111.3	111.4	98.5	99.6	113.9	109.5
Job Factor Type II (JF II)	95.8%	95.8	92.0%	92.0%	92.0%	92.0%

circumstance, the correct equations and constants for the conditions must be ascertained from the table appropriate for the machine in use (e.g., machine D901 in Table 5.1a).

The next step is to determine if this particular dig is hoist or swing limited. This is done by following the procedure described in section 3.3.1. The ratio of the hoist distance to swing angle is 1.31. This is less than 2.91 and therefore this particular operation is swing limited. The proper equation is chosen and swing time can be calculated.

$$\begin{aligned}\text{Swing time} &= 5.94 + .33\ \text{Swing Angle}\\ &= 5.94 + .33\ (106)\\ &= 40.9\ \text{secs.}\end{aligned}$$

The dump time and the loading time are selected from the table taking into account the dig mode employed and the material type being moved. The average dump time is 12.2 secs. And the average load time is 26.7 secs. The cycle time is found using equation 1.

$$\begin{aligned}\text{Cycle time} &= 40.9 + 12.2 + 26.7\\ &= 79.8\ \text{secs.}\end{aligned}$$

The availabilities, and the bucket load factor are then chosen from the table. The values found were: Am = 78.6%, JF I = 96.0%, JF II = 89.7%, and average bucket load = 101.4 lcy/cycle. Substituting into equation 3 the production rate expected under these conditions is found.

$$P = \frac{(72 \times .786 \times .96 \times .897 \times 3600 \times 101.4)}{(79.8 \times 1.2)}$$

$$= 185{,}770 \text{ BCY/period}$$

The actual production rate during the considered period can be taken from the output of the data recorder. For this particular period, the actual output recorded was 228,126 LCY or 190,105 BCY.

The actual production and the expected production under this set of conditions can then be compared and conclusions can be drawn. In this case the observed output was off only 2.3% the expected output. If actual production varies greatly from the expected, then further studies could then be done to ascertain the reason for the variation. A drawback of using the production rate function in this manner is that confidence intervals cannot be established analytically.

Another option is to compare the actual production to the D901 mean production rates from Table 4.9a. The mean production rate under frontcut, gray clay, for a swing angle of 90 degrees and greater is 2562.6 bcy/scheduled hour. The recorded hourly production rate was 2640.3 bcy/ scheduled hour. This is 3.0% off the expected value.

5.1.2 Production Prediction

In order for the function to be used for predicting future performance of a particular machine, the dig mode, the material type, the average swing angle, and the average hoist distance must be known. In most operations, all but the swing angle and the hoist distance are known. But since the depth of the overburden is known beforehand, the swing angle and the hoist distance may be estimated.

To demonstrate the anticipated relation between overburden depth and swing angle and overburden depth and hoist distance, dragline simulation techniques were used.
In order to do the simulation, current operating procedures must be known. Required information includes: the digging procedures (dig modes and the set up positions of the dragline), the pit width, the highwall angle, the spoil angle, the swell factor, the dragline tub diameter and the dragline operating radius.

The dragline operation is simulated by making cut diagrams in cross section and in plan view. An example is shown in Figure 5.1 for an overburden depth of 75 feet. The dragline is shown in plan view with its boom in the anticipated loading and dumping positions. Swing angles and hoist distances can be measured from the figures.

In the sidecasting dig mode, the measured swing angle

overburden = 75'
digmode: sidecasting

Area	% of total	Swing Angle	Extra Swing	Hoist Distance
1	34.5%	49	20	25
2	32.1%	39	20	58
3	7.7%	80	20	96
4	25.7%	51	20	126

avg. swing angle = 68.7
avg. hoist distance = 67.0

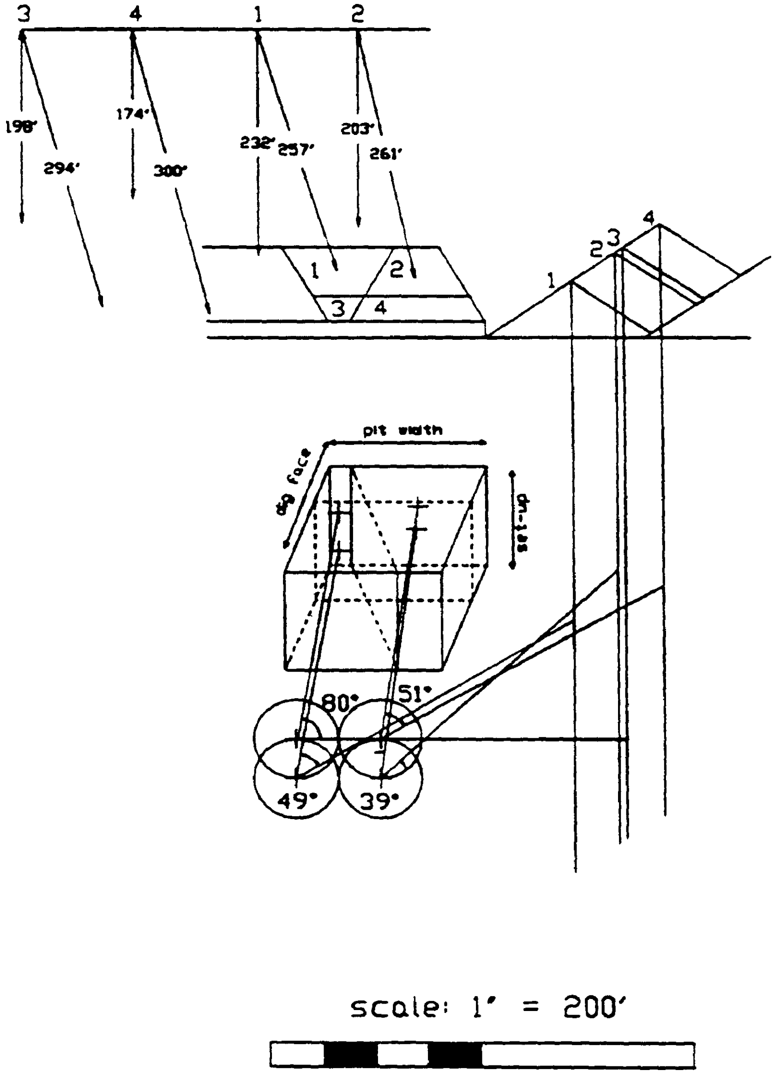


Figure 5.1
Swing Angle and Hoist Distance Prediction

in the drawings represent the smallest swing angle at which the dragline can begin its dump. As discussed in section 2.1, the dragline does not dump at one point but continues to swing while dumping. To account for this an angular increment of 20 degrees is added to get the total swing angle. In the double dig mode, this is not necessary, and the angle from the drawings are representative.

If this procedure is repeated over a range of overburden depths, a relation between overburden depth and swing angle, and overburden depth and hoist distance is arrived at. These relations are shown in Figures 5.2a and 5.2b. The complete set of figures is included in appendix B.

An attempt to establish the relation between overburden depth and swing angle was done by incorporating overburden depth data into the database. The only data available were monthly average overburden depths and these were plotted against the swing angles averaged over monthly periods (Figure 5.3a and Figure 5.3b). The graphs indicate that there are no apparent relations between the variables. This may be due to the overburden data being available only on a monthly basis, while the swing and hoist data are available on a more detailed shift by shift basis. If overburden depth data were collected on the same basis as the swing angle data, the relationship may be clearer.

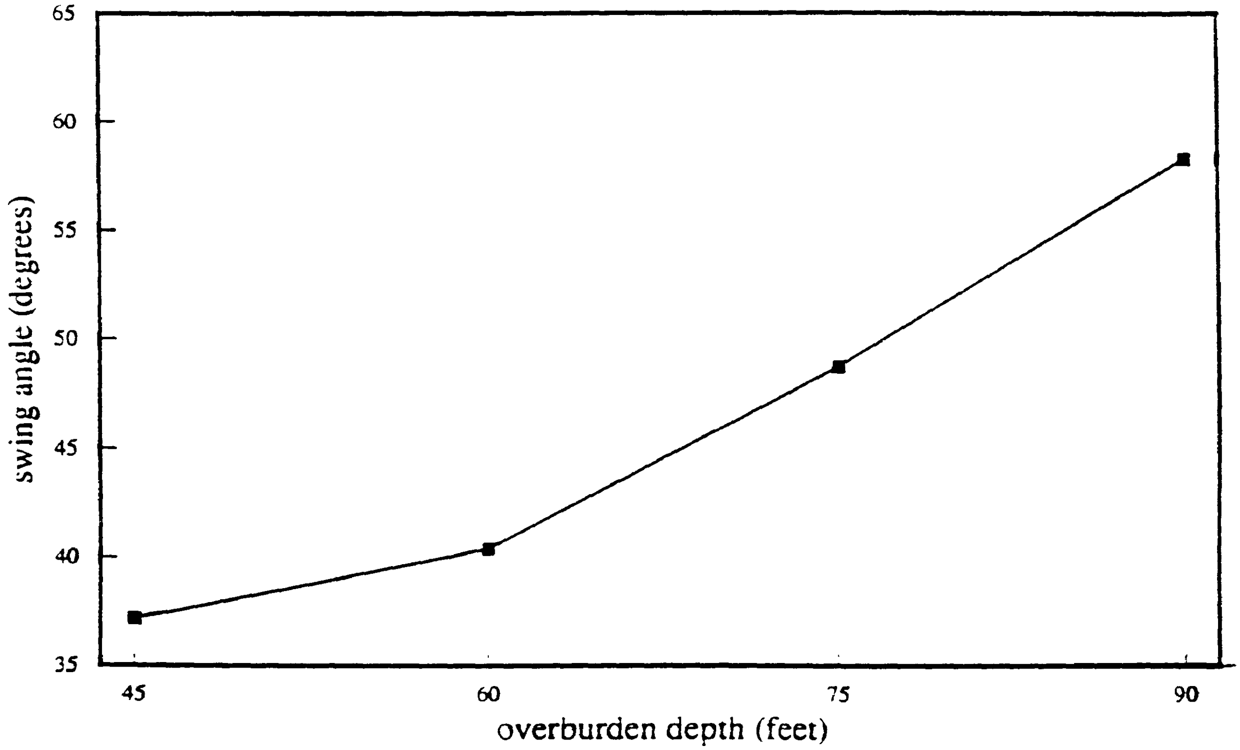


Figure 5.2a
Swing Angle vs. Overburden Depth
(Simulated)

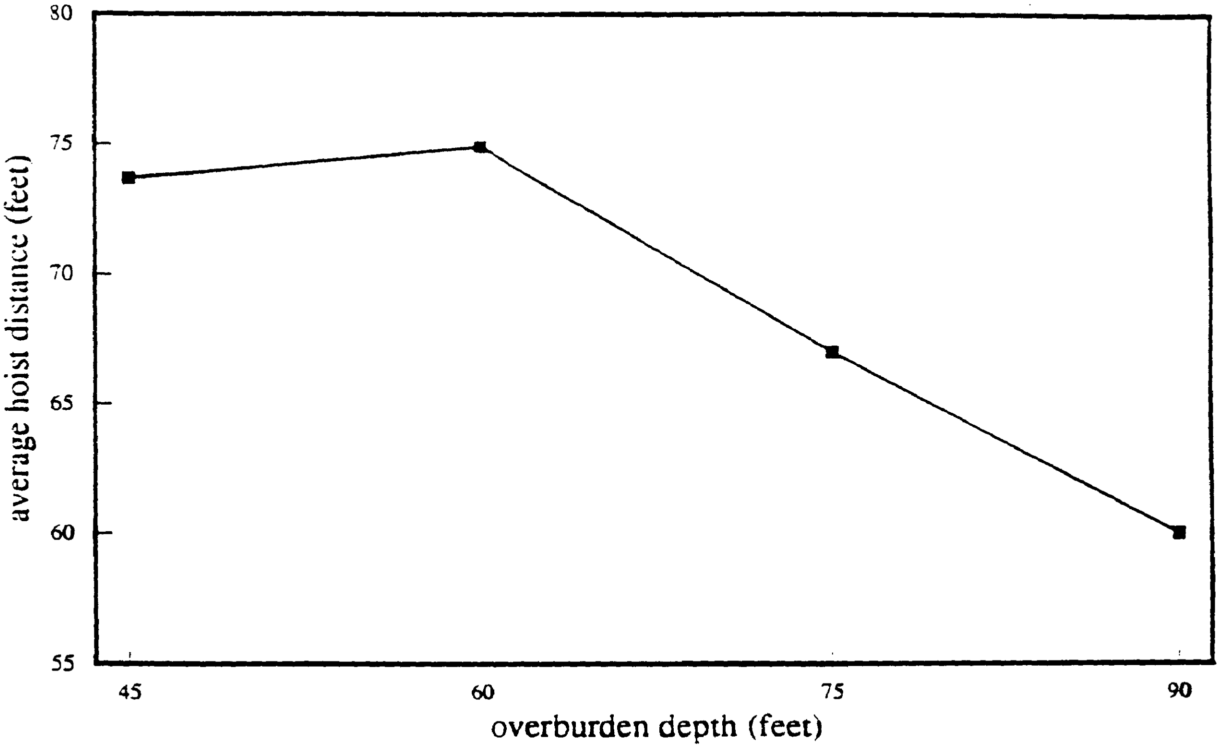


Figure 5.2b
Hoist distance vs. Overburden Depth
(Simulated)

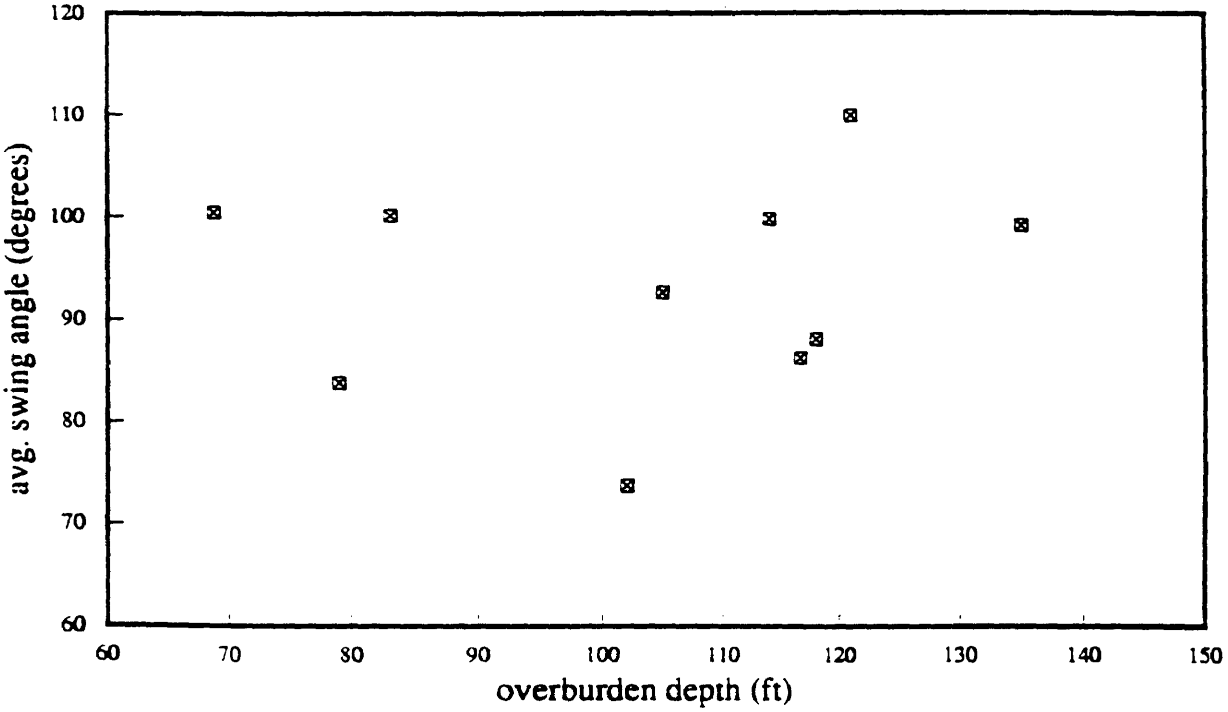


Figure 5.3a
Overburden Depth vs. Swing Angle
(Actual Data, All Dig Modes)

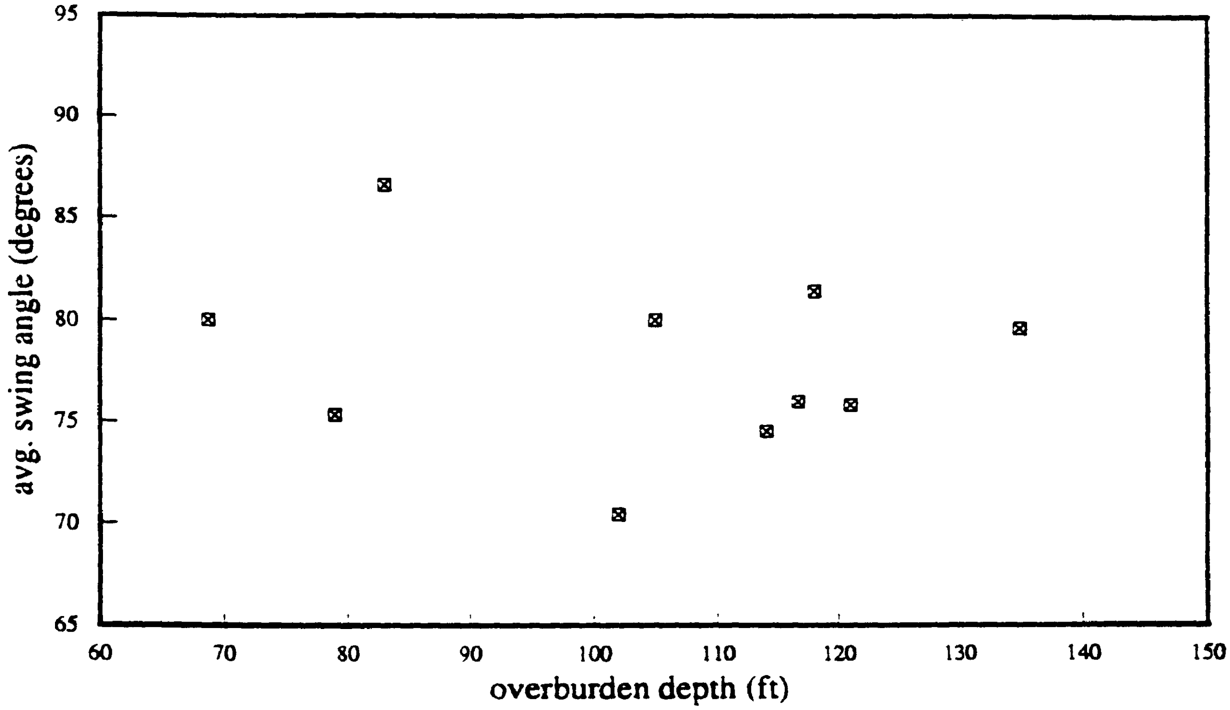


Figure 5.3b
Overburden Depth vs. Swing Angle
(Actual Data, Sidecasting Only)

To predict future performance of a dragline, the material and the overburden depth must be known. From the depth, dig mode can be forecast. Using figures similar to 5.2a and 5.2b, swing angles and hoist distances can be estimated. With that information, the function can then be applied to predict the production rates.

5.2 Method Application To Other Mines

To apply this method to other dragline operations a procedure similar to the one used in this study must be followed.

The first step is to make a list of possible influential factors. The best source of information are the mining engineers and the dragline operators at the mine. The second step is to sort the data and do an analysis of variance to determine which of the listed factors really are influential. The third step is to construct the "production factors" table similar to tables 5.1a and 5.1b. The fourth step would be the application of the production rate function, either as a performance gauge of current operations or a performance predictor for future operations.

Chapter 6

Conclusions And Recommendations

It has been shown that the production rates of draglines vary under different operating conditions. For production rate measurement to be representative, it should take into account the range of conditions under which these machines operate.

The production rate function derived can be very useful when utilized with a properly constructed "performance factors" table which includes all the factors found to be influential on production. These factors should include, dig mode and material type. Other factors that may be included, depending upon their influence, are weather, equipment considerations, and other factors that may be influential at particular mine sites.

For example the weather in the North Dakota operation was found to be unimportant but this may not be the case in the other states, such as Texas and Florida, where periods of heavy rainfall can be expected annually. The weather data for this study was based on historical daily averages and this may be the reason for the lack of a relation between the weather and the various production factors. If weather is expected to be influential, then weather data should be collected on a daily basis and incorporated into the database.

Another example of a potentially influential operating factor that was found not to be are the bucket types. The data showed that the high capacity and regular buckets performed evenly. This may not be the case in other operations. A table has to be made for each machine as differences exist even in the operation of identical machines.

In the future, it is recommended that the operational data collected should include overburden depth, individual cut depth for each dig mode, and pit width, most probably as part of the operator input data. This information would permit the determination of the relationship between overburden depth and swing angles and hoist distances, and would permit a more accurate forecast of prediction.

It would also be useful to develop a set of data recorder based production rate functions and factors from other stripping operations with different digging modes and geometries. The data base would be useful in benchmarking existing dragline performance. It would also provide a tool for estimating production in future operations at existing and new properties.

REFERENCES CITED

1. Learmont, Tom. 1975. Productivity improvement in large stripping machines. *Transactions (Society of Mining Engineers, AIME)* vol. 258: 239-246.

2. Chugh, Y.P. 1980. Surface mining of minerals by draglines in the U.S.A. *Trans. Instn. Min. Metall. (Sect. A: Min. Industry)*: A198-A204

3. Fish, Roger. 1987. *A productivity function for western dragline operations*. Masters Thesis, Colorado School of Mines.

4. Chironis,Nicolas. 1981. Draglines: King of the strippers. *Coal age's new handbook of surface mining*. New York: McGraw-Hill.

5. Boulter, George. 1968. Cyclical methods - draglines. *Surface mining* 1st ed. New York: AIME.

6. Humphrey, James D. 1990. Walking draglines. *Surface mining* 2nd ed. Littleton, CO: SME-AIME.

7. Gale Research. 1989. *Climates of the states* 3rd ed., vol. 2. Detroit: Gale Research.

8. Neter,J., Wasserman, W., and Kutner, M.H. 1985. *Applied linear statistical models*. Homewood, IL: Richard Irwin, Inc.

9. Farber,E., Schaefer, R. 1992. *The student edition of MINITAB users manual*. New York: Addison-Wesley.

10. _______. 1979. Mining shovels and draglines reviewed. *Mining Magazine*. (March): 223-239.

APPENDIX A

Part I: Description of Databases

1. "DIG" Database:

Fields:

DATE - common to all databases
SHF - shift, common to all databases
CREW - common to all databases
SCHED_HRS - scheduled hours, common to all databases
PIT - active pit identification, common to all databases
PASS - upper/lower pass, common to all databases
MAT_TYP - material type, operator input
OPR - operator code, common to all databases
DIGNAME - dig mode, operator input
TI_CYCLE - cycle time in seconds = swing+dump+load
TI_SWING - swing time in seconds, cumulative
TI_DUMP - dump time in seconds, cumulative
TI_LOAD - load time in seconds, cumulative
PU_SWING - swing angle in degrees, cumulative
PU_DRAG - drag distance in feet, cumulative
PU_HOIST - hoist distance in feet, cumulative
MXDEPTH - Maximum hoist distance
RELOADS - Did not meet criteria for a clean dump
DUMPS - Number of bucket loads moved
CUYDS - Volume of dirt moved, cumulative
CHGHST - Date of change of hoist ropes
CHGDRG - Date of change of drag ropes
CHGTEE - Date of change of bucket teeth
CHGCHN - Date of change of bucket chains
CHGRIG - Date of change of rigging

2. "DTR" Database

Fields:

DATE - common to all databases
SHF - shift, common to all databases
CREW - common to all databases
SCHED_HRS - scheduled hours, common to all databases
PIT - active pit identification, common to all databases
PASS - upper/lower pass, common to all databases
MAT_TYP - material type, operator input
OPR - operator code, common to all databases
DTR - downtime code
DOWNTIME - down time in minutes
OCCUR - number of occurrences by downtime event

3. "SHF" Database

Fields:

DATE - common to all databases
SHF - shift, common to all databases
CREW - common to all databases
SCHED_HRS - scheduled hours, common to all databases
PIT - active pit identification, common to all databases
PASS - upper/lower pass, common to all databases
MAT_TYP - material type, operator input
OPR - operator code, common to all databases
DL_NAME - dragline name
ENDSHF - time of end of shift
R_SWG - right swings
L_SWG - left swings
F_CIR - full circles
IDL_T - idle time
PPL_T - propel time
RLD_T - reload time
AC_T - total time AC current was on
STEPS - total number of steps taken
RUN_T - total run time
KWH_U - kilowatt hours used
KWH_R - kilowatt hours regenerated
PKW_U - peak kilowatt hours used
PKW_R - peak kilowatt hours regenerated
LV_MAX - line voltage maximum
LV_MIN - line voltage minimum
DMD_MAX - Maximum demand

4. "SWG" Database

Fields:

DATE - common to all databases
SHF - shift, common to all databases
CREW - common to all databases
SCHED_HRS - scheduled hours, common to all databases
PIT - active pit identification, common to all databases
PASS - upper/lower pass, common to all databases
MAT_TYP - material type, operator input
OPR - operator code, common to all databases
ANGL - swing angle in 10 degree increments
    DMPS_10 - number of dumps
    TONS_10 - number of tons
    TIME_10 - time per swing

Part II: Sample Data

1. "DIG" Database

DATE----	SHF	CREW	SCHED_HRS	PIT---	PASS	MAT_TYP	OPR	DTYP
02/01/92	01	1	8.00	619	L	GC	77	4
02/01/92	01	1	8.00	619	L	GC	93	4
02/01/92	01	1	8.00	619	L	GC	76	4
02/01/92	01	1	8.00	619	L	GC	93	4
02/01/92	03	3	8.00	619	L	GC	33	0
02/01/92	03	3	8.00	619	L	GC	33	4
02/01/92	03	3	8.00	619	L	GC	33	10
02/01/92	03	3	8.00	619	L	GC	77	0
02/01/92	03	3	8.00	619	L	GC	77	4
02/01/92	03	3	8.00	619	L	GC	77	10
02/02/92	01	1	8.00	619	L	GC	77	0
02/02/92	01	1	8.00	619	L	GC	77	4
02/02/92	01	1	8.00	619	L	GC	77	10
02/02/92	01	1	8.00	619	L	GC	93	4
02/02/92	01	1	8.00	619	L	GC	77	4
02/02/92	01	1	8.00	619	L	GC	93	4
02/02/92	01	1	8.00	619	L	GC	77	4

DIG_NAME----------------------	TI_CYCLE-	TI_SWING-	TI_DUMP--	TI_LOAD--
04 Overburden	9009	4240	1858	2917
04 Overburden	5455	2775	929	1751
04 Overburden	8060	4202	1219	2647
04 Overburden	3245	1869	403	977
00 Double Dig-Overburden	5972	4020	492	1464
04 Overburden	1822	953	361	514
10 Double Dig-Overburden	5571	2973	1132	1476
00 Double Dig-Overburden	5295	3576	512	1206
04 Overburden	2129	990	430	718
10 Double Dig-Overburden	4808	2837	735	1233
00 Double Dig-Overburden	171	117	15	39
04 Overburden	3642	2050	537	1059
10 Double Dig-Overburden	148	93	18	37
04 Overburden	8972	5717	893	2362
04 Overburden	3965	2221	719	964
04 Overburden	5415	3256	764	1401
04 Overburden	4237	2146	551	1544

```
PU_SWING-- PU_DRAG--- PU_HOIST-- MXDEPTH RELOADS DUMPS-- CUYDS---- CHGHST--
     10310      30770      35563     205      39     106     12312 01/22/92
      6754      20339      25236     215      17      67      7407 01/22/92
     10501      30257      35858     209      49     100      9466 01/22/92
      4876      11264      14905     208       5      39      4004 01/22/92
     11263      20941      26637     229       3      69      8040 01/22/92
      2224       6235       8195     217       0      26      3478 01/22/92
      7561      21981      27951     227      11      76      9070 01/22/92
     10116      17611      21697     237       0      64      7982 01/22/92
      2759       6941       8614     226       1      26      3148 01/22/92
      7259      17897      22648     234       2      65      7962 01/22/92
       321        524        641     161       0       2       208 01/22/92
      4884      10099      13826     186       0      42      4790 01/22/92
       236        531        663     168       0       2       234 01/22/92
     14667      30963      39534     212       4     109     12463 01/22/92
      5454      12313      15090     213       0      49      5893 01/22/92
      8367      18689      23839     211       0      70      8370 01/22/92
      5121      12590      18059     237       0      49      5493 01/22/92
```

```
CHGDRG-- CHGDMP-- CHGTEE-- CHGCHN-- CHGRIG-- CHGSP1-- CHGSP2-- CHGSP3--
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92 01/22/92
```

2. "DTR" Database

```
DATE---- SHF CREW SCHED_HRS PIT--- PASS MAT_TYP
02/01/92 01     1      8.00 619    L    GC
02/01/92 01     1      8.00 619    L    GC
02/01/92 01     1      8.00 619    L    GC
02/01/92 03     3      8.00 619    L    GC
02/01/92 03     3      8.00 619    L    GC
02/01/92 03     3      8.00 619    L    GC
02/01/92 03     3      8.00 619    L    GC
02/01/92 03     3      8.00 619    L    GC
02/01/92 03     3      8.00 619    L    GC
02/02/92 01     1      8.00 619    L    GC
02/02/92 01     1      8.00 619    L    GC
02/02/92 01     1      8.00 619    L    GC
02/02/92 01     1      8.00 619    L    GC
02/01/92 02     4      8.00 619    L    GC
02/01/92 02     4      8.00 619    L    GC
02/01/92 02     4      8.00 619    L    GC
02/02/92 02     4      8.00 619    L    ST
```

```
OPR DTR_TEXT--------------- DOWNTIME OCCUR--
77  13 Shift Change                4       1
76  14 Manuevering                10       1
93  80 MG Sets /P.C.M.            36       1
33  13 Shift Change                8       1
33  14 Manuevering                22       2
33  20 Blasting In Pit             3       1
77  14 Manuevering                 3       1
77  14 Manuevering                 9       1
77  15 Dozer Work                  8       1
77  14 Manuevering                 3       1
77  14 Manuevering                23       2
93  14 Manuevering                 4       1
93  15 Dozer Work                  6       1
99  14 Manuevering                49       0
99  74 Pit Power Dist. Eqp.       44       0
99  80 MG Sets /P.C.M.            44       0
77  13 Shift Change                9       1
```

3. "SHF" Database

```
)ATE---- SHF CREW SCHED_HRS PIT--- PASS MAT_TYP DL_NAME------------- ENDSHF OPR
)2/01/92 01     1      8.00 619     L    GC              DRAGLINE #901 01:18  77
)2/01/92 01     1      8.00 619     L    GC              DRAGLINE #901 02:50  93
)2/01/92 01     1      8.00 619     L    GC              DRAGLINE #901 05:15  76
)2/01/92 01     1      8.00 619     L    GC              DRAGLINE #901 06:45  93
)2/01/92 03     3      8.00 619     L    GC              DRAGLINE #901 19:01  33
)2/01/92 03     3      8.00 619     L    GC              DRAGLINE #901 22:45  77
)2/02/92 01     1      8.00 619     L    GC              DRAGLINE #901 23:55  77
)2/02/92 01     1      8.00 619     L    GC              DRAGLINE #901 02:24  93
)2/02/92 01     1      8.00 619     L    GC              DRAGLINE #901 03:54  77
)2/02/92 01     1      8.00 619     L    GC              DRAGLINE #901 05:35  93
)2/02/92 01     1      8.00 619     L    GC              DRAGLINE #901 06:45  77
)2/01/92 02     4      8.00 619     L    GC                            14:45  99
)2/02/92 02     4      8.00 619     L    ST              DRAGLINE #901 12:34  77
)2/02/92 02     4      8.00 619     L    ST              DRAGLINE #901 14:22  83
)2/02/92 02     4      8.00 619     L    ST              DRAGLINE #901 14:45  83
)2/02/92 03     4      8.00 619     L    ST              DRAGLINE #901 15:30  83
)2/02/92 03     4      8.00 619     L    ST              DRAGLINE #901 19:02  33
```

```
_SWG--- L_SWG--- F_CIR--- IDL_T-- PPL_T-- RLD_T-- AC_T--- STEPS- RUN_T----
    100      101        4       4       0      39     153      0      8735
     63       62        4       0       0      17      92      0      5519
     91       92        6      10       7      49     145      4      8084
     38       38        1      37       0       5      90      0      3084
    100      100       13      34      12      14     257     19     13107
     92       92        6      20       8       3     223      4     12035
     43       44        1       3       0       0      70      0      3855
    101      101        8       0       0       4     150      0      8974
     47       47        2      23      18       0      89     15      3916
     71       70        3      11       3       0     102      4      5204
     48       48        0       0       0       0      69      0      4169
    149      148       21     124      20      28     472     23         0
     92       93      118      71      29     103     349     30     16532
     69       68        0      39      19      42     109     11      4168
     18       18        0       0       0       1      22      0      1328
     35       35        0       0       0       0      45      1      2705
    102      103        5      34      19      17     213     27     10537
```

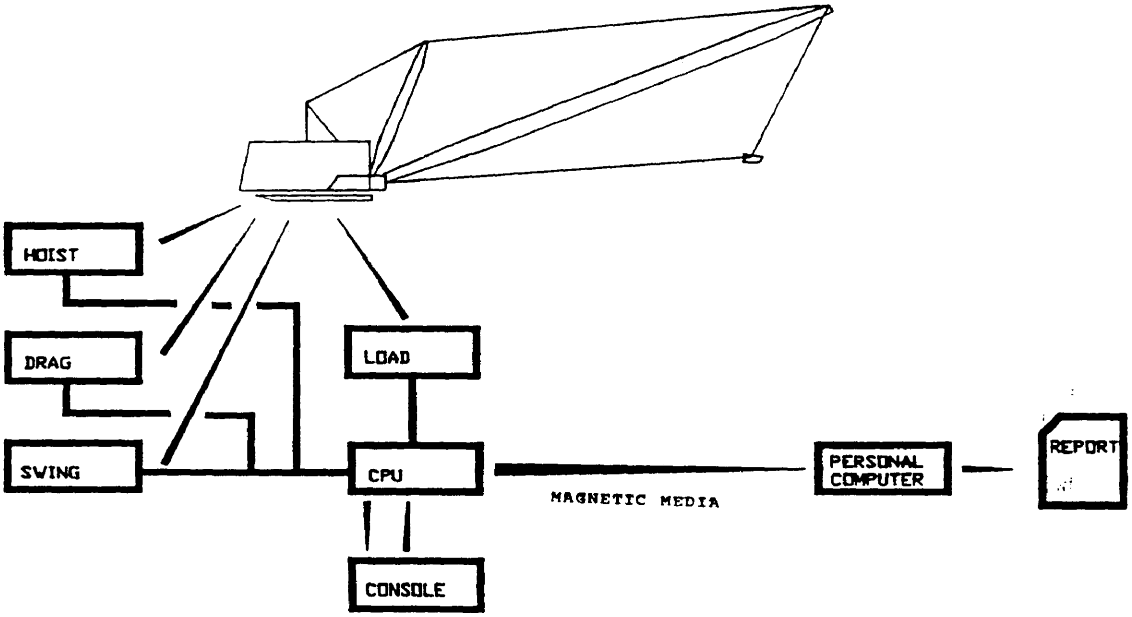
```
KWH_U--- KWH_R--- PKW_U--- PKW_R--- LV_MAX-- LV_MIN-- DMD_MAX-
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0        0        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
       0        0        0        0       35        0        0
```

4. "SWG" Database

```
ATE----  SHF CREW SCHED_HRS PIT--- PASS MAT_TYP
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
2/01/92  01     1      8.00 619    L    GC
```

```
OPR ANGL DMPS_10 TONS_10-- TIME_10---
77    20       1       257       0.87
77    40       2       494       2.32
77    50      14      3541      19.20
77    60      23      5823      32.90
77    70      33      7925      45.70
77    80      19      4460      28.73
77    90       9      2161      12.68
77   100       1       257       1.00
77   170       1       273       1.90
77   180       3       664       4.75
93    40       1       255       1.33
93    60       6      1515       7.38
93    70      41      9716      56.98
93    80      12      2612      16.53
93    90       3       664       3.75
93   100       1        84       0.92
93   180       3       709       3.98
```

Part III: ISI Data Recorder Flowchart

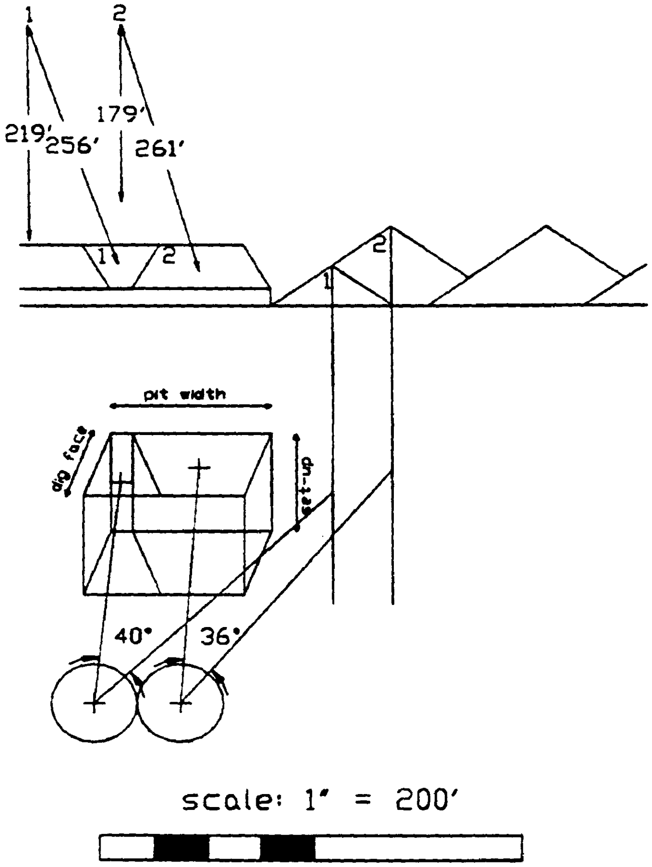


APPENDIX B
DRAGLINE CUT DIAGRAMS

overburden = 45'
digmode: sidecasting

Area	% of total	Swing Angle	Extra Swing	Hoist Distance
1	30.6%	40	20	37
2	69.4%	36	20	90

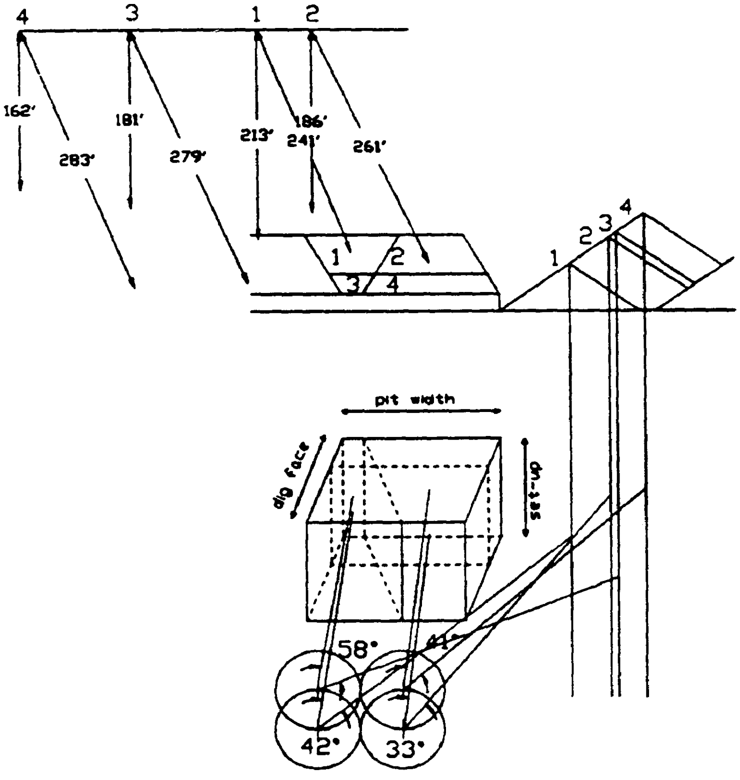
avg. swing angle = 57.2
avg. hoist distance = 73.8



overburden = 60'
digmode: sidecasting

Area	% of total	Swing Angle	Extra Swing	Hoist Distance
1	29.4%	42	20	28
2	37.2%	33	20	75
3	7.1%	58	20	98
4	26.3%	41	20	121

avg. swing angle = 59.5
ang. hoist distance = 74.9

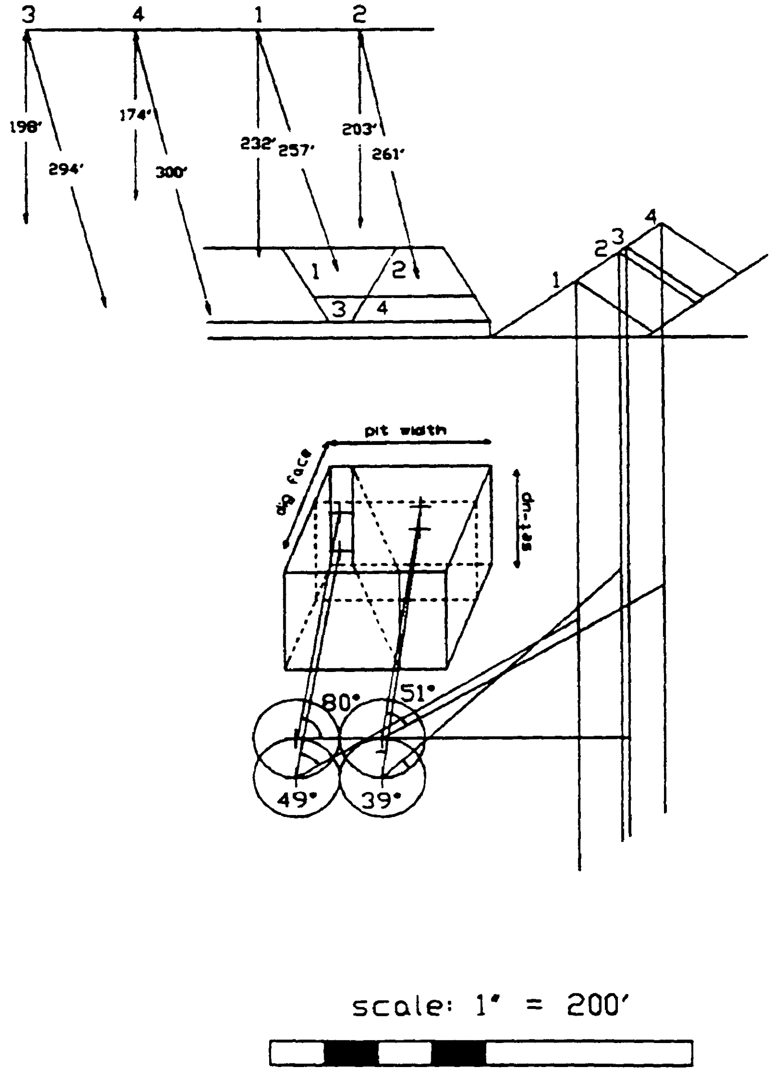


scale: 1" = 200'

overburden = 75'
digmode: sidecasting

Area	% of total	Swing Angle	Extra Swing	Hoist Distance
1	34.5%	49	20	25
2	32.1%	39	20	58
3	7.7%	80	20	96
4	25.7%	51	20	126

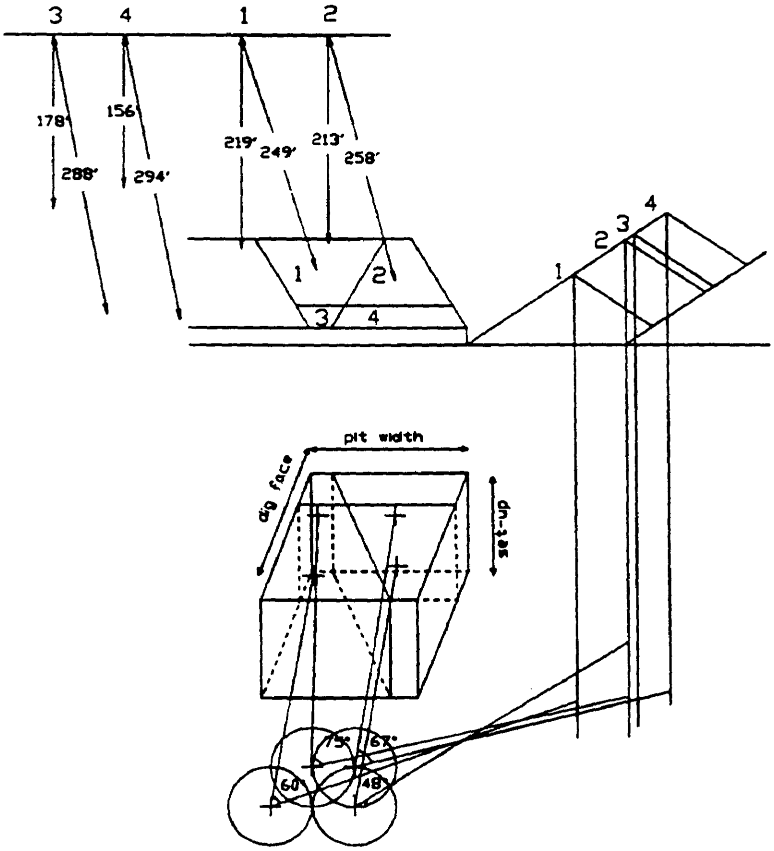
avg. swing angle = 68.7
ang. hoist distance = 67.0



overburden = 90'
digmode: sidecasting

Area	% of total	Swing Angle	Extra Swing	Hoist Distance
1	42.8%	60	20	30
2	32.5%	48	20	45
3	5.7%	75	20	110
4	19.0%	67	20	138

avg. swing angle = 78.3
ang. hoist distance = 60.0

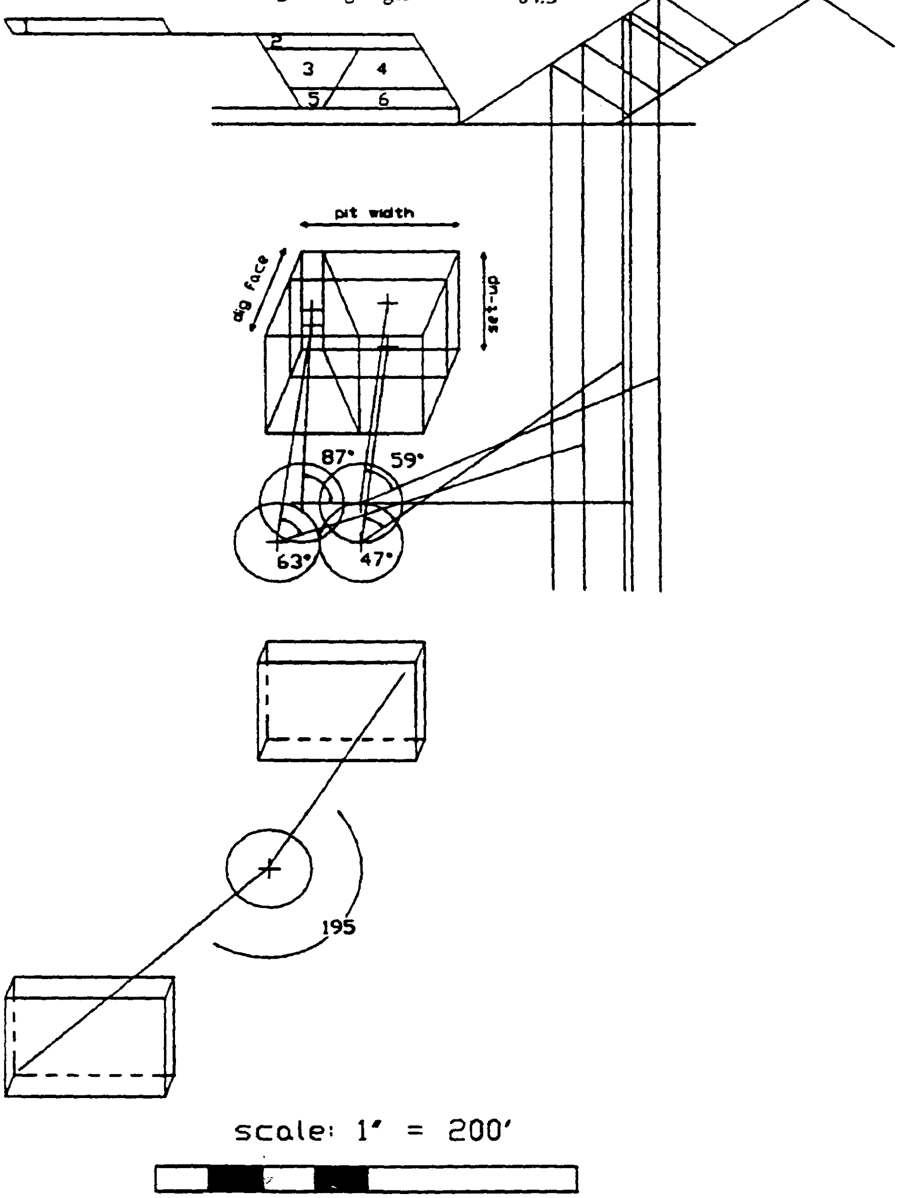


scale: 1" = 200'

overburden = 90'
digmode: sidecasting and double-dig

Area	% of total	Swing Angle	Extra Swing
1	16.7%	97.5	
2	16.7%	97.5	
3	19.6%	63	20
4	24.8%	47	20
5	4.7%	87	20
6	17.5%	59	20

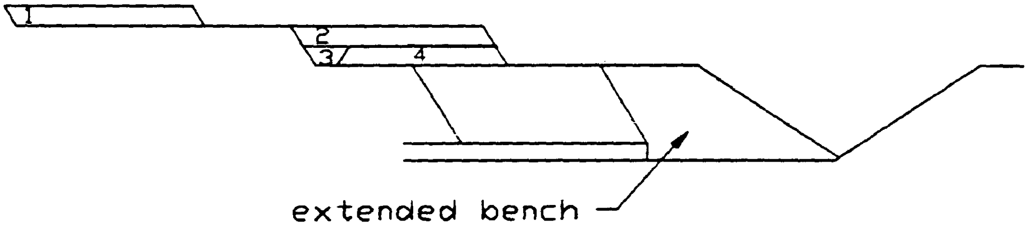
avg. swing angle = 84.3

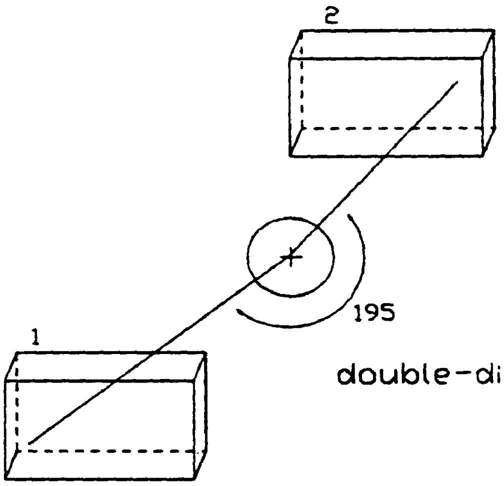


overburden = 135'
digmode: sidecasting and double-dig

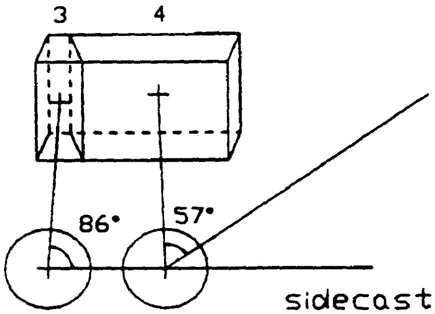
Area	% of total	Swing Angle	Extra Swing
1	10.7%	97.5	
2	10.7%	97.5	
3	1.9%	86	20
4	8.8%	57	20

(part 1: building the extended bench)





double-dig:frontcut-chopcut

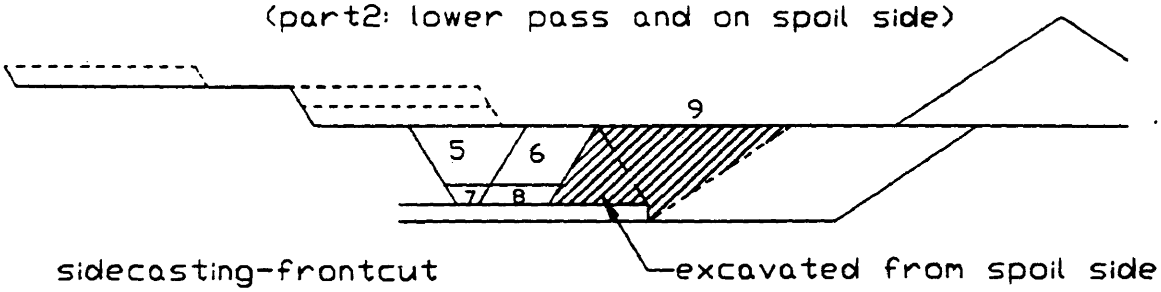


sidecasting-frontcut

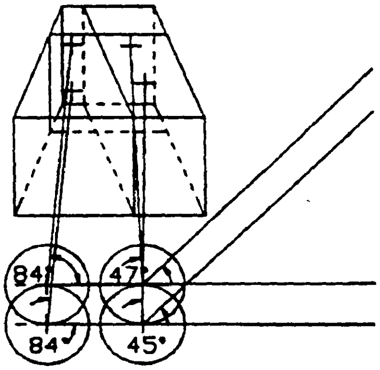
5	13.8%	84	20
6	11.8%	45	20
7	1.9%	84	20
8	3.9%	47	20
9	36.6%	172.5	

avg. swing angle = 119.4

(part2: lower pass and on spoil side)



sidecasting-frontcut



double-dig:frontcut-frontcut