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DEVELOPMENT OF AN EXPERT SYSTEM FOR DRAGLINE AND STRIPPING METHOD SELECTION IN SURFACE COAL MINES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BÜLENT ERDEM

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF
DOCTOR OF PHILOSOPHY
IN
MINING ENGINEERING

MAY 1996

Approval of the Graduate School of Natural and Applied Sciences.

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ABSTRACT

DEVELOPMENT OF AN EXPERT SYSTEM FOR DRAGLINE AND STRIPPING METHOD SELECTION IN SURFACE COAL MINES

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May 1996, 383 pages

Dragline selection is a complicated task where pit geometry, operation methodology and stripping cost aspects have to be considered during the design process. The dragline selection problem can well be solved with expert system approach where knowledge about the dragline operating scheme and application principles of dragline stripping methods can be accumulated in knowledge bases in the form of production rules. In this study, a model has been developed to select the optimum dragline-stripping method pair for a surface coal mine and equipped with sub models each of which has been aimed to solve a specific problem in dragline selection phenomenon. Seven basic dragline stripping methods applicable on one or two slices have been modeled in pit geometry studies which are direct side casting, extended bench casting, pullback stripping, two slice direct side casting, lower slice limited and full extended bench casting and two slice pullback stripping. Main

emphasis was placed on developing methodologies for keycut excavation and spoiling, pit width maximization, bench extension, spoil pile building on pullback pad and allocating total overburden into slices. Production simulation studies covered the application of both one and tandem dragline systems and algorithms have been developed to model block volumes and walking distances. Besides, simulation studies have been extended to investigate the synchronization of tandem dragline systems. Finally stripping cost studies have been included to determine the projected cost of removing the overburden with draglines in terms of total volume removed, prime volume removed and desired stripping volume. Numerous sample sessions have been conducted to validate the main expert model and critical output parameters have been compared to those published previously. Besides, the model has been applied for an operating mine. Interpretation of the outputs from both sample and real cases has revealed that the model is producing reasonable and correct results.

Key Words: Expert Systems, Pit Geometry, Stripping Techniques, Production Simulation, Stripping Cost

ÖZ

YERÜSTÜ KÖMÜR OCAKLARINDA DRAGLİNE VE ÖRTÜ KAZI METODU SEÇİMİ İÇİN UZMAN SİSTEM GELİŞTİRİLMESİ

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Mayıs 1996, 383 sayfa

Dragline seçimi, tasarım aşamasında ocak geometrisi, üretim yöntemi ve örtü kazı maliyeti gibi konuların gözönünde bulundurulması gerektiği karmaşık bir işlemdir. Dragline seçim problemi dragline çalışma planı ve örtü kazı metodlarının uygulama presiplerine ait bilgilerin bilgi tabanlarında üretim kuralları olarak toplandığı uzman sistem modellemesi ile çözülebilir. Bu çalışmada, yerüstü kömür ocaklarında optimum dragline ve örtü kazı metodu çifti seçimi için bir model geliştirilmiştir ve her biri dragline seçiminde karşılaşılan özel problemleri çözmek için geliştirilen alt modellerle donatılmıştır. Bunlardan ocak geometrisi çalışmaları bir veya iki dilimde uygulanabilen yedi temel örtü kazı metodunun modellenmesini kapsamaktadır. Bunlar; direkt yana döküm metodu, uzatılmış basamak metodu, geri çekimli döküm metodu, iki dilimde direkt yana döküm metodu, alt dilimde kısıtlı ve tam uzatılmış basamakta döküm metodu ve iki dilimde geri çekimli döküm metodu'dur. Ocak geometrisi

çalışmalarında ana ağırlık kılavuz dilim kazısı ve döküm modellenmesi, basamak genişliği maksimizasyonu, uzatılmış basamak paterni geliştirilmesi, geri çekme tablası üzerinde yığın tepesi oluşturma prensipleri ve basamak kalınlığının dilimlere ayrılması için metodolojiler geliştirmeye verilmiştir. Üretim simülasyonu modelleri bir veya iki dragline sistemi uygulamasını kapsayacak şekilde genişletilmiş ve kazılacak blok hacmi ve yürüme mesafelerinin modellenmesi için algoritmalar geliştirilmiştir. Ayrıca üretim simülasyonu çalışmaları ikili dragline sistemlerinin senkronizasyonunun araştırılmasına yönelik olarak genişletilmiştir. Son olarak dragline örtü kazı sistemlerinin toplam dekapaj, tekrar kazı içermeyen toplam dekapaj ve istenen dekapaj bazında örtü kazı maliyeti belirleme modelleri eklenmiştir. Geliştirilen ana uzman model, doğrulanmak amacıyla bir dizi örnek veri ile test edilmiş ve kritik çıktı parametreleri daha önce yayınlananlar ile karşılaştırılmıştır. Model, bunun yanında halen işletilen bir madene de uygulanmıştır. Örnek ve gerçek madenlerden elde edilen sonuçlar modelin mantıklı ve doğru olarak çalıştığını göstermektedir.

Anahtar Kelimeler: Uzman Sistemler, Ocak Geometrisi, Örtü Kazı Teknikleri, Üretim Simülasyonu, Örtü Kazı Maliyeti

To All Who Encouraged and Supported me During the Preparation of the Thesis

ACKNOWLEDGMENTS

I wish to express my appreciation to Assoc.Prof.Dr. Neş'e Çelebi for her kind supervision, valuable comments and suggestions throughout this research.

I also express my gratitude to Prof.Dr. A. Günhan Paşamehmetoğlu for his invaluable suggestions.

I would like to thank to Dr. Taylan Bozdağ, Şebnem Başkan Düzgün and Kaan Erarslan of Middle East Technical University and Assist.Prof.Dr. İhsan Özkan and Assist.Prof.Dr. Reha Özel of Cumhuriyet University for their technical and moral support.

Finally I would like to thank to members for serving on the examining committee.

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NOMENCLATURE

$A_{barrier}$:	Area of the Barrier Left on Highwall Side, m^2
A_{chop}:	Area of the Advance Bench, m^2
$A_{chopspoil}$:	Area of the Spoiled Advance Bench, m^2
A_{di}:	Area of ith Hollow Part in Empty Pit, m^2
A_{eb}:	Area of the Extended Bench, m^2
A_{keycut}:	Area of the Keycut, m^2
$A_{keyspoil}$:	Area of the Spoiled Keycut, m^2
A_{reh}:	Area to be Rehandled, m^2
A_{upsp}:	Area of the Spil Pile on the Pullback Pad, m^2
$dist_{i,j}$:	Distance between Points i and j
$Diameter_{tub}$:	Tub Diameter of the Dragline, m
fs:	Swell Factor, %
h_1:	Height the Dumped Spoil Pile Rises on the Highwall, m
h_{di}:	Height of ith Hollow Part in the Empty Pit, m
h_i:	Height of ith Dimension Used in Calculations, m
$h_{keyspoil}$:	Height of the Dumped Keycut Material, m
h_{upsp}:	Height of the Spoil Pile on Pullback Pad, m
H_b:	Advance Bench Thickness, m
H_{block}:	Overburden Block Thickness, m
H_c:	Coal Seam Thickness, m
H_{eb}:	Height of Extended Bench, m

H_{ls}: Lower Slice Thickness, m

H_o: Overburden Thickness, m

H_{pp}: Height of the Pullback Pad, m

H_{sp}: Height of Spoiled Highwall Side Material in the Empty Pit, m

H_{spoil}: Height of Spoil Pile, m

H_{us}: Upper Slice Thickness, m

L_i: Length of ith Dimension Used in Calculations, m

L_{ppsb}: Spoil Side Setback Distance, m

LR_i: Length of ith Dimension Used in Spoil Pile Area Calculations, m

LS_i: Length of ith Dimension Used in Spoil Pile Rehandle Calculations, m

L_{set}: Set Length, m

$L_{spoilset}$: Spoil Side Set Length, m

p_{reh}: Rehandle Percentage, %

r: Effective Dragline Reach (Measured from the Toe of the Coal Seam), m

R_{di}: Required Dragline Operating Radius on i^{th} Slice, m

R_{ei}: Required Dragline Reach on i^{th} Slice, m

R_{es}: Required Dragline Reach on Spoil Side, m

$V_{barrier}$: Volume of Highwall Barrier, m^3

V_{chopi}: Volume of ith Chopping Block, m^3

V_{keycut}: Volume of Keycut, m^3

$V_{maincut}$: Volume of Maincut, m^3

$V_{pullreh}$: Volume of Rehandle Part in the Pullback Pad, m^3

V_{reh}: Volume of Rehandle Part, m^3

W: Pit Width, m

W_{berm}: Width of Safety Berm Left between Slices, m

W_{buc}: Bottom Width of the Keycut, m

W_{eb}: Width of the Extended Bench, m

Wkeyspoil: Base Width of the Dumped Keycut Material, m

W_{pp}: Width of the Pullback Pad, m

$W_{upkeybank}$: Upper Width of the Keycut, m

W_{upsp}: Width of the Spoil Pile on Pullback Pad, m

Φ_c: Coal Seam Bench Angle, degrees

Φ_o: Highwall Angle, degrees

Φ_k: Keycut Right Wall Angle, degrees

θ: Angle of Repose of Waste Material, degrees

CHAPTER I

INTRODUCTION

Today surface mining has the largest share in total mining operations in the world. The common tendency is to apply surface mining methods for the extraction of assets as surface mining is simpler and more economical where planning of operations is easier, product recovery is higher with fewer casualties.

Dragline stripping has been reported to be simple, versatile and the most economical means among other overburden removal systems (Seymour, 1979; Mooney and Gibson, 1982; Özdoğan, 1984; Rodriguez, et.al., 1988; Humphrey, 1990; Anonymous, 1993a; Anonymous, 1993b; Walker, 1993). This can be attributed to its inherent capability to spoil the waste to the required distance from the shortest path.

The ultimate aim of every engineering design is to perform a task that would yield optimum output at the least cost. In dragline stripping, this is reflected in uncovering the desired area of product for a cost lower than alternative systems. Although dragline mining has numerous advantages over other systems, the key to a successful operation is, undoubtedly the thorough planning of overburden removal scheme in advance of stripping operations.

A dragline, first of all, is an equipment of limited displacement capability. Prior to putting a dragline into work, every aspect related with its application in a surface mine has to be investigated in detail. The basic aspects that play significant role in dragline application are the pit geometry and production simulation. A dragline must be capable to dig down to a depth and spoil up to a height without causing rehandling preferably. Furthermore, it must be capable to meet the stripping requirements in a given period of time. Finally, an analysis on the cost of overburden removal is needed as the bottom line to visualize how cost-effective the dragline stripping scheme is designed.

Solving the complicated dragline selection problem with the expert system approach is very profitable. Filtering and accumulating the knowledge about the dragline operating scheme, application principles of particular dragline stripping methods and stripping cost determination procedures into knowledge bases in the form of production rules help divide the complicated selection procedure into a number of smaller, thus manageable sub problems. Besides, association of rules of thumb in dragline stripping into the expert system leads to quick solutions.

A survey on dragline mine planning has revealed that there have been unexplored areas which could play significant role in dragline stripping scheme. Previous studies have concentrated on analyzing overburden removal operations of methods applied on one slice. However, keycut geometry and keycut spoiling procedures, bench extension patterns in extended bench method, geometrical modeling of pullback stripping method, spoil pile building principles on pullback pad, simulating the dragline operating scheme and synchronization studies of tandem dragline systems, allocation of total overburden into two slices and determination of cut volumes and walking distances are such areas that have not been investigated

intensively. Previously developed expert system approaches are too simplistic and narrow-scoped to solve the complicated dragline selection problem. For this reason, within the scope of the study, it has been aimed to develop an expert system that would cover the missing selection aspects mentioned above and contain dragline selection criteria related to pit geometry, production simulation and stripping cost.

Chapter II is devoted to the review of the literature on previous studies about dragline selection and dragline mine design. In Chapter III, the structure and methodology of the developed expert system for dragline and stripping method selection are presented and the pit geometry, production simulation and stripping cost models of the selected dragline stripping methods are explained in detail. Testing the validity of the expert system has been done by conducting three sample sessions. In Chapter IV are presented the results obtained from sample cases. Also critical output parameters have been compared to previous studies found in the literature. Finally, conclusions derived from this study and recommendations for future work are given in Chapter V.

CHAPTER II

LITERATURE SURVEY

2.1. General

This chapter is devoted to the review of the research carried out on dragline mine planning and dragline selection with or without employing expert systems in their methodology.

Uncovering mineral beds in surface mines where dragline is the primary means of overburden removal has been reported to be simple, versatile and the most economical means of stripping among other systems provided that suitable conditions are supplied. It has been reported that (Mourich, 1994), mines starting to overburden removal operations with systems other than those employing draglines in Powder River Basin area, USA have converted to dragline mining due mostly to economical reasons.

Draglines are designed for continuous operation if the least cost per cubic meter of material moved is desired (Steidle, 1977). Because the initial investment of a dragline stripping system is very high, the dragline has to be kept operational all year and must be worked 24 hours a day and every day to make it pay off (Chironis, 1980).

2.2. Previous Research Carried Out on Dragline Mine Planning and Dragline Selection

Although dragline stripping is a widely used and worldwide accepted overburden removal system, principles relating to dragline selection have not become fully transparent due mostly to the proprietary nature and complexity of dragline selection phenomenon. For instance, dragline manufacturing companies regard bucket manufacturing as a proprietary process and do not make bucket related data publicly available (Erickson, 1994a).

There have been found numerous studies on dragline mine planning and dragline selection. The nature of the studies lends itself to be categorized under three main groups: In the first group, the consideration is emphasized on pit geometry where a vast amount of effort is spent on designing the operational dimensions of both the dragline and the pit. The second group of studies covers dominantly the research relating to the productivity of a dragline system planned to be employed in a mine or the research relating to analyzing the results of proposed changes on the currently applied stripping system. This type of studies mostly include production simulation modeling of dragline stripping systems. The last group of research is based on the combination of the above two.

2.2.1. Previous Research Based on Geometrical Aspects

There exist numerous overburden removal techniques using draglines and a large number of intermediary design parameters are concluded by them. For this reason the research conducted on geometrical aspects of dragline selection is further divided into the following respective areas.

Bench Extension

Greenfield and Snowdowne (1977) define the need to shift to techniques including rehandle by the inability of draglines to reach the final spoil pile and attempted to solve the amount of necessary rehandle as it is a significant economic consideration. Main variables in their rehandle calculations are the reach and dumping height of dragline, thickness of coal seam and overburden, angles of highwall, spoil pile and coal seam, pit width and finally swell factor at the point of consideration. Their methodology is based on calculating the area of bridge between highwall and spoil side and deducting from it any virtual areas used to facilitate calculations.

Aiken and Gunnett (1990) formulize the area to be rehandled assuming a constant width extended bench. This is a case that is very unlikely to occur because a change in one of the pit design parameters can immediately necessitate an enlargement or a contraction in the width of the bench to be extended. Their rehandle volume calculation methodology takes into consideration the depth of cut, highwall angle and angles in the area to be rehandled. The formulation relating to the area to be rehandled is given below (Equation 2.1);

$$A_{reh} = \frac{H_o^2}{\tan \Phi_o} + \frac{(\frac{H_o}{\sin \Phi_o})^2 * \sin \varepsilon * \sin \rho}{2 * \sin \beta} \quad (2.1)$$

where

A_{reh} : Area to be rehandled, (m^2)

H_o : Depth of cut, (m)

Φ_o : Highwall angle, (°)

ε, ρ, β : Angles in the rehandle portion of extended bench, (°)

Seymour (1979) and Özdoğan (1984) favor the use of extended benches. Anonymous (1979b), Seymour (1979), Brett (1995) and Erickson (1995d) indicate that as the pit gets enlarged, this results in a decrease in percent rehandle. According to Baafi, et.al. (1995), however, although rehandle is decreased for wider strips, the total productivity is decreased due to longer cycle times for those strips. According to Brett (1995), Australian operators prefer wide (+60 m) pits and extended benches. Seymour (1979) gives the following formula (Equation 2.2) relating to the rehandling percentage under flat lying coal seam and surface topography for a swell factor of 1.25, an angle of repose of 38.5°, and a highwall angle of 63.5°;

$$p_{reh} = -0.025 + \frac{(1.125*H_c + 0.684*H_o + 0.1*R)}{W} + \frac{(0.25*H_c^2 - 0.4*R*H_c - 0.16*R^2)}{H_o*W} + \frac{(0.1*H_c + 0.08*R - 0.01*W)}{H_o} \quad (2.2)$$

where

p_{reh} : Percentage of rehandle, (%)

H_o : Depth of overburden, (m)

W : Pit width, (m)

R : Effective reach of dragline from the highwall edge, (m)

H_c : Thickness of coal, (m)

According to Rodriquez, et.al. (1988) and Seymour (1979) the material to build an extended bench is supplied from the widened key cut. After spoiling the key cut material in the adjacent empty pit in a way to lean on the old highwall, its conical surface is leveled thus adopting the form of the ideal level rehandle surface area. Although the same material supply methodology is proposed by Anonymous (1979b) and Aiken and Gunnett (1990), a difference between them comes in the latter approach when an advance bench casting is applied. This time part of the material is supplied from advance bench provided that it can support the dragline.

The methodologies developed by Michaud and Calder (1988) and Stuart and Cobb (1988) in extended bench construction are leaving the control to the user. The main aim is to assist the mine engineer in designing the dragline pit interactively

through the computer with supplying immediate visual feedback of the pit design. They announced the development of interactive computer programs with which the user would possess full control on dragline positioning in the cut. In case where a bench would have to be extended due to geometrical constraints, the user would decide on the location of the dragline pad and the pad slope would be automatically drawn and the required fill material calculated and displayed. However both bench extension approaches suffer from the point that before locating a dragline on a pad, it must be checked whether sufficiently large amount of material can be supplied from the cut to build the desired length extended bench.

Bandopadhyay and Sundararajan (1986) and Artan (1990) decide on the need for rehandling with comparing the volume of spoil room as calculated by considering the effective reach of dragline to the actual volume of the material to be spoiled. In cases where the volume of spoil is larger than that of the room then rehandling becomes necessary. Bandopadhyay and Sundararajan (1986), in their two-bench stripping approach, build the extended bench next to the lower slice. However no attempt is made to determine how long a bench is required to reach the crest of the final spoil pile and spoil the material in the lower and extended benches.

Among other approaches related with rehandling through extended benches may be mentioned the ones developed by Hrebar and Dağdelen (1979), Gibson and Mooney (1982), Sadri and Lee (1982), Lee (1988), from which no information could be derived about their methodology but the inclusion of rehandling in the form of bench extension into the program modules.

Key Cut Geometry

It is declared that the most efficient stripping operation is when the key cut is as wide as possible (Chironis, 1978; Anonymous, 1979a). Anonymous (1979b) and Rodriguez, et.al., (1988) calculated the minimum keycut cross-section area by taking the bottom width of it equal to that of the bucket in direct side casting operations.

Chopping

It is stated that (Humprey, 1990; Anonymous, 1993a; Erickson, 1995b; Govier, 1995) stripping through chopping is most effective in unconsolidated overburdens with an advance bench of no more than the fairlead height of the dragline. Erickson (1995b) adds that he has heard of and seen large draglines (~ 75 m^3) chop material that was 15-18 meters above their tub elevations. These are extreme cases and the draglines were used to chop this material because it was a soft layer that the dragline could not sit on. On the other hand, Fishler (1986) asserts that, contrary to popular belief, the practice of chopping could be a cost-effective tool allowing 50-75% of the fairlead height to be chopped without penalty. As an example, in their approach, Gibson and Mooney (1982) designed a pit where the dragline could reach all the material in the advance bench from both sitting positions.

Although computer programs developed by Bandopadhyay and Ramani (1979), Hrebar and Dağdelen (1979), Sadri and Lee (1982), Bandopadhyay and Sundararajan (1986), Lee (1988), Michaud and Calder (1988), Stuart and Cobb (1988) have been declared to include chopping in their stripping modules, no

explanations are available as to what height a dragline could be employed for chopping.

Pit Width

Pundari (1981) states that by narrowing pit widths, total rehandle may be reduced. Wider pits, however, can lower overall percent rehandle, resulting in less dragline walking time and better maneuverability of loading equipment in the pit. Sadri and Lee (1982) indicate that pit width has the most important effect on dragline productivity. A small dragline should work a pit as narrow as practical. However medium or large sized draglines should work on pits as wide as possible without rehandling. According to Gibson and Mooney (1982), pit width must be less than or equal to the dragline spoiling radius minus a safe distance from the new highwall. This requires that the dragline reach past the old highwall at the keycut position.

According to Humphrey (1990) and Anonymous (1993a), dragline pit widths commonly vary between 25 to 60 m. Variance from either extreme occurs to cope with local conditions and equipment. Chironis (1978) indicates that narrowing the pit does not necessarily increase the stripping rate. Optimal pit width varies with overburden height and dragline characteristics but tends to be in the middle to wide range. For the most efficient operation, it is indicated that (Anonymous, 1979a) the pit width should be kept of medium width rather than narrow.

Atkinson (1971) emphasizes on the width of pit and states that narrow cuts provide more efficient use of the spoil place since they reduce the valleys between the spoil peaks.

Seymour (1979) determine the pit width by the need to cast the key cut material over the old highwall. According to their approach, pit width is determined on the basis that material dug from the key cut must be placed in the adjacent old pit without necessitating another rehandling from where it is spoiled in direct side casting techniques. In techniques employing extended benches, the pit width is equal to the lateral reach of the dragline.

Rodriguez, et.al. (1988) consider the minimum value of the pit width equal to the truck turning radius in the pit in direct side casting technique. In case where the dragline is incapable to provide minimum pit width due either to shortage of dumping radius or hoisting height of the dragline then their methodology is thinning the overburden layers by secondary stripping means like truck/shovel excavation.

Denby and Schofield (1992) state that the suggested pit width is a contentious value and is a matter of subjective judgment. They estimate it using certainty factors within the expert system they have developed. First, the maximum pit width is determined on the basis of several mine parameters, such as rehandle material, overburden depth, spoil and highwall angles and the operating radius of the selected dragline. The minimum pit width is then calculated on the basis of the minimum width needed for turning circles and drainage requirements.

Safe Working Distance

It is stated that (Anonymous, 1981a; Humphrey, 1990; Anonymous, 1993a) the minimum stand-off (setback) distance varies depending on machine size,

operator preference and overburden conditions. In case where field data is lacking, a minimum stand-off distance of the width of the dragline from the outside of the shoes or 75% of the tub diameter are commonly used values for planning purposes.

Anonymous (1977b) and Speake, et.al. (1977) define the safe setback distance one-half the width of the dragline over shoes plus an allowance for a safety berm at the edge of the highwall. On the other hand, it is stated that positioning the dragline is not a fixed distance near the edge of the highwall (Anonymous, 1977a) and this value may change between 50% to 75% of the tub radius.

2.2.2. Previous Research Based on Productional Aspects

The research conducted on production assessment aspects of dragline selection has further been divided into the following respective areas.

Set Length

It is stated that (Chironis, 1978; Anonymous, 1979a) a longer set length is more productive than a shorter set length. Although average swing angle increases as does the set length, the average cycle time will decrease. A rule of thumb is "shorten up when it gets deeper" (Anonymous, 1977b).

Sadri and Lee (1982) assert that the set length has a strong influence on dragline productivity. Longer set lengths are better but if they are too long then the dragline may not be able to "tie" spoils together completely and utilize the maximum

spoil room available to the machine. They indicate that the optimum set length is not the longest.

Hrebar and Dağdelen (1979) state that as the set length increases, the required operating radius increases as the square of the set length. Opposed to this approach, Gibson and Mooney (1982) prefer to choose the set length the maximum possible. According to another approach (Anonymous, 1993a), the set length for larger machines are in the order of 30 m. (100 ft) or about 16 steps for the dragline. However, in all of the approaches mentioned above, a universal rule of thumb can not be generated on the set length for any unique type of dragline.

Govier (1995) and Erickson (1995a, 1995b) calculate the maximum set length possible by taking into consideration the operating radius, dig depth to the deposit, slope of the digging face and dragline positioning (setback distance). However, Erickson (1995a) indicates that typically for a large dragline, mines have used set lengths of between 25-30 meters, whether or not the dragline's geometry would permit larger lengths. Erickson (1995b) indicates that the only reason that most mines don't utilize large set lengths is because they don't know any better. He adds that a dragline working with a set length as large as it can handle would not have to propel as much, and the operator would be forced further out under the boom. The further out from the the dragline that the bucket is lifted from the digging face, the less electrical energy would be used because the hoist and drag ropes would not be exerting as much force upon each other (Anonymous, 1987).

Determination of Capacity of the Bucket

Anonymous (1977b), Pundari (1981), Erickson (1994a), Riese (1994a) and Govier (1995) formulate the bucket capacity of the dragline considering the maximum allowable load, density of overburden material, swell factor and unit weight of bucket plus rigging per cubic meter of bucket capacity. Pundari (1981) concludes that bucket design has still been an inexact science and there are no hard and fast rules.

Hrebar and Dağdelen (1979) convert the maximum allowable load into the bucket capacity considering the weight/cubic meter of the bucket and weight/cubic meter of the material being dug. On the other hand, Wolski and Prince (1986) explain the suspended load a dragline could carry in the form of the mass of the bucket and its rigging and the payload mass.

Dupret (1983) indicates that there are numerous dragline buckets available to be employed as light, medium, heavy and very heavy for varying type of materials with each of which the capacity of the bucket would change. He prefers to use the heavy bucket type of 1160 kg/m^3 unit weight.

Brett (1995) states that dragline productivity has been attempted to improve by research on bucket design. The main aim has been to reduce the dead weight of the bucket so it can carry a greater payload and to improve its digging, holding and dumping capability so that the cycle time is reduced. Pippenger (1995) stresses on the improvement of dragline buckets by reducing their weight thus increasing capacities by modifying bucket parameters. In a mine in the USA, he points, a dragline bucket was increased 25% in capacity from 21.4 m^3 to 26 m^3.

Cycle Time

It is stated that (Humphrey, 1990; Anonymous, 1993a) typical designed cycle time for larger machines is within the range of 50 to 60 s for a 90° swing with a low dump and smaller draglines are, as a rule, generally faster than larger ones. On the other hand, Steidle (1977) indicates that approximate cycle time of a dragline is between 65 - 75 s.

Humphrey (1990) indicates that productivity in operating chopping mode is decreased by the lower fill factor and increased drag to fill time as well as longer swing angles that result in higher cycle times.

Pundari (1981) notifies that advance bench material entails larger swing angles and cycle times, especially when it is dug above the dragline operator's eye level. Pippenger (1995) states that powering drag motors with new ones could make it easy to reduce the cycle time.

Atkinson (1971) gives cycle time of draglines with respect to their bucket capacity and swing angle (Table 2.1). The cycle time values are valid for cases where the average overburden thickness is about one third of dumping radius.

Table 2.1. Approximate Cycle Time of Draglines Based on Bucket Capacity Groups and Swing Angle (After Atkinson, 1971)

Bucket Capacity (m^3)	Cycle Time (s) (Based on Swing Angle)			
	90°	120°	150°	180°
≤15	55	62	69	77
16-26	56	63	70	78
27-44	57	64	71	79
45-57	59	65	72	80
58-92	60	66	73	81
93-150	62	69	76	84

Seymour (1979) states that digging the keycut is the slowest thus the highest cycle time operation in each block since the bucket must be lifted to clear the surface before the machine can start swinging. However, in a wide strip, the keycut is a smaller proportion of the total overburden.

Lee (1988) states that draglines have different cycle times for different types of digging-spoiling operations; for example chopping, building an extended bench or normal side casting.

Gibson and Mooney (1982) include a fixed penalty of 30% (12.4 s) for each swing for overhand chopping (side bench chopping) in the extended bench model.

According to Reddy and Dhar (1988), one of the causes of lower than normal dragline productivity is the higher cycle times associated with larger than ordinary swing angles in Indian open-pit coal mines.

Sadri and Lee (1982) assert that cross-section diagrams have their limitations in that they assume that all the material is spoiled at 90° swing angle. The spoil pile is in the form of a ridge and it produces an approximate cycle time.

Bandopadhyay and Ramani (1979) and Bandopadhyay and Sundararajan (1986) estimate the cycle time based on recorded field values. They define it as the sum of expectations of each individual item constituting a cycle with the following formula (Equation 2.3). Estimation of the cycle time is performed by using a random number generator and the associated Weibull distribution of the events composing the cycle time. Input parameters relating to cycle time are maximum, minimum, mean and standard deviation times for each individual event.

$$E(\text{cycle time}) = E(\text{digging}) + 2*E(\text{swing}) + E(\text{dump}) + E(\text{positioning}) \quad (2.3)$$

Manula, et.al. (1979), in their OPMHS (*O*pen *P*it *M*aterials *H*andling *S*imulator) program, simulate the time spent for a cycle a dragline makes by using the mean, maximum, minimum cycle times and the deviation of the cycle time from the mean.

Hrebar and Dağdelen (1979) calculate the walking time of the dragline in a cycle. Average cycle time is calculated by adding a fixed time and a calculated walking time to the swing time. The fixed time includes digging, dumping, repositioning the bucket and delay time/cycle. The delay time/cycle represents unrecorded delays such as cleaning coal, operator delays, etc. The walking time per set-up is calculated on the basis of an input walking rate and distance calculated from

the input dragline positions. The walking time is averaged over the number of cycles per set-up to arrive at a per cycle time.

Digging Sequence

Rodriguez, et.al. (1988) state that the cut sequence in extended bench casting is as follows; the dragline sits on the keycut and excavates and dumps it near the old highwall and then excavates main cut and rehandle from where it sits closest to the final spoil pile.

According to Lee (1988), if no keycut is planned, then a central position is assumed by his model to perform digging to shape the new highwall slope. Sadri and Lee (1982) addresses the excavation possibility of keycut either fully before excavation of main cut or simultaneously in layers. They prefer layered methods as they reduce cycle time and allow the dragline operator a better view of the operation. In their approach, Hrebar and Dağdelen (1979), remove the keycut in one lift and in two lifts if the overburden is deep following the same cut sequence.

Bandopadhyay and Sundararajan (1986) plan the excavation of a cut in slices. According to the methodology developed, each bench is divided into slices and the whole cut is dug accordingly. The dragline is positioned on midline of the keycut and excavates the uppermost slice of the keycut and then advances to where it is closest to the spoil piles and excavates the uppermost slice of the main cut. It moves back and forth between key and main cuts until whole set is completed.

It is stated that (Anonymous, 1993a), the digging sequence in fairly consolidated overburden is performed in four phases where the upper layers of the cut are dug from where the dragline sits from a distance to the digging face and the lower layers are excavated with the dragline sitting closer to the digging face.

In a mine in the USA, the cut sequence is as follows (Darling, 1990): firstly a band of dirt of clay is removed and deposited in the old pit. Then the upper lift of keycut is taken and the dragline moves closer to endwall and removes the lower keycut (2 and 3). Then it moves close to spoil piles and removes lifts 4 and 5 accordingly. A schematic view related to digging sequence of overburden layers in the mine is presented in Figure 2.1.

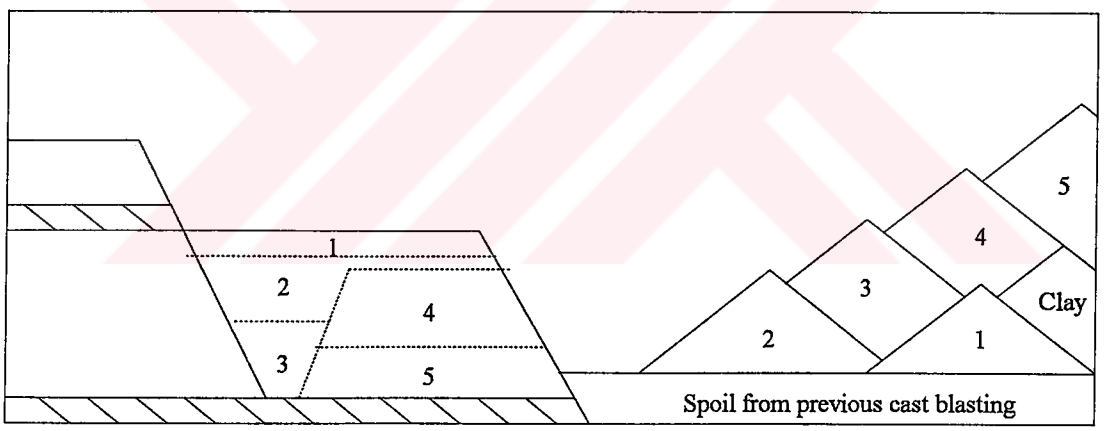


Figure 2.1. Digging Sequence in a Mine in the USA (After Darling, 1990)

Walking Grades

For walking, Chironis (1983) indicates that the maximum grade is 4% for draglines. On the other hand, it is stated that (Anonymous, 1979a) ramp gradients must be limited, for example Bucyrus Erie Co. recommends a maximum of 10% for models up to and including the 1300W and 7.5% for larger machines. However, when walking across a ramp the slope should not exceed 5%. According to Baafi, et.al. (1995), walking draglines are capable of a maximum ±10% grade walk. They state that dragline grade ability has a significant impact on ramp length required for any dragline level changes and also on amount of pre-strip material for dragline access. In their computer program, Baafi et. al (1995) control the maximum grade by comparing the average level for adjacent sections and the maximum grade a dragline can operate on.

Walking Speed and Time to Take a Step

According to Erickson (1995a), normally it should take no longer than 2 min from the time a dragline dumps its last bucket until it takes a step. All cable handling and pad preparations should be done before a dragline dumps its last bucket. In extreme cases, the time from dump to step could be 5 min, if there were some cable that could not be moved due to dragline rotation.

Erickson (1994c) gives the step distance of smaller machines as about 1.83 to 1.98 m, while this value is 2.29 m per cycle for larger machines like Marion 8200 and 8750. In general, he adds, most draglines are designed to take a step every 40 s. For long distance walks, Erickson states that, most Marion walking draglines are

in the 160 to 193 m/h range. It is assumed that a dragline walks 1600 m in 10 hours. As an example, Mourich (1994) notes that a dragline walked 45 km from a mine to another in Powder River Basin, USA, in 30 days. This equals approximately to a walk of 1500 m/day.

Atkinson (1971) proposes a factor of 0.94 to adjust the inclusion of propelling into the dragline operating system in cases where time studies are absent. This means that 6% of the scheduled time is spent during moving. This figure is based on normal operations and includes the deadheading associated with such operations. In a similar fashion, production is calculated by adjusting it with a propel time factor (Anonymous, 1977b). However, Sadri and Lee (1982) estimate the time spent for walking around 2 to 3% of the scheduled time. After performing production simulation runs on the computer, Bandopadhyay and Ramani (1979) report the walking time as 3.43% of the total scheduled time while this value is calculated 2.9% by another approach (Anonymous, 1979b).

Walking Pattern

Gibson and Mooney (1982) express the walk time in terms of rectilinear distance moved which consists of a constant time and a variable time. The fixed time is input by the user whereas the variable time is computed by multiplying the distance between positions by the moving speed. The methodology by Chironis (1978) on dragline movement patterns is similar to the previous approach where movement patterns are rectangular, dragline stepping parallel to X and Y axis. The number of steps to be taken are calculated and the step time is calculated by multiplying the number of steps by the step time constant. The grounds-man preparation time is

simulated as a percentage of the step time and the dragline move time is the sum of the step time and grounds-man preparation time.

Bandopadhyay and Ramani (1979) and Bandopadhyay and Sundararajan (1986) simulate dragline walking in a two bench pit within following situations; from a keycut position to a maincut or *vice versa*, walking from one block to another, walking from overburden to the interburden of the same cut and finally walking from interburden of one cut to overburden of the next cut. Dragline walk time is based on the shortest distance between two dragline positions. In other words walking is assumed diagonal instead of in a rectangular pattern. The move distance, move preparation time, time required to move each step and the length of each step are inputs in the calculation of time spent for walking.

Hrebar and Dağdelen (1979), contrarily, calculate the walking time of the dragline in a cycle. Here, average cycle time is determined by adding a fixed time and a calculated walking time to the swing time. The walking time is averaged over the number of cycles per set-up to arrive at a per cycle time.

Delays Associated with Stripping Operations

In some approaches (Boulter, 1968; Atkinson, 1971; Stefanko, et.al., 1973; Anonymous, 1977b; Hrebar and Dağdelen, 1979; Anonymous, 1993a; Parlak, 1993), delays associated with stripping operations are expressed in terms of overall efficiency of the whole stripping system when determining the required bucket capacity. In such approaches, a factor of efficiency governs the total of expected and unexpected delays likely to occur in a specific mine.

Bandopadhyay and Ramani (1979) and Bandopadhyay and Sundararajan (1986) simulate the failure of the dragline and the required service time for each failure as random variables in their model. In the process of simulation, a random number (r) is generated from a uniform distribution between 0 and 1 at the end of each continuous run time. If r is greater than mechanical availability, then there exists some delay and the delay time is given with the following formula (Bandopadhyay and Ramani, 1979), (Equation 2.4);

$$Delay = \sum Continuous\ Runtime * (\frac{1}{availability} - 1) \qquad (2.4)$$

Synchronization of Stripping Operations

Niemann-Delius and Thiels (1988) indicate the recognition of any critical operational situations in advance such as inadmissible closure of two stripping units in the same pit as a situation that would never be allowed.

According to Sadri and Lee (1982), in single-seam mining with dragline, stripping is not affected by other operations. The major part of the mining cost lies in dragline stripping. Improving the dragline's excavation capability decreases the cost of the overall operation. In multiple-seam mining, however, layers of material are excavated in sequential order and several types of equipment are used in conjunction with each other. All the elements must be considered as one system and this has to be in equilibrium.

Bandopadhyay and Sundararajan (1986) state that in multiple-seam mining, one of the complications is the sequencing stripping and coal handling operations.

2.2.3. Previous Research Based on Stripping Cost Aspects

Buchella, et.al. (1973) state that repair and maintenance can be expected to account for 40 to 50% of direct mining costs. Moreover, in a well-balanced mine organization, maintenance personnel will comprise 40% of the total.

Steidle (1977) reveals that maintenance costs include labor, parts, cable, etc. for the life of the machine. For walking draglines, it is stated that (Atkinson, 1971; Steidle, 1977; Anonymous, 1993a) maintenance costs on above basis are approximately 7% per year of the purchasing cost. Cable costs which is a part of it, on stripping shovels and walking draglines run approximately 30 to 35% of the total maintenance costs. Steidle (1977) prefers to calculate the erection direct labor hours for stripping shovels and walking draglines as approximately one man-hour per 45 kg (~90 lbs) of machine weight. According to him, ownership and operating costs per cubic yard are approximately the same. Operating costs include maintenance, parts and labor.

Fishler (1986) stresses on the fact that most mine managers are involved more in direct operating costs. Although ownership cost is more abstract, it is equally important and can not be overlooked. According to him, erection cost of field-welded types has been estimated at 20 to 25% of the capital cost. However, the ultimate erection cost of a modular design is only a fraction of that for a similar sized field

welded design. He adds that the cost per m^3 moved is considerably less for a smaller machine than for a larger design.

Mourich (1994) indicates that dragline costs in the Powder River Basin, USA, are within the range of 26-39 ¢/m^3 while truck-shovel costs are 38-92 ¢/m^3. After simulating dragline operations for a sample case, Lee (1988) determines the overburden stripping cost as 39 ¢/m^3.

Atkinson (1971) estimates erection costs based on machine weight in 1971 prices. Wolski and Prince (1986) formulate the maintenance and repair cost based on dumping radius. On the other hand, Gibson and Mooney (1982) calculate the ownership and operating cost based on an equation as a function of its MUF developed by Fluor Utah Inc. In addition, total purchase price of the dragline is computed with an equation as a function of maximum boom length and bucket capacity.

Lee (1988) calculates the cost of stripping per m^3 of overburden stripped and per ton of coal extracted from input hourly owning and operating cost values.

Hrebar and Dağdelen (1979) calculate ownership and operating costs in the conventional manner where ownership costs can be based on the average annual investment approach for interest, insurance and taxes and either straight line depreciation or the capital recovery factor approach for the capital component.

According to Brett (1995) sometimes cast-blasting is more expensive than conventional extended-bench type dragline operations. However, it is a means of

increasing overall dragline productivity. It represents a more cost-effective method of offsetting the adverse effects of increasing depth than the use of prestripping methods.

2.2.4. Computer Programs Developed on Dragline Mine Planning and Dragline Selection

A series of micromodels were developed by Fluor Utah, Inc., (Anonymous, 1977b) to solve the mine geometry, determine the production requirements and select draglines which meet the conditions of production, dumping radius, dumping height and digging depth. The mining methods simulated were basic (direct) stripping method, extended bench method and contour stripping with draglines. The models were valid for single coal seam cases with flat or gently-sloping terrain. The basic stripping model included factors such as minimum, average and maximum heights of overburden, thickness of coal seam, densities, swell factors, etc. Data about 200 draglines in the database were compared to required ones to be considered for selection by the model. For this model, geometrical constraints were dumping radius, dumping height and dragline reach. Production simulation calculations were performed conventionally where a rated bucket capacity was calculated by taking into consideration efficiency of overall stripping system and factors representing propelling, deadheading and moving in the set. Each machine was cost on two bases. First, a machine operating at full production capacity was simulated and the coal was assumed to be extracted at the rate it is uncovered. This was the cheapest method. Second, the machine operation was simulated that would uncover coal to meet the user-specified coal mining rate. For each cost basis, the lowest-cost machines were indicated. The extended bench method was used in situations when a single machine could not be used; the model simulated the use of

two machines rather than one. The extended bench model solved the pit geometry to allocate the overburden between the primary and secondary draglines. The primary machine operated on the highwall in the normal dragline fashion; however, it removed only a portion of the overburden to the spoil area. The secondary machine operated on a bench in the highwall and on the spoils. The overburden was allocated so that the two benches would have the same elevation and the secondary machine could move freely from one bench to the other. The same procedures relating to production and cost aspects were used in this model. The contour stripping model was designed to evaluate the operation of draglines for stripping in areas where mining proceeds in meandering pits or along hillside contours.

Niemann-Delius and Thiels (1988) developed a computer program on production simulation of both a bucket wheel excavator with a cross-pit spreader and a dragline. The dragline was assumed to work with direct side casting method. At the end of the simulation, a plotter output of pit geometry drawn to scale was provided for better understanding of calculations.

Michaud and Calder (1988) announced the development of a dragline planning computer package. The program leaves the critical decision making like dragline positioning, cut dimensions and spoil pile placement to the user where the approximate mining limit is generated from the maximum digging depth and maximum allowable stripping ratio. Individual cut limits are determined by considering the ultimate pit limit, maximum cut depth and maximum and minimum permissible cut width. Also, the program can represent a 3D view of the pit geometrically. All spoil placement is planned to be directed by the user and spoiling limits controlled by the computer. Corresponding spoil pile area and volume will be calculated and sides of the pile is automatically drawn at a predefined angle of repose

of the material and extended down to the existing topography. Besides, in situ coal and waste volumes will be calculated by dividing each 3D shape in the model into a series of tetrahedra and spoil volumes from a 3D model by incorporating a series of overlapping cones. Michaud and Calder (1988) demand a vast number of input data from the user. The data for material characteristics are; swell factors, highwall angles, safety berm width and spoil pile angle. The data for dragline parameters are; maximum reach, maximum spoil height, maximum digging depth, maximum chopping height and minimum pad width.

Stuart and Cobb (1988) developed a computer program related with dragline planning in surface mines. The philosophy of the program which was a part of a larger geological modelling and mine planning system was to automate the preparation of range diagrams and volumetric calculations. It was a strict design criteria that the computer not make engineering decisions and was aimed at assisting the engineer reach a design satisfactory to him. The program had a database of draglines to store, retrieve and modify records of draglines. In addition, final design of the pit could be taken from a plotter or a dot-matrix printer.

Lee (1988) developed a computer program, namely MDS, for modeling dragline operations in single or multiple seam coal mining environments, simulating several draglines in conjunction with each other with auxiliary equipment and modeling dipping geometry (seam) situations. His program can model up to 3 draglines in multiple-dipping seam applications, use extended benches from any dragline working level and model explosive-cast extended bench for the first dragline operating level. His methodology to perform pit geometry analyses is to use range-diagrams and two-dimensional sectioning methods with plots provided in the program output. From one to eight coal seams can be modeled in a dipping seam environment.

The software performs simulation of the dragline operations of digging, spoiling, rehandling, walking in the set, deadheading and ramping walks and operation delays such as maintenance and layover. The MDS program informs the user whether it has a valid solution for the given input data. If not, it recommends possible adjustments in the data to reach a solution. Typical input parameters are target coal production, bucket fill factors, density of burdens, burden thickness and lifting capability of a specific desired dragline. Draglines working on benches may be merged as one dragline to be employed on both benches. The MDS program draws the range diagram on the screen for review and then on the printer to the scale selected. The program has a datafile of 264 draglines. It is menu-driven. It works interactively through menus and messages output to the user. Dragline data may be modified and saved in an other file to run.

Sadri and Lee (1982), in their methodology of computer program, emphasized on two basic problems. The first is geometrical and the second is productional. They state that previously dragline sizing was determined by drawing two-dimensional cross-section diagrams or by deriving mathematical geometry equations. The system they developed can model simulation in 3D. It can simulate normal side casting, extending the bench, chopping and rehandling. It analyses changes in pit width, keycut routine, walking pattern, spoil patterns and the dragline production cycle. The input data supplied by the user is of three types: dragline variables include boom length and angle, dumping height, dumping radius, fairlead height, digging depth, step length, walking speed, base diameter, bucket capacity, ownership and operating cost and cycle time related inputs. Physical site inputs include coal seam and burden thickness, highwall, chop face, coal seam and spoil pile angles, coal seam and burden density, swell percentage and bucket fill factors for various phases of digging. Inputs related with job application are pit width, bench

height, set length, coal recovery factor, efficiency factors for various operations that dragline performs, maintenance schedule and safe working distance from highwall edge. They also provide switches to the user for controlling excavation and spoiling methodology and printouts.

Bandopadhyay and Ramani (1979) and Bandopadhyay and Sundararajan (1986) developed similar computer packages for simulating two-bench dragline stripping operations. They simulated dragline digging, spoiling, walking, cycling and delays occuring in operations.

Manula, et.al. (1979) developed a computer program (OPMHS) to simulate the draglines working in direct side casting technique. They validated the model through comparison of the simulated and actual production data, prior to applying it to the projected short and long-term plans.

Hrebar and Dağdelen (1979) handled the dragline selection problem with a 3D approach to overcome problems related with conventional reach determination. The stripping models include a single side casting model with a chopping option, an extended bench model with a chopping option and a pullback model. They developed a modified operating radius equation which accounted for the variation in effective dragline reach. The approach taken involved segmenting the spoil room for each setup into unit volumes. The volume available on each segment was dictated by the operating radius of the machine and increased as spoil angle increases.

Gibson and Mooney (1982) developed a comprehensive surface mine and reclamation program that consisted of the following modules: data entry and review, production analysis, reclamation analysis and impact analysis. Six basic dragline

mining techniques were modeled. For one pass dragline operations four methods can be analyzed; simple side casting, side bench, extended bench and extended bench with a side bench. Two methods of two-pass operations are modeled; single dragline and tandem draglines. The stripping modules incorporate numerous features relative to analyzing various solutions. For example, the user may input decision variables and request the model to evaluate the plan's overall feasibility. The model allows the user to choose between two productivity measures; minimize time to remove overburden or minimize the cost per ton of coal uncovered.

Baafi, et.al. (1995) can simulate different mining options and dragline operating sequences using the abilities of the simulation language after constructing the pit geometry. In their approach, a mining operation is carried out using a series of linked geological cross-sections that are spaced along a particular strip design with the user defined interval. Like a normal dragline operation, the simulation can be run in incremental section mode, where the program routines move the dragline from one geological section to the next along a strip until it reaches the end wall and return it to the initial geological section to the next strip. The user can define various practical criteria such as checking the maximum of spoil room and finding the shovel/truck base or checking that if the thickness of partings at particular area exceeds a predefined value then change the mode of operation automatically.

2.2.5. Approaches on Dragline Mine Planning and Dragline Selection Based on Expert Systems

Dragline selection or dragline mine planning with expert systems approach has not been fully evaluated and employed by researchers working on this

subject. There can be found very few examples of this approach of which none is taking the problem from as much points of view as possible satisfactorily to deserve the title "expert". Most of the above mentioned approaches are in prototype form, in other words, they are "in-house" programs which would have no possibility to be employed in real situations but giving the feeling of what could resemble an expert system after feeding it with satisfactory amout of knowledge.

Among the approaches mentioned above, an example is the one developed by Denby and Schofield (1992). They developed a multi-level expert system, namely MINDER (acronym for ***MIN***e ***D***esign using ***E***xpert ***R***easoning), that consisted of a hierarchical structure of knowledge-bases, each dealing with a particular aspect of the design process. The basic factors the system takes into consideration are the bucket size, operating radius, digging depth and the maximum usefulness factor (MUF). The MINDER system can provide operational and geometrical advices. The operational advices are on the use of key cut, method of bucket loading, spoil placement method, spoil placement technique and advance benching. The geometrical advices are on the maximum and minimum pit width, suggested pit width, suggested set length, advanced bench height and miscellaneous.

Stuart and Cobb (1988) developed a computer program which addresses the problem of geometrical constraints of extraction. The program does it by equipping the selection system with fact and rules related to dragline selection. The expert system applies all the rules and checks specified by the rule base and the results are, therefore, independent of the user. They state that this program may be regarded as an expert system as the engineering logic is built into the system. The dangers of such a system are that the rule base is unlikely to be complete for all circumstances.

For example, a dragline may be "failed" because the operating radius is 1 cm shorter than the required value.

2.3. Objective of the Thesis

After having reviewed the previous studies on dragline mine planning and dragline selection, it has been observed that some significant aspects are missing or overlooked and ignored in the pit design criteria. These are listed below.

Most studies for dragline stripping have been done to analyze and in some cases to propose changes in the ongoing procedures to boost the performance of stripping systems where there could be found no opportunity to totally modify the stripping system and the size and quantity of draglines employed (Bandopadhyay and Ramani, 1979; Hrebar and Dağdelen, 1979; Manula, et.al., 1979; Bandopadhyay and Sundararajan, 1986; Niemann-Delius and Thiels, 1988; Rodriguez, et.al., 1988).

Most of the approaches and their developed computer programs have been implemented in a way that enormous amounts of data are demanded from the user as inputs to design the pit for dragline stripping (Hrebar and Dağdelen, 1979; Sadri and Lee, 1982; Gibson and Mooney, 1982; Michaud and Calder, 1988).

Among all the studies, almost none of the researchers have analyzed the spoiling of the keycut material into the old pit. However, this procedure has a serious effect on stripping methods especially in those which do not include rehandling. A dragline employed in a stripping technique which does not include rehandling has to be capable to dump the keycut material clear of the coal seam to prevent burial of the

coal seam, partial or complete and still must be able to excavate and dump the rest of the material lying in the maincut with its designated operating radius. In this case, it can be clearly seen that any dragline working without rehandling has to accomplish two tasks together, excavation of keycut and maincut using the same horizontal reaching capability. A dragline designed to dump the maincut material to a sufficiently long distance may not be doing it so for the keycut material. For this reason, design studies have to consider the clear dumping of keycut waste.

In most of the studies contemplated, the need to extend the working bench has not been clearly defined and in some cases it has been demanded as input from the user. Actually, many a researcher has formulized the dimensions of the extended bench in a very rough way. But, the dimensions, thus the amount of material to construct the extended bench is very important because as the bench gets wider, the amount of material required to build it gets larger too. Knowing the necessary extension to be added to the existing horizontal reach of the dragline employed in the pit is the key for switching to systems with rehandling. This may be a limiting factor to employ dragline stripping where it is no more economical then other types of overburden removal that do not include rehandling in their nature such as truck/shovel stripping.

Pullback stripping has not been popular among researchers due mostly to its eccentric nature of geometrical design calculations as well as complicated procedures in production scheduling particularly when tandemly working draglines are employed. This stripping system, although explained in numerous investigations with its basic operating scheme, is another virgin part of the dragline stripping methods among researchers.

The formation of a spoil pile built on the spoil side in pullback stripping is another severe step making the pit design studies even more complicated. Since in pullback stripping technique an extra room has to be furnished on spoil side to store the material excavated from rehandling part of pullback pad and the barrier, a dragline may easily become "spoil bound" in cases where the pit is considerably deep or the space for storing this material would not meet the spoil room requirements. This reveals the fact that designing the pit on highwall side in pullback casting technique is by no means a satisfactory arrangement as long as enough consideration is not spent for spoil placement on pullback pad as a design work without this stage would be a misleading one. Though this subject is outlined to a limited degree on some issues most of which are published by dragline manufacturing companies, no endeavors have been found among research studies on this topic.

Although referred to by some researchers, very few provisions have been made for the synchronization of tandem dragline stripping systems (Niemann-Delius and Thiels, 1988). This subject is perhaps the most significant consideration in planning stage of tandem dragline systems to properly match their production in the pit. Overlooking this subject would eventually be resulted in catastrophic conclusions such as continually delaying the production of one of the draglines whose rate of advance is completely dependent upon the stripping pace of the other. In such a case, one of the draglines would be performing stripping much more expensive than what has originally been designed due to lower than designed rate of uncovering the coal seam. Moreover, in such a case, draglines would approach inadmissibly than they are planned to each other frequently which would again result in halting one of their advance giving the indication of poor matching.

Determining the proper set length is another design stage that the researchers have not been interested in generously. In most of the research studies this design parameter has been demanded from the user during consultations. There must be designed two sets in a stripping technique which includes overburden removal from both sides of the pit. Although there have been some effort spent on set length optimization on highwall side, there has not been encountered any records relating to the set length determination on spoil side.

Some of the studies on dragline mine planning require that the hourly owning and operating cost be given as input data prior to starting to calculations to determine the cost of per cubic meter of stripping and per ton of coal uncovered respectively (Sadri and Lee, 1982). This is a case where several unknowns exist that can not be determined in ahead of operations. Although ownership cost may be forecasted the same rule does not work for the operating cost as it includes parameters such as electricity consumption and maintenance cost whose values are dependent on the respective performance of draglines. The more the dragline works in a given unit of time the more it produces and the more it consumes. This necessitates a detailed investigation into the components that constitute the operating cost to more explicitly determine its value.

Almost very little effort has been spent for two bench stripping operations (Anonymous, 1977b) where either one or two draglines are employed on benches. In such systems, allocation of slices between draglines is of utmost importance when tandem draglines are used in stripping to accord the synchronization between them. As mentioned in previous clauses, dragline stripping sequencing has a greater impact on the overall performance of the mine and this is very closely interrelated with the allocation of slices between draglines. For example, allocating a thicker overburden

slice to a smaller capacity dragline on a bench and doing the reverse for a larger capacity one on another bench in a two-bench operation is very likely to fail the production requirement target due to unsatisfactorily allocating the overburden among draglines.

In the light of the information given in previous studies on dragline mine planning and selection, it has been decided to start a study covering the general aspects mentioned above.

The objective of the thesis is to evolve an expert methodology for selecting proper stripping methods and draglines working with these methods in surface coal mines where one flat-lying coal seam exists. The logic behind the expert system is to develop a number of knowledge bases each of which is devoted to a specific area of interest in the dragline selection phenomenon. These areas would cover geometrical, productional and economical aspects of selection. The details of each aspect are presented as follows:

1. Pit geometry and range diagramming studies are planned to include to determine and satisfy geometrical reaching necessities set by each stripping method. The expert system is planned to cover dragline stripping techniques with one bench or two benches. The stripping techniques used with one bench are; direct side casting, extended bench casting and pullback casting. Those used with two benches are; direct side casting in two slices, limited and full extended bench casting on lower slice and pullback casting in two slices. Each model of stripping systems will be equipped with essential geometrical formulations used to determine the adequacy of a particular dragline in satisfying the conditions given in input parameters.

2. Stripping production simulation studies will be included to forecast the capability of a specified dragline or a couple working tandemly in meeting the coal production target by performing a predetermined amount of overburden removal. It is planned to develop different methodologies to simulate draglines employed in different stripping techniques each of which has inherent procedures with varying complexity.

3. Finally studies relating to stripping cost will be covered by the expert system to determine the charge of removing a unit of waste material in a specific technique as well as to rank the satisfactory combinations based on economical constraints. Besides, it has been aimed to clarify the raw and effective cost of stripping by presenting the difference of simulated and demanded stripping production of draglines employed in various methods on an economical basis.

The above mentioned procedures have been planned to be translated into computer programs all of which would be driven by an expert system shell. Besides, implementation of numerous facility procedures and modules have been intended each of which would be responsible for a specific duty; a dragline database manager for accessing, modifying and storing records of draglines, a dragline selection program by which the user could have choices to select draglines for examining their applicability for the given input data about a mine, a screen output facility on geometrical design parameters to give an immediate visual feedback of what has the expert system designed out of the given input data, a hardcopy output facility to equip the user with a permanent output of geometrical pit design on an pen plotter and finally another printout facility to present the user the results of geometry, simulation and cost modules.

CHAPTER III

THE DEVELOPED EXPERT SYSTEM MODEL FOR STRIPPING METHOD AND DRAGLINE SELECTION

3.1. General

Numerous equipments can be used for overburden removal operations in surface mining. It is known that draglines can accomplish this task cheaper than alternatives provided that suitable operating conditions are supplied and this has to be proved before putting a dragline into work and it can be done by determining the cost of removing a unit volume of waste in dragline stripping.

Selection of the most optimum dragline is closely related with the selection of a stripping method because although a dragline can be employed in various stripping methods the best performance can only be achieved when it is employed in a specific stripping method that best characterizes the conditions of a surface mine. For instance, employment of a dragline in extended bench method would be uncecessary and cause an increase in stripping costs if it was possible to employ the same dragline in direct side casting method in a particular surface mine. This reveals the fact that minimizing the costs in dragline stripping is highly dependent on finding an optimum dragline-stripping method pair. The most striking lacking point

in the previous studies is that the importance of selecting the optimum stripping method along with the dragline has been ignored.

Selecting the optimum dragline-stripping method pair for overburden removal in a surface mine necessitates the interaction of several aspects in the design stage. A dragline must be capable to meet the geometrical contraints of a particular stripping method and remove the desired volume of overburden in a given period of time. Finally the cost of stripping must be determined for a comparison with alternative draglines or overburden removal systems.

Within the scope of the thesis, an expert system has been planned to develop to cover the aspects that would help resolve the geometrical constraints of individual stripping methods, estimate the production capability of specific draglines and determine the cost of stripping.

The ultimate goal of the expert system is to select a specific dragline or a combination employed in a particular stripping technique that satisfies both geometrical and production constraints optimally at the least cost. Achievement of this aim, however, requires an elaborate analysis of the situation from as many points as possible to fine tune the selection process. Actually, as a rule, the more knowledge embedded into the expert system results in the more accurate end product and the less probability for failing the cases analyzed by the expert system (Waterman, 1986; Wolfgram, et. al, 1987; Patterson, 1990).

The selection aspects of the pit geometry, stripping production and stripping cost have been coded into rules and heuristic procedures and embedded into

knowledge bases in the expert system. The architectural structure of the expert system developed in this study is shown in Figure 3.1.

The knowledge bases each of which has been provided with specific knowledge are gathered in layers in a descending fashion where in each layer is placed a criterion to select draglines. The uppermost layer houses the geometrical selection criteria set by the stripping techniques. By incorporating pit geometry analyses into the expert system, draglines that have failed to satisfy geometrical needs have been eliminated from further consideration.

The production simulation measures are placed on the intermediate layer. The main aim is to estimate whether a dragline could complete its allocated portion of stripping within a predetermined period of time. As mentioned above, one of the purposes of this layer is to exclude those draglines that can not accomplish the necessary stripping from further interest as it would be a nonsense attempt to determine the stripping cost of a dragline that does not match the overburden removal demand.

In the lowest layer are captured the criteria related with the monetary charge of dragline stripping. The main purpose of this layer is to determine the cost of removing one cubic meter of waste in addition to rank the successful draglines on the basis of stripping cost. A hierarchical view of the knowledge bases embedded into the expert system is presented in Figure 3.2.

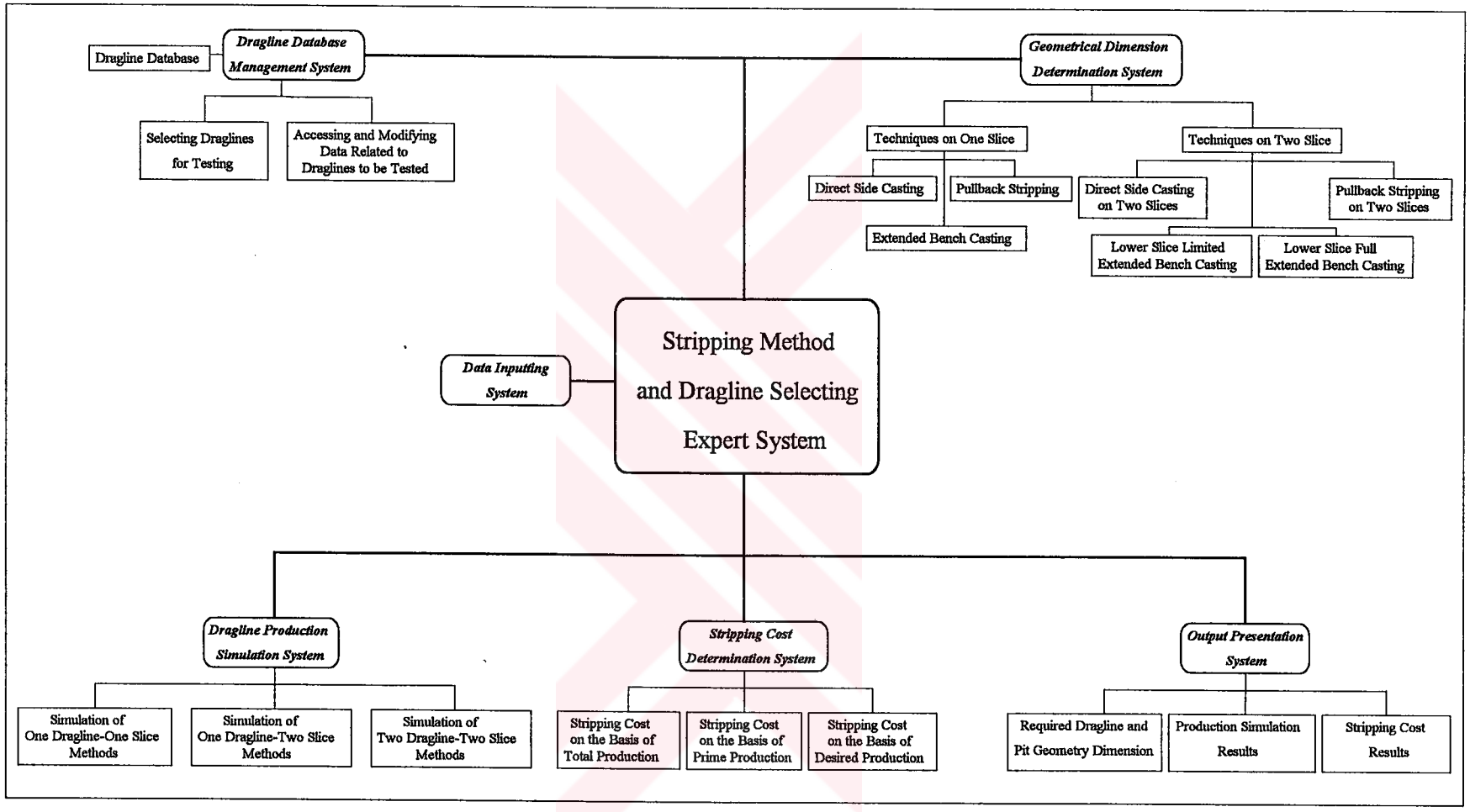


Figure 3.1. The Architectural Structure of the Expert System

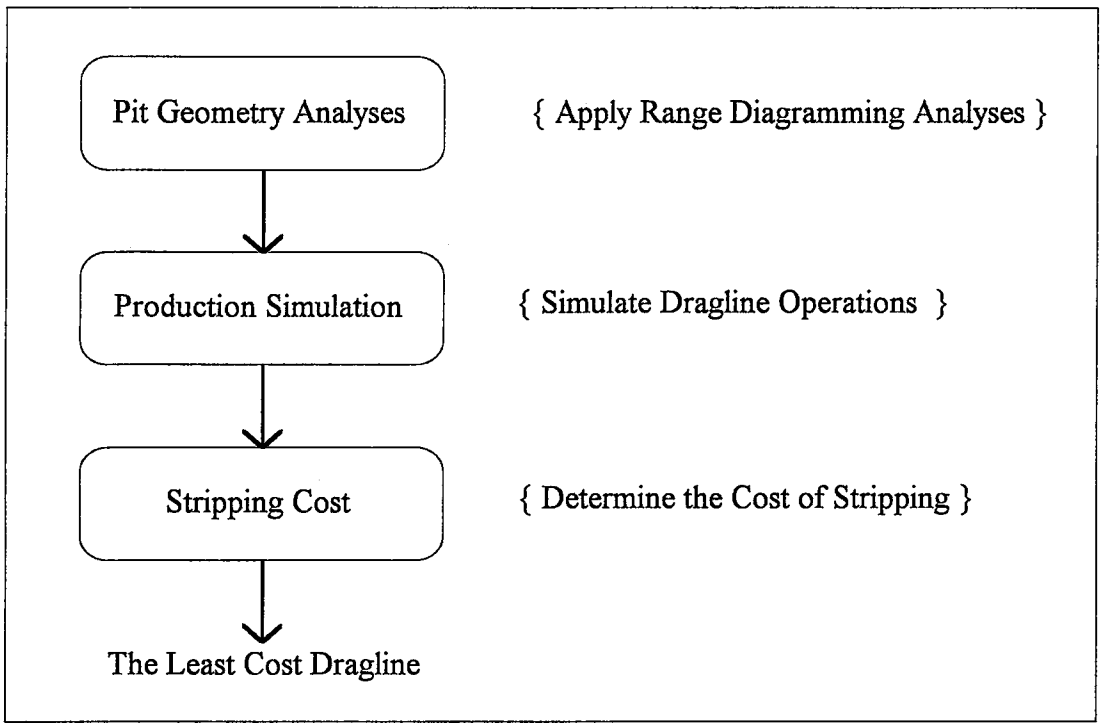


Figure 3.2. The Hierarchy of Knowledge Bases in the Expert System

Description of various design aspects and the dragline selection methodology, the problem representation strategy, the search strategy and the problem solving strategy of the expert system are given in the following sections. The description of the facility aspects in the expert system is followed by detailed explanations of each design aspect namely, the pit geometry, production simulation and stripping cost.

3.2. Aspects Covered by the Expert System

The domain of the developed expert system is composed of a collection of perspectives that help resolve the complicated dragline selection phenomenon. Each perspective has further been separated into particular sections to operate on the problem of fitting a proper solution.

3.2.1. Pit Geometry Aspect

One perspective is the pit geometry studies of which the main aim has been defined as to find an appropriate stripping method-dragline pair in which the dragline would meet geometrical constraints set by that particular technique. For this purpose, a number of stripping techniques have been selected which are applicable in cases where the coal seams are level. They are listed below;

- Direct side casting (one dragline)
- Extended bench casting (one dragline)
- Pullback stripping (one or two draglines)
- Two slice direct side casting (one or two draglines)
- Lower slice extended bench methods (one or two draglines)
  - Limited extended bench
  - Full extended bench
- Two slice pullback stripping (one or two draglines)

The reason to associate above techniques into the expert system is to cover a great portion of dragline stripping methods applied in surface mines where the first three methods have been applied for one slice operations while the remaining four for two slice operations respectively.

Fundamental geometrical characteristics of each stripping technique have been modeled by translating them into formulations and embedding into knowledge bases. By this way it has been made possible to develop geometrical decision rules by which the dimensions of a specific dragline and those of the pit could be matched. A list of critical geometrical parameters that have to be met by dragline operating parameters in order to be further considered by the following aspects embedded into the expert system are given below and illustrated in Figure 3.3 through 3.6. Geometrical parameters that are common to all or some methods, such as required digging depth, dumping height and operating radius are given once. Complete illustrations related to geometrical parameters are given in Appendix B.

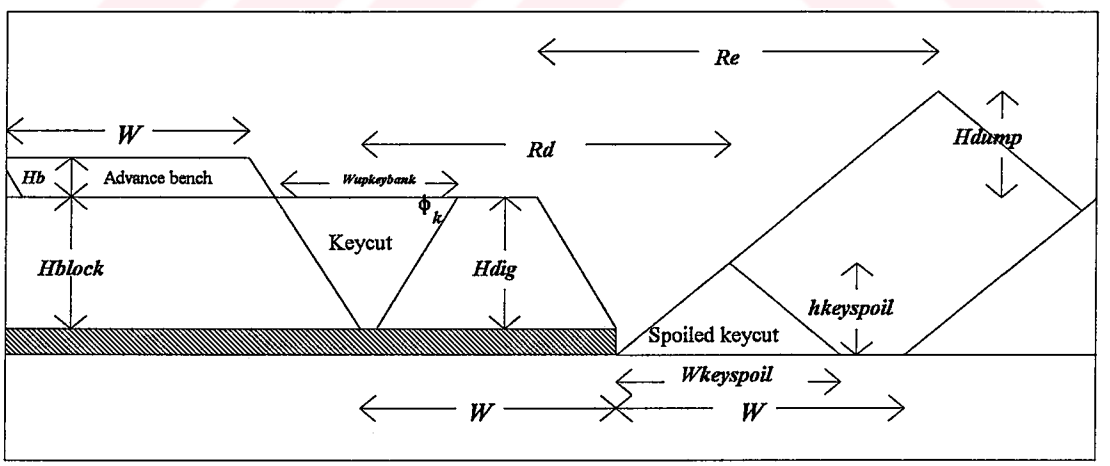


Figure 3.3. Dimensions that Have to be Satisfied by Draglines in Direct Side Casting Geometry Model

- Advance Bench Dimensions (H_b, W)
- In Place Key Cut Dimensions (upper and lower slices in case of two benches)
    1. Area
    2. Upper Mouth Width ($W_{upkeybank}$)
    3. Right Keywall Angle (Φ_k)
    4. Lower Mouth Width (in Extended Bench Casting, W_{buc})
- Spoiled Key Cut Dimensions
    1. Area
    2. Height ($h_{keyspoil}$)
    3. Width ($W_{keyspoil}$)
- Pit Width (W)
- Required Operating Radius to Spoil the Keycut Waste Clear of the Coal Seam (for upper and lower slices in case of two benches, R_d)
- Required Effective Reach to Spoil the Maincut Waste Clear of the Coal Seam (for upper and lower slices in case of two benches, R_e)
- Required Digging Depth (for upper and lower slices in case of two benches, H_{dig})
- Required Dumping Height (for upper and lower slices in case of two benches, H_{dump})

- Extended Bench Dimensions
    1. Area of Material to Construct the Extended Bench (A_{ext})
    2. Width of the Extended Bench (W_{eb})
    3. Sources of Material to Build the Extended Bench (keycut or advance bench or both)
- Area of Material to Be Rehandled (A_{reh})
- Percent Rehandle

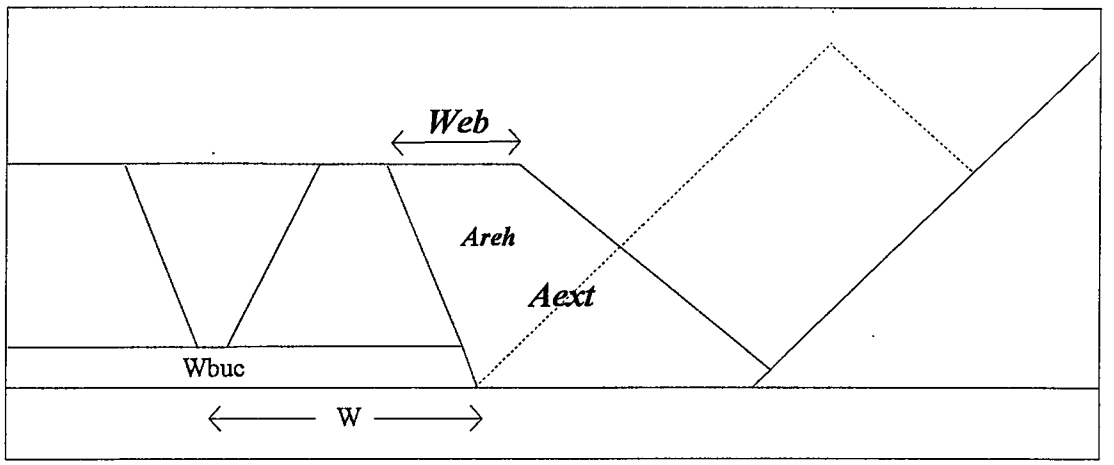


Figure 3.4. Dimensions that Have to be Satisfied by Draglines in Extended Bench Casting Geometry Model

- Dimensions of the Barrier Left on Highwall Side (in Pullback Stripping)
    1. The Height the Dumped Spoil Rises on the Highwall (h_1)
    2. Area of the Barrier ($A_{barrier}$)
- The Height of Spoiled Highwall Side Material in the Empty Pit (h_{sp})
- Pullback Pad Dimensions
    1. Height of the Pullback Pad (h_{pp})
    2. Width of the Pullback Pad (W_{pp})
    3. Area of Material to be Rehandled in the Pullback Pad (A_{reh})
- Dimensions of the Spoil Pile Formed by Rehandle and Barrier Waste on Spoils Side
    1. Height of the Spoil Pile (h_{upsp})
    2. Base Width of the Spoil Pile (W_{upsp})
    3. Area of the Spoil Pile
- Required Effective Reach on Spoil Side (R_{es})
- Required Digging Depth on Spoil Side

- Required Dumping Height on Spoil Side

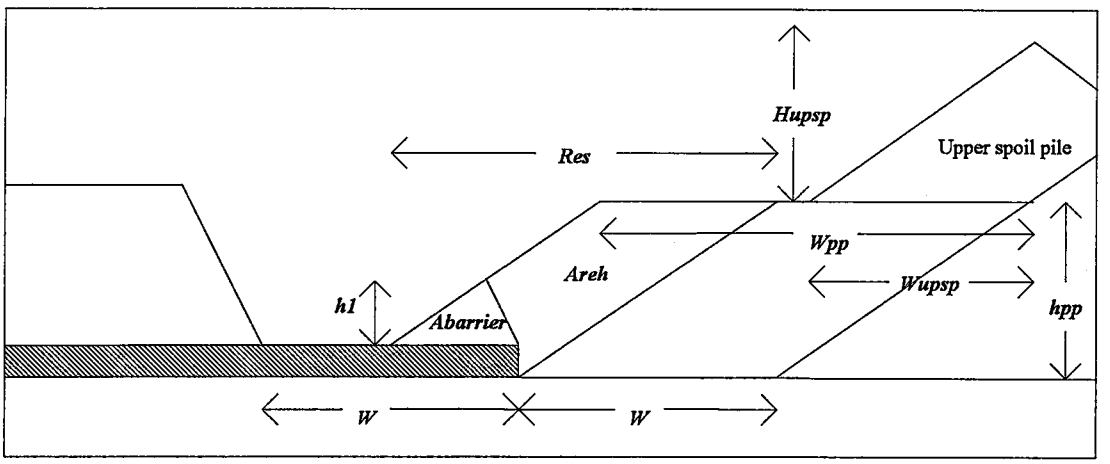


Figure 3.5. Dimensions that Have to be Satisfied by Draglines in One Slice Pullback Stripping Geometry Model

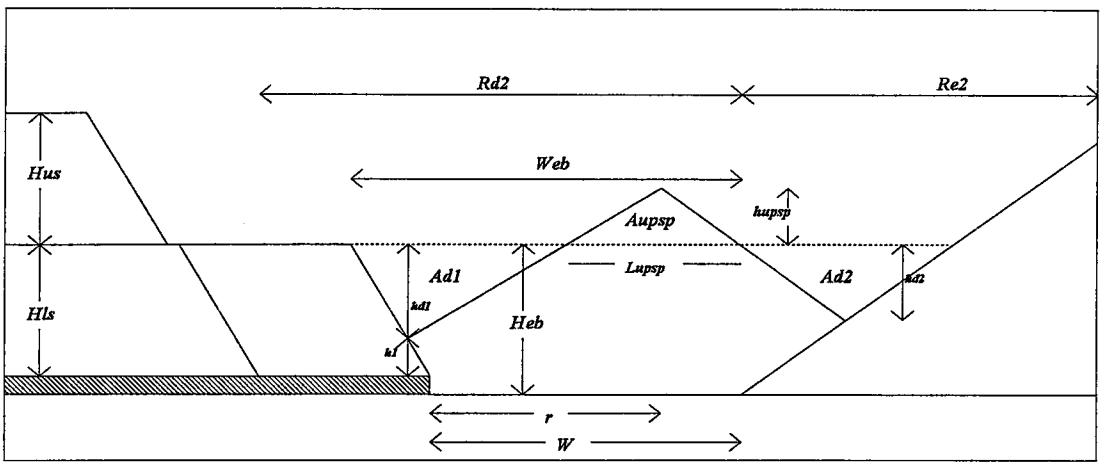


Figure 3.6. Dimensions that Have to be Satisfied by Draglines in Lower Slice Extended Bench Casting Geometry Models

- Effective Reach of the Dragline (r)
- Allocation of Overburden into Slices (H_{us}, H_{ls})
- Dimensions of the Voids on Each Side of the Temporary Spoil Pile
    1. Depth of the Voids (h_{d1}, h_{d2})
    2. Area of the Voids (A_1, A_{d2})
- Dimensions of the Upper Part of the Temporary Spoil Pile
    1. Height (h_{upsp})
    2. Width (W_{upsp})
    3. Area (A_{upsp})
- Width of the Extended Bench Near the Lower Slice (W_{eb})
- Height of the Extended Bench Near the Lower Slice (H_{eb})
- The Height the Toe of Dumped Spoil Rises on the Lower Slice (h_1)
- Required Operating Radius on the Lower Slice (R_{d2})
- Required Dumping Radius on the Lower Slice (R_{e2})

3.2.2. Production Simulation Aspect

The simulation of production capability of a particular dragline employed in a specific stripping technique has many advantages as follows;

1. Simulation helps forecast the amount of volume to be spoiled in a given period of time, thus evaluate a dragline on the basis of capability for required production. Besides, prime rate of stripping can well be determined by simulation since not all the effort a dragline has spent for overburden removal is resulted in right placement of the dirt to its final location. Obviously, some material will eventually have to be handled twice because of extending benches or constructing spoil side pullback pads. For this reason, even if the dragline can meet the production requirement in terms of total volume, this may be a misleading point if rehandling is experienced in some way. By simulating stripping operations, an estimation can be done related to how long it takes to reach the prime stripping volume.

2. Simulation helps design sequencing of stripping operation. As it is a well-known fact, overburden removal encompasses a wide range of primary and secondary procedures such as topsoil removal, drilling and blasting, bench preparation and stripping of waste layers each of which has a remarkable share in the overall stripping operations. The performance of each item is highly dependent on that of the one performed prior to it as overburden removal consists of a series of sub operations where each one is performed after one other. Since dragline stripping has to be continued uninterruptedly, operations performed prior to it must be advancing at least equal or preferably at a faster rate not to delay it. This requires an establishment of balance between operations and in turn this

can be achieved by estimating the likely linear advance rate of a dragline. Simulating stripping operations can well serve this aim.

3. Another point of concern is the synchronization of tandem dragline systems where two draglines are allowed to strip overburden layers. Here, one of the equipments is called the independent dragline and the other as dependent dragline (Anonymous, 1977b). The independent dragline is the one that sets the pace of the system. It is employed on the upper slice where both of them work on highwall side and employed on highwall side where each dragline is assigned a side of the pit. In other words the independent dragline is the one that has no obstruction against stripping. It can strip as fast as it can. However the linear advance of the dependent dragline is always determined by the independent one. Because its portion of stripping could only be freed after the burden lying on it has been spoiled. In such cases there is always possibility of poor matching due principally to improper allocation of overburden slices between draglines and improper sizing of draglines. In the case of poor matching two situations are likely to arise; in the first one the dependent dragline advances at a faster rate than the independent dragline. Here the dependent dragline will have to be delayed frequently to allow for the independent dragline to uncover the portion that the dependent dragline will excavate. In the second case the independent dragline advances at a faster rate than the dependent dragline. Here, there exists no problem related with delaying the dependent dragline. However, independent dragline will strip as more waste as it can and eventually advance at a comparably higher rate than the dependent dragline. The problem that arises is the following; in tandem dragline systems is the dependent dragline that uncovers the coal seam. In other words, it sets the coal production rate. The higher its pace the higher the coal production rate. In case of poor sizing

draglines, there always exists the danger of missing the required coal production target. By simulating tandem dragline systems, occurrence of such problems can be estimated prior to commencing stripping of overburden layers or even selecting draglines.

4. One other point that stripping simulation clarifies is whether demanded coal production could be met. This point gains particular importance in techniques where one dragline is employed on both benches or on both sides of the pit. Because of their nature of excavation, techniques employed on two benches do not allow immediate exposing of coal seam when one dragline is employed to dig both slices. Here, a dragline firstly excavates the upper slice and then the lower slice. Consequently, coal seam remains buried even after a full block length of upper slice is removed. Only after the removal of the lower slice can the coal seam be exposed and extracted. A dragline very rarely makes frequent sojourns between sides or benches but instead it takes a full or semi length of the block from a bench as walking the dragline is a time-consuming and costly operation especially when it is walked between benches. This reveals the fact that a dragline can well spend all its time only digging the upper slice for a given period of time and its performance in this operation is wasted because it can not expose even a square centimeter of coal. A similar situation arises in the pullback stripping with one dragline. In this case, part of the coal seam under the highwall barrier remains unextracted until the dragline moves to the spoil side and pulls the barrier back on the pad. In this situation again, the dragline has to excavate along the full length of the pit twice to completely uncover the coal seam. Simulation of techniques mentioned above can help to correctly set the stripping requirements with a particular dragline or precisely calculate the yearly coal production rate.

5. It is possible to estimate the distance a dragline travels and the time spent for walking by simulation. Walking is an unproductive item. The loss in productivity due to spending time for walking can be calculated by simulating the walking pattern of draglines.

6. It is also possible to estimate the delays occurring during operations. Besides planned pausing mostly because of yearly, monthly, weekly maintenance and holidays, numerous sources of unplanned delays do occur. These include electric shortages, unexpected break downs, strikes, etc. Like walking, delays are unproductive items that have to be taken into consideration too. The loss in productivity due to wasting time for delays can be calculated by simulating possible causes of delays.

7. A significant item in dragline stripping is the closeness to the actual coal production demand. The main aim of the management must be to optimize the stripping production so that only that amount of stripping have to be performed which is required to uncover the coal seam. In other words, the capacity of the dragline must closely meet the yearly stripping requirements plus some percentage of it for safety. In this concern, draglines having a much greater capacity than is required would eventually be stripping much more than demanded or be delayed frequently to slow down and meet stripping requirements. The shortcomings of such a situation is twofold: firstly the owning cost of the dragline would be higher than needed thus the management would suffer financially. Secondly, operating costs would be higher because more coal would be exposed than that to be sold. By simulating the stripping performance of several draglines, a more realistic selection among them can be done by comparing their suitability to meet demanded coal production.

As described in the preceding sections, working principles of most of the stripping techniques have been organized with one or two draglines. Although employment of one or tandem dragline systems has no impact on geometrical side when the required pit parameters are concerned, it does have on simulation side. For this reason, stripping techniques with one or tandem dragline systems have been modeled twice to cover both one and tandem dragline employment. The simulation models are listed below;

- Direct side casting simulation
- Extended bench casting simulation
- Pullback stripping simulation
    1. one dragline
    2. two draglines
- Two Slice direct side casting simulation
    1. one dragline
    2. two draglines
- Lower slice extended bench simulation
    1. one dragline
    2. two draglines
- Two slice pullback stripping simulation
    1. one dragline
    2. two draglines

Dragline production simulation methodology has been analyzed in two ways; geometrical and operational. In the expert system, range diagramming and pit geometry methodology has been developed considering two dimensions across the pit. However simulation geometry studies have taken a third dimension into consideration, the one along the dragline block to formulate the walking pattern and volume of blocks to be removed. Besides, operational parameters have been formulated like the time spent to complete a certain task and the volume of material moved in a portion of the pit. The following geometrical and operational parameters have been formulized and embedded into the expert system and parameters related to simulation geometry are given below and illustrated in Figures 3.7 through 3.11. Common parameters such as block volumes and walking distances are given once. Complete illustrations related to geometrical parameters are given in Appendix D.

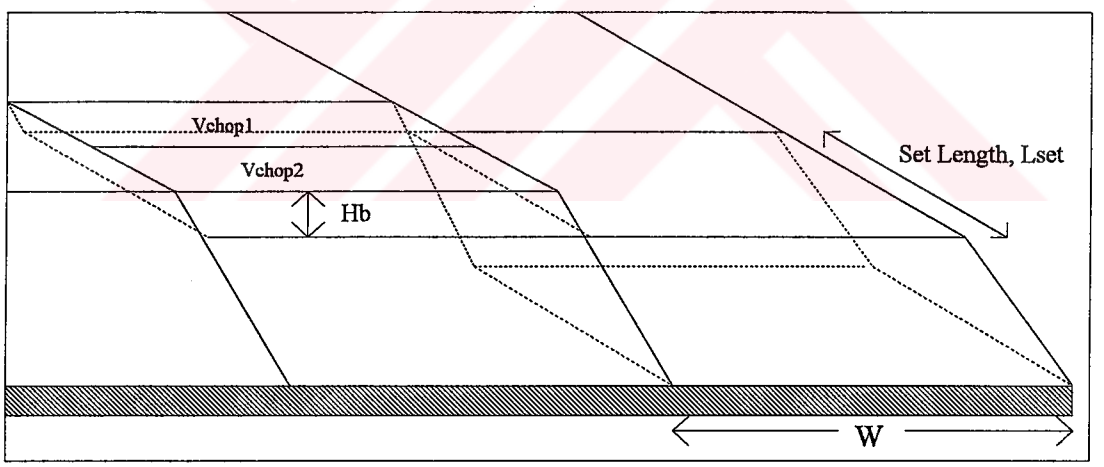


Figure 3.7. Volume of the Advance Bench Blocks

Geometrical Parameters

- Volume of Advance Bench Blocks (V_{chop1}, V_{chop2})
- Set Length on Highwall Side (L_{set})

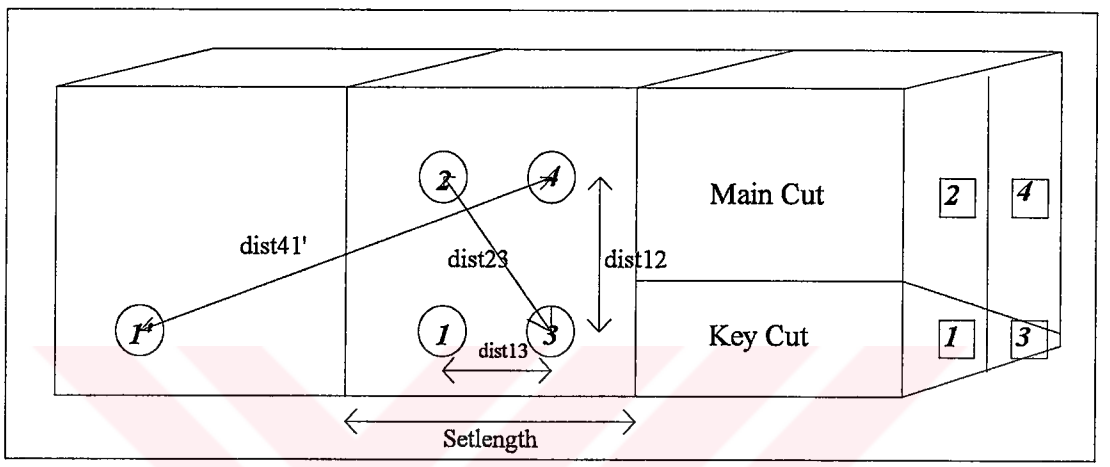


Figure 3.8. Walking Distances between Sitting Points on Highwall Side

- Distance Between Sitting Positions on Highwall Side ($dist_{12}$, $dist_{13}$, $dist_{41'}$)
- Volume of Keycut and Maincut Blocks (V_{keycut}, $V_{maincut}$)
- Volume of Extended Bench (V_{reh})

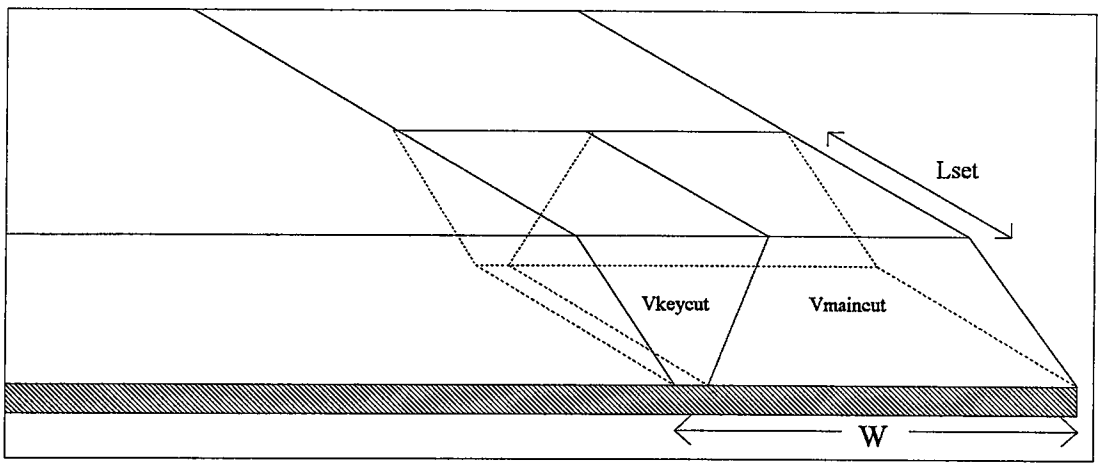


Figure 3.9. Volume of Keycut and Maincut Blocks

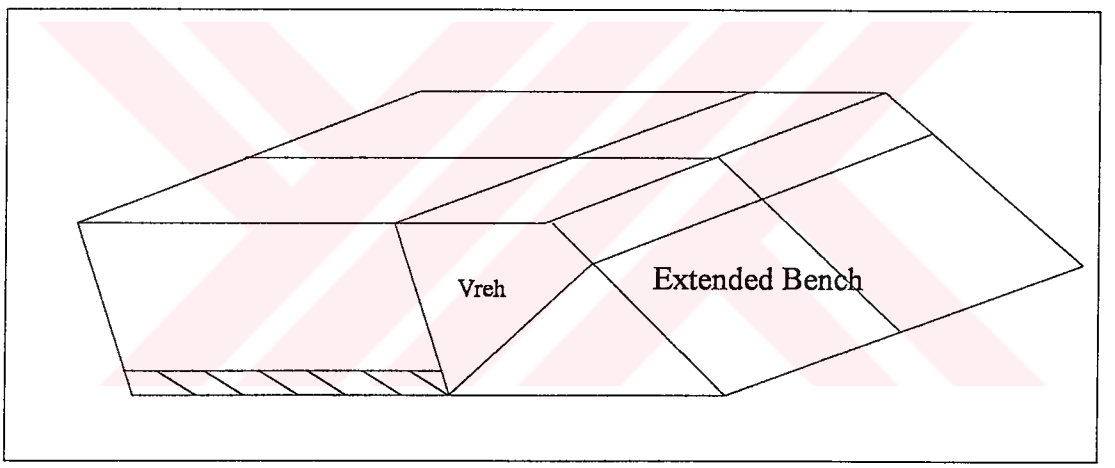


Figure 3.10. Volume of Block in the Extended Bench

- Set Length on Spoil Side (Only for models stripping from spoil side)
- Volume of Part to be Rehandled (Pullback pad)
- Volume of Highwall Barrier (Pullback stripping)

- Distance Between Sitting Positions on Spoil Side (Only for models stripping from spoil side)
- Deadheading Distance Between Highwall and Spoil Sides or *vice versa* (Only for models stripping from spoil side)
- Walking Distance Between Upper and Lower Slices or *vice versa* (Only for two-slice models stripping from highwall side)

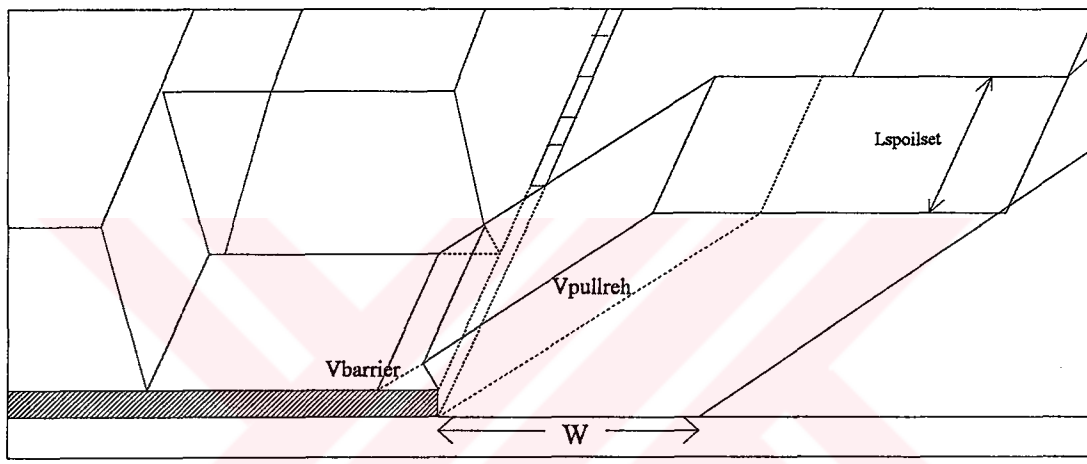


Figure 3.11. Spoil Side Parameters in the Simulation Geometry

Operational Parameters

- Time to Remove a Certain Block of Overburden (Chopping, Keycut, Maincut, Rehandling)
- Time to Walk Between Two Sitting Points
- Time to Walk Between Highwall and Spoil Side or *vice versa* for Pullback Models

- Time to Walk Between Upper and Lower Slices or *vice versa* for Highwall Side Two Slice Models
- Time for Unexpected Delays
- Total Time Spent for Excavation
- Total Time Spent for Walking
- Total Time Spent for Unexpected Delays
- Total Time Spent for Waiting for the Primary Dragline (Two Dragline Models)
- Volume of Total Overburden Removed in a Given Period of Time (Including Rehandle)
- Volume of Prime Overburden Removed in a Given Period of Time (Excluding Rehandle)
- Volumetric Share of Prime Overburden of Each Dragline in the Desired Stripping (Two Dragline Models)
- Total Distance Walked in a Given Period of Time
- Total Distance Walked Along Pit Advance Direction in a Given Period of Time
- Average Cycle Time for Chopping Operation Over a Given Period of Time
- Average Cycle Time for Pullback Operation Over a Given Period of Time
- Average Cycle Time for Other Type of Stripping Operations Over a Given Period of Time

3.2.3. Stripping Cost Aspect

Within the scope of the expert system, it has been planned to include cost of stripping with draglines. The objectives of including stripping cost into the expert system are listed below;

1. By determining the stripping cost where draglines are primary means of overburden removal, a comparison can be made between it and alternative systems on the basis of stripping economy. Although dragline stripping, as a rule of thumb, is more economical than its alternatives, existence of diverse factors like ever increasing rates of rehandle may easily make it a non preferable selection.

2. There exist several overburden removal techniques applicable with draglines. For a given set of data describing the characteristics of a surface mine, more than one method can be found appropriate. Only the projected cost of each potentially applicable technique can reveal the most proper one among them. Also, there may exist numerous draglines each of which can be employed in a specific technique and the only way to select the most suitable dragline is to rank them on the basis of stripping cost.

3. Equally important is the determination of the cost in terms of desired stripping. This method is a good way of computing the actual charge of digging overburden layers. A dragline is a type of equipment that performs excavation and spoiling phases in one cycle while most alternative large-scale systems employ two distinct operations for earth-moving. However, the benefit of two-in-one cycling is blurred with inclusion of rehandling into stripping scheme. In such a situation, part of already spoiled waste must be handled again to completely uncover the coal seam. In desired stripping cost calculations however, only that volume required strictly to uncover the coal seam has to be considered whatever the total volume is. This exposes the existence of three different stripping costs. The first is the total cost of earth moving where the total volume is taken into account in estimating the cost of stripping. The

second is the prime cost of overburden removal where the volume of the material covering the coal seam is taken into consideration. The last one, however, is interested in the quantity that must be spoiled to uncover coal seams. This is the pure quantity that does not include rehandling of any form as rehandling is caused by the very nature of the method applied. Consequently, a particular stripping method may well seem to be cost-effective compared to other techniques or alternative overburden removal means when the total cost of overburden removal is considered. But it is the cost of stripping in terms of desired volume to be moved that completely resolves the cost-effectiveness of a dragline stripping method.

As in the stripping simulation case employment of one or tandem dragline systems has a significant impact on cost side. For this reason, cost modeling of dragline stripping systems capable to employ one or tandem draglines have been done twice. The parameters concluded by this methodology are listed below;

- Cost of Options and Extras
- Cost of Freight
- Cost of Trail Cable
- Cost of Ballast
- Cost of Erection
- Yearly Depreciation Cost
- Yearly Investment Cost
- Yearly Interest, Taxes and Insurance Cost
- Yearly Owning Cost

- Yearly Maintenance and Supply Cost
- Amount of Electricity Consumed to Remove a Cubic Meter of Waste
- Yearly Electricity Cost
- Yearly Operating Cost
- Yearly Owning and Operating (O&O) Cost
- Stripping Cost in Terms of Total Volume Moved (Including Rehandle)
- Stripping Cost in Terms of Prime Volume Moved (Excluding Rehandle)
- Stripping Cost in Terms of Desired Volume

3.3. The Dragline Selection Methodology

The expert system has been equipped with a hierarchical or top-down search strategy. According to the logic embedded into the system, each knowledge base is entered once and draglines are rated after executing rules within individual knowledge bases.

There exist two direction control mechanisms in the expert system; a broad control and a limited control. The broad control is responsible from the management of the driving mechanism of the expert system and the transfer of control between selection criteria. The data the system uses is arranged in such a way that the output of a knowledge base higher in the rank is taken as the input of another one lower in the hierarchy. By this way draglines are processed in a similar fashion that pebbles are screened in a sieve. This methodology prevents unnecessary processing of draglines that have failed in one of the above knowledge bases. The broad control methodology on dragline selection is viewed schematically in Figure 3.12.

The limited control on the other hand, provides a more detailed and purified selection in the geometry module. According to the logic developed for dragline selection in the geometrical aspect, stripping methods are executed from the simplest to the most difficult in hierarchical order. The objective behind this logic is to save a dragline from being repeatedly screened in successive stripping criteria as soon as it satisfies the requirements of a specific stripping technique. It has been accepted that increase in the number of slices, increase in the number of draglines and introduction of rehandling into stripping operations makes the stripping techniques complicated, thus difficult. So, simple methods have been assumed to be applied primarily on one slice and secondarily including no rehandling.

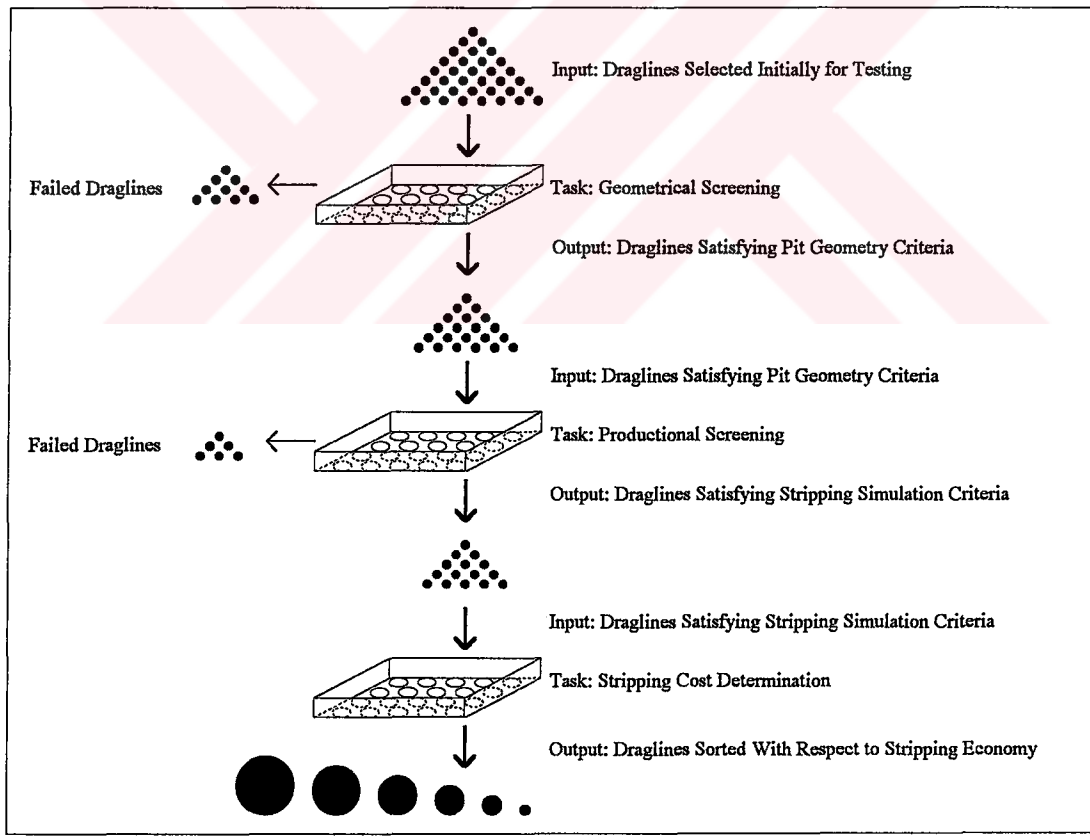


Figure 3.12. Dragline Selection Methodology of the Expert System

Among the methods applied on one slice, direct side casting is taken as the simplest method because it includes no rehandling and it is a straightforward process. Following this method, the extended bench technique has been favored over the pullback stripping because of the relatively complexity of the latter one in its pit configuration. Besides, frequent deadheading of the dragline between either side of the pit makes this method unfavorable against the extended bench casting where all stripping operations can be performed with the dragline sitting on one side of the pit. One other disadvantage of pullback stripping comes from the pit coal inventory. While in the extended bench method, with every set, the dragline is always uncovering a width of pit that can then have its coal removed. However, the pullback method is not always uncovering coal because the dragline must excavate down the highwall side first then excavate on the spoil side before a full pit width of coal is uncovered. Only after mining a spoil side set is the coal fully uncovered. So if a pullback method is used in a mine, the mine must be designed to allow an adequate inventory of uncovered coal in other parts of the pit, so that coal production remains uninterrupted while the dragline in uncovering the next block length (Erickson, 1995d).

The geometrical selection methodology continues with techniques applied on two benches. The simplest among them has been defined as the direct side casting on two slices technique as it involves no rehandling. Then follows this two similar methods that include rehandling; the limited and full extended bench casting methods on two slice. The limited bench has been favored over the full bench because in the former the bench extension is "limited" as its name implies while in the latter the dragline working on the bench can freely move between spoil and highwall sides thus requiring more percentage of rehandling. The most complicated technique has been taken as the pullback stripping method on two slices. Because this technique incorporates all the inconvenient aspects mentioned above. It is applied on two

benches, includes rehandling and frequent long walks between sides of the pit each of which is an efficiency-reducing item. The simplicity ranking assumption of the stripping techniques is given in Figure 3.13.

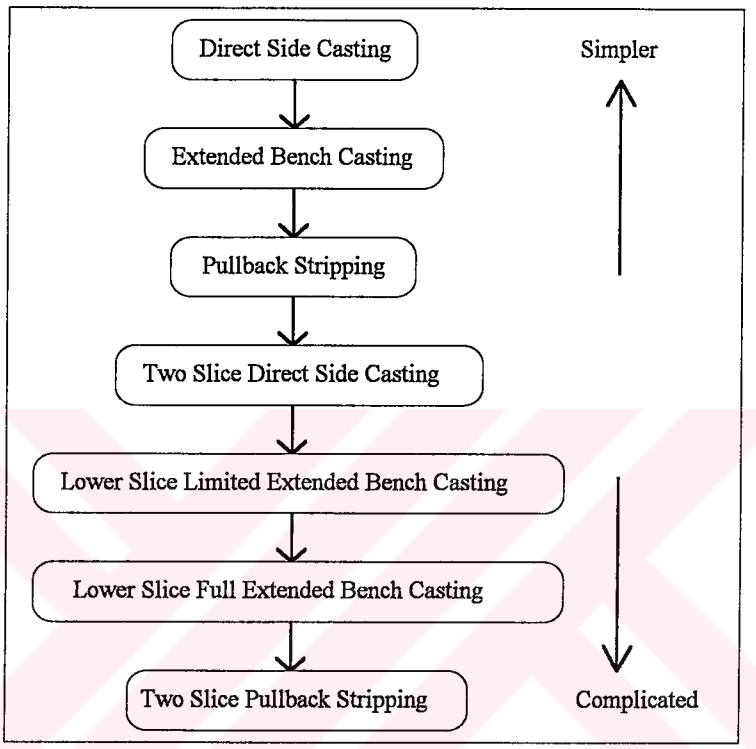


Figure 3.13. Simplicity Ranking Among Stripping Techniques

The limited control also accounts for the testing of draglines within particular stripping techniques. According to the methodology developed, all the draglines picked for testing with the expert system are allowed for evaluation in the direct side casting technique. Draglines meeting the geometrical requirements set by this method are selected as satisfactory ones. Failing draglines are input into extended bench casting and pullback casting methods for geometrical evaluation. After this

step, all the draglines are entered into two slice methods regardless of their performance in previous one slice techniques. The reason for this move comes from the fact that in two-bench operations, a dragline is not assigned the full thickness for stripping. Since the height of benches is cut down considerably, a dragline that failed to meet geometrical needs of a particular stripping technique that is applied in a full-height overburden may become a working solution when it is allowed to remove only a portion of it. The dragline selection methodology is presented in Figure 3.14.

3.4. The Problem Representation Strategy of the Expert System

The problem of dragline selection has been thought of containing numerous decisive areas each of which covers several subsequent parameters that help resolve the complex dragline selection problem.

For this purpose, the problem reduction representation methodology has been used (Rich, 1983; Wolfgram et.al, 1987). Problem reduction representation starts with a problem statement. From there the statement is broken apart into sub problems. Repeatedly, the sub problems are broken down until a solution is immediate, in other words, until no further subdivision is necessary. The concept is simple: reduce the problem down to workable sub problems. Problem reduction representation consists of:

1. The initial problem statement
2. A set of operators that transform the problem into a set of sub problems
3. Primitive problem statements that are solvable immediately (this is the lowest level of the problem)

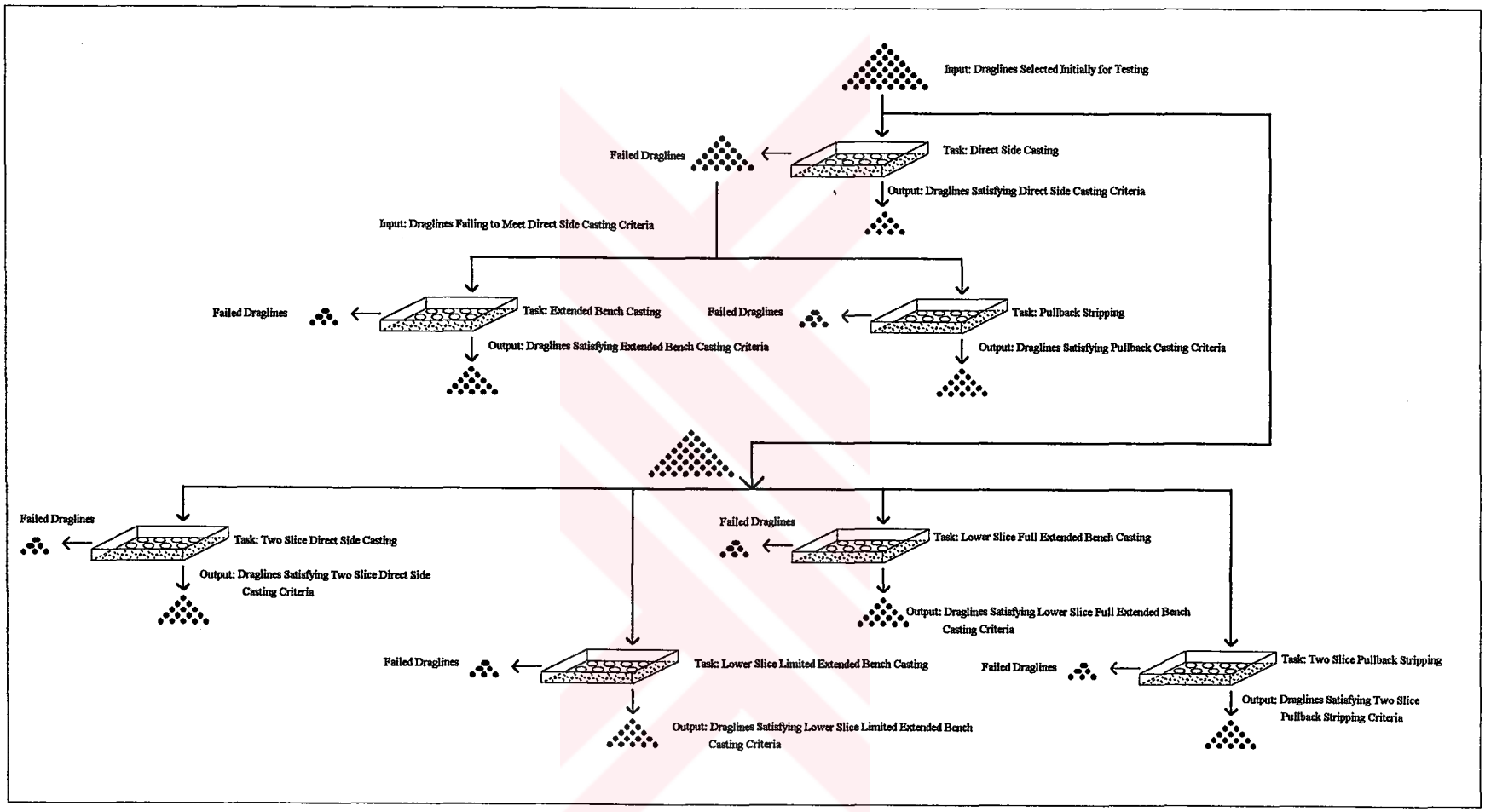


Figure 3.14. The Dragline Selection Mechanism Among Stripping Techniques

The best illustrations of problem reduction representations are AND/OR graphs with some additional definitions:

1. Primitive problem statements are considered terminal nodes.
2. Each node is a set or single problem statement.
3. A node with several branches and a connecting arc between the branches is an AND branch, and all nodes must be solvable. An AND node is a node which is attached to an AND branch.
4. A node with several branches and no connecting arc between each branch is an OR branch (where the problem is solved by any branch node). An OR node is a node which is attached to an OR branch.

The dragline selection problem has been divided into three main sub problems; pit geometry studies, production simulation studies and finally stripping cost studies, all of which are connected with an AND arc and must be solved for the final solution. These sub problems have further been separated into respective areas as mentioned above to get primitive problem statements solvable by the system. The dragline selection problem representation is viewed in Figure 3.15.

3.5. The Search Strategy of the Expert System

The search strategy of the dragline selection expert system is based on forward chaining. The forward chaining works in the following way: the application of operators in a data-driven search starts with the initial given conditions and searches forward through the knowledge base towards a solution (Wolfgram et.al, 1987). The system begins with a fact and proceeds to search for a rule whose premise

is verified by that fact. The conclusion is then added to working memory in pursuit of the solution. The forward chaining is also known as bottom-up processing or antecedent reasoning. For example, deciding which computer hardware configuration to purchase for home use is an example of forward reasoning technique. Here, a salesperson will start at the beginning and ask a series of questions to determine the level of utilization for each software package. Based on these responses, he will then recommend a computer configuration best suited to customer's needs.

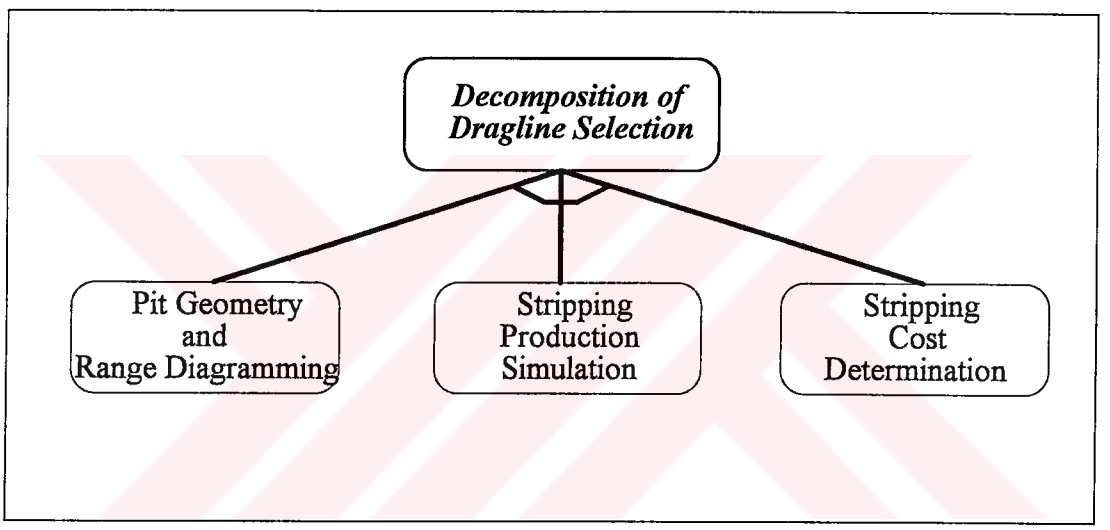


Figure 3.15. The Broad Problem Representation of the Expert System

A very good example of expert systems developed under forward chaining methodology is the XCON expert system (e*X*pert *CON*figurer) (Wolfgram et.al, 1987). XCON configures VAX and PDP-11 computer systems. It is a forward-chaining rule-based system, developed in OPS5, embodying over 12000 rules (Patterson, 1990). XCON does not employ certainty factors and/or probabilities. Components under consideration are either included or excluded. The procedure

begins by requiring the user to input a customer's order. Considering more than 400 components, XCON then builds a customized configuration. The system first checks for gross errors and unbundles the order to a configuration level recognized by the other sub tasks. It begins by adding the primary components to the central processing unit (CPU). Next, the rest of the peripheral components are added to the CPU cabinet and configured. Finally, a floor room layout is made for cabling connections. These diagrams display the spatial relationship among the components in the customer's order which are used in assembling the system.

The dragline selection expert system works in a similar way as XCON does. The system requires inputs from the user and draglines under consideration are either continued to process or excluded from further analysis with the system.

3.6. The Problem Solving Strategy of the Expert System

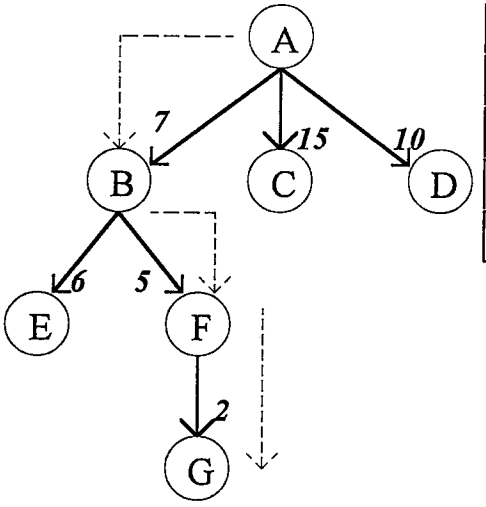
Having described the problem in a representation model, an appropriate problem solving strategy is embedded into the expert system. Among problem solving strategies, searching is by far the most widely used one (Rich, 1983; Wolfgram et.al, 1987). Searching involves choosing a path through the knowledge base to find a solution. The method of solving is to test alternatives until a solution is found. The goal in problem solving is to find the best search technique which locates a solution path efficiently and effectively by limiting the number of data items or solution paths examined.

The problem solving strategy of the expert system is the hill climbing method. Hill climbing is a heuristic technique and is referred to a "strong" search.

Heuristic searches involve the analysis of domain-specific information which is not built into the state-specific or operator definitions and can often reduce the size of the state-space for searching.

Hill climbing is similar to the blind search of depth-first, but the path selection is not arbitrarily sequential; it is based on an estimate of the closeness to the goal. If a particular search were unsuccessful, a path that was declined earlier would be reevaluated using additional rules to determine a goal's proximity before trying a new path not applied to determine the distance from goal (Wolfgram et.al, 1987). An example to this methodology is presented in Figure 3.16.

The pit geometry criteria is based on hill climbing. As mentioned previously in section 3.3., The Dragline Selection Methodology, the distance to goal is expressed with the relative simplicity of the stripping techniques. According to this methodology, the simpler the stripping technique the more closer is the dragline to the goal. In other words, draglines satisfy the goal of being a potential candidate for a mine as far as they meet the requirements of a relatively simple technique.



Step	Choices	Selection
1	(A)	A
2	(BCD)	B
3	(EF)	F
4	(G)	G

Figure 3.16. Hill-Climbing Search. The Number is the Distance to the Goal (After Wolfgram et.al, 1987)

3.7. Facility Aspects Covered by the Expert System

Several facility modules have been provided with the expert system. These modules can be grouped under data entrance, dragline database management and outputting headings. They are explained below.

3.7.1. Data Inputting

The expert system requires a minimal size of data to run, controversial to other developed dragline selection methodologies (Bandopadhyay and Ramani, 1979; Hrebar and Dağdelen, 1979; Gibson and Mooney, 1982; Sadri and Lee, 1982; Bandopadhyay and Sundararajan, 1986; Artan, 1990). Some of the input data demanded by the other models like pit width and set length have significant effect on

dragline productivity. It has been believed that it is the developed methodology that must provide the expertise in optimizing the value of the pit variables, not the user. For this reason the expert system has been designed in a way to extract the data it needs from those already known by developing methodologies.

The data the expert system requires can be divided into three main categories; data related to pit geometry, data related to required production and those related to stripping cost. These are given below:

Data Related to Pit Geometry

1. Average overburden thickness, m
2. Average coal seam thickness, m
3. Highwall angle, degrees
4. Coal seam angle, degrees
5. Spoil pile angle, degrees
6. Swell factor, %
7. Width of safety berm, m

Data Related to Production Simulation

8. Yearly coal demand, tons
9. Density of waste, t/m^3
10. Density of coal, t/m^3
11. Length of dragline block, m

12. Yearly scheduled hours, h
13. Overall efficiency of overburden removal operations, .00
14. Fill factor for chopping operations, .00
15. Deviation in chopping fill factor, .00
16. Fill factor for non-chopping operations, .00
17. Deviation in non-chopping fill factor, .00

Data Related to Stripping Cost

18. Estimated life of the dragline, yr
19. Interest, taxes and insurance (ITI) percentage, %
20. Cost of electricity, US$/KWh
21. Yearly labor cost, US$

To feed the expert system with the required data, a data inputting module has been developed. The module, as others, runs under the expert system shell and the user-defined input data is written into an ASCII type text file to be later processed by the following programs. Figure 3.17 shows a part of the inputting operation.

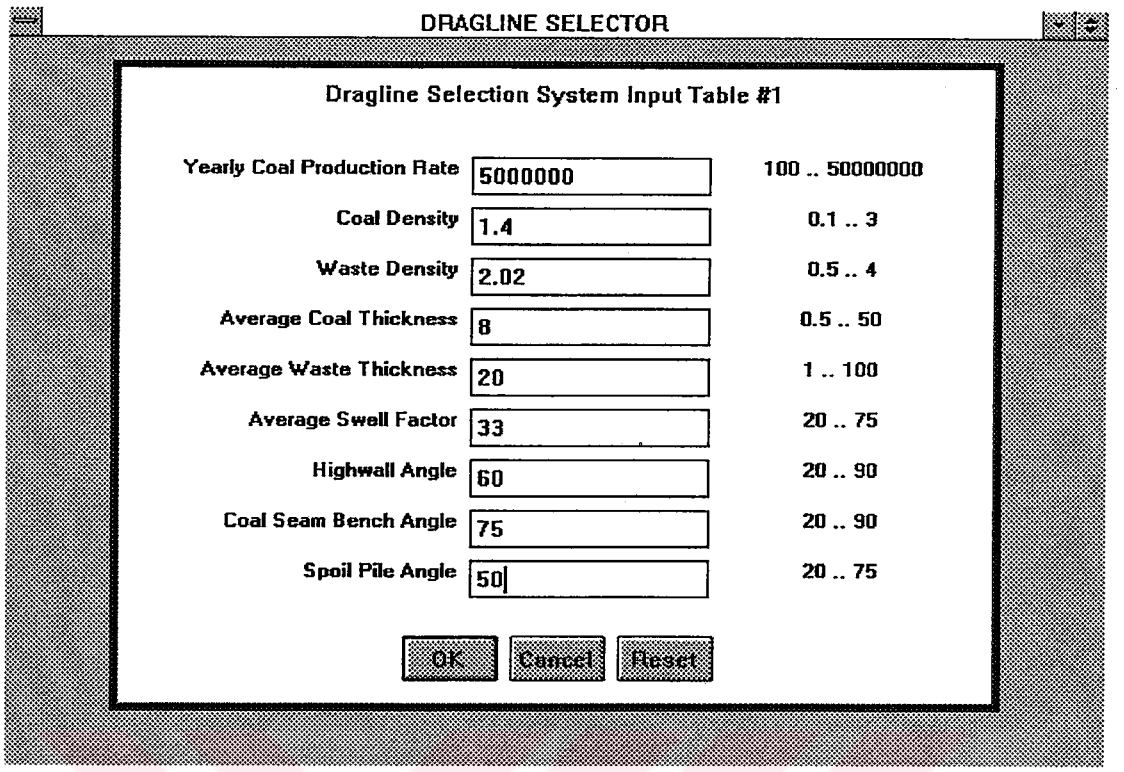


Figure 3.17. Data Inputting within the Expert System

3.7.2. Dragline Database Management

A database is very helpful in organizing the information related to similar type of objects into records. For the developed expert system, a database that contains information related to physical working dimensions of draglines is important from two aspects. The first is that there must be a compilation of draglines among which the user could select some or all of them for testing for a specific set of input data about a mine. The second aspect is related with comparison purposes that after performing pit geometry computations, the expert system matches the required dragline dimensions to those available. To be able to do this, a database has to be built of the necessary dragline working dimensions.

There has been developed a database consisting of dragline working dimensions and two dragline management modules each of which is used for a specific purpose. They are explained below.

Dragline Database

For the purpose of collecting necessary data, dragline manufacturing companies have been investigated. However, like other sectors of the mining industry, dragline manufacturing has been subject to consolidation over the past decade and on an international basis, large draglines are now available from three principal suppliers, the Marion of Indresco, Inc., Bucyrus-Erie Company and P&H-Page Company, all American (Walker, 1993). For this reason, data related to draglines manufactured by these companies have been extracted and coded into computer files (Anonymous, 1981b; Anonymous, 1981c; Anonymous, 1981d). The dragline database contains data related to some 245 draglines. The working dimensions of draglines embedded into the database are as follows and given in Appendix A.

1. Brand
2. Model
3. Working Weight, kg
4. Boom Length, m
5. Boom Angle, degrees
6. Operating Radius, m
7. Dumping Height, m
8. Digging Depth, m

9. Tub Radius, m
10. Sitting Area, m^2
11. Sitting Pressure, kPa
12. Maximum Allowable Load, kg
13. Clearance Radius, m
14. Clearance Height, m
15. Boom Foot Radius, m
16. Boom Foot Height, m
17. Distance Between Feet, m
18. Step Length, m
19. Walking Speed, m/h

The Module to Select Draglines For Testing

The stripping method and dragline selection expert system is based on evaluating the applicability of draglines for conditions specified by the input parameters and as many draglines as possible can be tested. This module has been developed to ease the preliminary dragline selection process for testing and is run before the geometry modules. It is a user-friendly and menu-driven program written in Borland PASCAL V.7.0. The directions on how to use the program and sample screen outputs are given in Appendix A.

The Module to Access, Modify and Save Data Related to Draglines

The data embedded into the dragline database has been extracted from manufacturer catalogs. The data in the catalogs about a particular dragline however, may not match that of a real model. For instance, the boom angle of a particular dragline may have been decreased to have a longer boom in which case the penalty would be a decrease in the carrying capacity. Since such cases are site-specific and can not be known in advance of manufacturing, the user is given the opportunity to overcome such inconvenient cases by accessing the data related to a particular dragline and modify and save it. Every time the expert system is executed, the saved dragline data files are used. The database management module is also a user-friendly and menu-driven program written in Borland PASCAL V.7.0. It has been equipped with controlling routines to prevent the entrance of out of range data. The directions on how to use the program and sample screen outputs are given in Appendix A.

3.7.3. Output Presentation

The pit geometry and production simulation modules produce large volume of output data. However, bare numbers do not help in visualization of the designed pit and the percentage time spent to accomplish a particular task. For this reason, the expert system has been furnished with the graphical outputs showing capability as well as text output capability.

Pit Geometry Outputting

The stripping method modules are capable to present the pit design in two forms. The first form is the text outputs where the designed pit dimensions are presented in text format. A hardcopy output of relevant dimensions can be retrieved on a printer. The second form is the graphical outputting. Every stripping method upon completion, can exhibit the geometrical design phases in a slide show format on the graphics screen. The graphical outputs have been designed for at least a VGA display adapter with 1024X768 pixel resolution with a color monitor. The number of slides vary between 4 and 8 according to the stripping method. At the same time, the geometrical pit design outputs can be taken from a plotter. The drawings are done true to scale with the scale indicated on the upper right corner of the plot. The hardcopy plotting of designed dragline pits are limited to Houston Instrument DMP-29 pen plotters.

Production Simulation Outputting

The production simulation modules are capable to present the outputs in two modes. The first form is the text outputs where the simulation outputs are presented in text format. A hardcopy output can be taken from a printer. The second form is the graphical outputting. The percentage time spent for each task like chopping, keycutting, walking, delaying and waiting are presented in a pie-chart form on the graphics screen. The graphical outputs have been designed for at least a VGA display adapter with 1024X768 pixel resolution with a color monitor.

3.8. Pit Geometry Studies

The methodologies to conclude the applicability of a particular dragline to be employed in a specific stripping technique have been developed by modeling the fundamental geometrical characteristics of each stripping technique into mathematical formulations. The developed formulations are used as decision rules to compare the required pit dimensions to dragline dimensions. The geometrical decision parameters related to stripping techniques are given in the following sections.

3.8.1. Direct Side Casting Technique

Direct side casting technique is a very commonly applied and well-known method with respect to other dragline stripping techniques. This stripping technique is preferred whenever the conditions permit its use (Anonymous, 1977a; Anonymous, 1993a). Among main characteristics of this method can be mentioned one dragline employment, stripping the overburden in one slice and stripping without rehandling.

3.8.1.1. Modeling Direct Side Casting Geometry

The basic operation sequence coded into the geometrical model varies with inclusion of chopping into the stripping scheme. In case no chopping is done, key and main cuts are excavated and spoiled. In case the dragline can not excavate to the required depth it has to chop the material in the advance bench and then excavate and spoil key and main cuts. Since this method does not allow rehandling, the dragline has to have required working dimensions to excavate and then spoil waste material to

where the final spoil pile is planned to locate thus avoid the burial of the coal seam under the toe of the final spoil pile.

3.8.1.2. Modeling Methodology When Chopping is Done

It has been reported that chopping is very useful in areas with uneven terrain or in overburdens with a top layer of unconsolidated material (Anonymous, 1977a; Anonymous, 1993a; Parlak, 1993; Govier, 1995). Although association of chopping has not been widely favored due to poor bucket filling, larger-than-normal swing angles that result in higher cycle times and severe impact loads on the bucket, a universal rule in chopping is that the dragline should not chop overburden above its fairleads (Anonymous, 1993a; Parlak, 1993; Erickson, 1995b; Govier, 1995).

Because the overburden is assumed level and free from undulations along the mining advance, chopping is associated in the expert system only to compensate the negative effect of shallow digging depth. In case the thickness of overburden is larger than the digging depth of a dragline, it is checked whether the height of the part to be chopped is smaller than the fairlead height. If it is so, then the dragline excavates the material in the lower bench conventionally while those in the advance bench are chopped. The logic for switching to chopping is illustrated in Figure 3.18.

The excavation sequence in the model when chopping must be done is as follows: the dragline excavates the material in the advance bench with chopping. Then dirt in the keycut is excavated and spoiled. The material from the main cut is placed onto previously cast chopping and keycut spoils. A series of views showing the phases when chopping is included in direct side casting model is given in Figure 3.19.

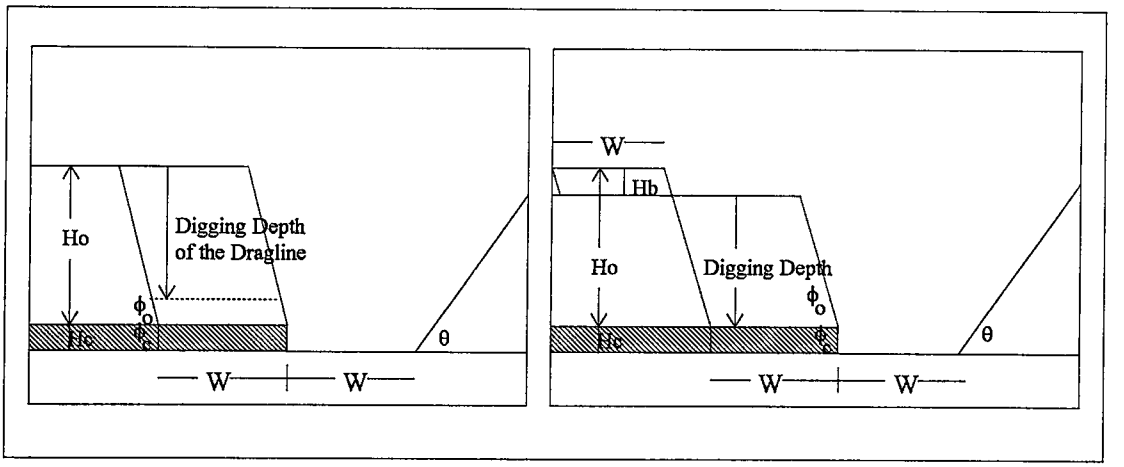


Figure 3.18. Switching to Chopping When Digging Depth of the Dragline is Shallower than Overburden Height

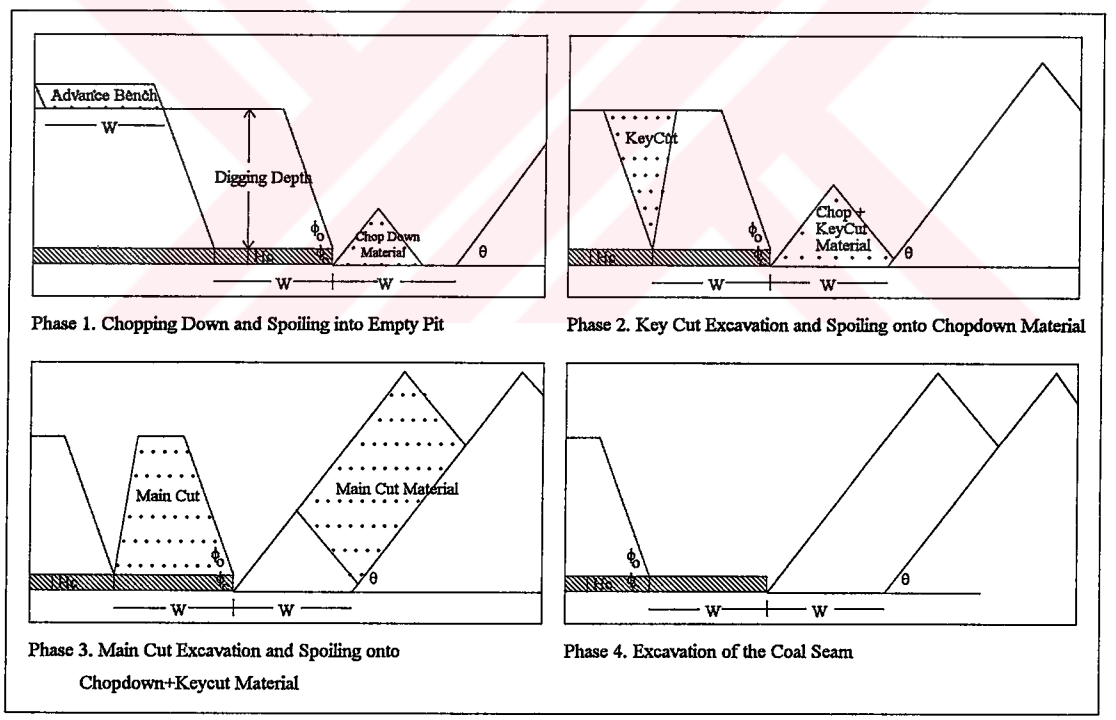


Figure 3.19. Phases in Direct Side Casting Model When Chopping is Done

The developed methodology on determining required dragline and pit dimensions when chopping must be done is presented in Figure 3.20.

3.8.1.3. Modeling Methodology When No Chopping is Done

The excavation sequence in the model when no chopping is included is as follows: The keycut is excavated and spoiled into the empty pit. The material from the main cut is placed onto previously cast keycut spoil. A series of views showing the phases when chopping is included in direct side casting model is given in Figure 3.21.

The developed methodology on determining required dragline and pit dimensions when chopping is not done is presented in Figure 3.22.

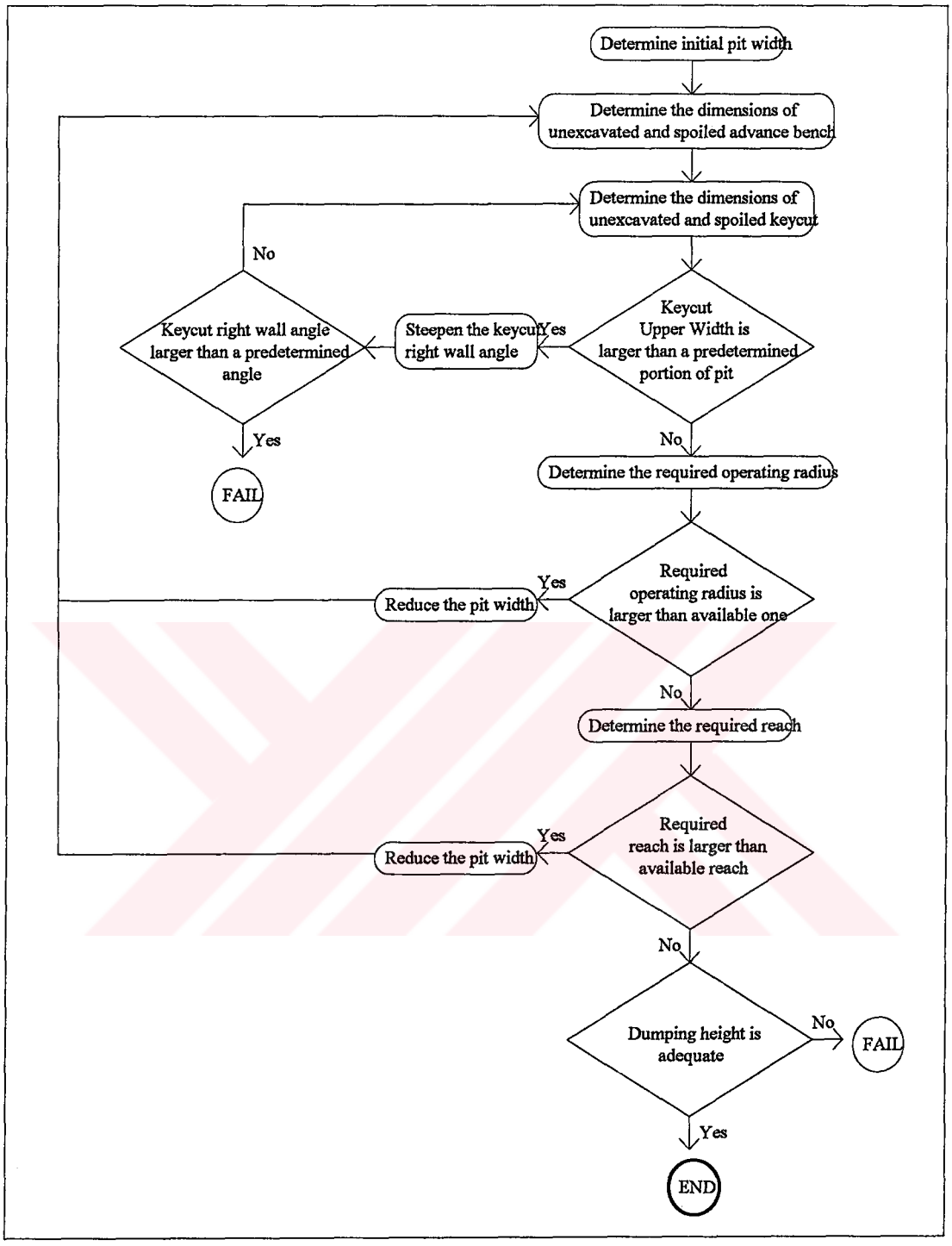


Figure 3.20. The Developed Methodology on Determining Required Dragline and Pit Dimensions When Chopping is Included

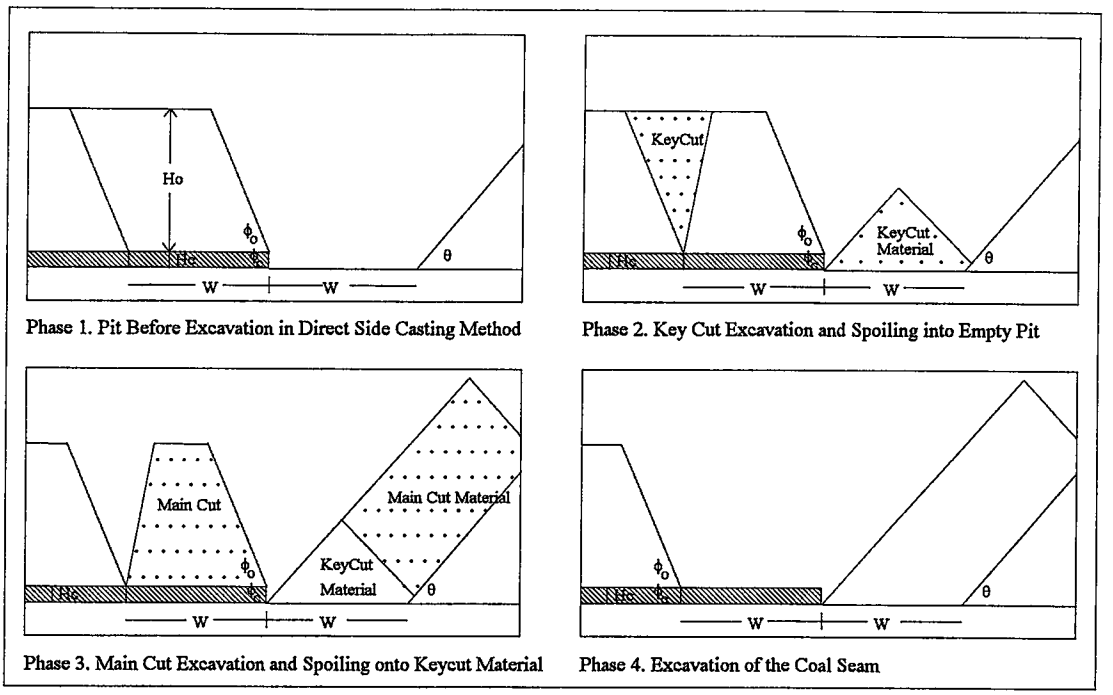


Figure 3.21. Phases in Direct Side Casting Model When No Chopping is Done

3.8.1.4. Geometrical Aspects of Design

The geometry model developed for direct side casting technique has been equipped with design aspects to determine necessary working dimensions of draglines. They are explained in the following sections. General view of the pit with and without chopping with geometrical dimensions are presented in Appendix B.

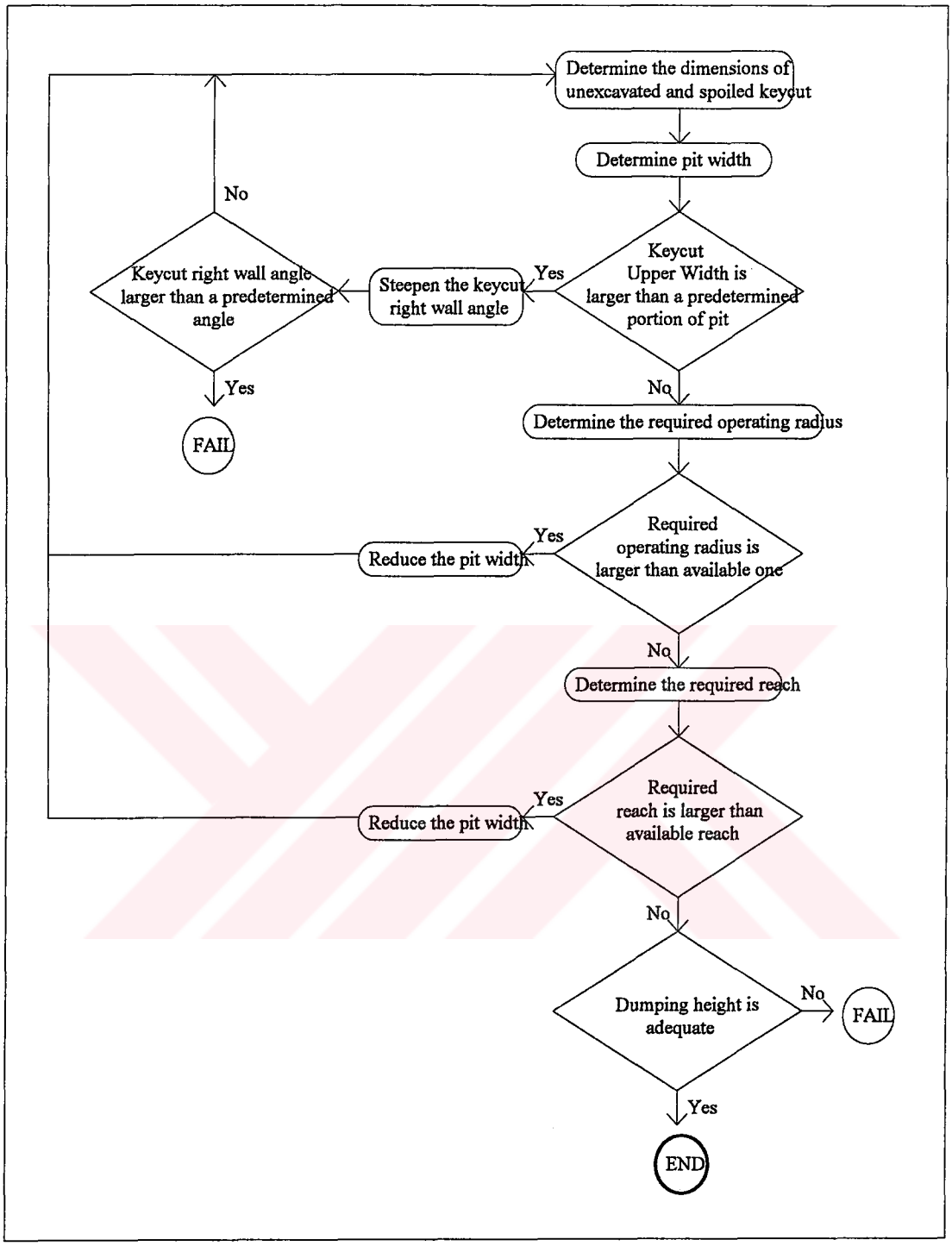


Figure 3.22. The Developed Methodology on Determining Required Dragline and Pit Dimensions No Chopping is Included

Advance Bench Dimensions

There are mainly two approaches regarding the advance bench width. In the first one, advance bench is assigned a different width than the pit (Anonymous, 1981a; Anonymous, 1993a; Parlak, 1993) and in the second one advance bench width and pit width are assigned the same value (Stefanko, et.al., 1973).

In the expert system model, advance bench width has been taken equal to that of the pit and chopped material is placed in the empty pit in a way not to ride over the coal seam (Figure 3.19, Phase 1). Besides, dragline is located closer to the advance bench during chopping down than it is during normal excavation operations. The formula related to the area of the advance bench is given in Appendix B.

Keycut Dimensions

Almost all highwall-side stripping schemes include the excavation of keycut. This necessitates the development of keycut excavation and spoiling models. However, the importance of keycut in determining the pit dimensions has been overlooked. Although numerous formulations regarding the necessary pit dimensions has been given in the literature, no one of them has considered the role the keycut plays (Anonymous, 1981a; Stefanko, et.al., 1973; Anonymous, 1977a; Anonymous, 1977b; Anonymous, 1993a; Parlak, 1993). Sadri and Lee (1982) declared that their program analyzed the keycutting routine but presented no information related to how this is achieved. The only mutual point researchers agree on is that when modeling the keycut, the bottom width is taken equal to that of the bucket (Anonymous, 1979b; Rodriguez, et.al., 1988; Parlak, 1993).

In the expert system model, there has been made two assumptions regarding the dimensions of the keycut. The upper width of the keycut is not allowed to exceed 60% of the pit width and the right wall angle can be steepened up to 80 degrees. The formulas related to the area of unexcavated and spoiled keycut are given in Appendix B.

Pit Width

The pit width must be kept as wide as possible to minimize the unproductive walking time of the dragline. The pit width is assigned such a value that the toe of the keycut spoil does not override the coal seam when spoiled but instead it coincides with it. The formula related to pit width is given in Appendix B.

Required Operating Radius and Required Reach

In direct side casting, a dragline must satisfy two range limitations with its horizontal dumping capability. The dragline must have sufficiently long operating radius to spoil the keycut material clear of the coal seam. It must also be capable to spoil the maincut waste in the same way. The first constraint is related with the operating radius and the second is related with the reach.

The methodology to meet the required operating radius and reach ranges is as follows: The areas of excavated keycut and spoiled keycut are determined. In case the available operating radius is shorter than that needed then the geometry model attempts to overcome this problem by reducing the pit width and the area of

the keycut by steeping the right wall angle. An illustrative view is presented in Figure 3.23. The formulas related to required operating radius and required reach are given in Appendix B.

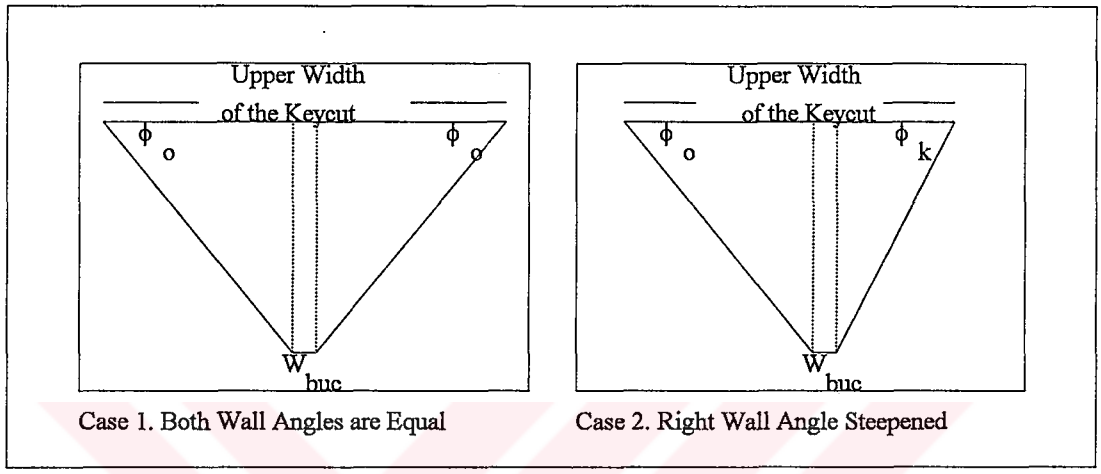


Figure 3.23. Keycut Area Reduction in the Model

3.8.2. Extended Bench Casting Technique

Extended bench casting technique is another commonly applied and well-known method in overburden stripping with draglines in surface strip mines. The basic differentiating property of this system is the excavation of some of the dumped material again which is known as rehandling.

Even though inclusion of rehandling into the system reduces the productivity notably there are cases where this incorporation is inevitable. These cases are numerous where the main reason to shift to a method with rehandling is caused by

the inability of a dragline to be employed in a technique that do not include rehandling under specified conditions. Another reason to favor this technique is the deviations encountered in the conditions that led to the employment of a particular stripping method. A very good example is the irregularities in overburden thickness throughout the boundaries of a surface mine. Since this is a case that can be encountered very frequently and the mine management has almost no solutions against this abnormality then the only choice left is to modify and adopt the previously employed stripping technique to changing conditions to cope with them. One other reason to shift to this technique is again related with gradual changes in design variables. If after a point, the conditions deviate from which the dragline and the stripping technique is designed for, the only alternative becomes to change the stripping technique and allow certain amounts of rehandle thus continuing to employ previously selected dragline.

3.8.2.1. Modeling Extended Bench Casting Geometry

In the extended bench casting model inclusion of chopping into the stripping scheme is only allowed when the dragline can not dig down to the coal seam. In such a case part of material to construct the extended bench is supplied from here. Like advance bench material, waste dug from the keycut is spoiled into the empty pit in a way to lean against the old highwall and provide material for the extended bench. After preparing the extended bench the dragline moves out in the bank and gets closer to spoil pile in which position it meets the required operating radius constraint and excavates both the main cut and part of the material used to construct the extended bench. A series of views illustrating the phases of stripping in this technique with and without chopping is presented in Figures 3.24 and 3.25 respectively.

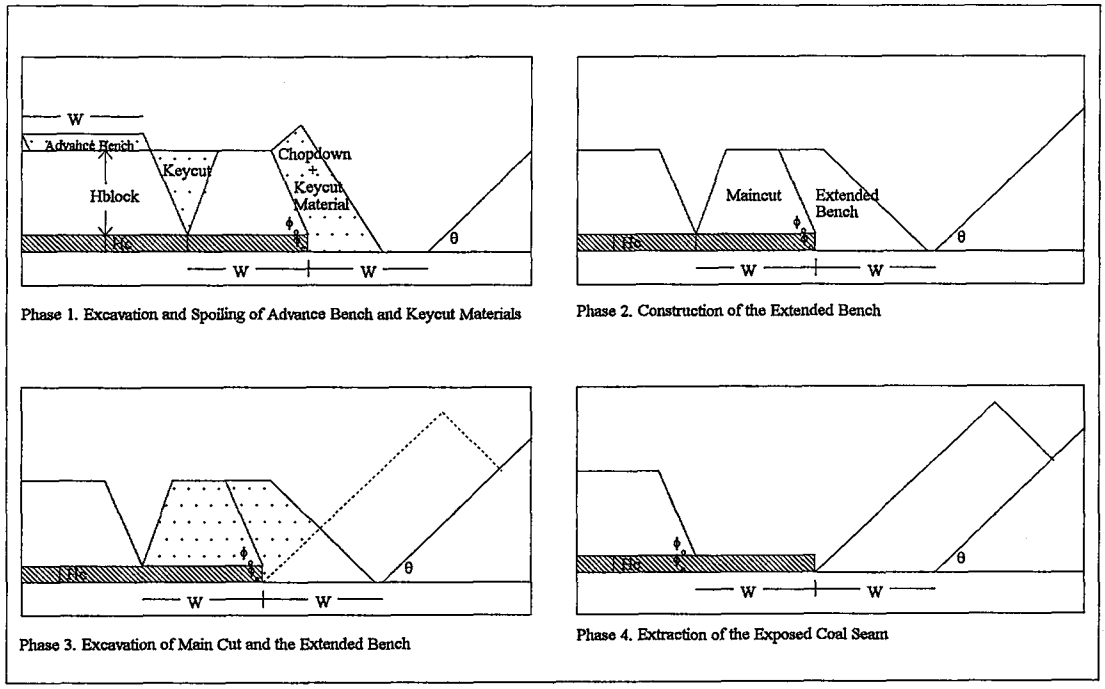


Figure 3.24. Phases in Extended Bench Casting Model When Chopping is Done

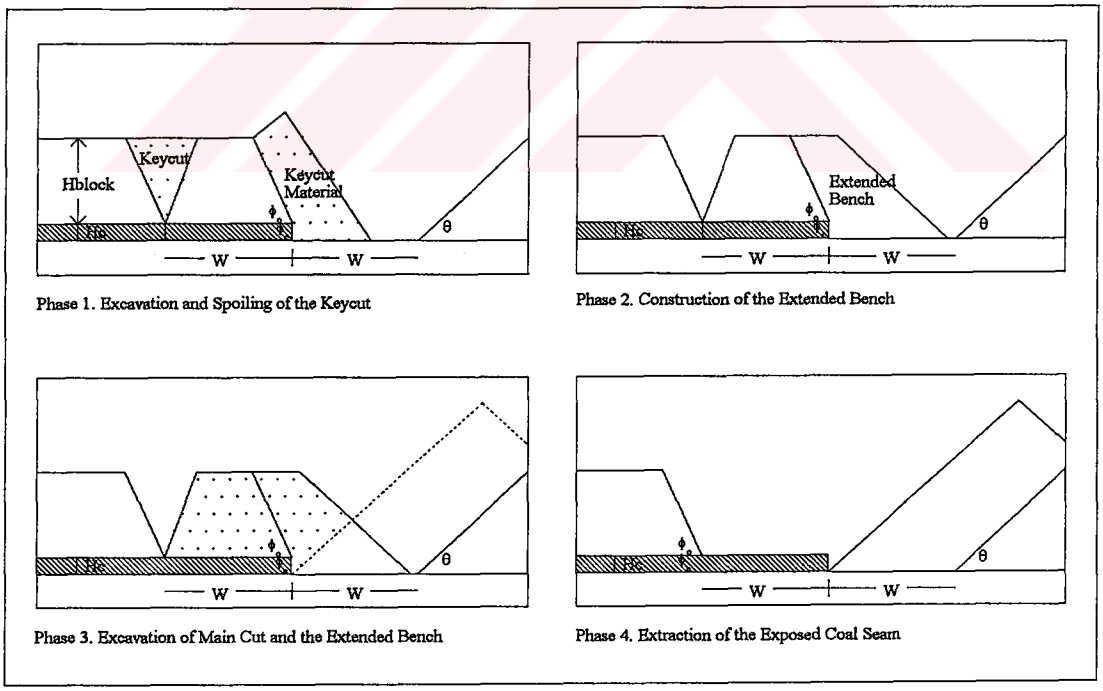


Figure 3.25. Phases in Extended Bench Casting Model When No Chopping is Done

The developed methodology on determining required dragline and pit dimensions is presented in Figure 3.26.

3.8.2.2. Geometrical Aspects of Design

There are numerous design aspects for the extended bench casting model. They are explained in the following sections. General view of the pit with and without chopping with geometrical dimensions are presented in Appendix B.

Necessary Bench Extension

Although extended bench casting modeling has been one of the mostly investigated fields in dragline mine planning, almost no effort has been spent on the width of the bench to be extended (Greenfield and Snowdowne, 1977; Seymour, 1979; Özdoğan, 1984; Michaud and Calder, 1988; Rodriquez, et.al., 1988; Stuart and Cobb, 1988; Aiken and Gunnett, 1990; Parlak, 1993). Most of the previous studies have utilized static extended bench determination formulations that were developed for specific conditions which could not be used for some other condition. Basic bench extension concepts are explained in some manufacturers' dragline manuals, however no information has been made available as to how wide an extended bench should be constructed (Anonymous, 1977a; Anonymous, 1993a).

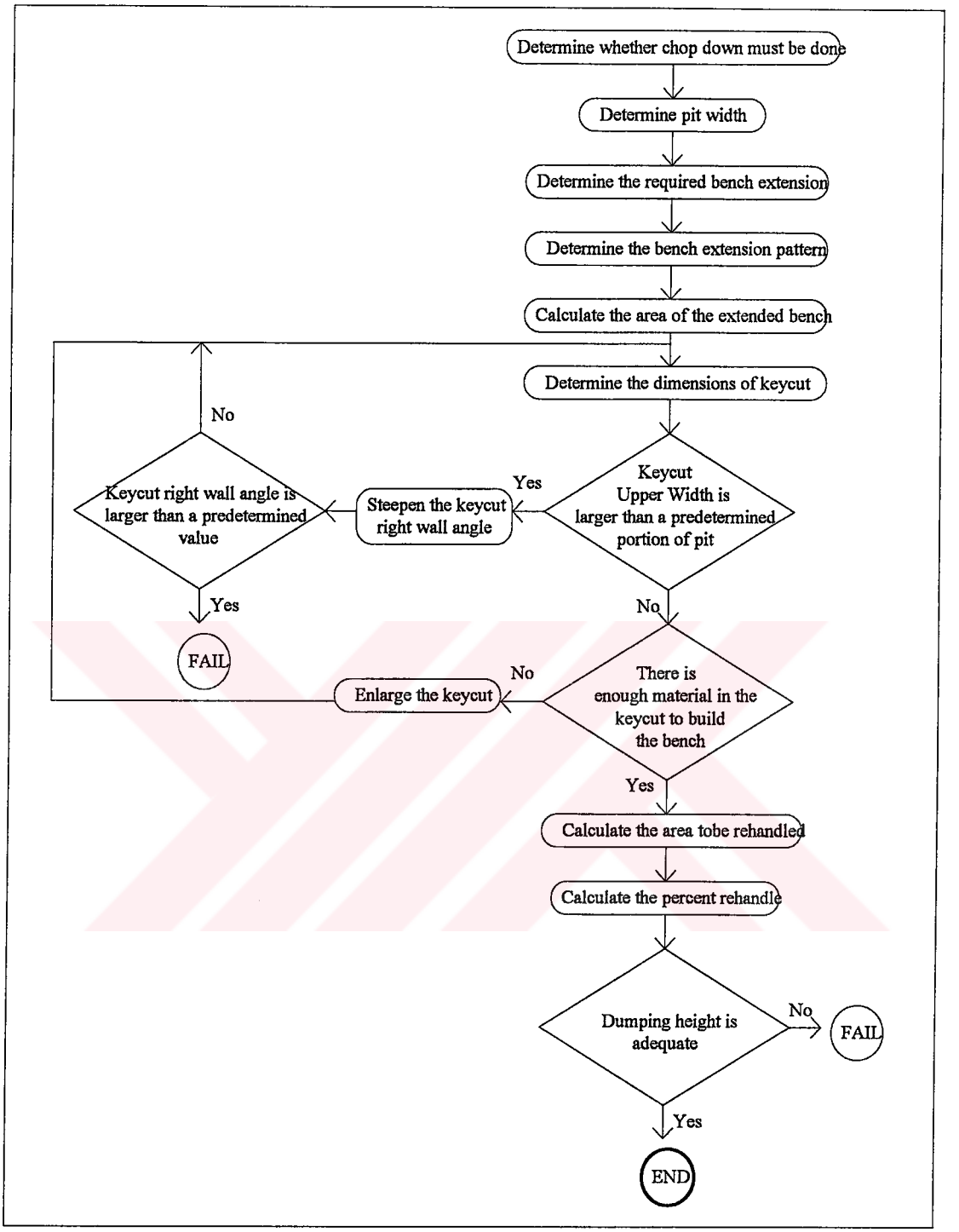


Figure 3.26. The Developed Methodology on Determining Required Dragline and Pit Dimensions in Extended Bench Casting Model

Determining how wide a working bench is needed is vital in extended bench casting because rehandling increases stripping costs and slows down ore production. If extended bench casting must be applied, rehandling percentage must be known ahead of operations. This technique should not be applied if the cost of stripping would be higher than that of alternative overburden removal systems and the estimation of extra cost caused by rehandling can only be determined by knowing the bench extension.

In the expert system model, the necessary closure has been defined as the additional distance that must be supplied in order to make the dragline spoil the waste in the pit clear of the coal seam. This extra distance is taken the difference between the range needed to dump the waste clear of the coal seam and the actual range in which the dragline could operate. This case is illustrated in Figure 3.27 and given in Equation 3.1.

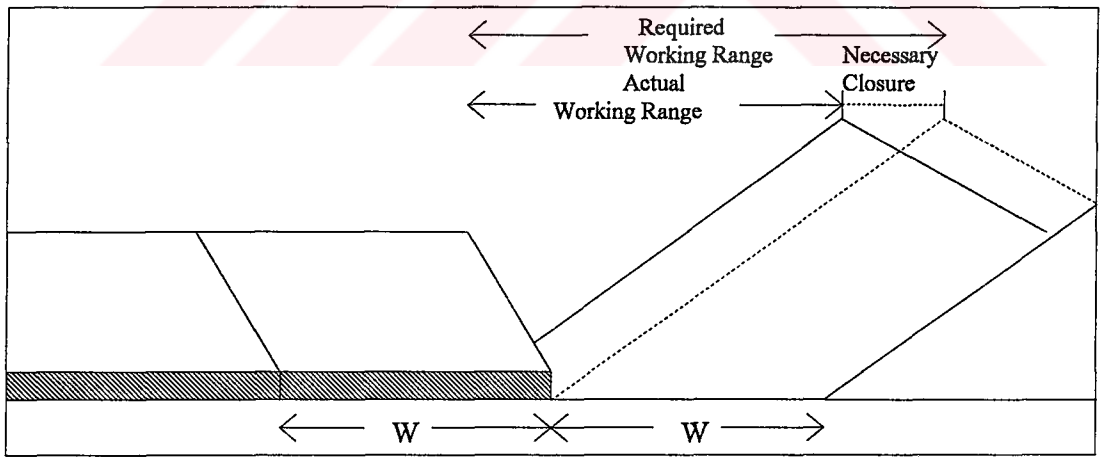


Figure 3.27. Necessary Closure to the Final Spoil Pile

Necessary Closure = Re*quired Working Range - Actual Working Range* (3.1)

Pit Width

In extended bench casting only those draglines that can not perform production in direct side casting model are regarded and the pit width is kept larger than that in direct side casting method. So the pit width is assigned a value no larger than the distance the dragline dumps the keycut material at the toe of the coal seam. Since the extended bench has to be constructed the keycut material need not be dumped clear of the coal seam but the pit width should not be taken any larger than this distance as not to spoil the keycut waste on the highwall. The pit width is kept as wide as possible because in extended bench casting the wider the pit the more material used in construction of the extended bench will be located in the final spoil pile and proportionally the lesser material will be rehandled (Seymour, 1979; Özdoğan, 1984; Brett, 1995; Erickson, 1995d). The formula related to the determination of pit width is given in Appendix B.

Sources of Waste for Extended Bench Construction

There are two approaches for supplying material for extended bench construction. Seymour (1979), Rodriquez, et.al. (1988) and Parlak (1993) state that the material to build the extended bench is supplied from the widened key cut. Anonymous (1979b), Aiken and Gunnett (1990) and Anonymous (1977a) propose that when an advance bench casting is applied part of the material is supplied from advance bench provided that it can support the dragline.

The methodology embedded into the geometrical calculations requires that the material for the extended bench is primarily gathered from the key cut unless the dragline fails to provide the required digging depth. In such a case, extended bench material is excavated from both sources provided that the thickness of overburden left for chopping is within allowable limits. The hierarchical order of supplying the material is as follows: material above the level on which dragline sits is excavated with chopping and the rest of material needed to construct the extended bench is dug conventionally from key cut.

In cases where material in the key cut would not meet the requirements it may be enlarged to a certain limit by extending the right side wall of the keycut until sufficient material is gathered. This case is given in Figure 3.28. However, the upper width of the keycut is not allowed to exceed 80% of the pit width in the model. Also, in case where there is more material to build the extended bench than needed then the right wall of the keycut is steepened until the material in the keycut is equal to that in the extended bench.

Formulation of Working Parameters in the Extended Bench Casting Model

As explained in the preceding sections, the most striking property of previous studies on extended bench modeling has been the width of the extended bench. In some studies it is the input the user has to provide while in some others the calculations are based on static extended bench assumptions. However, a thorough design task must consider every possible configuration on bench extension. There has been developed four patterns of bench extension according to the required width of

the extended bench and the position of its base in the pit. Even though the occurrence of each of them is not equally likely they have been embedded into the model to compensate the conditions that are specified by the input parameters. These extended bench forming patterns are given in Figure 3.29. The formulas related to area of extended bench, area to be rehandled and rehandle percentage are given in Appendix B.

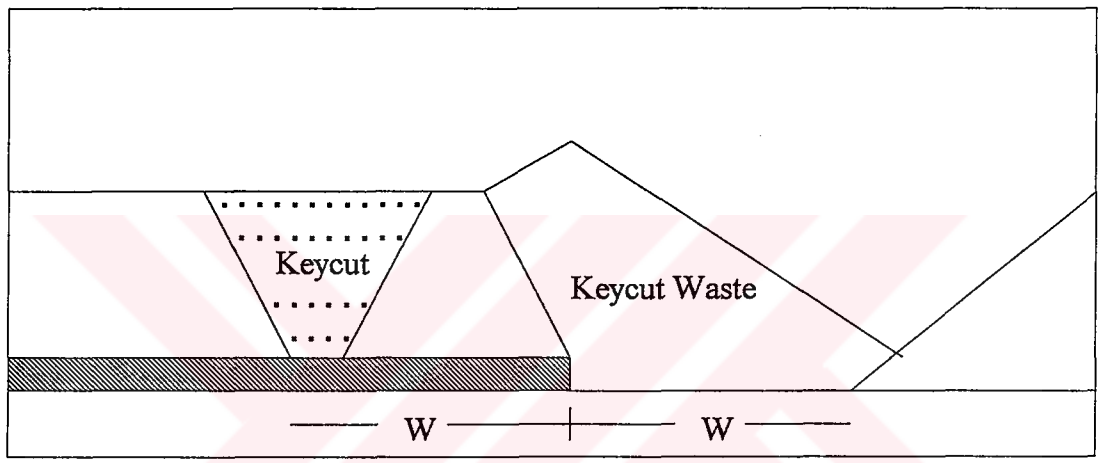


Figure 3.28. Enlargement of Keycut to Gather Material Needed to Construct the Extended Bench

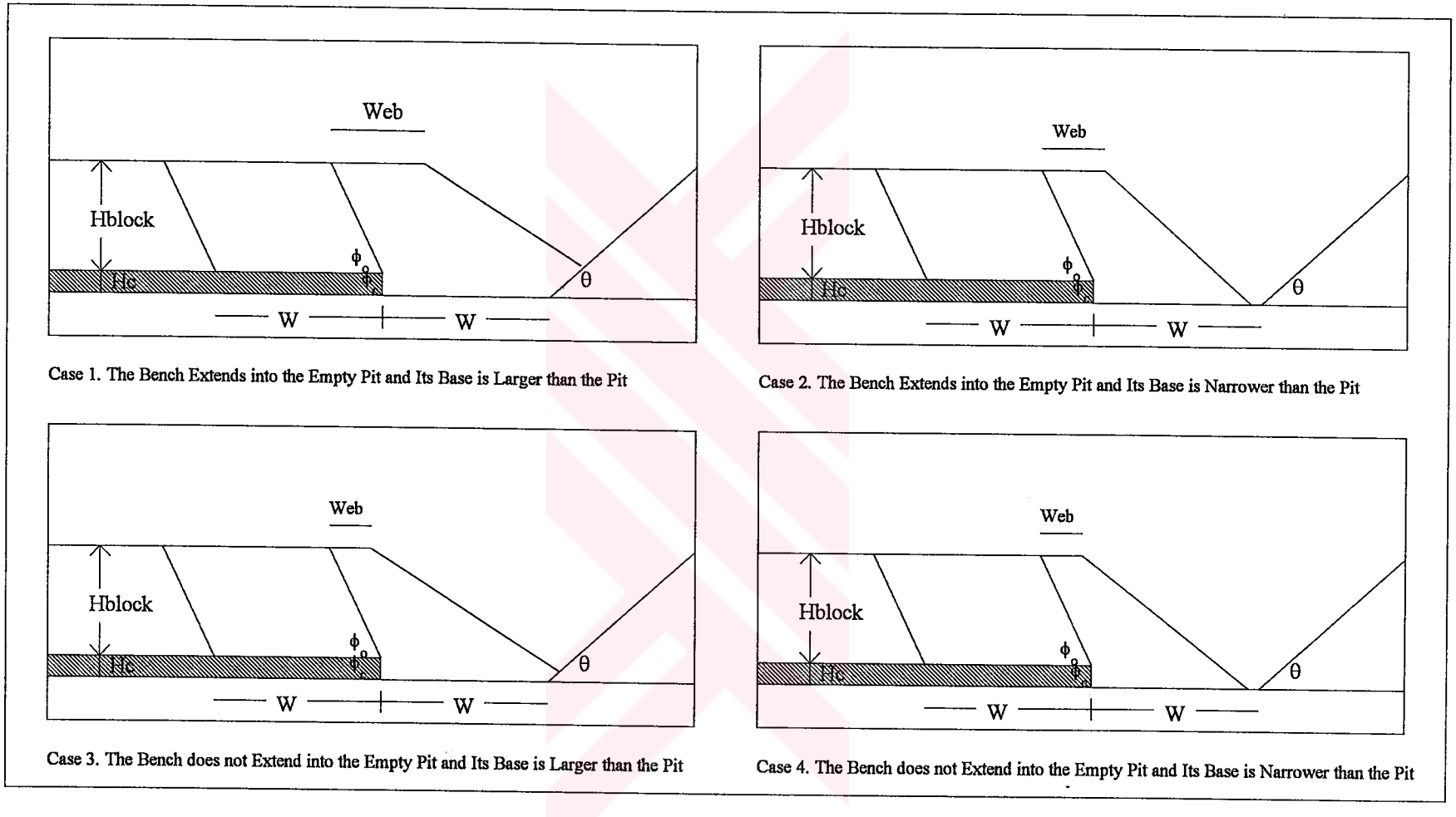


Figure 3.29. Four Different Extended Bench Patterns in Extended Bench Casting

3.8.3. Pullback Stripping Technique

The pullback stripping is a method that is applied where the operating dimensions of draglines would be inappropriate for uncovering coal seams without rehandling. Main purposes to employ this stripping technique are similar to those in extended bench casting method and the main advantage of this method is to enable a dragline which has a limited operating radius to handle overburden covers of greater depth than would normally be contemplated (Anonymous, 1977a). The basic difference between this technique and the extended bench casting is the possibility of employing a secondary dragline. Although extended bench casting allows the use of only one dragline the pullback stripping technique can be modified to employ two draglines in which case one dragline excavates the slice in the highwall side and the other strips the part of the overburden used as a barrier for the area to be rehandled plus the rehandle material. In cases where only one dragline has to be utilized with pullback stripping then the dragline takes periodic sojourns across on the spoil pile, getting there either on a section of extended bench or bridge or around the end of the pit (Anonymous, 1993a).

Like extended bench casting the most important drawback of this stripping technique is the inevitable inclusion of rehandling into the system. However the shortcoming of performing rehandling thus reducing the productivity could turn a previously unworking dragline system into a working solution for a mine. Another point for the employment of the pullback stripping is mines with deep overburden covers (Anonymous, 1977a).

3.8.3.1. Modeling Pullback Stripping Geometry

The basic operation sequence in the model is as follows; the operations commence by excavating the cut by side casting either from the original ground surface or from an advance bench. Like in previous methods, the inclusion of chopping is allowed when the dragline can not dig down to the coal seam. Since in this method the dragline is unable to spoil all the material in the slice clear of the coal seam, some of the waste will rill over the coal seam. For the material rilling over the highwall there must be left a waste barrier to hold it from flowing onto the coal seam. After this operation the spoil side pullback pad is prepared either by the dragline itself or by dozing. Then the dragline positioned on the pullback pad excavates this material and the part that should be rehandled to completely uncover the coal. A series of views illustrating the phases in pullback stripping technique with and without chopping is given in Figures 3.30 and 3.31.

The developed methodology on determining required dragline and pit dimensions is presented in Figure 3.32.

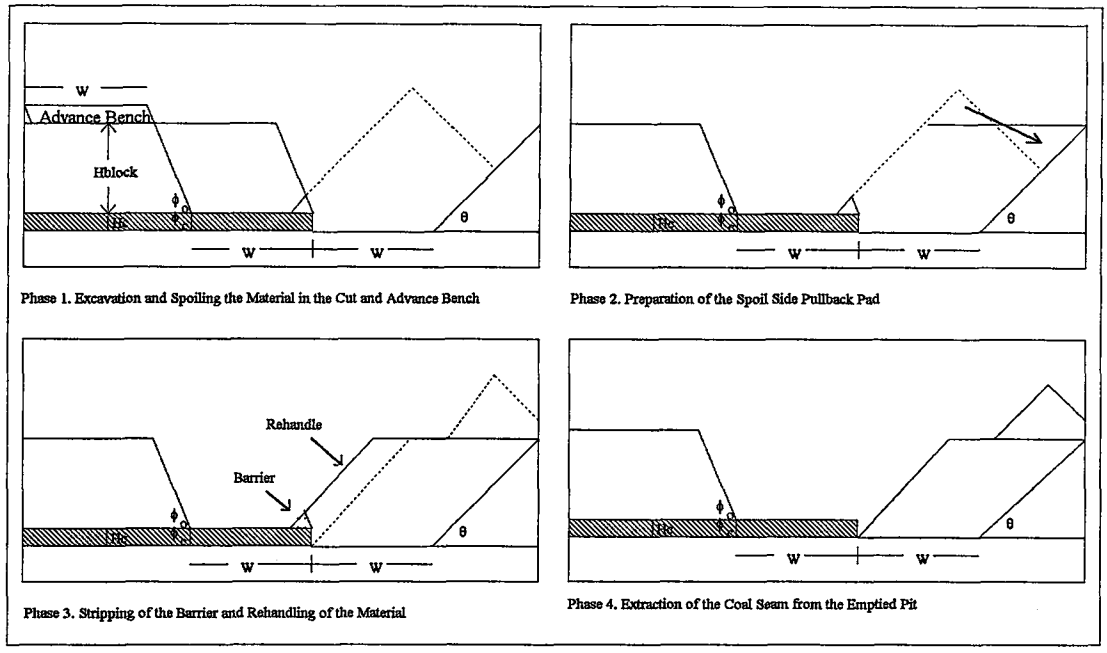


Figure 3.30. Phases in Pullback Stripping Model When Chopping is Done

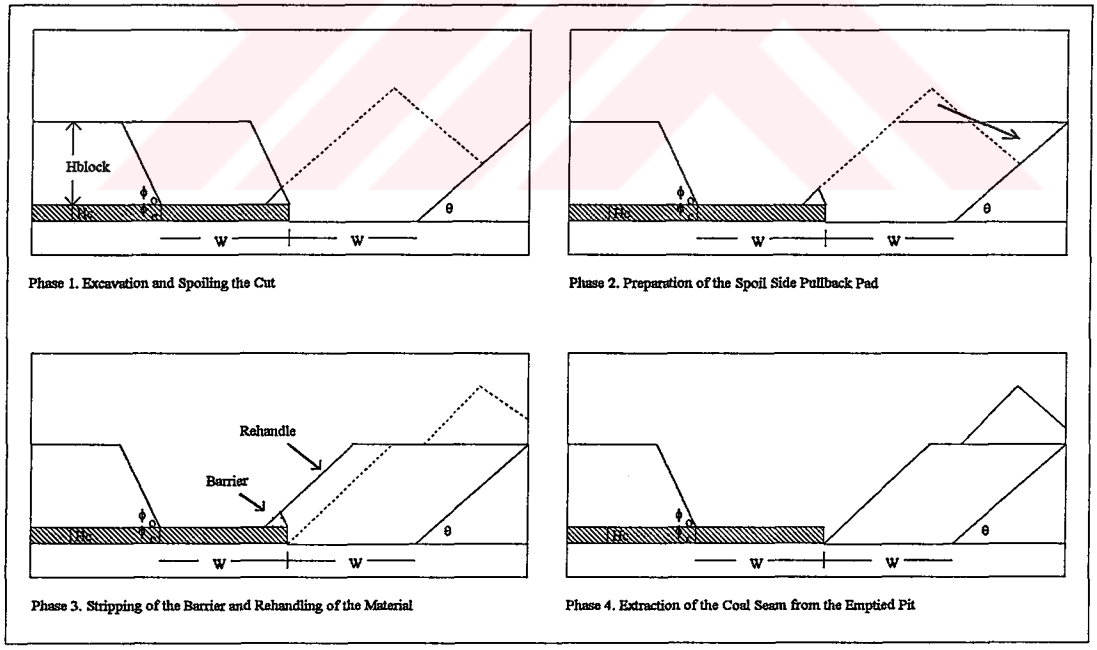


Figure 3.31. Phases in Pullback Stripping Model When No Chopping is Done

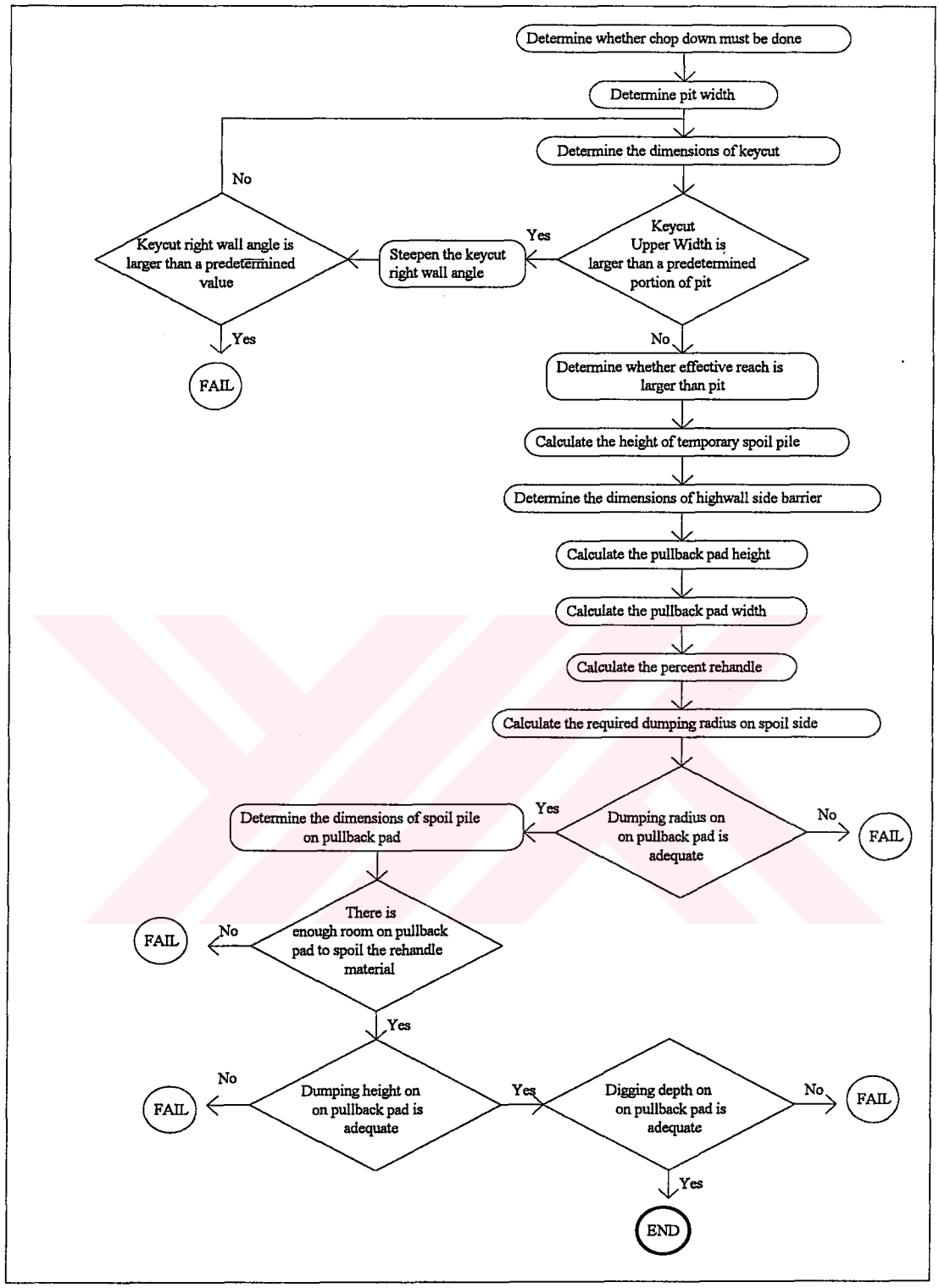


Figure 3.32. The Developed Methodology on Determining Required Dragline and Pit Dimensions in Pullback Stripping Model

3.8.3.2. Geometrical Aspects of Design

Although pullback stripping has been among the overburden removal techniques applied in strip mines it has not been deeply investigated by researchers. Most of the available information about the method is conceptual in nature which is mostly relevant to its application (Anonymous, 1977a). In the expert system model, parameters used in pit design have been determined. They are explained in the following sections.

Pit Width

It is known that in pullback stripping a dragline can not spoil the waste clear of the coal seam and it is allowed to do so. One of the interesting points related with this technique is that there must be left an unexcavated barrier on the highwall side of the pit to prevent the material from flowing onto the uncovered coal seam. So the dragline is allowed to spoil the material at the toe of the coal seam when it is positioned in the middle of the keycut. Formulas regarding the pit width with and without chopping are given in Appendix B.

Effective Dumping Radius (r)

In calculating pit dimensions a very useful concept is the effective dumping radius (r). The effective dumping radius is the range a dragline could reach horizontally from the toe of the coal seam into the pit (Workman, 1985). Formulation

of pit parameters depends on the length of pit width and effective dumping radius. This concept is shown in Figure 3.33.

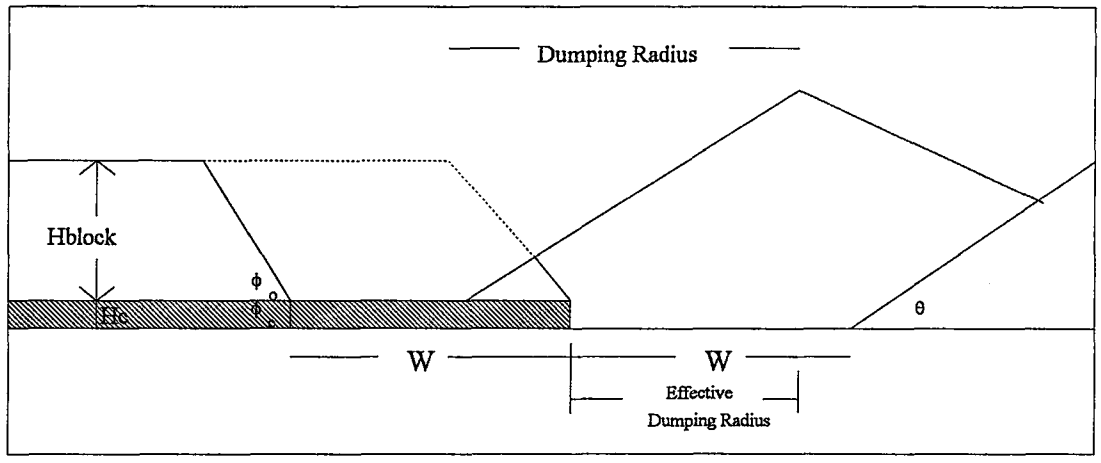


Figure 3.33. The Effective Dumping Radius of a Dragline

Height of the Temporary Spoil Pile in the Empty Pit

Formulation of the design parameters on highwall and pullback sides are heavily dependent on this parameter. There exist two different formulations of this parameter according to the relative length of effective reach (r) and pit (W). Formulations regarding this parameter are given in Appendix B.

Area of the Highwall Side Barrier

The formulations regarding the area of the highwall side barrier are given in Appendix B.

Construction of the Spoils Side Pullback Pad

The logic the pullback stripping model employs to construct a spoil side bench is as follows; part of the material located on the upper part of the spoil pile is truncated and moved behind towards the hollow portion between the temporary spoil pile and the previously built pile. The area of the truncated material is equal to that of hollow part. By this way the spoil pile is leveled and a pullback is formed. Figure 3.34 illustrates this case. Formulations regarding width and height of the pullback pad built on the spoil side are given in Appendix B.

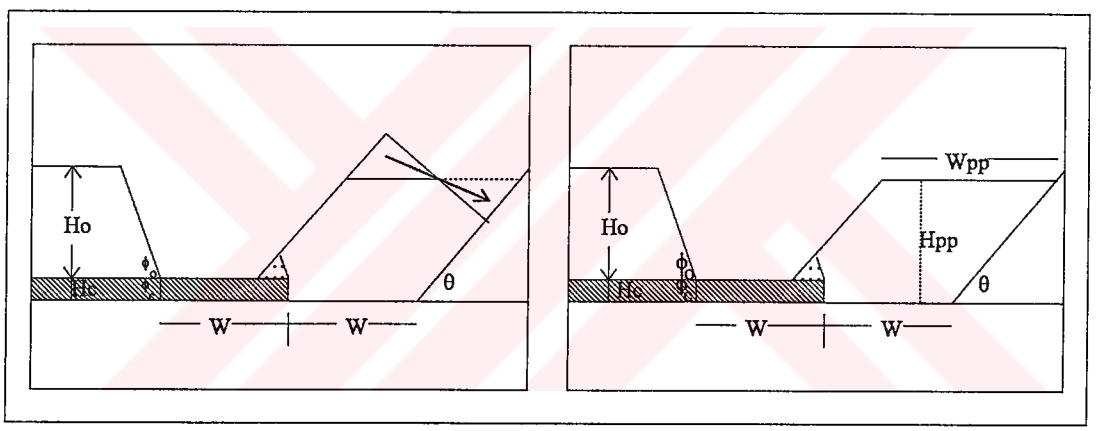


Figure 3.34. Preparation of the Pullback Pad by Filling the Hollow Part in the Empty Pit

Area to be Rehandled and Rehandle Percentage

The amount of rehandle that must be performed by the dragline and rehandle percentage are given in Appendix B. As mentioned before although the waste barrier is stripped at the same time with rehandle material it is not considered rehandle as this part is handled only once during excavating and spoiling the material back onto the pullback pad.

Dimensions Required on Spoil Side

The last consideration in the pullback stripping model is towards determination of the required dumping radius and parameters related with placing the material excavated from pullback pad on the leveled spoils side. These parameters are particularly important in determining the room available to spoil the extra waste coming from the highwall barrier and the pullback pad. In case of deep overburden covers, there may not be provided enough room to place all the material on spoil side and a dragline facing such a problem is called "spoil-bound" dragline (Anonymous, 1979b; Michaud and Calder, 1988). A thorough design of pullback stripping must not overlook this design task as omitting it might end in the selection of a spoil-bound dragline.

The methodology embedded in the model is to build an upper spoil pile on the leveled pad. In this method, the spoil pile formed by the waste from rehandling and highwall barrier leans against previous spoil pile. The existence of enough spoil room and stacking capability of the dragline is controlled. The formulas related to above parameters are given in Appendix B.

3.8.4. Two Slice Direct Side Casting Technique

Two slice direct side casting is a dragline stripping method where no rehandling is included. In this method, either one or two draglines can be employed. In cases where one dragline is employed the same dragline works on both upper and lower slices moving frequently between them. In cases where two draglines are employed each dragline is assigned a slice (Anonymous, 1993a).

3.8.4.1. Modeling Two Slice Direct Side Casting Geometry

The basic principle behind the model is excavation and dumping of slices beginning with upper slice and continuing with lower one without covering the coal seam which would cause coal losses due to burial of the seam under the toe of the final spoil pile. Principally operations series in the model is as follows; firstly upper slice is dug and spoiled into the empty pit followed by the excavation of the lower slice material. The waste excavated from the lower overburden slice is completely dumped onto the previously cast upper slice waste to avoid any likely rehandling. Finally the coal seam is extracted from the emptied pit. A series of views illustrating the phases in this method is given in Figure 3.35. The developed methodology on determining required dragline and pit dimensions is presented in Figure 3.36.

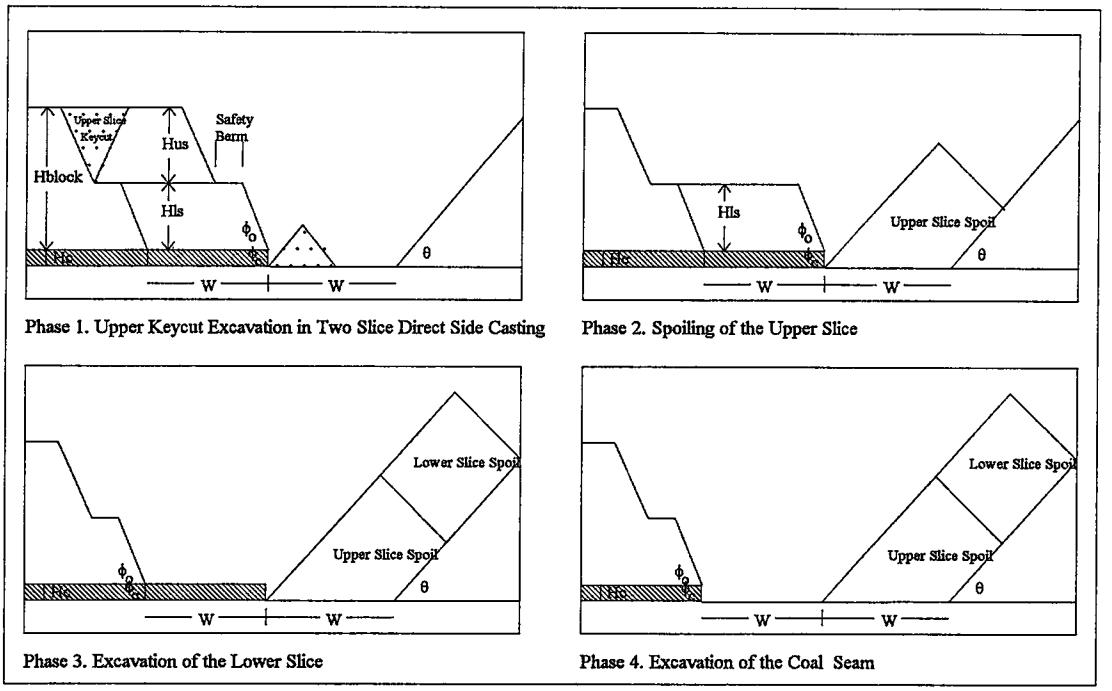


Figure 3.35. A Series of Views Illustrating the Phases of Stripping in Two Slice Direct Side Casting Model

3.8.4.2. Geometrical Aspects of Design

There have been included numerous dimensional formulations in two slice direct side casting model. The following geometrical range dimensions have been investigated and formulized.

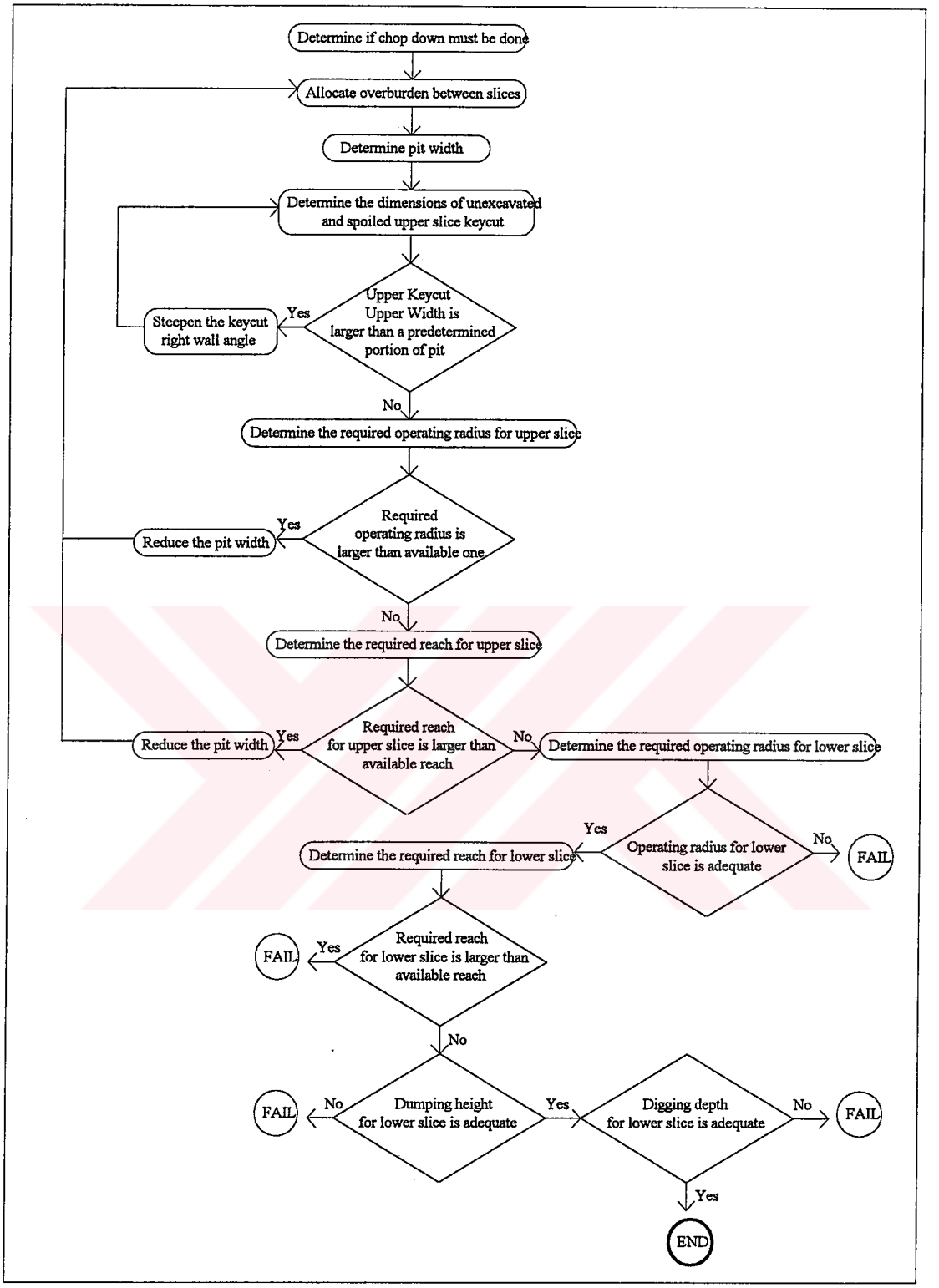


Figure 3.36. The Developed Methodology on Determining Required Dragline and Pit Dimensions in Two Slice Direct Side Casting Model

Pit Width

A very important parameter is the pit width for each possible dragline to be employed in the upper slice. As in previous methods, it is planned as wide as possible to avoid unproductive walking time of the dragline. The pit width is basically dependent upon the positioning of the upper keycut spoil into the empty pit. As explained before, the main aim in determining the pit width is to assign such a value that after placement of the upper keycut spoil the toe of it does not rill over the coal seam. Formulations regarding the pit width with and without chopping are given in Appendix B.

Allocating Total Overburden into Slices

Optimum sharing of overburden layers is one of the most important items. Allocation of overburden into two slices must be optimized in such a way that finally both upper and lower slice draglines could be able to excavate and dump the waste in their allocated parts with their operating dimensions. This is particularly important for the model for two reasons; firstly because this method does not include rehandling and normally the dragline working on the lower slice has to have relatively long range to dump its waste onto the spoil pile formed by the upper dragline, the distance it has to reach increases drastically if the thickness of the slice allocated for it is kept high. Secondly if the thickness of the slice allocated for the dragline working on the upper slice is kept high, then this dragline has to have extremely large working dimensions to avoid burial of the coal seam with the waste excavated from the upper slice and consequently the portion left for the lower slice dragline will be too thin to excavate and consequently this dragline would be working inefficiently.

Required Dimensions for the Upper and Lower Slices

The required operating radius and reach for the upper and lower slices are given in Appendix B.

3.8.5. Lower Slice Extended Bench Casting Techniques

This stripping technique is a combination of the simple side casting and extended bench techniques. Basic operating properties of this system are stripping the overburden in two slices and rehandling some of the waste already spoiled into the pit to uncover the coal seam. The stripping technique of extended bench casting on two slices is safer than pullback stripping in that the dragline employed on the lower slice works on an extended bench and is not subjected to likely spoil pile failures (Anonymous, 1977a; Anonymous, 1993a).

For a two dragline situation the equipment employed on the upper slice has generally shorter boom and larger bucket capacity while the one employed on the lower slice is equipped with longer boom and smaller bucket capacity. One of the main reasons to apply this stripping technique is the relatively high thickness of overburden layers. In such a case this technique may be preferred due partly to highwall stability matters and partly to inappropriate dragline working dimensions because of larger than usual range requirements (Anonymous, 1977a; Parlak, 1993).

3.8.5.1. Modeling Lower Slice Extended Bench Geometry

As outlined above this technique incorporates stripping of overburden layers in two slices. Uncovering operations commence with excavation and spoiling of the upper slice waste into the previously excavated pit. Then follows this the preparation of an extended bench on which the dragline employed on the lower slice moves freely between the lower slice and the extended bench to excavate and spoil the waste in the slice plus part of the material used to construct the extended bench to uncover the coal seam. The lower slice extended bench may be of limited or full length according to the required operating radius on the lower slice. The last operation is the extraction of uncovered coal seam and preparing an empty pit for the spoiling of the adjacent passes of the dragline. A series of views showing the phases of lower slice limited extended bench casting are illustrated in Figure 3.37 and those of lower slice full extended bench casting are illustrated in Figure 3.38. The developed methodology on determining required dragline and pit dimensions is presented in Figure 3.39.

3.8.5.2. Geometrical Aspects of Design

There have been included numerous dimensional formulations in lower slice extended bench model. The methodology behind geometrical design aspects are given in the following paragraphs.

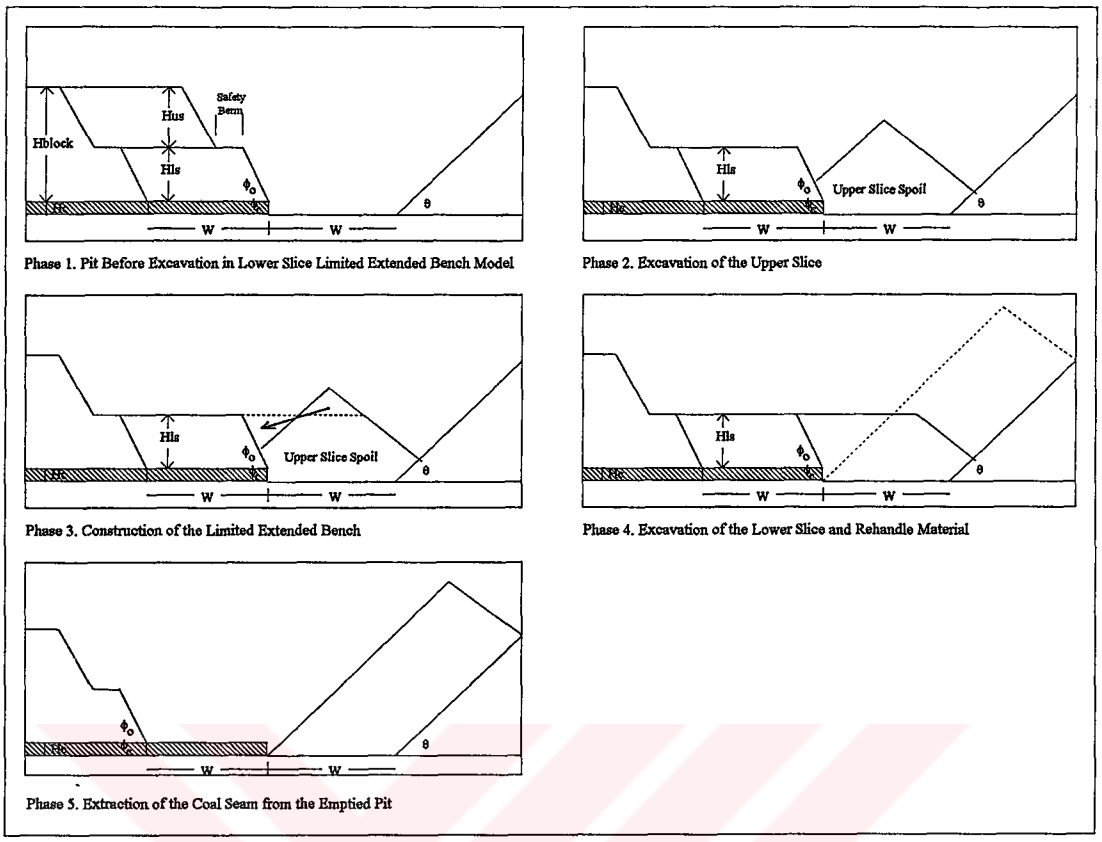


Figure 3.37. A Series of Views Illustrating the Phases of Stripping in Lower Slice Limited Extended Bench Model

Pit Width

This parameter is another important item of which the value must be determined optimally for a good operation. The pit width is assigned as wide a value as possible to minimize the percent rehandle within the working dimensions of the dragline. Since the system includes certain amount of rehandle the keycut spoil of the upper slice need not be dumped clear of the coal seam. The model assumes that this waste is dumped at the toe of the coal seam and the pit width is assigned such a value to allow this operation. However, inclusion of chopping into stripping scheme

necessitates an adjustment in the value of the pit width. Formulations regarding the pit width with and without chopping are given in Appendix B.

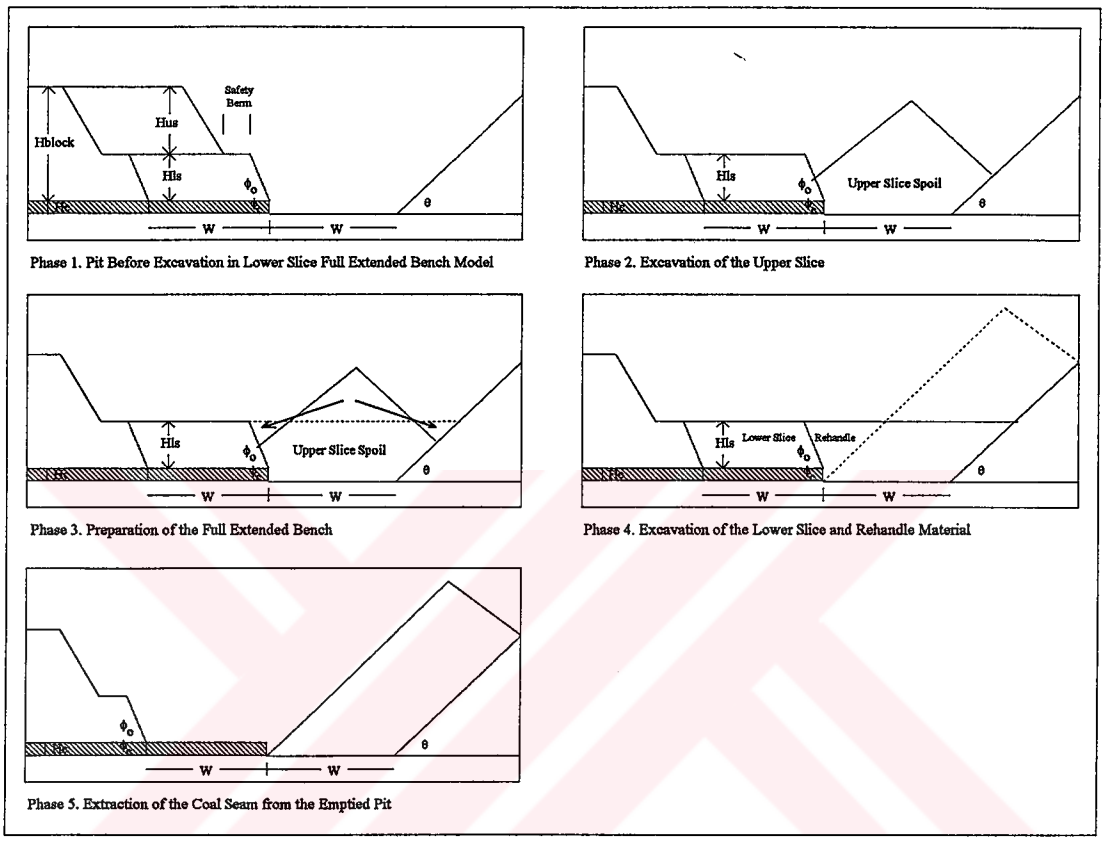


Figure 3.38. A Series of Views Illustrating the Phases of Stripping in Lower Slice Full Extended Bench Model

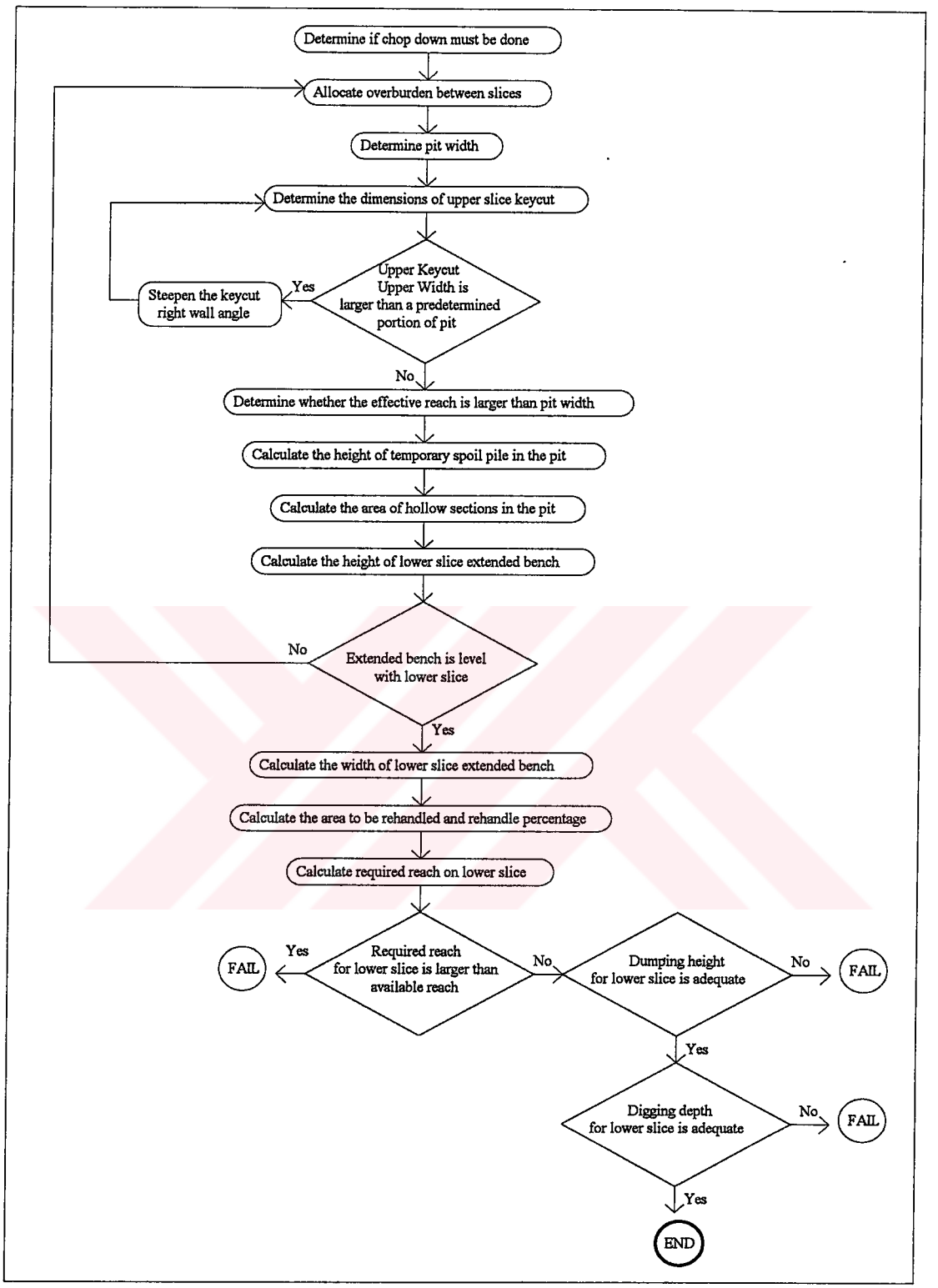


Figure 3.39. The Developed Methodology on Determining Required Dragline and Pit Dimensions in Lower Slice Extended Bench Model

Allocation of Total Overburden into Slices

One of the main aims of the model is the optimum allocation of slices between draglines. Since this technique utilizes two draglines either in the form of one dragline working on both slices or two draglines each of which is employed on one slice then such an optimum slice sharing must be found that both draglines could excavate their portions. Optimum allocation of slices is of utmost importance because if the thickness of any slice is kept high then the dragline employed on the other slice will have to have extremely large working dimensions to compensate the shortcomings caused by this dragline. The optimized point where the two draglines are accepted to match is where the lower slice is the same height with the extended bench after leveling by dragline working on the lower slice itself or by dozing. This case is illustrated in Figures 3.40 and 3.41 for limited and full extension of lower slice bench.

Height of Temporary Spoil Pile in the Pit

There exist two different formulations of this parameter according to the relative length of effective reach (r) and pit (W). Formulations regarding this parameter are given in Appendix B.

Area of Hollow Section between Upper Slice Spoil and the Lower Slice

Construction of the extended bench is modeled as filling the hollow sections between the upper slice spoil and the lower slice by moving a part of spoiled

material into the void hence producing a leveled pad for the dragline working on the lower slice. Building the extended bench for both limited and full extended bench models are presented in Figures 3.40 and 3.41. The formulations relating to the area calculations of the void part are given in Appendix B.

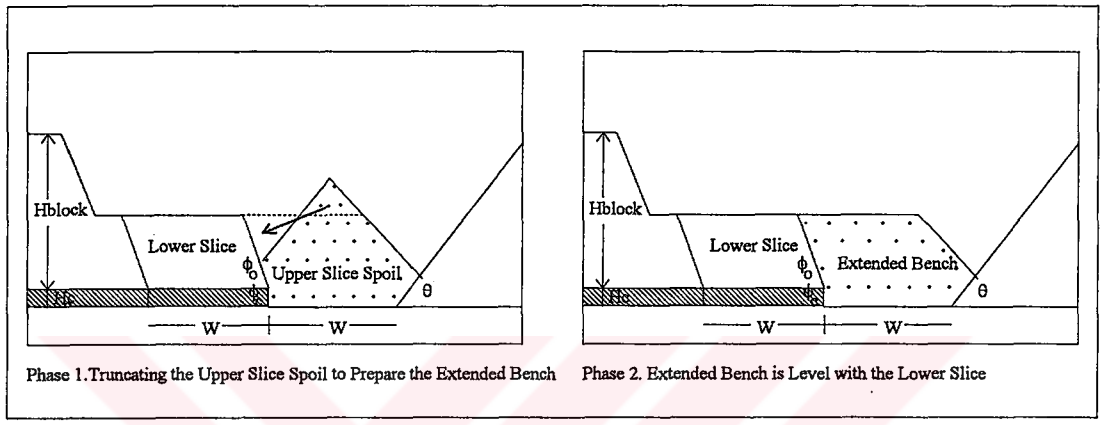


Figure 3.40. Optimum Allocation of Slices in the Lower Slice Limited Extended Bench Geometry Model

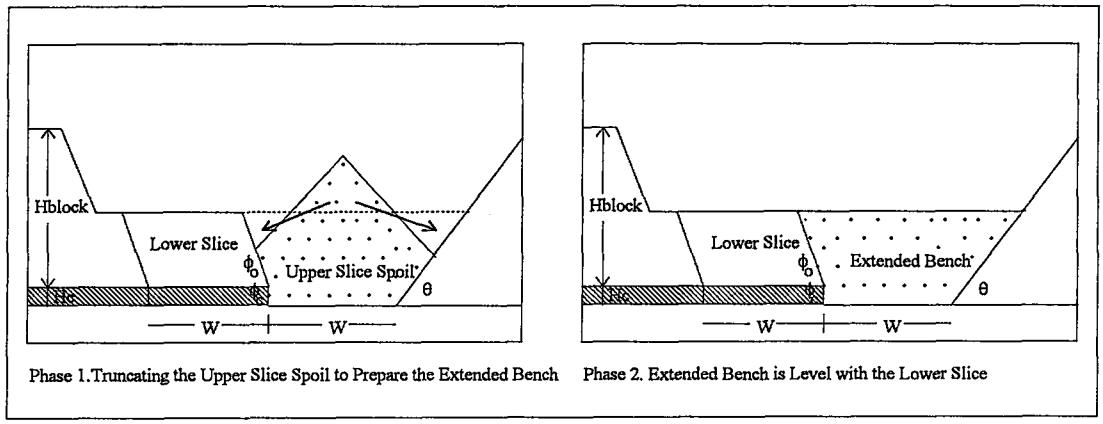


Figure 3.41. Optimum Allocation of Slices in the Lower Slice Full Extended Bench Geometry Model

Height of the Lower Slice Extended Bench

The formulations relating to the height of lower slice extended bench are given in Appendix B.

Width of the Lower Slice Extended Bench

The formulations relating to the width of lower slice extended bench are given in Appendix B.

Area to be Rehandled and Rehandle Percentage

The area of the material to be rehandled in the lower slice extended bench and rehandle percentage are given in Appendix B.

Required Dumping Radius for the Dragline Employed on the Lower Slice

The last parameter the lower slice extended bench casting model determines is the required dumping radius of the dragline employed on the lower slice. The dragline must be capable to spoil the keycut waste excavated from the lower slice to at least a point where the projected spoil pile coincides with the extended bench. Also it has to have appropriate dumping radius from the point where the projected spoil pile coincides with the extended bench to the peak of it. Actually the first dumping radius requirement is larger than the second one. This is because the dragline

is never allowed to spoil the keycut waste onto the extended bench thus causing triple handling of the material (Erickson 1995c, 1995d). The formulations related with dumping radius requirements on lower slice are given in Appendix B.

3.8.6. Two Slice Pullback Stripping Technique

The two slice pullback stripping, also called the "Horseshoe Method" or "Double Pass with Rehandling" method is a combination of the simple side casting and the pullback stripping methods. Among differentiating properties of this system can be mentioned stripping the overburden from both sides of the pit, stripping in two slices and rehandling some of the waste already spoiled into the pit to uncover the coal seam. It is appropriate to utilize this technique in deep overburden covers by which the dragline reach requirements are greatly reduced (Anonymous, 1977a; Anonymous, 1979b; Anonymous, 1993a). A shorter boom dragline with a large bucket can be used to spoil the high volume upper slice where a long boomed dragline with a small bucket digs lesser volume lower slice under more adverse operating conditions and through larger swing angles (Anonymous, 1977a).

This stripping technique is applicable with one or two draglines. In cases where only one dragline is used for overburden stripping, the equipment excavates the upper slice and takes periodic sojourns between the highwall and the spoil side to dig the lower slice and the part to be rehandled. In cases where two draglines are used each dragline is employed on each side of the pit.

3.8.6.1. Modeling Two Slice Pullback Stripping Geometry

This technique includes stripping of the overburden layers in two passes. According to the logic embedded into the model, operations begin with excavation and spoiling of the upper slice waste into the previously excavated pit. This step is followed by the preparation of a spoil side pullback pad on which the dragline employed on this side excavates and spoils the lower slice material and part of the material used to construct the pullback pad. The last step in this technique is the extraction of the uncovered coal seam and preparing an empty pit for the spoiling of material from adjacent passes. A series of views showing the phases of this technique are illustrated in Figure 3.42. The developed methodology on determining required dragline and pit dimensions is presented in Figure 3.43.

3.8.6.2. Geometrical Aspects of Design

There have been included numerous dimensional formulations in two slice pullback stripping model. The methodology behind geometrical design aspects are given as follows.

Pit Width

The pit width is assigned as wide a value as possible to minimize the percent rehandle. It is assumed in the model that the upper slice keycut waste is dumped at the toe of the coal seam and the pit width is assigned such a value to allow this operation. However, inclusion of chopping into stripping scheme necessitates an

adjustment in the value of the pit width. Formulations regarding the pit width with and without chopping are given in Appendix B.

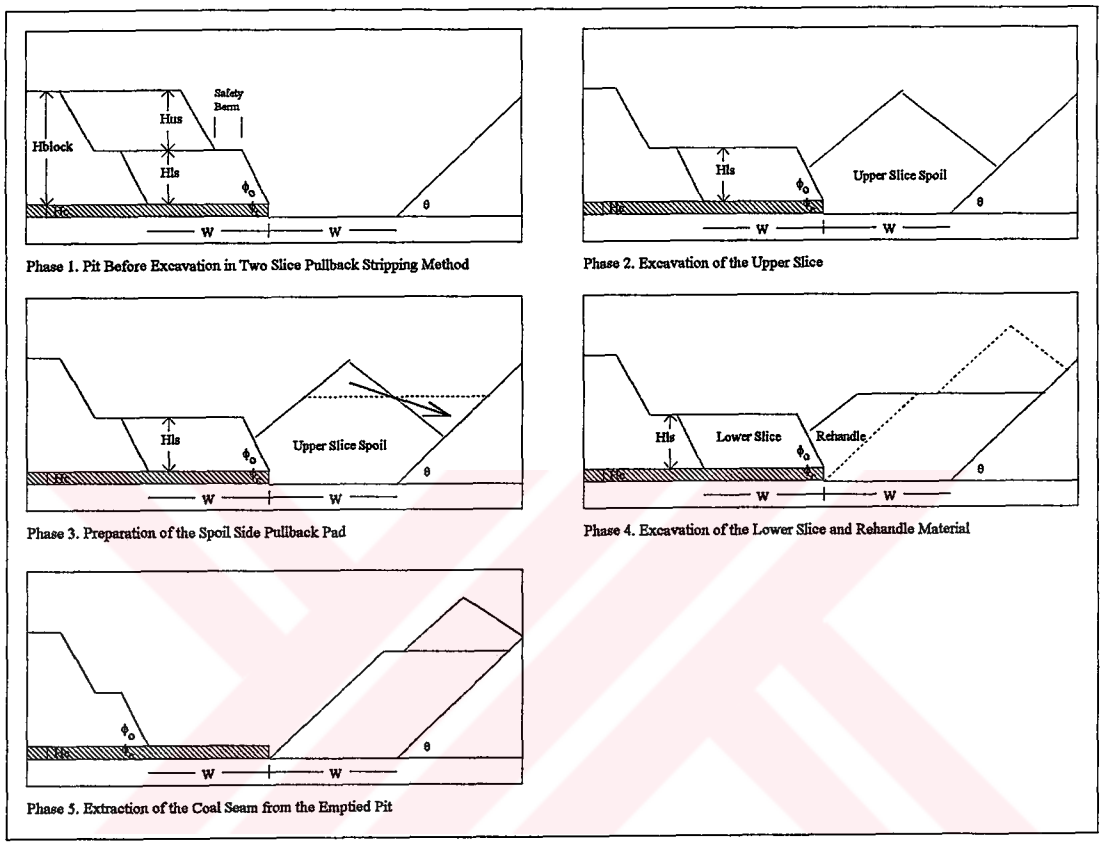


Figure 3.42. A Series of Views Illustrating the Phases in Two Slice Pullback Stripping Model

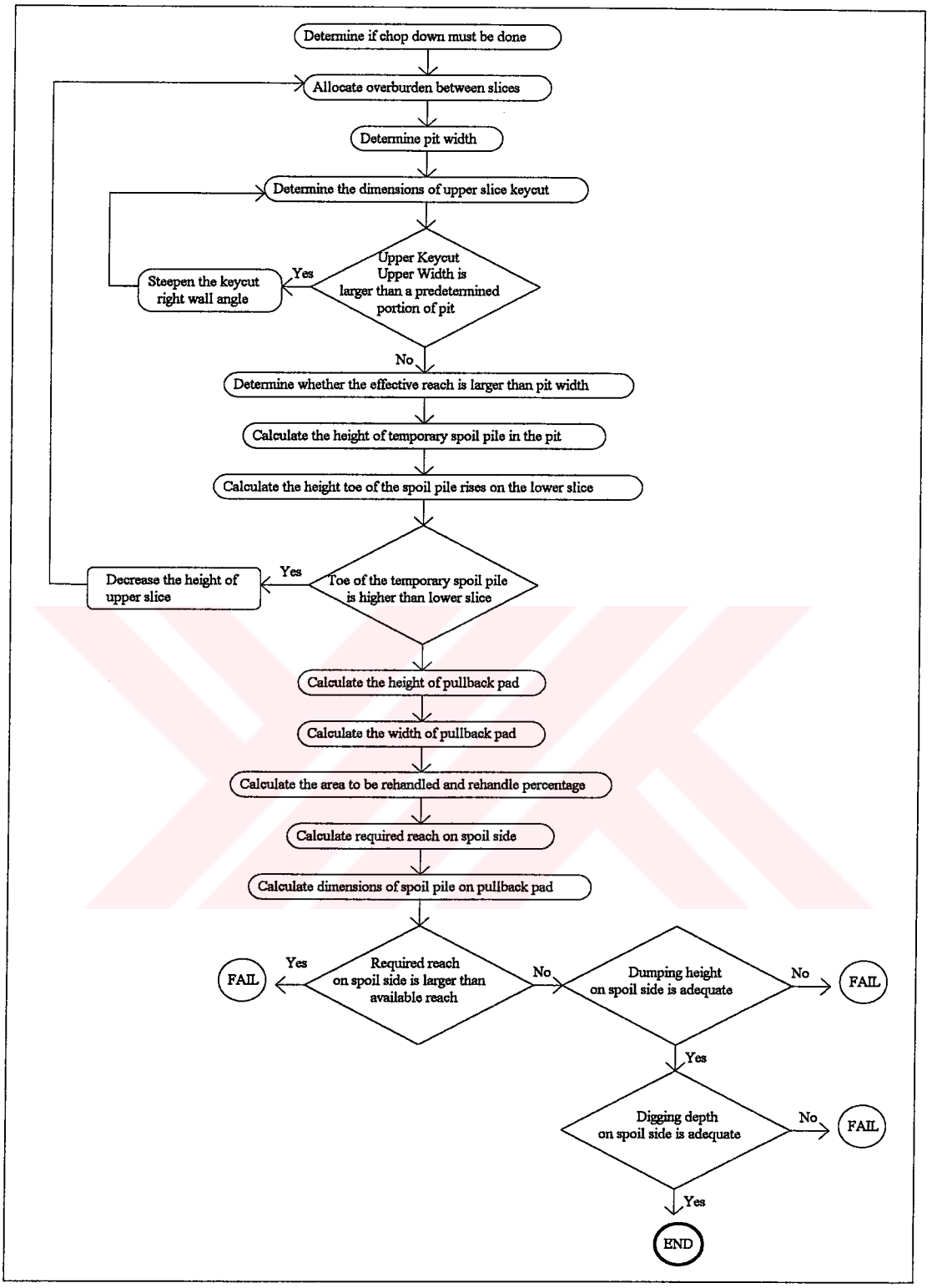


Figure 3.43. The Developed Methodology on Determining Required Dragline and Pit Dimensions in Two Slice Pullback Stripping Model

Allocation of Overburden Slices between Draglines

The model attempts to perform an optimum allocation of overburden into slices. Since this technique utilizes two draglines either in the form of one dragline working on both sides of the pit or two draglines of which each is employed on one side then such an optimum slice sharing must be found that both draglines could excavate their portions. Optimum allocation of slices is of utmost importance because if the thickness of any slice is kept high then the dragline employed on the other side will have to have extremely large working dimensions to compensate the shortcomings caused by this dragline.

The optimized point for the overburden allocation is assumed to exist where two draglines are found in the database each of which meets the working range requirements of its own side. This could be a dragline that is employed on both sides or two draglines each of which is employed on each side of the pit. According to this approach, the dragline employed on the highwall side must have the desired working range requirements for the upper slice and the dragline for the spoils side must be capable to strip the material in the lower slice plus the part of the waste used to construct the pullback pad. The construction of the pullback pad is given in Figure 3.44. Another optimization constraint is the thickness of the upper slice. It should be assigned in such a way that the left-side toe of pile formed by spoiling the material must not rill onto the lower slice thus causing extra reach problems. This case is illustrated in Figure 3.45.

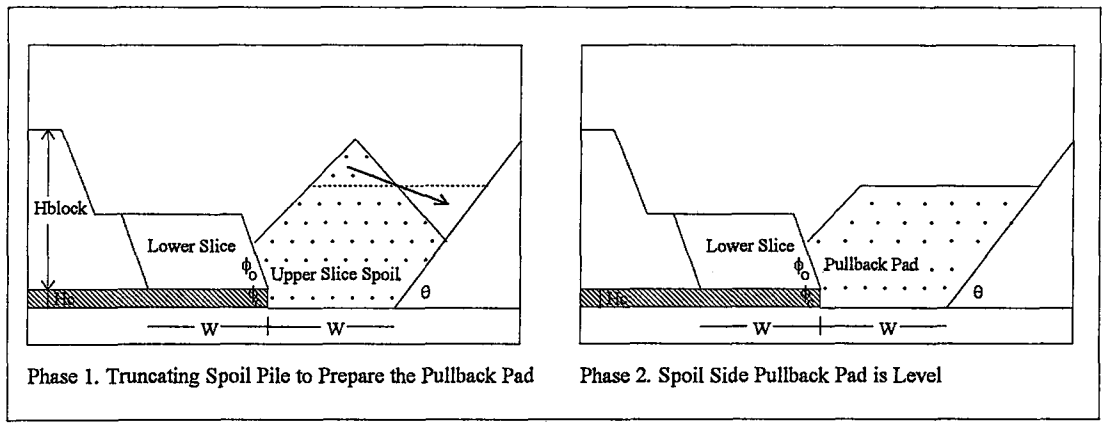


Figure 3.44. Construction of the Spoil Side Pullback Pad

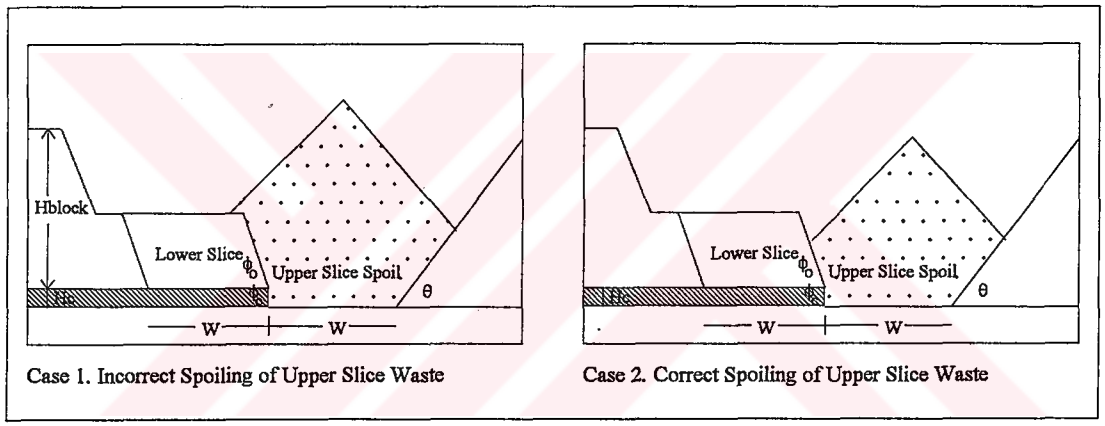


Figure 3.45. View Showing Incorrect and Correct Spoiling of the Upper Slice Waste into the Pit

Height of Temporary Spoil Pile in the Pit

There exist two different formulations of this parameter according to the relative length of effective reach (r) and pit (W). Formulations regarding this parameter are given in Appendix B.

Height and Width of Pullback Pad

The pullback pad on which the spoil side dragline is employed is prepared by filling the hollow part between the intermediate and the previously formed adjacent spoil piles. The area of the truncated material is equal to that of hollow part. By this way the spoil pile is leveled and a pullback is formed. Figure 3.44 illustrates this case. The calculation of the spoil side pullback pad height (H_{pp}) and width (W_{pp}) are given in Appendix B.

Area of Material to be Rehandled and Rehandle Percentage

The formulation of the area of the material to be rehandled in the pullback pad and the rehandle percentage are given in Appendix B.

Required Dumping Radius on Spoils Side

The required dumping radius for the dragline employed on the spoils side is given in Appendix B.

Dimensions of the Spoil Pile Constructed on Pullback Pad

The next step in the model is the determination of parameters related with the placement and location of the lower slice and rehandle materials on the leveled

spoil side. The existence of enough spoil room and stacking capability of the dragline is controlled. The formulas related to above parameters are given in Appendix B.

3.9. Production Simulation Studies

To simulate the way a dragline strips overburden layers, it is essential to firstly comprehend the working principle of a dragline. The components of overburden excavation have been divided into groups of similar function and it has been accepted that stripping is composed of excavation and walking.

Excavation may be in the form of digging the advance bench, key cut, main cut or some sort of rehandling like digging the extended bench or pulling back. The principle behind this operation is digging a full bucket and spoiling it as far as possible onto spoil piles in approximately 60 s (Humphrey, 1990). A dragline excavates from a sitting position as long as there is material in a specific part of the cut.

Dragline walking is interrelated with digging. After finishing excavating a portion of the cut the dragline has numerous alternative places to move. It may move to another sitting position in the same cut or it moves to an adjacent cut or it may walk to another bench or it may cross the pit to continue digging. It takes some time for draglines to prepare before walking and they take a step of nearly 2 meters in approximately 40 s (Erickson, 1994c).

Besides there exist unexpected delays of which frequency of occurrence is not predictable. When determining the coal production rate for a period of time, say a

year, the amount of hours available for stripping is taken into consideration. This is the time left from total hours in that period after deductions are made. The deductions are planned stoppages which include mainly maintenance and holidays. However, not every operation, especially mechanical, must be expected to run at full performance. There is likely to occur numerous break downs during working because of severe operating conditions and heavy loads imposed on draglines. Also electric shortages, mechanical failures and strikes may prevent the dragline from operating in a round-the-clock fashion. All of these factors are unplanned delays and they are not predictable in most times. It must be accepted that this type of delays do occur during stripping and so they must be taken into account as they decrease the efficiency of stripping.

Resolution of Deterministic and Non-Deterministic Variables

Excavation is a process in which the size of individual overburden blocks can be figured out deterministically. Here, volumetric calculations can be performed with exact formulations. However, bucket fill factor and cycle time are two non-deterministic parameters in excavation of which the value is dependent upon numerous factors. It would not be realistic to expect to reach the heaped capacity of bucket in every cycle. In some instances the load could well be more than the rated capacity of the bucket where the material is well-blasted and composed of small-sized particles. However in some other instances digging a boulder could prevent the bucket from carrying its rated capacity due to voids around boulders. Although the mineralogical composition of a particular overburden formation can give signals on its average diggability and blockiness it is almost impractical to predict whether the

material to be dug in a cycle would be small-sized or blocky in nature. For this reason the bucket fill factor is estimated by assigning random values to it.

Estimating the time elapsed to perform a cycle is another element that is hard to calculate exactly. Although the cycle time can be divided into its components, the time spent to perform each component may change largely due to numerous environmental factors involved in cycle time. Again the nature of cycle time lends itself well to random assignment.

Dragline walking is a static process where step length, time to take a step and total time to move from a position to another can be formulated and calculated literally.

Since delays in operations can not be determined prior to occurrence and a formal representation is not possible then they are simulated randomly.

Simulation Methodology

For estimating dragline productivity, Monte Carlo simulation has been applied. Monte Carlo simulation is a scheme employing random numbers, that is, U(0,1) random variables, which is used for solving certain stochastic or deterministic problems where the passage of time plays no substantial role (Law and Kelton, 1982). Thus, Monte Carlo simulations are static rather than dynamic.

The Methodology for Generating Random Variables for Estimating the Values of Non-Deterministic Variables

There are two problems related with the cycle time and bucket fill factor. The first is assigning an approximate value for a specific digging operation and the second is generating random values for each cycle a dragline makes.

To assign a cycle time for each mode of operation, the values proposed by Atkinson (1971) have been used where cycle time values are listed for different bucket capacity ranges and swing angles. In the simulation model, a slight modification has been done on the bucket capacity to accurately allocate a cycle time value for a specific size dragline. For this reason, a regression analysis has been performed where the cycle time was the dependent variable and the bucket capacity was the independent one. To increase the efficiency of analysis, each bucket capacity range was represented as a series of capacities with 5 m^3 increments. After performing statistical analyses, the best relationship was obtained with the multiplicative model where the goodness of fit was around 90%. The results of the regression analyses are presented in Table 3.1. The resulting multiplicative cycle time model is presented in Figure 3.46.

Table 3.1. Results of Regression Models for the Cycle Time Determination for Draglines (for 90 degree swing angle)

Regression Model	Y:Cycle Time (s) X:Bucket Capacity (m^3)	***Intercept a***	***Slope b***	***R^2 (.00)***
Linear	$Y=a+bX$	55.4347	0.0547859	0.8884
Multiplicative	$Y=aX^b$	48.886926	0.0483011	0.9081
Exponential	$Y=\exp(a+bX)$	4.01613	9.29308E-4	0.8830
Reciprocal	$Y^{-1}=a+bX$	0.0180077	-1.5779E-5	0.8772

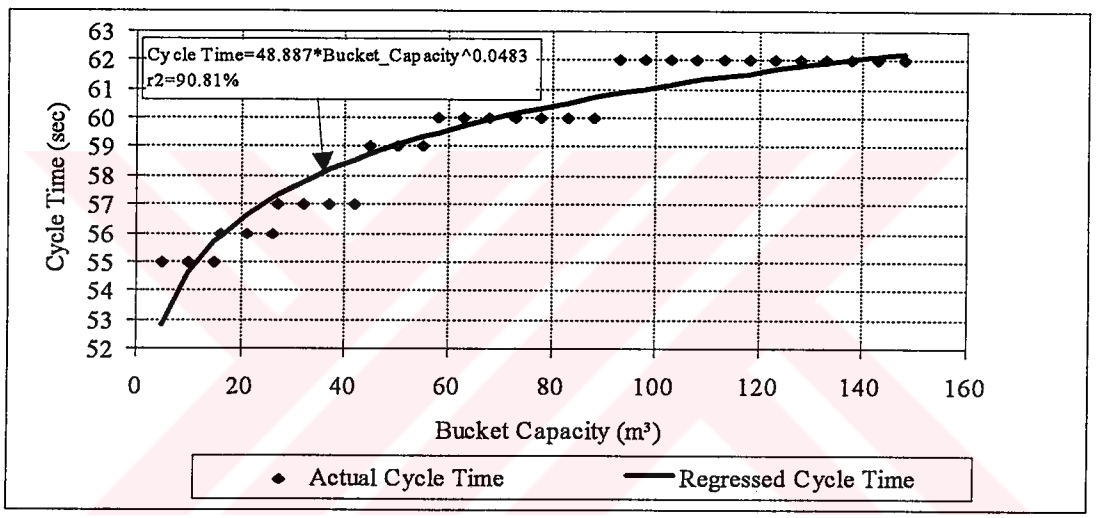


Figure 3.46. Approximating Cycle Time Values by Regressing it On Bucket Capacity

In planning dragline excavation operations, every effort is spent to keep the cycle time at a minimum to increase productivity and in actual operations the cycle time tends to accumulate around a particular value in digging a specific cut. However, there are cases where the cycle time is much lower than the expected value and there are ones where it is much higher. Lower values for cycle time can be experienced

when starting to dig a cut where the dragline starts swinging without waiting for hoisting. Higher values can be experienced in deep-digging situations where hoisting to clear the cut before starting to swinging adds several seconds to cycle time. The way to fill the bucket has also severe impact on the cycle time. This reveals the fact that although the cycle time and bucket filling have a tendency to gather around an average value, it would not be correct to assign the same value throughout the excavation of a cut where the dragline performs hundreds of cycles.

During stripping simulation the value of bucket fill factor and cycle time are estimated for each cycle a dragline performs. For generating these values, normal distribution has been used because of its relative applicability for the nature of these parameters where the majority of values in normal distribution tends to converge to an average both from upper and lower sides. To make sure that a correct stream of random numbers are generated from normal distribution to simulate cycle time and bucket fill factor, a check has been done to compare the generated numbers to those generated using a commercially available statistical software. For this purpose, the random number generator coded into the expert system and STATGRAPHICS V.5 (STSC, Inc., 1991) have been used. For testing, 1500 random numbers have been generated by both programs. It has been observed that the expert system has generated random numbers in a similar way with the commercial program. The resulting histograms for the expert system and the commercial program are given in Appendix C.

In the model the approach developed by Bandopadhyay and Ramani (1979) has been employed to simulate the delays occurring during operations. After finishing each continuous working period, a random number is generated from uniform distribution between 0 and 1. If the generated number is greater than the

availability of dragline stripping system then the operations are delayed for the following time (Equation 3.2). Again to validate that a correct stream of random numbers are generated from uniform distribution, a check has been performed on 1500 randomly generated uniform numbers by both programs. The resulting histograms are shown in Appendix C.

$$Delay = Continuous\ Operating\ Time * (\frac{1}{availability} - 1) \tag{3.2}$$

3.9.1. Production Simulation in the Direct Side Casting Model

Simulation of dragline stripping is an important aspect in assessing the productivity of a dragline prior to commencing overburden removal operations. However, it is essential to firstly decompose and then investigate the problem into geometrical layout of the pit and simulation aspects for stripping estimation.

3.9.1.1. Geometrical Formulation of Block Dimensions Used in Simulation

Numerous formulations have been developed within the context of the study to model geometrical dimensions used in simulation calculations. The reason for this is the necessity of representing pit dimensions in a 3-D environment to calculate the volumetric parameters such as waste tonnage in various sections within a slice.

Besides walking distances within an overburden set have to be determined to estimate the time required to move from one sitting position to another.

This section covers dimensional parameters of a dragline pit for the direct side casting technique. The following range and volumetric parameters are formulized; highwall side setback distance, highwall side set length, bucket capacity of dragline, volume of advance bench, volume of key cut and volume of main cut.

Highwall Side Setback Distance

In dragline stripping simulation, apart from pit geometry terminology, the setback distance is defined as the distance from where the dragline is sitting to the crest of the next set it is excavating and it is measured along the pit advance. Although numerous dragline stripping studies have been performed previously, no information has been made available on how the setback distance is determined (Anonymous, 1977b; Bandopadhyay and Ramani, 1979; Hrebar and Dağdelen, 1979; Manula, et.al., 1979; Sadri and Lee, 1982; Bandopadhyay and Sundararajan, 1986; Lee, 1988; Rodriguez, et.al., 1988; Artan, 1990; Baafi, 1995).

The setback distance is notably important in dragline stripping simulation. The shorter the distance a dragline is set back, the larger the length of the set it can excavate and the more productive it becomes because it can excavate for a longer period of time without moving. However the setback distance must be optimized for a satisfying stripping performance. In the direct side casting simulation model, the optimum setback distance is achieved when the dragline is located on the adjacent set. If after preliminary set length calculations the dragline is located in one of the sets that

are two or more set ahead of the one to be dug (mostly because the set length is shorter due to thick overburden) the model attempts to adjust the setback distance to locate the dragline within the block next to the one to be dug. Setback distance is represented in Figure 3.47.

In the direct side casting simulation model, the setback distance is initially taken equal to 1.75 times the diameter of dragline tub and the set length is determined based on this assumption. However this assumption is subject to modification if the resulting set length is shorter than the setback distance which means that the dragline is located in one of the ahead sets. In such a case, the model attempts to reduce the distance between first and second excavation rows until the set length gets larger than setback distance as illustrated in Figure 3.48. The distance between the second excavation row and the crest of the block is taken at least equal to half the diameter of dragline tub. This distance plus the distance between excavation rows constitute the setback distance.

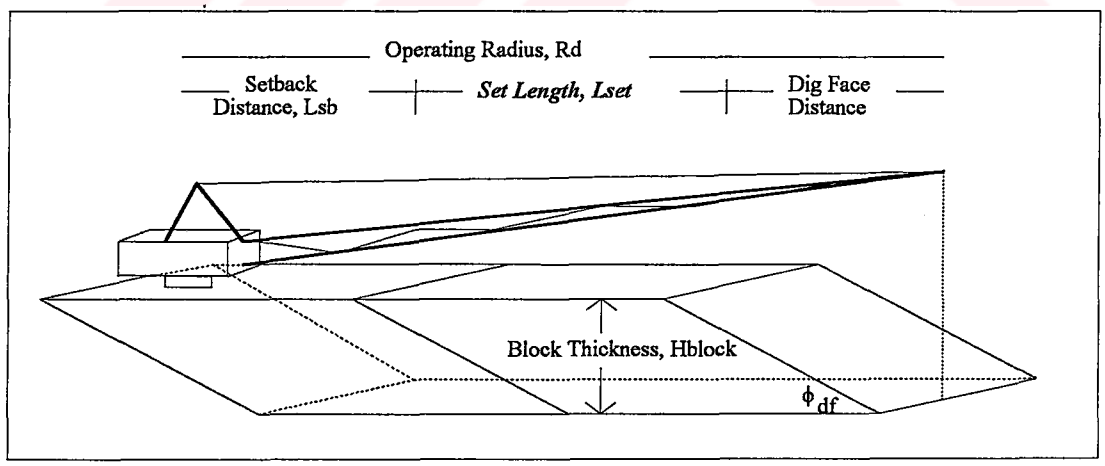


Figure 3.47. Determination of the Set Length with Other Pit Dimensions

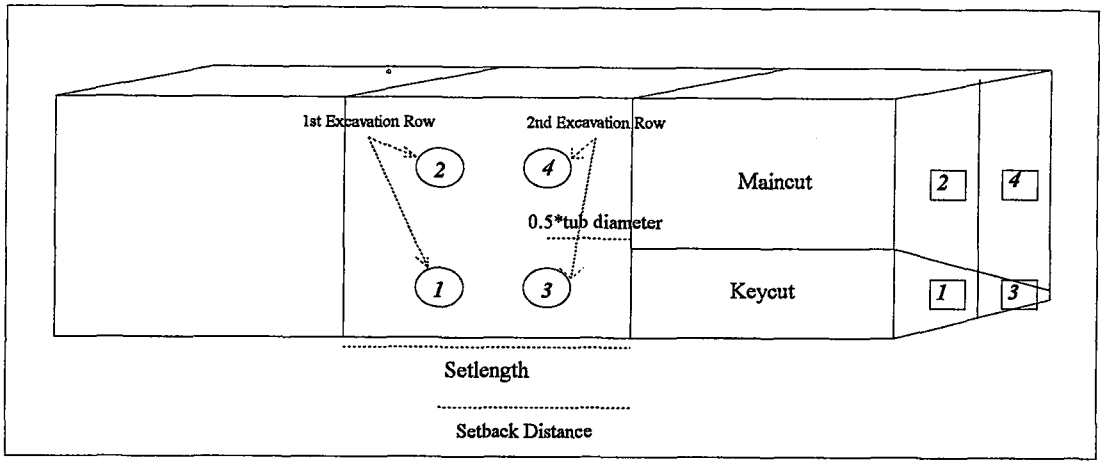


Figure 3.48. Reducing the Distance between Excavation Rows

Set Length

The set length has a large impact in dragline stripping. Like setback distance there can be established a direct relation between the production performance of a dragline with the set length. According to this relation, the longer the set length the more productive is the dragline. The reason is the elimination of unproductive in-pit walking. In cases where a longer set length is planned, the dragline will have to spend more of its time digging. In case where a shorter than optimum set is planned, the dragline will move more frequently thus waste part of scheduled time by this unproductive item. The reason for frequent movements either within the block or between sets is the relatively rapid excavation of each portion in a set. The ultimate aim of set size determination must be to adjust the length as long as possible to force the dragline excavate from one sitting position and prevent it from walking unnecessarily.

Erickson has defined the set length conceptually (1995a, 1995b). The length of the set (or block) is determined in the excavation simulation model by the following formula (Equation 3.3) and a representative illustration is given in Figure 3.47.

$$L_{set} = R_d - L_{sb} - H_{block} * \cot \Phi_{df} \tag{3.3}$$

There exists numerous assumptions in the determination of set length. These are listed below;

1. The basic assumption is that the dragline must be capable to reach the toe of the block with its bucket. In other words, the dragline must be capable to dig every portion of the block within its operation range and determined set length.

2. The dragline must be located in the adjacent block. According to this assumption, the dragline always sits on the block next to the one to be excavated.

3. The block thickness is taken equal to that of overburden strata if there would be carried out no chopping. In cases where chopping is necessary the block thickness is taken the overburden thickness less the chopping height, or the digging depth.

4. The dig face angle (Φ_{df}) is taken as 45 degrees (Erickson, 1995b).

Bucket Capacity of Dragline

Another important parameter the stripping simulation model attempts to conclude is the bucket capacity of dragline(s). The amount of material a dragline could excavate and carry volumetrically is a relative quantity depending dominantly on the density of the material to be dug and on the type of material used in the construction of the bucket (Pundari, 1981; Dupret, 1983; Erickson, 1994a; Riese, 1994a; Govier, 1995). Having realized this concept, it is clear that every unique dragline could be assigned a series of buckets with various capacity depending on the density of the overburden material. As a rule, the lighter the material the larger the bucket capacity or *vice versa*. To avoid underestimating or overestimating a dragline's capacity the stripping simulation model calculates the volumetric capacity of draglines for each session with the following formula (Equation 3.4). In the simulation models, heavy duty type bucket that could be used for most type of stripping operations has been selected of which the unit weight is 694 kg/m³ of the bucket.

$$C_{Buc} = \frac{M.A.L.}{\left(\frac{d_o}{fs} + W_{bucket}\right)} \qquad (3.4)$$

where

C_{buc}:	Bucket capacity of the dragline (m³)
M.A.L.:	Maximum allowable load a dragline could carry (including bucket+rigging) (kg)
d_o:	Insitu density of overburden (kg/m³)
fs:	Swell factor ((100+percent swell)/100)
W_{bucket}:	Weight of bucket per rated cubic meters of bucket (kg)

Volume of Advance Bench

In the stripping models chopping is performed only when the digging depth of a dragline is not adequate for the block assigned to it. In case where chopping is necessary, the excavation of corresponding advance bench volumes are designed to complete in two cycles. The first portion is stripped with upper key and main cuts and the second one is dug with lower key and main cut material. The width of the advance bench is taken equal to that of the pit. Formulations related to advance bench volume are given in Appendix D.

Volume of Key and Main Cuts

According to the logic embedded into the stripping simulation model, the keycut and the maincut blocks are divided into two sub blocks. Formulation of the keycut and maincut dimensions is given in Appendix D.

Geometrical Formulation of Distances between Sitting Points

In direct side casting stripping model, there exist two rows of sitting points. A dragline excavates upper slices from the first row and the lower ones from the second row (Anonymous, 1993a). The distance between points on which a dragline sits and excavates are determined regarding whether chopping is included into the system or not.

Distance between Points When No Chopping is Included

When the overburden removal operations in direct side casting model do not include chopping, a dragline makes 4 moves to strip the waste volume in the slice. According to this logic the upper portions of key and main cuts are stripped from the first row and lower portions from the second row. Formulations related to distances between sitting points are given in Appendix D.

Distance between Points When Chopping is Included

When the overburden removal operations in direct side casting model include chopping, a dragline makes 6 moves to strip the waste volume in the slice. According to this logic upper portions of key and main cuts and chopping volume #1 are stripped from the first row and lower portions of key and main cuts plus chopping volume #2 from the second row. Formulations related to distances between sitting points are given in Appendix D.

3.9.1.2. Excavation Hierarchy of the Direct Side Casting Model

In the direct side casting simulation model the excavation of a set (block) is completed in two cycles. The block is divided into an upper and a lower slab. In the first cycle the upper portion of the block is dug and in the second one the lower part is stripped. If chopping is included into the excavation cycle then it is performed in both cycles.

Excavation of Slice When No Chopping is Done

The excavation of a slice which is composed of a key and a main block is performed in the following order. The digging sequence is listed below and a representation of the moves the draglines makes while excavation is presented in Figure 3.49.

1. Locate on ①.
2. Excavate upper portion of the keycut (❶).
3. Walk to ②.
4. Excavate upper portion of the maincut (❷).
5. Walk to ③.
6. Excavate lower portion of the keycut (❸).
7. Walk to ④.
8. Excavate lower portion of the maincut (❹).
9. Walk to ①' of the adjacent block.

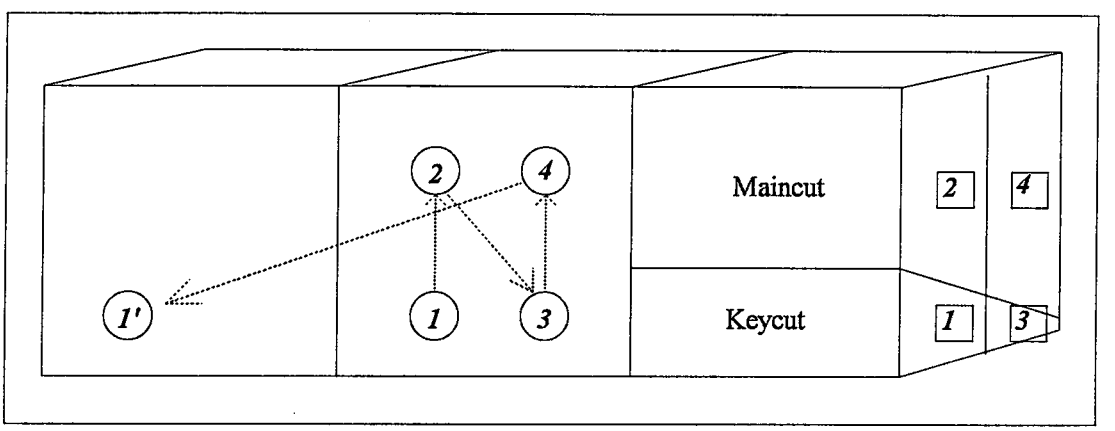


Figure 3.49. Digging Sequence When No Chopping is Done

Excavation of Slice When Chopping is Done

In cases where chopping is included into the stripping scheme, excavation of a slice is performed in a different way that two more sitting positions are added into the excavation rows. The digging sequence is listed below and a representation of the moves the draglines makes while excavation is presented in Figure 3.50.

1. Locate on ①.
2. Excavate Chopping portion (❶).
3. Walk to ②.
4. Excavate upper portion of the keycut (❷).
5. Walk to ③.
6. Excavate upper portion of the maincut (❸).
7. Walk to ④.
8. Excavate Chopping portion (❹).
9. Walk to ⑤.
10. Excavate lower portion of the keycut (❺).
11. Walk to ⑥.
12. Excavate lower portion of the maincut (❻).
13. Walk to ①' of the adjacent block.

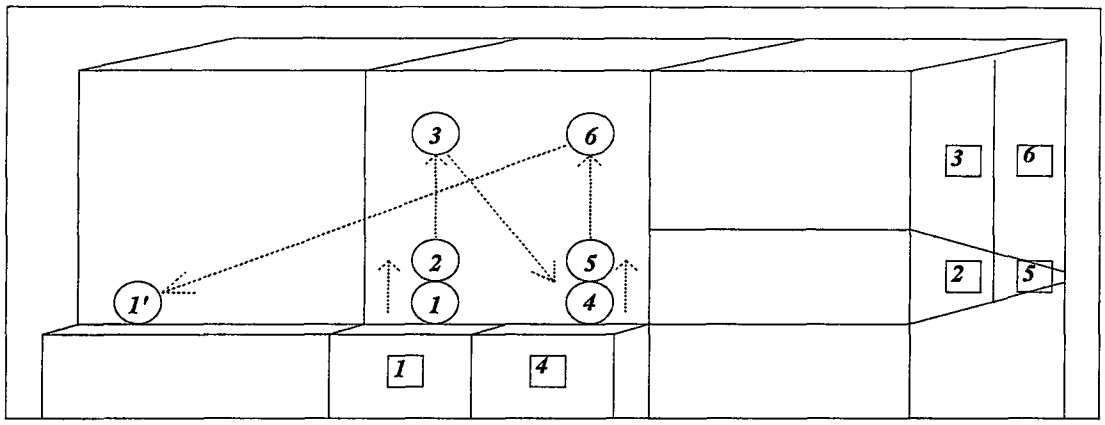


Figure 3.50. Digging Sequence When Chopping is Done

The Methodology for Determining the Time Spent During Walking Between Points

The time spent during walking between blocks or within the block is calculated in two ways depending on the availability of hourly walking speed of draglines. It has been accepted that the dragline follows the shortest path available between two points, walking diagonally rather than in a rectilinear way. The logic developed to determine the time spent for walking is given in below formula (Equation 3.5),

Walktime, s = (# of steps to move)*(time required for a step, s) (3.5)

Number of steps required to move from one sitting point to another is calculated below (Equation 3.6),

$\#_{step}$=(Distance between two points, m)/(Length of a step, m) (3.6)

The time required to take a step when the hourly walking speed is known is calculated by the following way (Equation 3.7),

time for a step, s = (Length of step, m)*(3600 s/h)/(hourly speed, m/h) (3.7)

In case where the hourly walking speed of a dragline is not known, an assumption is made to estimate the number of steps a dragline could take in an hour. Erickson (1994c) states that most draglines are designed to take a step every 40 s. In such a case, a dragline is allowed to take 90 steps in an hour as shown in Equation 3.8,

#steps/h = (3600 s/h)/(40 s/step) = 90 steps/h (3.8)

3.9.2. Production Simulation in the Extended Bench Casting Model

Simulation gains particular importance in this method because extended bench casting includes rehandling which slows down stripping operations and so the coal production. By simulating the dragline stripping scheme, it can be realized whether the projected production rate could be reached.

3.9.2.1. Geometrical Formulation of Block Dimensions Used in Simulation

In the extended bench casting model, the determination of volumes of the advance bench, key and main cuts are similar to those described in the direct side casting model and only the volume of the part to be rehandled in the extended bench is given in this section.

Volume of the Part to be Rehandled in Extended Bench

In the extended bench production simulation model, the extended bench is split into two parts as upper and lower rehandle slices and part of extended bench that has to be rehandled is stripped in two cycles along with the key and main cuts. Formulations regarding volume of upper and lower parts to be rehandled are given in Appendix D.

Geometrical Formulation of Distances between Sitting Points

In extended bench casting model, there exist two rows of sitting points. A dragline excavates upper slices from the first row and the lower ones from the second row. The distance between points on which a dragline sits and excavates are determined regarding whether chopping is included into the system or not.

Distance between Points When No Chopping is Included

When the overburden removal operations in extended bench production simulation model do not include chopping, a dragline makes 4 moves to strip the waste volume in the slice. According to this logic the upper portions of key and main cuts are stripped from the first row and lower portions from the second row. Formulations related to distances between sitting points are given in Appendix D.

Distance between Points When Chopping is Included

When the overburden removal operations in direct side casting model include chopping, a dragline makes 6 moves to strip the waste volume in the slice. According to this logic upper portions of key and main cuts and chopping volume #1 are stripped from the first row and lower portions of key and main cuts plus chopping volume #2 from the second row. Formulations related to distances between sitting points are given in Appendix B.

3.9.2.2. Excavation Hierarchy of the Extended Bench Simulation Model

As in the direct side casting production simulation model, excavation of a set is completed in two cycles. In the first cycle the upper portion of the block is dug and in the second one the lower part is stripped. In case chopping is done, each advance bench block is taken in each cycle.

The main difference of the extended bench casting model comes from the point that not all the material excavated from the set is cast onto the spoil pile but the material from the keycut and advance bench is used to build the extended bench. In the simulation model, the extended bench is constructed near the set that is adjacent to the one the dragline sits on. In other words, extended bench construction operation advances two sets ahead of spoiling operations and the dragline is located on a set of which the extended bench has been built and flattened by dozers. It has also been assumed that a dragline, once located on a set, excavates material in the maincut and extended bench block from the same sitting position.

Excavation of Slice When No Chopping is Done

Excavation of a slice which is composed of a key, a main block and the part of the extended bench to be rehandled is performed in a hierarchical order. The digging sequence is listed below and a representation of the moves the draglines makes while excavation is presented in Figure 3.51.

1. Locate on ①.
2. Excavate Upper Portion of Key Cut (❶).
3. Walk to ②.
4. Excavate upper portion of the maincut (❷).
5. Excavate upper portion of the Extended Bench (❷).
6. Walk to ③.
7. Excavate lower portion of the keycut (❸).
8. Walk to ④.

9. Excavate lower portion of the maincut (❹).
10. Excavate lower portion of the Extended Bench (❹).
11. Walk to ①' of the adjacent block.

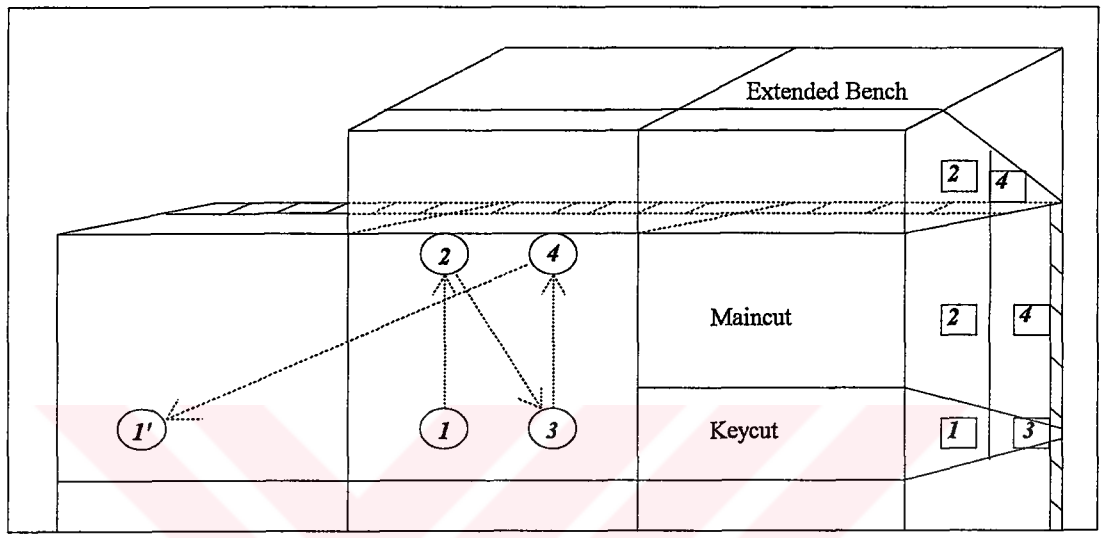


Figure 3.51. Digging Sequence When No Chopping is Done

Excavation of Slice When Chopping is Included

The digging sequence of the slice when chopping is done is listed below and a representation of the moves the draglines makes while excavation is presented in Figure 3.52.

1. Locate on ①.
2. Excavate Chopping portion (❶).

3. Walk to ②.
4. Excavate upper portion of the keycut (❷).
5. Walk to ③.
6. Excavate upper portion of the maincut (❸).
7. Excavate upper portion of the Extended Bench (❸).
8. Walk to ④.
9. Excavate Chopping portion (❹).
10. Walk to ⑤.
11. Excavate lower portion of the keycut (❺).
12. Walk to ⑥.
13. Excavate lower portion of the maincut (❻).
14. Excavate lower portion of the Extended Bench (❻).
15. Walk to ①' of the adjacent block.

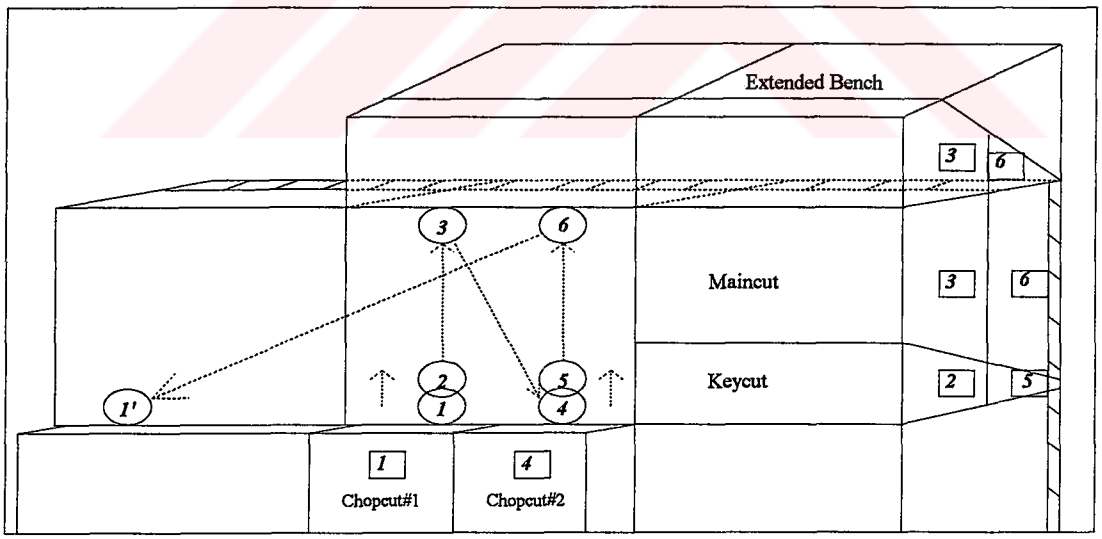


Figure 3.52. Digging Sequence When Chopping is Done

3.9.3. Production Simulation in the Pullback Stripping Model

Pullback stripping is the first method mentioned so far that utilizes one or two draglines in stripping. Long deadheading across the pit in one dragline case and the need to synchronize the draglines in tandem dragline case makes the simulation of operations in this method more complicated than previous ones.

3.9.3.1. Geometrical Formulation of Block Dimensions on Highwall Side Used in Simulation

In the pullback stripping model, the determination of volumes of the advance bench and keycut are similar to those described in the direct side casting model and the volume of the maincut is given in this section.

Volume of Main Cut

Calculation of the main cut volume in pullback stripping model differs from those in previous models because of the highwall barrier. Formulation of the main cut and components is given in Appendix D.

3.9.3.2. Geometrical Formulation of Block Dimensions on Spoil Side Used in Simulation

The formulations regarding dimensional parameters on spoil side of the pit are different from those on highwall side in the pullback stripping model. A dragline makes simpler moves and excavates only the rehandle material plus the waste in the barrier left unexcavated on the highwall side. Following range and volumetric parameters are formulized; setback distance, set length and volume of rehandle material.

Setback Distance

The setback distance on spoil side is taken equal to ¾ of the tub diameter of dragline plus the range from the edge of the final spoil pile to that of pullback pad. It is measured from the edge of pullback pad to the center of rotation of the dragline. The setback distance is formulized in Appendix D.

Set Length

The set length on the spoil side is determined on the assumption that a dragline can reach and excavate the barrier and rehandle materials from one sitting position without moving within the block. In other words, after positioning at a specific point on spoil side the dragline is capable to strip all the barrier and rehandle materials without locating at another point. The spoil side set length is formulized in Appendix D.

Volume of the Rehandle Material

In the pullback stripping production simulation model, the highwall barrier and the rehandle material in the pullback pad is stripped in one cycle. The formulation regarding the volume of rehandle part is given in Appendix D.

Geometrical Formulation of Walking Distances between Sitting Points on Spoil Side

In the pullback stripping simulation model, there exists only one row of sitting points on spoil side. A dragline, after positioning at the midpoint of the block on the pullback pad, excavates the barrier material and the waste to be rehandled in the pullback pad from one sitting position. The dragline makes no in-block movements on this side. The only movement is passing to the adjacent block after all the material is dug. The distance a dragline takes is equal to the set length on spoil side. The distance between sitting points is given in Appendix D.

Geometrical Formulation of Walking Distances between Highwall and Spoil Sides

When one dragline is employed for excavation in the pullback stripping simulation model, it makes periodic sojourns between either side. However, a dragline is only allowed to pass to another side when it has finished digging the material on one side. So, after excavating the material on the highwall side along the user-defined block length, a dragline passes to the spoil side from the end of the pit and walks

down to the starting point of the pit on the leveled pullback pad. The dragline rehandles the material in the pullback pad and digs that in the highwall barrier until it finishes excavating the waste blocks on the spoil side. Finally it walks to highwall side to continue stripping another block. The distance a dragline walks to pass from the highwall side to the spoil side and from the spoil side to the highwall side are given in Appendix D.

3.9.3.3. On the Simulation Methodology of the Pullback Stripping Model

The pullback stripping model allows employment of both one or two dragline systems. In case of one dragline employment, the dragline strips a full length of the cut before it moves to the spoil side.

In case where two draglines are allowed to operate, each dragline is assigned a side of the pit. The one working on highwall side is called the independent dragline and the one on spoil side is called the dependent dragline because the stripping performance of the spoil side dragline is totally dependent on that of highwall side dragline. It can only start stripping its allocated part after highwall side dragline has finished stripping and moved to an adjacent cut.

The production simulation logic of the highwall side dragline is similar to the direct side casting model. However, the dragline employed on spoil side makes no movements before it completely finishes the rehandle and barrier volumes. In the model, a gap of 3 set lengths is always left between two draglines to prevent them from approaching to each other inadmissibly (Niemann-Delius and Thiels, 1988) and

to allow pullback pad preparation. According to this methodology the distance between draglines is taken at least 3 set lengths. Here it is clear that if draglines are mismatched then one of them will suffer either from waiting or from missing the coal production rate. In case where the linear advance rate of dependent dragline is higher than the independent dragline, it will slow down by frequently halting operations. In case where the independent dragline is producing at a faster rate, the required coal production rate may be missed because it is the dependent dragline that completely uncovers the coal seam.

Excavation Hierarchy of the Pullback Stripping Model

The excavation of blocks on highwall side is similar to that performed in direct side casting technique. However the excavation sequence on pullback side is completely different from conventional way.

Excavation Sequence on Spoil Side

Excavation of a set of waste on spoil side is composed of sequential digging of the rehandle material and the waste in the barrier left on highwall side. The digging sequence is listed below and a representation of the moves the draglines makes while excavation is presented in Figure 3.53.

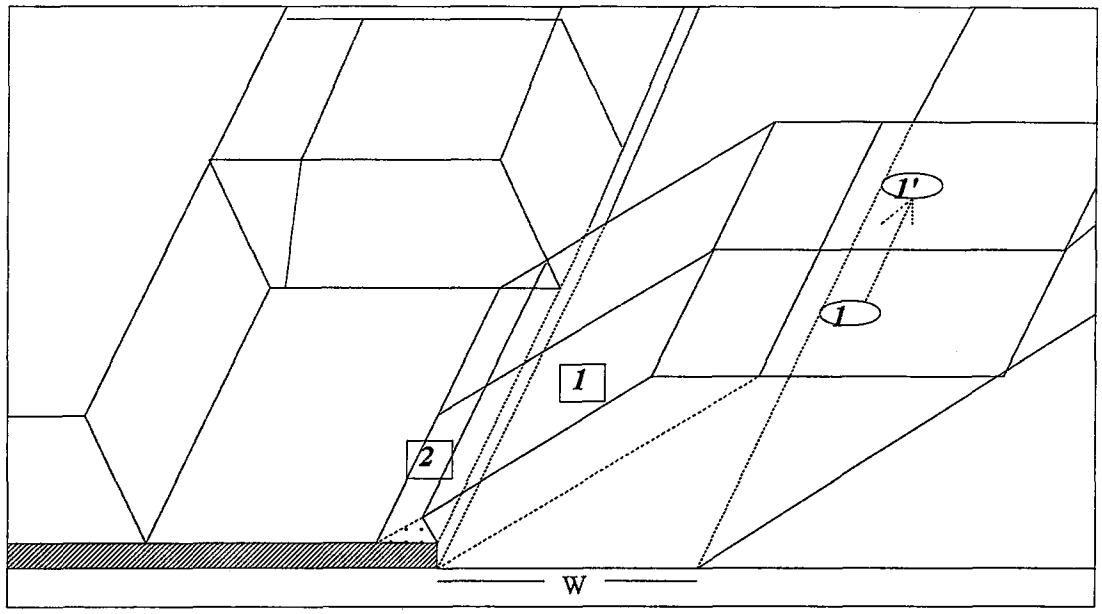


Figure 3.53. Moves a Dragline Makes When Digging on Spoil Side

1. Locate on ①.
2. Excavate Rehandle Area (❶).
3. Excavate Waste in the Barrier (❷).
4. Walk to ①' of next block.

3.9.4. Production Simulation in the Two Slice Direct Side Casting Model

The two slice direct side casting method is characterized by the employment of one or two draglines and stripping the overburden layers in two slices. Simulating the stripping scheme in this method is beneficial from several points as it clarifies the achievement of the required coal production. Besides, likely performance

of tandem dragline system can be illustrated and the linear advance of upper and lower draglines can be matched.

3.9.4.1. Geometrical Formulation of Upper and Lower Slice Dimensions Used in Simulation

This section covers dimensional parameters of a dragline pit for the two slice direct side casting technique. The following range and volumetric parameters are formulized; volume of key cut and volume of main cut.

Geometrical Formulation of Walking Distances between Upper and Lower Slices

In case one dragline is employed for overburden removal, it has to walk between slices to uncover the coal seam. In the two slice direct side casting simulation model, however, a dragline is allowed to pass to another slice when it has finished digging all the waste along a block. After starting digging the material on the highwall side along the user-defined block length, a dragline continues stripping the upper slice until it has finished removing all the waste in this slice. Then it walks down on the lower slice from a ramp and moves to the point where it has started stripping. As in the upper slice, it excavates the lower slice in the same manner. Finally it walks up on to the upper slice to continue stripping another block.

The inclination of dragline ramps has been taken between 4 and 10 degrees among researchers (Anonymous, 1979a; Chironis, 1983; Baafi, et.al., 1995).

In the production simulation models, the dragline ramp grade has been taken as 10 degrees as recommended by the Bucyrus-Erie Co. (Anonymous, 1979a). The distances a dragline walks to pass from the upper slice to the lower slice and from the lower slice to the upper slice are given in Appendix D.

3.9.5. Production Simulation in the Lower Slice Extended Bench Casting Models

The lower slice extended bench methods like other two slice techniques, are characterized by the employment of one or two draglines, stripping the overburden layers in two slices and rehandling part of the waste in the extended bench. Simulating the stripping scheme prior to application has significant advantages. Employment of two draglines in a pit may create sequencing problems and result in inefficient operations if the linear advance rate of draglines can not be matched. In one dragline employment, however, the required coal production target may be missed due to frequent walking of dragline between blocks.

3.9.5.1. Geometrical Formulation of Upper and Lower Slice and Extended Bench Dimensions Used in Simulation

This section covers dimensional parameters of a dragline pit for the limited and full bench extension patterns. Since the volume of key cut and volume of main cut have been formulized in the Two Slice Direct Side Casting model, only the dimensions related to limited and full bench extensions are formulized in this section.

Walking Distances between Sitting Points on the Lower Slice Extended Bench Methods

In the lower seam extended bench casting simulation models, the dragline working on the lower slice has two rows of excavation. It has been designed in such a way that draglines are located in two positions in a row. The first position is in the midpoint of the keycut and the second position is where the dragline is nearest to the final spoil pile. Since the material from the lower slice keycut is not used to extend the bench, it is spoiled within the ultimate spoil pile area (Erickson, 1995d; Govier, 1995). In the simulation model, the keycut spoil is dumped beyond the final spoil pile not to triple handle the material in the extended bench. The second point is placed where the dragline is closest to the final spoil pile. The distances between sitting points are given in Appendix D.

3.9.5.2. Excavation Sequence on Lower Slice

Excavation of a set of waste on the lower slice is composed of sequential digging of the lower slice waste and the rehandle material in the extended bench. As in the previous methods, a full slice is stripped in two cycles. In the first cycle the dragline sits a distance from the dig face and takes the upper slabs. It is followed by getting closer to the dig face and excavation of the lower slabs. The digging sequence is listed below and a representation of the moves the draglines makes while excavation is presented in Figure 3.54.

1. Locate on ①.
2. Excavate Upper Portion of Key Cut (❶).
3. Walk to ②.
4. Excavate upper portion of the maincut (❷).
5. Excavate upper portion of the Lower Slice Extended Bench (❷).
6. Walk to ③.
7. Excavate lower portion of the keycut (❸).
8. Walk to ④.
9. Excavate lower portion of the maincut (❹).
10. Excavate lower portion of the Lower Slice Extended Bench (❹).
11. Walk to ①' of the adjacent block.

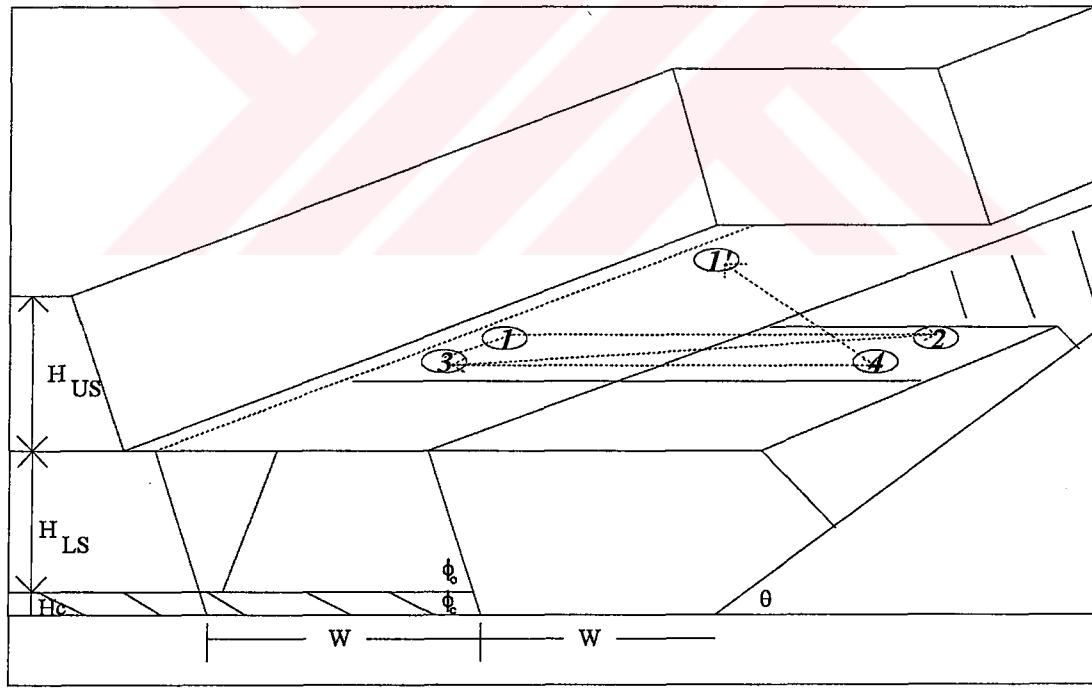


Figure 3.54. Moves a Dragline Makes When Digging on the Lower Slice

3.9.6. Production Simulation in the Pullback Stripping Simulation Model

In the two slice pullback stripping method, the performance of the dragline operating on the pullback pad is of prime importance because of higher than normal swing angles that increase the cycle time notably and the availability of a limited volume spoil room makes the application of this method more difficult. By simulating the overburden removal scheme in the two slice pullback stripping, the likely capability of one or two dragline systems can be clarified.

3.9.6.1. Geometrical Formulation of Block Dimensions on Spoil Side Used in Simulation

The formulations regarding dimensional parameters on spoil side of the pit are different from those on highwall side in the two slice pullback stripping model. The dragline excavates the rehandle material and the waste in the lower slice from the spoil side. The following range and volumetric parameters are formulized; setback distance, set length, volume of rehandle material and volume of lower slice.

Setback Distance

The setback distance is taken equal to ¾ of the tub diameter of dragline plus the length from the edge of the final spoil pile to that of pullback pad. This distance is taken from the edge of pullback pad to the center of rotation of the dragline. The setback distance is formulized in Appendix D.

Set Length

The set length on the spoil side is determined on the assumption that a dragline can reach and excavate the barrier and rehandle materials from one sitting position without moving within the block. In other words, after positioning at the midpoint of the set on spoil side the dragline is capable to strip all the waste in the lower slice and the pullback pad. However in actual cases this does not reflect the reality due to arching action of a dragline during swinging. When attempting to dig the rehandle and lower slice materials, a dragline fails to reach every point in the lower slice due to swinging on an arc. This inconvenience has been attempted to overcome by taking the spoil side set length half of its calculated value. The spoil side set length is formulized in Appendix D.

Volume of the Lower Slice and the Rehandle Material

In the two slice pullback stripping production simulation model, the lower slice and the rehandle material in the pullback pad is stripped in one cycle. The formulation regarding the volume of rehandle part and the lower slice are given in Appendix D.

Geometrical Formulation of Distances between Sitting Points on Spoil Side

In two slice pullback stripping model, there exists only one row of sitting point on spoil side. A dragline, after positioning at the midpoint of the block on the

pullback pad, excavates the lower slice material and the waste to be rehandled in the pullback pad from one sitting position. The dragline makes no in-pit movements on this side. The only movement is performed after all the material is dug to pass to the adjacent block. The distance the dragline takes is equal to the set length on spoil side. The formulation related to the distance between blocks is given in Appendix D.

3.9.6.2. Excavation Sequence on Spoil Side

Excavation of a set of waste on spoil side is composed of sequential digging of the rehandle material and the waste in the lower slice on highwall side. The digging sequence is listed below and a representation of the moves the draglines makes during excavation is presented in Figure 3.55.

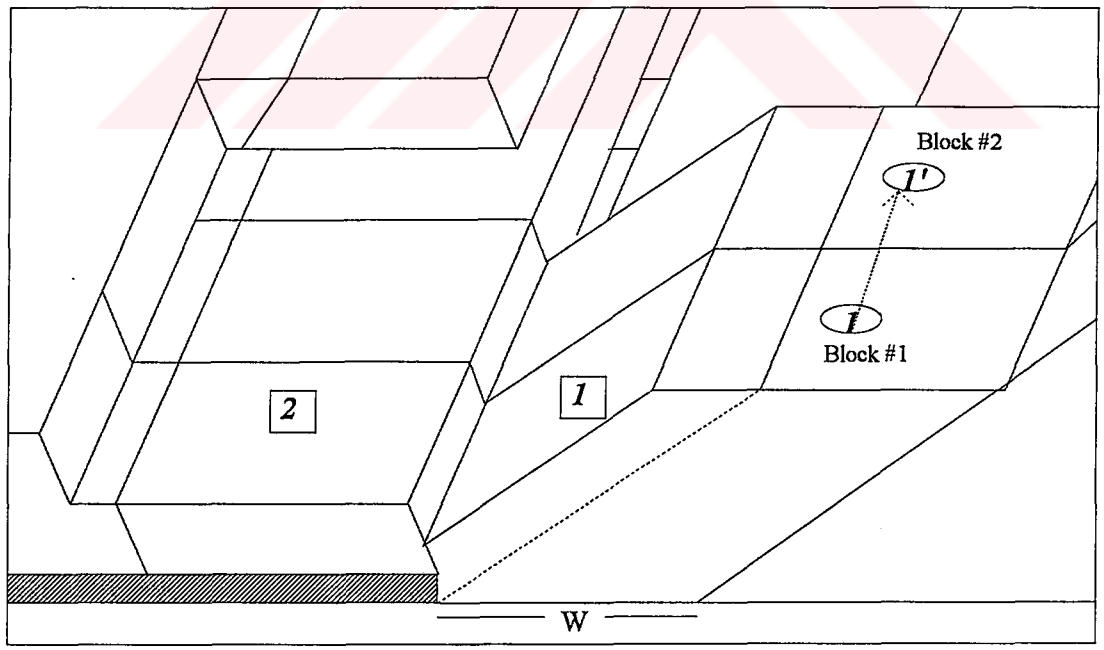


Figure 3.55. Moves a Dragline Makes When Digging on Spoil Side

1. Locate on ①.
2. Excavate Rehandle Area (❶).
3. Excavate Waste in the Lower Slice (❷).
4. Walk to ①' of next block.

3.10. Stripping Cost Determination Studies

Determining a series of draglines' suitability for stripping can only be achieved by ranking them on some basis and the cost of stripping has always been the bottom line in dragline selection (Anonymous, 1993a).

Determination of the stripping cost in the expert system has been done on two bases; the cost per scheduled hour and the cost per bank cubic meter of waste. The methodology to compute these cost items is to calculate the yearly cost and divide it by the desired unit. The currency used in cost calculations is the American dollar (US$). Because the currency for buying draglines, necessary attachments and spare parts is the US$.

The methodology to compute the cost of stripping is similar to that recommended by the MARION Power Shovel Company (Anonymous, 1993a). However, the stripping cost model of the expert system has been enlarged to cover the cost of stripping in terms of the desired amount to be removed. These cost items have been explained in the following sections.

3.10.1. Hourly Cost of Stripping

The hourly cost of a dragline comprises of both owning and operating items. The duration mentioned in this cost criterion is one hour of scheduled working time. The hourly cost is computed by calculating the yearly cost of a dragline and dividing it by the scheduled working hours.

3.10.2. Cost of Stripping of 1 m³ of Waste

The cost per cubic meter of waste comprises of both owning and operating costs and is computed by dividing the yearly cost of a dragline to the bank volume of overburden spoiled. In the expert system, the cost of stripping per unit volume of waste has been calculated on three bases. These are explained below:

- ***Stripping Cost in Terms of Total Volume Removed***: The total volume is defined as the amount of waste a dragline has stripped within a given period of time and it includes rehandling (Anonymous, 1993a; Parlak, 1993). In the model, this item is computed by taking into consideration the total volume moved and the total cost to move the total volume. It is formulized with the following equation (Equation 3.9)

$$Cost_{Total} = \frac{Owning\ and\ Operating\ Cost\ (\$/year)}{Total\ Volume\ \ (bank\ m^3)} \qquad (3.9)$$

- ***Stripping Cost in Terms of Prime Volume Removed***: The prime volume is defined in the stripping cost model as the volume of overburden a dragline has stripped within a given period of time and does not include rehandling. For instance, the prime volume will be 4,000,000 bank m^3 in a stripping operation where the total volume is 5,000,000 bank m^3 and the percent rehandle is 25%. In the stripping cost model, this item is computed by taking into consideration the prime volume moved and the total cost to move the total volume. It is formulized with the following equation (Equation 3.10).

$$Cost_{\Pr ime} = \frac{Owning\ and\ Operating\ Cost\ (\$ / year)}{\Pr ime\ Volume\ \ (bank\ m^3)} \qquad (3.10)$$

- ***Stripping Cost in Terms of Desired Volume Removed***: The desired volume is defined as the prime volume of overburden above the coal that was uncovered and does not include rehandling (Anonymous, 1993a). This cost item is different from those previously mentioned in that previous ones are related with the stripping capacity of draglines while this one is related with the projected coal extraction goal. In the stripping cost model of the expert system, the draglines are ranked in the order of stripping cost. The optimum dragline that the expert system advises is the one with the lowest stripping cost and the ranking mechanism is based on the stripping cost in terms of the desired volume. In the stripping cost model, this item is computed by taking into consideration the desired volume to be moved and the total cost to move the total volume. It is formulized with the following equation (Equation 3.11).

$$Cost_{Desired} = \frac{Owning\ and\ Operating\ Cost\ (\$ / year)}{Desired\ Volume\ (bank\ m^3)} \quad (3.11)$$

3.10.3. Decomposition of Stripping Cost Items

The cost of overburden removal is mainly composed of the owning and operating costs each of which in turn involves numerous parameters. Below is a line-by-line explanation of these parameters.

Ownership Cost

The ownership cost is composed of the following factors;

- *Purchase Price* : This is the F.O.B. factory price of the dragline. To get prices of draglines, the three dragline manufacturers have been communicated and estimated prices have been obtained (Erickson, 1994b; Riese, 1994b; Özdoğan, 1996).

- *Options and Extras* : It has been reported that 3 to 7% of the purchase price is a good average (Anonymous, 1993a). This includes one extra bucket and a standard selection of options. This factor has been taken as 5%.

- *Freight* : Cost of freight has been calculated as if the dragline has been shipped to Turkey. Calculation of the freight charge must take into account the shipping weight of a particular dragline, so dragline manufacturers have been

communicated and these values have been obtained (Erickson, 1994b; Riese, 1994b; Anonymous, 1981d). Estimation for freight charge is $60/ton for a 1600 km ship distance (Anonymous, 1993a).

- *Trail Cable* : The length of the trail cable has been taken as 500 m. The cost of cable is $100/m (Anonymous, 1993a).

- *Sub Total* : This is the sum of purchasing, options and extras, freight and trail cable costs.

- *Ballast* : Specific ballast requirement of draglines has been obtained from dragline catalogs (Anonymous, 1981b; Anonymous, 1981c; Anonymous, 1981d). The cost of ballast is estimated at 210$/ton (Anonymous, 1993a).

- *Erection* : It is estimated that 26 to 30 man hours are required to erect per ton of ship weight (Anonymous, 1993a). Erection cost has been calculated based on $37/man-hour charge.

- *Total Price* : Total price is the sum of sub total, ballast and erection costs.

- *Depreciation Cost per Year* : Calculated with the following formula (Equation 3.12), (Anonymous, 1993a).

$$DepreciationCost/year = \frac{Total\ price}{Depreciation life} \qquad (3.12)$$

- *Average Investment per Year* : Calculated with the following formula (Equation 3.13), (Anonymous, 1993a).

$$Average\ Investment\ /\ year = \frac{Total\ price * (Depreciation\ life + 1)}{(2 * Depreciation\ life)} \qquad (3.13)$$

- *Interest, Taxes and Insurance (ITI) per Year* : Calculated with the following formula (Equation 3.14), (Anonymous, 1993a).

$$ITI\ Cost\ /\ year\ =\ ITI\%\ *\ Average\ Investment\ /\ year \qquad (3.14)$$

- *TOTAL OWNERSHIP COST PER YEAR* : Calculated with the following formula (Equation 3.15), (Anonymous, 1993a).

$$Total\ Ownership\ Cost/year = Depreciation Cost/year + ITI\ Cost/year \qquad (3.15)$$

Operating Cost

The operating cost is composed of the following parameters;

- *Maintenance and Supply Cost per Year* : It is stated that (Anonymous, 1993a) this item includes costs for ropes, wear parts, lubricants, major parts, etc., as well as repair labor. The 7% multiplier is based on actual experienced costs. It is, however, averaged for the life of the dragline. Some years will have costs significantly above this percentage and some significantly below. This item is calculated below (Equation 3.16).

$$Maintenance\ and\ Supply\ Cost\ /\ year = 7\% * Sub\ Total \quad (3.16)$$

- *Electric Power Cost per Year* : It is declared that the electric consumption of draglines varies from 0.9822 KWh/m³ to 1.7679 KWh/m³ for small to large machines, respectively (Anonymous, 1993a).

Calculation of the electricity consumption cost per year is entirely dependent upon the electricity consumed to spoil one cubic meter of waste. As mentioned above, although the electricity consumption of the smallest and largest dragline models have been declared, the respective power consumption of a specific dragline model has not been published. For this purpose, it has been aimed to develop a regression model by which the power consumption of a particular dragline would be determined. It has been accepted that the power consumption is related with the

maximum allowable load a dragline could carry which in turn is related to its working weight. After applying several regression models, the one that best represented the relation between the maximum allowable load and the working weight has been found as the multiplicative function. The results of regression analysis between the working weight (kg, independent variable) vs. maximum allowable load (kg, dependent variable) and the power consumption for Marion draglines are presented in Table 3.2.

The derived formula related to electricity consumption of draglines is given in Equation 3.17. Figure 3.56 represents the relation between working weight, maximum allowable load and electricity consumption of draglines.

$$EC = 0.9513 + \frac{0.7857 * (0.2123137809 * W_W^{0.895358})}{299684.811} \tag{3.17}$$

where

EC: Electricity Consumption, (KWh/BCM)

W_W: Working Weight of a Dragline, (kg)

Table 3.2. The Results of the Regression Analysis between the Maximum Allowable Load and Working Weight of Draglines

Regression Model	Y:Max. Allow. Load (kg) X:Working Weight (kg)	***Intercept a***	***Slope b***	***R^2***
Linear	Y=a+bX	6154.15	0.0427227	0.9378
Multiplicative	$Y=aX^b$	0.21231378	0.895358	0.9564
Exponential	Y=exp(a+bX)	10.2045	4.1917E-7	0.8565
Reciprocal	Y^{-1}=a+bX	3.49588E-5	-6.359E-12	0.6030

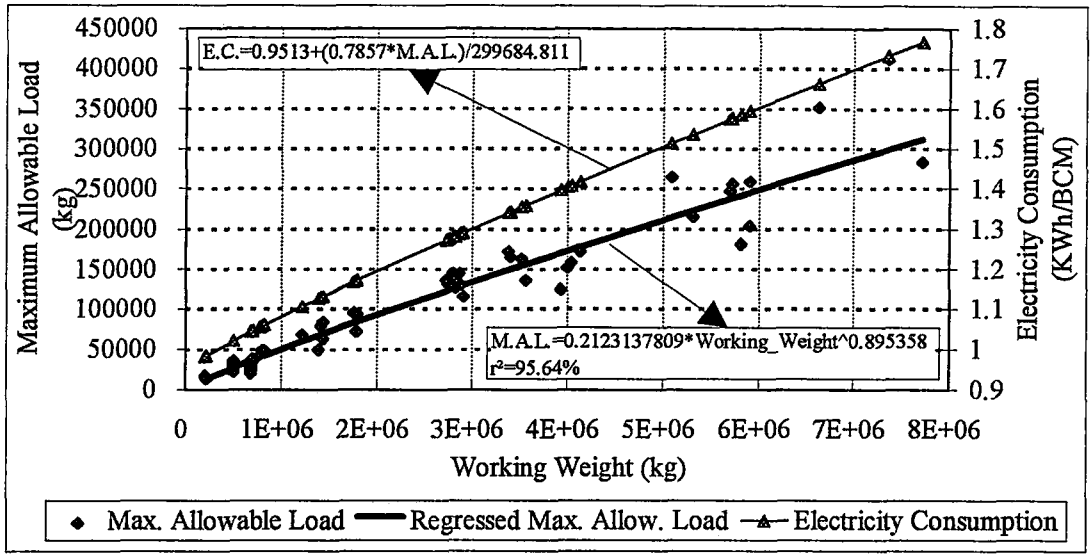


Figure 3.56. Relation Between Working Weight and Electricity Consumption of Draglines

- *TOTAL OPERATING COST PER YEAR* : Calculated with the following formula (Equation 3.18), (Anonymous, 1993a).

$$\begin{aligned} \textit{Total Operating Cost/year} = {} & \textit{Maintenance Cost/year} \\ & + \textit{Electric Power Cost/year} \\ & + \textit{Labor Cost/year} \end{aligned} \qquad (3.18)$$

Owning and Operating (O&O) Cost

- *TOTAL OWNING AND OPERATING COST PER YEAR* : Calculated with the following formula (Equation 3.19).

$$\begin{aligned} Total\ O\&O\ Cost/Year &= Total\ Owning\ Cost/Year \\ &+ Total\ Operating\ Cost/Year \end{aligned} \tag{3.19}$$

- *Owning and Operating Cost per Scheduled Hour* : Calculated with the following formula (Equation 3.20).

$$O\ \&\ O\ Cost\ /\ Sched.\ hour = \frac{Owning\ \&\ Operating\ Cost\ /\ Year}{Scheduled\ Hours/\ Year} \tag{3.20}$$

CHAPTER IV

DISCUSSION ON THE DEVELOPED EXPERT SYSTEM

4.1. General

This chapter is devoted to the testing of the developed expert system and then validating the results produced by it. Testing the expert system has been done with feeding input data about a hypothetical surface coal mine. The validation of the results, however, has been performed with comparing the critical output parameters to those published in the previous studies.

Validating the expert system has been carried out by numerous sample runs. Some important input parameters, such as the operating efficiency and the overburden thickness have been modified gradually to observe the positive or negative effects. In each sample run, the best dragline-stripping method pair has been indicated by presenting the relative performance of draglines on the basis of pit geometry, production simulation and the stripping cost. Besides, critical output values produced by the expert system have been compared to those encountered in the literature.

During the expert system development, some assumptions relating to design stage have been made. The most significant reason of the assumptions has been that the available information about a specific point is very scarce or has not been made publicly available due to its proprietary nature. The developed expert system is valid for the items given below.

1. Overburden formations in the mine have been assumed diggable for dragline stripping.

2. The study has been based on the existence of one flat-lying coal seam.

3. The draglines considered for the expert system are tub-mounted (walking) and driven with electric power. Crawler draglines driven by diesel engines have been excluded from considerations.

4. The formed spoil piles have been assumed to have a continuous ridge line with no peaks and valleys.

5. The length of the spoil pile built during excavation of a block is equal to the length of the set.

6. The width of the cut being dug is the same as the width of the adjacent open cut.

7. There are no curves along the block. It has been assumed linear during excavation phases.

8. The spoil pile built in the open cut has been assumed to have the swelled form of the cross-sectional area of the block on the highwall side. The area of a set on highwall side is calculated by bank measures whether it is relaxed by blasting prior to dragline excavation.

9. Up to two draglines have been allowed to work in the pit.

10. Draglines have been allowed to work on up to two slices.

11. Operational safety of draglines has been limited with a safe working distance from the highwall or pullback pad edge.

12. Pit geometry and range diagramming studies have been done on a two-dimensional space. However, production simulation models have been based on a three-dimensional space.

13. All spoiling modes excluding chopping and spoil side stripping have been based on a 90 degree swing and the corresponding cycle time has been calculated accordingly. Chopping and pullback modes have been based on a 150 degree swing. The cycle time for these spoiling modes have been calculated by adding a constant 14 s to a 90 degree swing cycle time for a dragline (Atkinson, 1971).

4.2. Description of the Input Data Entered into Expert System

The expert system developed for dragline and stripping method selection has been executed four times. The input data set related to first three sample run is given below in Table 4.1.

Table 4.1. List of Input Data Used in Validation of the Developed Expert System

INPUT VARIABLES	*Sample Run #1*	*Sample Run #2*	*Sample Run #3*
Average Overburden Thickness (m)	20	30	40
Average Coal Seam Thickness (m)	8	6	6
Highwall Angle (degrees)	60	60	55
Coal Seam Bench Angle (degrees)	75	85	80
Spoil Pile Angle (degrees)	50	50	45
Swell Factor of the Waste (%)	33	33	36
Width of Safety Berm Between Slices (in Two Slice Methods), (m)	0	5	10
Yearly Coal Demand (mton)	5,000,000	2,000,000	4,500,000
Density of Waste (t/m^3)	2.02	2.1	2.61
Density of Coal (t/m^3)	1.4	1.4	1.4
Dragline Block Length (m)	500	500	500
Yearly Scheduled Working Time (h)	5,500	6,000	8,000
Operating Efficiency (.00)	0.6	0.7	0.7
Average Fill Factor for Chopping (.00)	0.7	0.74	0.7
Deviation in Chopping Fill Factor (.00)	0.1	0.1	0.1
Average Fill Factor for Non-Chopping Digging (.00)	0.95	0.95	0.9
Deviation in Non-Chopping Fill Factor (.00)	0.05	0.05	0.05
Projected Life of the Dragline (yr)	27	27	30
Interest, Taxes and Insurance (ITI, %)	18	18	18
Cost of Electricity (US$/kWh)	0.1	0.1	0.1
Yearly Labor Cost (US$)	50,000	50,000	50,000

4.3. Sample Run #1

The data about a hypothetical surface coal mine with one horizontal coal seam for the first run is characterized by a relatively shallow overburden thickness, a medium coal production demand and a lower operating efficiency. The draglines selected for testing are the BUCYRUS-ERIE 1370W series which consists of 7 units with slightly varying operating parameters. The list of draglines to be tested and their basic operating parameters are presented in Table 4.2.

4.3.1. Results of Sample Run #1

After executing the expert system for the data given for sample run #1, the best dragline and stripping method pair has been concluded as the ***Bucyrus-Erie 1370W-1*** and the ***Direct Side Casting*** method. The optimum selection and the cost of stripping from different aspects are given in Table 4.3 (See Appendix E for results).

4.3.2. Results of Pit Geometry and Range Diagramming Models

The execution of the expert system commences with pit geometry models where draglines are examined to satisfy the geometrical requirements of stripping methods. However, the limited control of the expert system never permits the initially chosen draglines to be tested in every stripping method. In one slice methods, a dragline is immediately taken out of the test list as soon as it has satisfied the geometrical needs of the direct side casting model. A dragline can only be tested in the extended bench casting and one slice pullback stripping models if it is failed in the

direct side casting model because both methods have been developed to cope with cases where rehandling is inevitable. However, all draglines are entered in two slice models either in the form of combinations or alone because a dragline that may have failed in one slice methods is allowed to strip only a part of the total overburden.

Table 4.2. Basic Operating Parameters of Draglines in Sample Run #1

Model	1370W-1	1370W-2	1370W-3	1370W-4	1370W-5	1370W-6	1370W-7
Working Weight (kg)	2,903,494	2,903,494	3,022,790	3,022,790	3,070,872	3,070,872	3,075,408
Boom Length (m)	86.9	86.9	94.5	94.5	97.5	97.5	99.1
Boom Angle (degrees)	38	30	38	30	38	30	38
Operating Radius (m)	77.7	84.4	83.8	91.1	86.3	93.9	87.5
Dumping Height (m)	38.1	28.0	42.7	32.0	44.8	33.5	45.7
Digging Depth (m)	29.0	50.3	33.5	44.2	35.1	45.7	48.8
Tub Radius (m)	19.4	19.4	19.4	19.4	19.4	19.4	19.4
Bearing Area (m^2)	294	294	294	294	294	294	294
Bearing Pressure (kPa)	98.69	98.69	102.74	102.74	104.37	104.37	104.53
Maximum Allowable Load (kg)	138,348	127,008	129,276	117,936	127,008	115,668	129,730
Step Length (m)	2.59	2.59	2.59	2.59	2.59	2.59	2.59
Walking Speed (m/h)	225	225	225	225	225	225	225

Table 4.3. The Best Dragline and Stripping Method Pair for the Sample Run #1 (See Appendix E for Complete Results)

Stripping Method	Direct Side Casting
Dragline	BUCYRUS-ERIE 1370W-1
Cost in Terms of Total Stripping	0.61159 US$/bank m³
Cost in Terms of Prime Stripping	0.61159 US$/bank m³
Cost in Terms of Desired Stripping	0.6334 US$/bank m³

After executing pit geometry models, all the initially chosen draglines have satisfied the geometrical requirements of the direct side casting geometry model and have not been subjected to geometrical selection criteria of the extended bench and one slice pullback stripping models. The results of the direct side casting geometry model related to the best combination are presented in Table 4.4 and those related to all draglines are given in Appendix E.

The chosen draglines have failed to satisfy the geometrical requirements of the stripping models applicable on two slices because of the relatively shallow thickness of the overburden strata.

Table 4.4. Results of the Direct Side Casting Geometry Model for 1370W-1

Dragline	Pit Width (m)	Avail. Operating Radius (m)	Required Operating Radius (m)	Avail. Reach (m)	Required Reach (m)	Keycut Upper Width (m)	Keycut Right Wall Angle (deg)	Pit Geometry Model Result
1370W-1	59.5	77.7	77.7	63.1	50.9	23.1	60	PASS

4.3.3. Results of Production Simulation Models

Production simulation models in the expert system work from two ways sequentially. Firstly the pit geometry is analyzed to compute the relevant dimensions related to volumes to dig and distances to walk. In geometrical computations the length along the pit advance is taken into account as the third dimension. After satisfying geometrical constraints, the operating environment of the dragline is simulated. Since only the direct side casting model have proved successful, only direct side casting production simulation model has been executed and only ***Bucyrus-Erie 1370W-1*** has satisfied the production requirements. The results of the direct side casting simulation geometry and production simulation models related to the best combination are presented in Table 4.5 and 4.6 and those related to all draglines are given in Appendix E.

Table 4.5. Results of the Direct Side Casting Simulation Geometry Model for 1370W-1

Dragline	1370W-1
Bucket Capacity (m^3)	51.14
Set Length (m)	28.99
Setback Distance (m)	28.71
Keycut Volume (m^3)	6694
Maincut Volume (m^3)	27803
Distance 1-2 (m)	33.41
Distance 2-3 (m)	38.34
Distance 1-3 (m)	18.82
Distance 4-1' (m)	58.32

Table 4.6. Results of the Direct Side Casting Production Simulation Model for 1370W-1

Dragline	1370W-1
Average Keycut Cycle Time (s)	59.12708
Average Maincut Cycle Time (s)	59.11993
Average Fill Factor (.00)	0.94998
Time Spent for Keycut (s)	2917094
Time Spent for Maincut (s)	12049647
Time Spent for Walking (s)	836945
Time Spent for Delaying (s)	4003348
Percent Time for Keycut Excavation (%)	14.73
Percent Time for Maincut Excavation (%)	60.84
Percent Time for Walking (%)	4.22
Percent Time for Delaying (%)	20.21
Total Stripping Time (s)	19807034
Scheduled Time (s)	19800000
Total Walked Distance (m)	43681
Total Production (m^3)	9246959
Prime Production (m^3)	9246959
Desired Production (m^3)	8928571
Simulation Result	PASSED

4.3.4. Results of the Stripping Cost Models

Since in the direct side casting production simulation model only the ***1370W-1*** has satisfied the desired production, only its stripping cost is calculated. The results of the direct side casting cost model related to the best combination are presented in Table 4.7. The stripping cost results of other draglines and other stripping systems are presented in Appendix E.

Table 4.7. Results of the Direct Side Casting Stripping Cost Model for 1370W-1

Dragline	1370W-1
Purchase Price (US$)	17,500,000
Options and Extras (US$)	875,000
Freight (US$)	1,624,080
Trail Cable (US$)	49,213
Ballast (US$)	57,154
Erection (US$)	3,008,020
Total Price (US$)	23,113,466
Yearly Depreciation Cost (US$)	856,054
Yearly Investment Cost (US$)	1,198,760
Yearly ITI Cost (US$)	2,157,257
Yearly Total Owning Cost (US$)	3,013,311
Yearly Maintenance & Supply Cost (US$)	1,403,380
Electricity Consumption (KWh/BCM)	1.28544
Yearly Electricity Cost (US$)	1,188,637
Yearly Labor Cost (US$)	50,000
Yearly Total Operating Cost (US$)	2,642,017
Yearly Total Owning & Operating Cost (US$)	5,655,328
Hourly Owning & Operating Cost (US$/h)	1028.24153
Cost in Terms of Total Production (US$/bank m^3)	0.61159
Cost in Terms of Prime Production (US$/bank m^3)	0.61159
Cost in Terms of Desired Production (US$/ bank m^3)	0.6334

4.3.5. Discussion on the Results of Sample Run #1

The dragline selecting expert system has been based on three main criteria, namely pit geometry and range diagramming, production simulation and finally the cost of stripping with draglines. Each criterion has been equipped with procedures to rank draglines in the order of suitability for a given set of specifications. The pit geometry and simulation models serve as a screening agent to either pass or fail a dragline. The cost models however, rank those draglines that have satisfactorily passed previous criteria on the basis of stripping economy and select the cheapest-

producing one. However, to validate the dragline selection procedures embedded into the expert system, it is necessary to analyze them and compare to outputs of similar procedures published previously in the literature. For this purpose, several analyses have been carried out on the outputs that the system has produced and compared to those in literature.

Validation of the expert system has been performed on two aspects; the first one is the trend a particular selection criterion follows. This is because not every output the system has produced has been done previously, or not encountered in the literature. In such cases the tendency in the value of alternatives has been analyzed to observe a trend that would be interpreted as logical. The second aspect is the comparison of the outcomes of selection procedures to those already known. Below is an item-by-item analysis of critical parameters output by the models related to Direct Side Casting method of Sample Run #1.

Operating Radius vs. Pit Width

It is obvious that the distance a dragline spoils the waste is closely related with its horizontal reach. This in turn is reflected in that the more material can be spoiled from a sitting position because longer horizontal reach means more room to spoil the waste and this in turn is reflected in wider pits. So, a dragline with a longer operating radius, *ceteris paribus*, can work on a wider pit than a dragline with a shorter radius. The graphical reflection of this assertion is given in Figure 4.1 where the draglines are ranked on the basis of their operating radii and corresponding calculated pit width indicating that the expert system has produced consistent results.

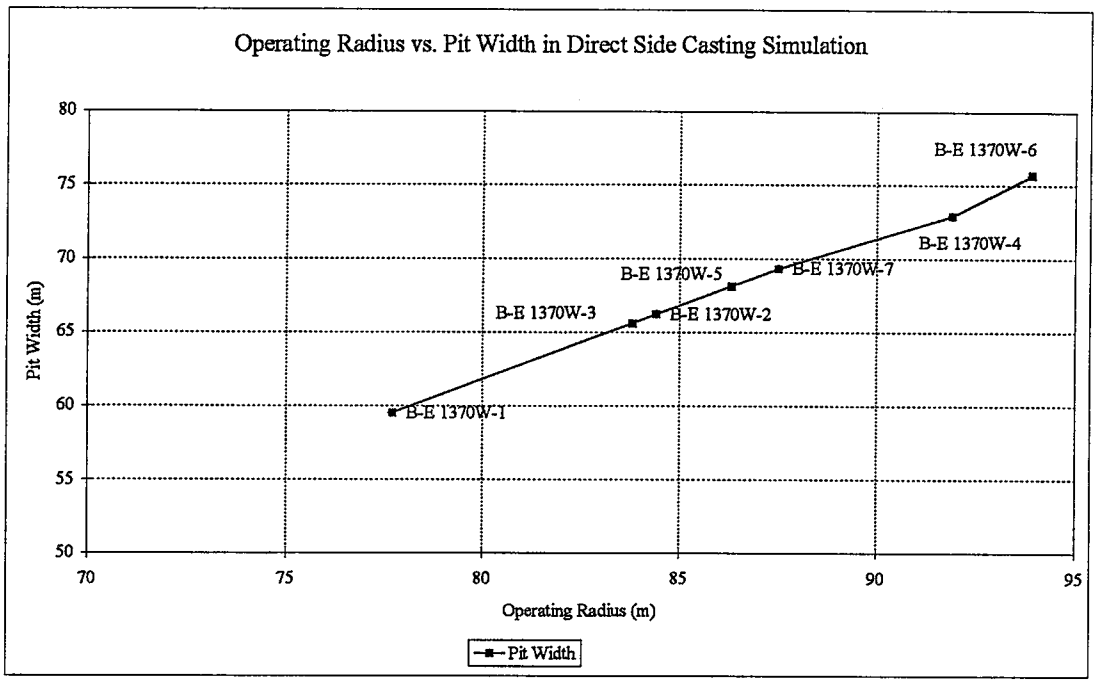


Figure 4.1. The Relation Between Operating Radius and Pit Width of Draglines

Operating Radius vs. Set Length

Since a dragline with a larger horizontal reach can spoil material to a longer distance than a dragline with a shorter reach across the pit than it can reach a longer distance along the direction of pit advance. This reveals the fact that a larger operating radius dragline will, *ceteris paribus*, in turn have a longer set length than a shorter dragline. The gently upward sloping trend of set length in Figure 4.2 indicates that the set length increases with the operating radius.

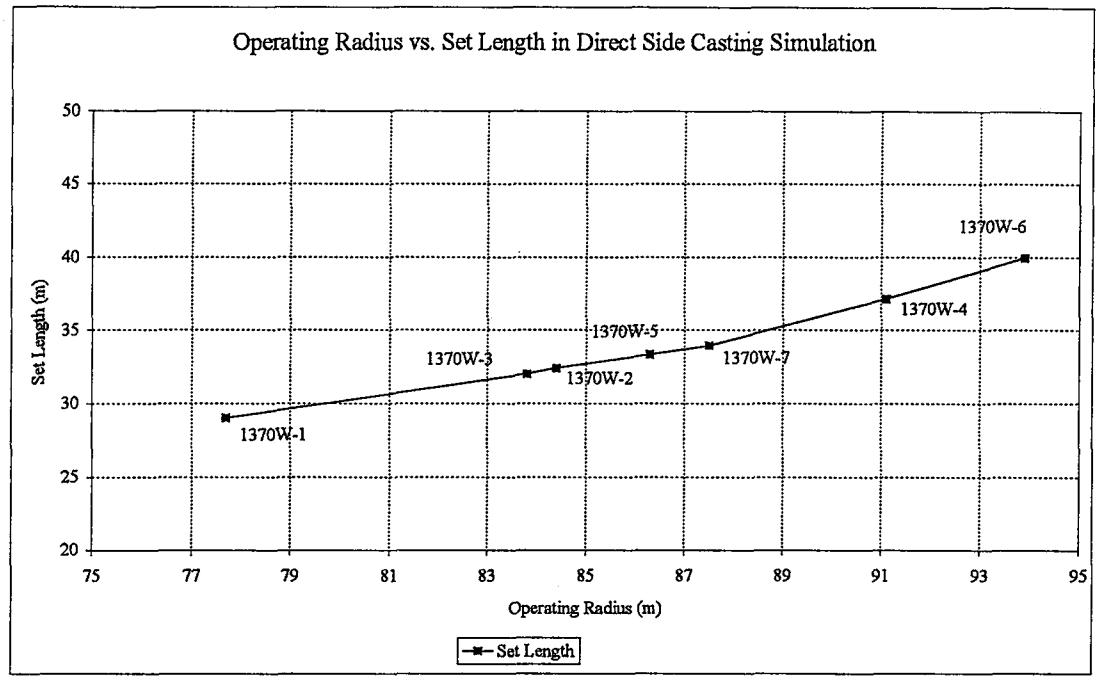


Figure 4.2. The Relation Between Operating Radius and Set Length of Draglines

Bucket Capacity vs. Stripping Capability

It has been accepted that a dragline employed in a particular stripping technique with a larger capacity can produce more than a dragline with a smaller capacity in a given period of time. After estimating the likely stripping capability of draglines entered into the expert system, it can be observed from the trend in Figure 4.3 that larger capacity draglines produce more than smaller capacity ones. Fluctuations in the trend is due to the introduction of random variables such as delays into the estimation procedures. As mentioned in previous sections, the total output of a dragline is taken as the prime output as no rehandling is performed in direct side casting scheme. Again it can be seen from the graph that only 1370W-1 can perform the desired production.

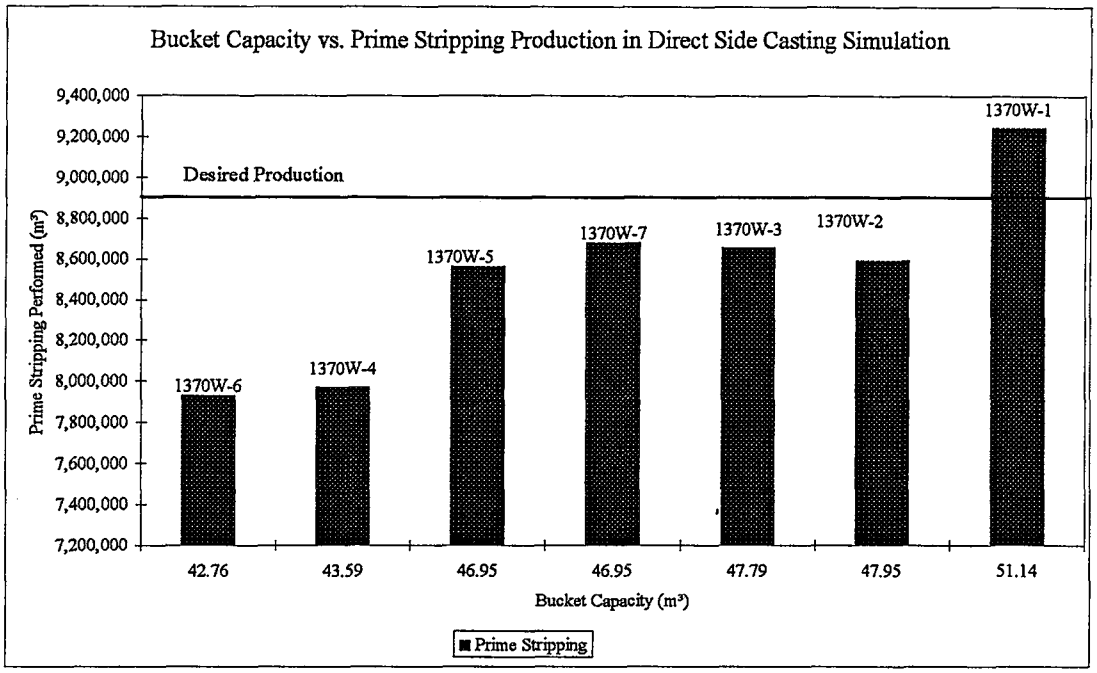


Figure 4.3. The Relation Between Bucket Capacity and Production Capability of Draglines

Bucket Capacity vs. Production Factor

The production factor is defined as the volume of waste moved per cubic meter capacity of a dragline (Anonymous, 1993a). It is stated that a dragline strips 200,000 to 300,000 bank m^3 of waste in a year per cubic meter of its capacity where the operating efficiency is taken ~ 0.72. After analyzing the production figures in sample run #1, it is seen that the production factor of draglines range between 180,000 to 185,000 bank m^3/m^3 of bucket capacity. The drop in the production factor of draglines are caused by the lower operating efficiency, 0.6, for this case. Figure 4.4 indicates that production factor of all draglines fluctuate around 180,000 m^3 that means it is producing consistent results.

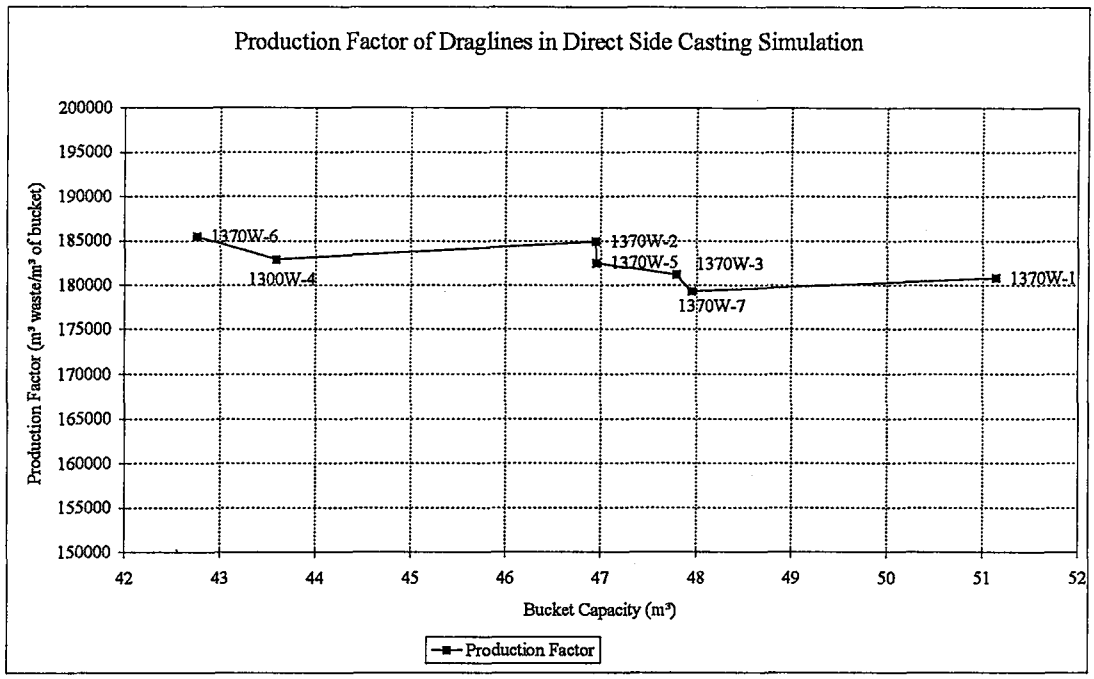


Figure 4.4. The Relation Between Bucket Capacity and Production Factor of Draglines in the Direct Side Casting Simulation Model

Bucket Capacity vs. Total Walked Distance and Percent Time Spent for Walking

Another point revealed by the expert system is the relation between dragline walking and bucket capacity. A dragline with a larger bucket capacity will, *ceteris paribus*, produce more than another one with a smaller capacity as stated in the previous clause. This means that the larger capacity dragline will perform the stripping phase faster and move between sitting positions more frequently. This in turn states that this dragline will walk more than its smaller capacity counterpart. Besides, the time spent for walking will increase as the distance walked increases and percent

time for walking will increase. The trends in walking distance and percent time spent for walking are presented in Figure 4.5.

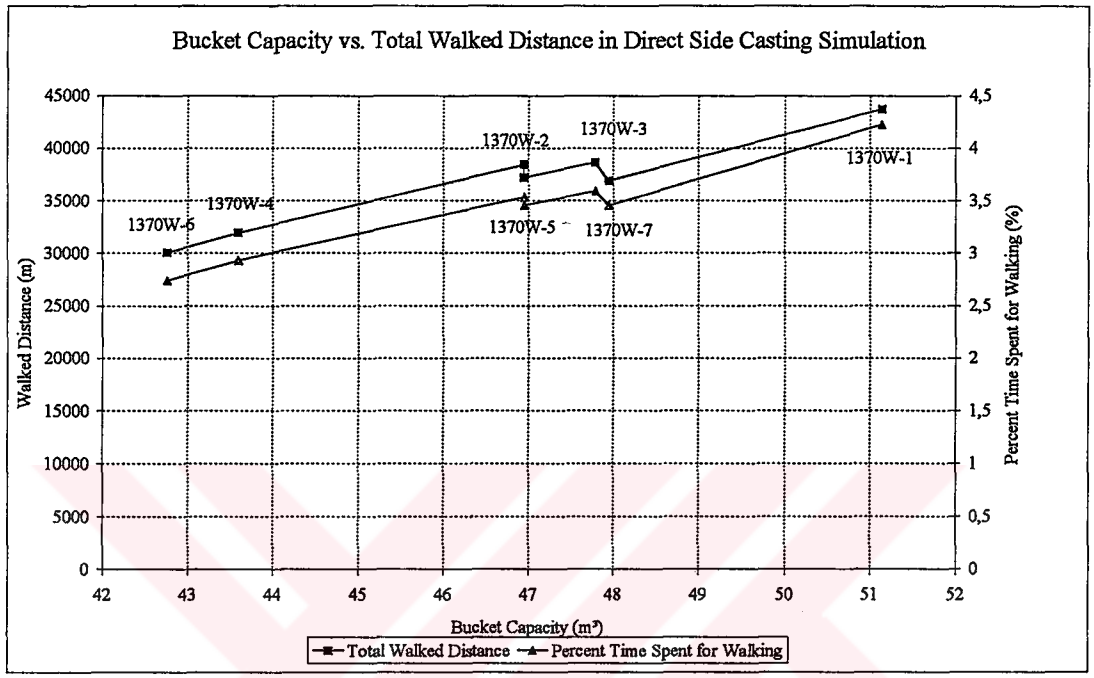


Figure 4.5. The Relation Between Bucket Capacity to Walking Distance and Percent Time Spent for Walking

Decomposition of Total Time Spent For Specific Operations in Dragline Stripping

In direct side casting technique, five different phases have been modeled. These are chopping, keycut excavation, maincut excavation, walking and delays. A dragline spends some portion of the allocated time to complete each task. In a particular technique, the percentage time spent for each task should be around a value

for every dragline. It can be clearly observed from Figure 4.6 that the expert system produces consistent results for every tested dragline.

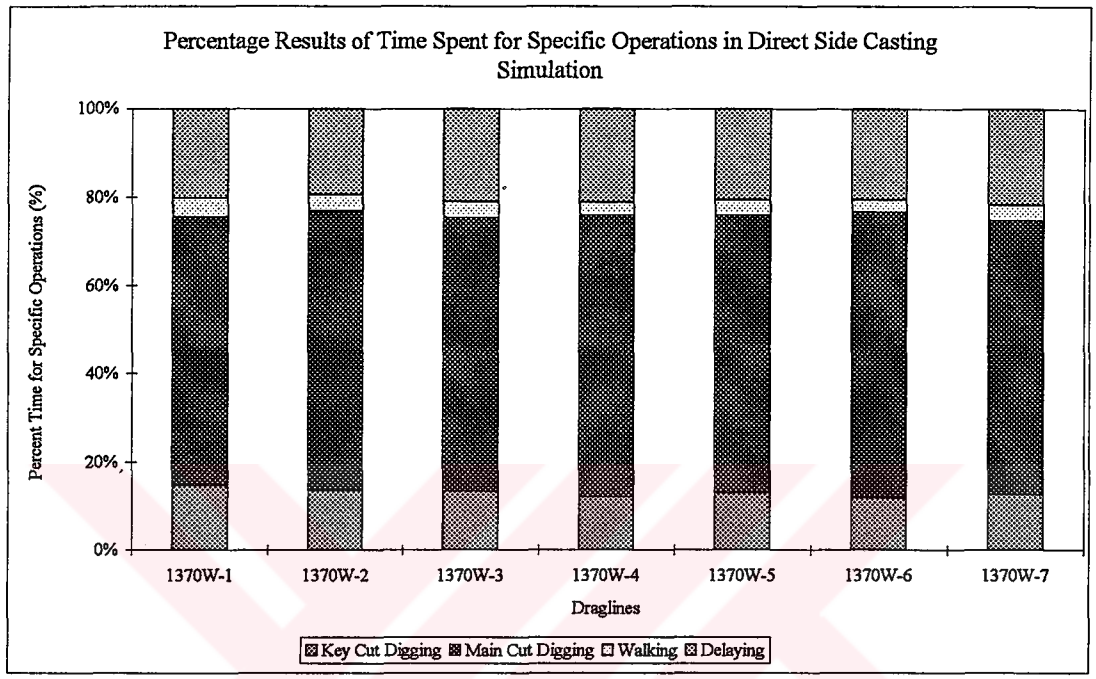


Figure 4.6. Decomposition of Total Time Spent for Completing Specific Tasks in Direct Side Casting Simulation

4.4. Sample Run #2

The second run has been performed for a moderately severe operating environment characterized by a fair overburden height, a small coal production demand and a medium operational efficiency. The draglines selected for testing were the MARION 7820 series which consists of 5 units and BUCYRUS-ERIE 1300W

series which consists of 8 units. The list of draglines to be tested and their basic operating parameters are presented in Table 4.8.

4.4.1. Results of Sample Run #2

After executing the expert system for the data given for sample run #2, the best dragline and stripping method pair has been concluded as the ***Bucyrus-Erie 1300W-6*** and the ***Direct Side Casting*** method. The optimum selection and the cost of stripping from different aspects are given in Table 4.9.

4.4.2. Results of Pit Geometry and Range Diagramming Models

After executing pit geometry models, not all the initially chosen draglines have satisfied the geometrical requirements of the direct side casting geometry model. The successful draglines are 1300W-4, 1300W-5, 1300W-6, 1300W-7, 1300W-8 and 7820-3. The results of the direct side casting geometry model related to the best combination are presented in Table 4.10 and those related to all draglines are given in Appendix E.

Those that have failed have entered into the extended bench and one slice one dragline pullback stripping geometry models. All the draglines entering into extended bench geometry model have satisfied the geometrical requirements. These are; 1300W-1, 1300W-2, 1300W-3, 7820-1, 7820-2, 7820-4 and 7820-5. The results of the extended bench geometry model are given in Appendix E.

Table 4.8. Basic Operating Parameters of Draglines in Sample Run #2

Model	1300W-1	1300W-2	1300W-3	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8
Working Weight (kg)	2109240	2109240	2154600	2154600	2154600	2154600	2222640	2222640
Boom Length (m)	79.2	79.2	87.0	87.0	92.0	92.0	99.1	99.1
Boom Angle (degrees)	38	30	38	30	38	30	38	30
Operating Radius (m)	68.6	75.0	75.0	81.7	78.9	86.0	84.4	92.0
Dumping Height (m)	37.2	28.0	42.7	32.6	45.7	35.1	50.9	39.6
Digging Depth (m)	41.1	50.3	50.3	59.4	47.2	61.0	47.2	61.0
Tub Radius (m)	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8
Bearing Area (m^2)	221	221	221	221	221	221	221	221
Bearing Pressure (kPa)	95.56	95.56	97.62	97.62	97.62	97.62	100.70	100.70
Maximum Allowable Load (kg)	106596	106596	102060	92988	95256	86184	74844	65772
Step Length (m)	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18
Walking Speed (m/h)	241	241	241	241	241	241	241	241

Among draglines entering into one slice one dragline pullback stripping geometry model, only 1300W-1 and 7820-4 have satisfied the geometrical limitations. The results of the one slice one dragline pullback stripping geometry model are given in Appendix E.

Table 4.8. Basic Operating Parameters of Draglines in Sample Run #2 (Continued)

Model	7820-1	7820-2	7820-3	7820-4	7820-5
Working Weight (kg)	1750896	1406160	1778112	1428840	1791720
Boom Length (m)	76.2	76.2	91.4	71.6	83.8
Boom Angle (degrees)	32	35	32	32.5	38
Operating Radius (m)	71.9	69.8	84.7	67.1	73.2
Dumping Height (m)	29.3	34.7	39.3	25.9	40.8
Digging Depth (m)	44.2	36.6	53.3	41.8	39.0
Tub Radius (m)	15.2	15.2	15.2	15.2	15.2
Bearing Area (m^2)	182	182	182	182	182
Bearing Pressure (kPa)	95.98	77.09	97.48	78.33	98.22
Maximum Allowable Load (kg)	95256	79380	72576	83916	93895
Step Length (m)	2.13	2.13	2.13	2.13	2.13
Walking Speed (m/h)	0	0	0	0	0

Table 4.9. The Best Dragline and Stripping Method Pair for the Sample Run #2

Stripping Method	Direct Side Casting
Dragline	BUCYRUS-ERIE 1300W-6
Cost in Terms of Total Stripping	0.54014 US$/bank m³
Cost in Terms of Prime Stripping	0.54014 US$/bank m³
Cost in Terms of Desired Stripping	0.54669 US$/bank m³

Table 4.10. Results of the Direct Side Casting Geometry Model for 1300W-6

Dragline	Pit Width (m)	Avail. Operating Radius (m)	Required Operating Radius (m)	Avail. Reach (m)	Required Reach (m)	Keycut Upper Width (m)	Keycut Right Wall Angle (degrees)	Pit Geometry Model Result
1300W-6	61.4	86.0	86.0	73.4	66.7	34.6	60	PASS

The one slice two dragline pullback stripping geometry model allows the combinations of those failing in direct side casting on highwall side and all others on spoil side. After executing this geometry model, 26 combinations have been produced that have satisfactorily met the geometrical requirements where the 1300W-1 and 7820-4 were on the highwall side and all others on the spoil side. The results of the one slice two dragline pullback stripping geometry model are given in Appendix E.

No singular or tandemly operating dragline systems have met the two slice direct side casting, lower slice extended bench casting and two slice one dragline pullback stripping geometry models.

Execution of the two slice two dragline pullback stripping geometry model has revealed the existence of 12 combinations that have satisfactorily met the geometrical requirements. The results of the one slice two dragline pullback stripping geometry model are given in Appendix E.

4.4.3. Results of Production Simulation Models

In direct side casting production simulation model, 3 draglines, 1300W-4, 1300W-5 and 1300W-6 have met the desired production rate. The results of the simulation geometry and production simulation model related to the best combination are presented in Tables 4.11 and 4.12 where those related to all draglines are given in Appendix E.

Table 4.11. Results of the Direct Side Casting Simulation Geometry Model for 1300W-6

Dragline	1300W-6
Bucket Capacity (m^3)	31.16
Set Length (m)	28.11
Setback Distance (m)	27.89
Keycut Volume (m^3)	14607
Maincut Volume (m^3)	37170
Distance 1-2 (m)	31.47
Distance 2-3 (m)	35.68
Distance 1-3 (m)	16.8
Distance 4-1' (m)	54.84

Table 4.12. Results of the Direct Side Casting Production Simulation Model for 1300W-6

Dragline	1300W-6
Average Keycut Cycle Time (s)	58.38719
Average Maincut Cycle Time (s)	58.38594
Average Fill Factor (.00)	0.95002
Time Spent for Keycut (s)	5363389
Time Spent for Maincut (s)	13598319
Time Spent for Walking (s)	379620
Time Spent for Delaying (s)	2293382
Percent Time for Keycut Excavation (%)	24.79
Percent Time for Maincut Excavation (%)	62.85
Percent Time for Walking (%)	1.75
Percent Time for Delaying (%)	10.6
Total Stripping Time (s)	21634710
Scheduled Time (s)	21600000
Total Walked Distance (m)	21363
Total Production (m^3)	7229430
Prime Production (m^3)	7229430
Desired Production (m^3)	7142857
Simulation Result	PASSED

In extended bench casting production simulation model, 3 draglines, 1300W-1, 1300W-2 and 1300W-3 have met the desired production rate. It should be noted that only the prime stripping rates are considered in meeting the desired stripping volume. The results of the extended bench casting simulation geometry and production simulation models are given in Appendix E.

No draglines has been successful in meeting the required production rate in the one slice one dragline pullback stripping model. The results of the simulation geometry and production simulation models are given in Appendix E.

13 dragline combinations out of 26 that had previously satisfied the pit geometry criteria have been successful in the one slice two dragline pullback stripping production simulation model. The results of the simulation geometry and production simulation models are given in Appendix E.

All the dragline combinations that had previously satisfied the pit geometry criteria have been successful in the two slice two dragline pullback stripping production simulation model. The results of the simulation geometry and production simulation models are given in Appendix E.

4.4.4. Results of the Stripping Cost Models

In the stripping cost models, the stripping cost is computed on three bases; the stripping cost in terms of total production a dragline has performed in a given period of time which includes rehandling, the stripping cost in terms of prime production a dragline has performed in the same period which does not include rehandling and finally the stripping cost in terms of desired production to uncover the required area of coal. The results of the direct side casting cost model related to the best combination are presented in Table 4.13 and those related to all others are given in Appendix E.

Table 4.13. Results of the Direct Side Casting Stripping Cost Model for 1300W-6

Dragline	1300W-6
Yearly Total Owning Cost (US$)	2,052,390
Yearly Total Operating Cost (US$)	1,852,534
Yearly Total Owning & Operating Cost (US$)	3,904,924
Hourly Owning & Operating Cost (US$/h)	650.82075
Cost in Terms of Total Production (US$/bank m^3)	0.54014
Cost in Terms of Prime Production (US$/bank m^3)	0.54014
Cost in Terms of Desired Production (US$/ bank m^3)	0.54669

4.4.5. Discussion on the Results of Sample Run #2

Below is listed a critical review of the results that the expert system has produced. In the following discussions, the main emphasis is on the models other than direct side casting model as it has been analyzed in the discussion of the sample run #1.

Pit Width vs. Percent Rehandle in Extended Bench Casting Simulation

In extended bench casting, pit width is kept wider than conventional methods because the wider the pit the more material used to built the extended bench is placed in the final spoil pile (Anonymous, 1979b; Seymour, 1979; Özdoğan, 1984; Brett, 1995; Erickson 1995d). After analyzing Figure 4.7., it can be clearly proved that the expert system has produced consistent results.

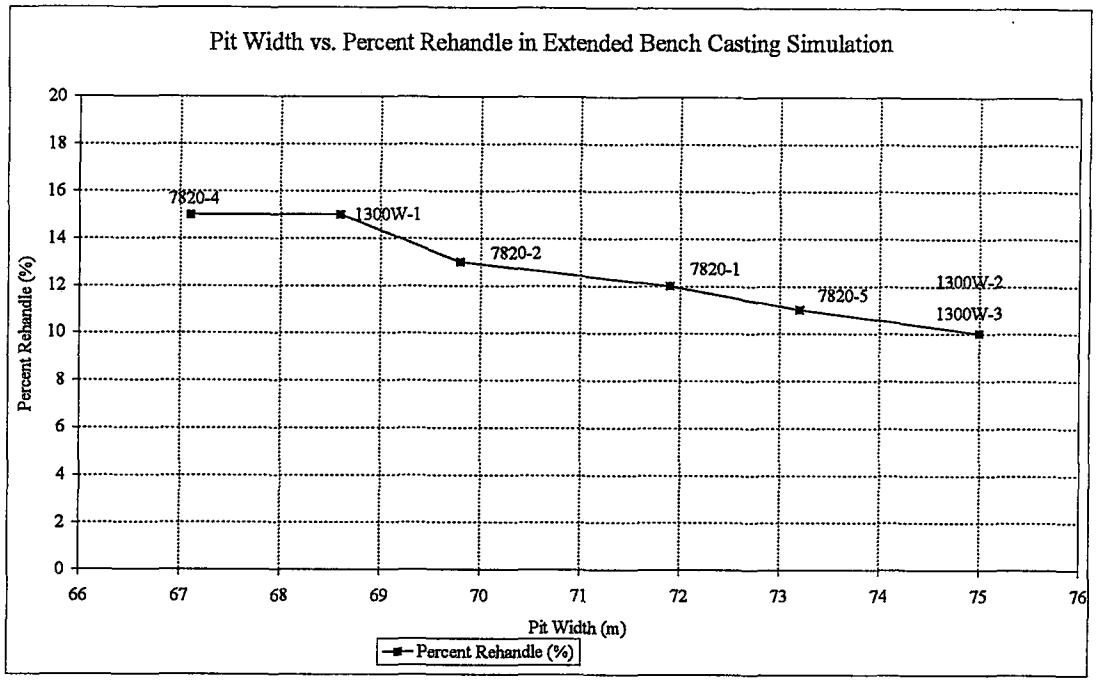


Figure 4.7. The Relation Between Pit Width and Percent Rehandle

Bucket Capacity vs. Stripping Capability in Extended Bench Casting Simulation

As mentioned before in the previous sections, not the total amount a dragline has stripped could be regarded as the prime output as in this technique some of the waste has to be handled twice. Thus it is the prime stripping that must be taken into account to determine whether a dragline has passed the desired production barrier. Figure 4.8 represents the simulation results where the bucket capacity is related to the productivity. As it can be clearly seen, stripping capability has a positive relation with the capacity as would be expected. Besides, five draglines seem to pass the barrier however only the last three, namely, 1300W-1, 1300W-2 and 1300W-3 have produced more than the desired amount when the prime stripping is concerned.

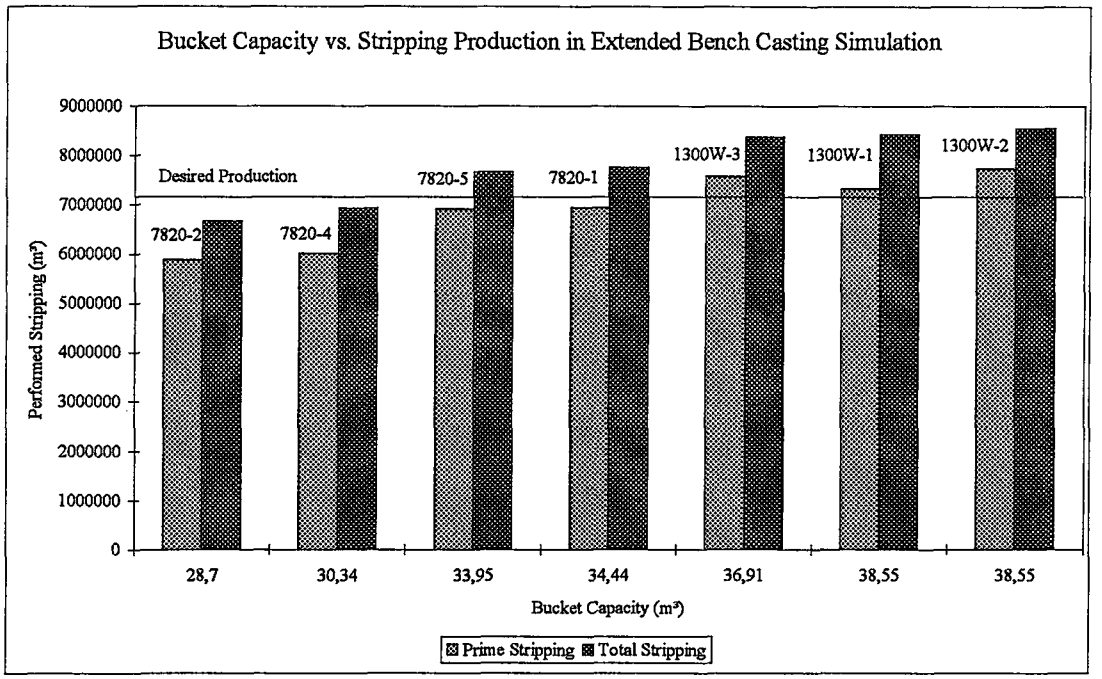


Figure 4.8. The Relation Between Bucket Capacity and Production Capability of Draglines in the Extended Bench Casting Model

Decomposition of Total Time Spent For Specific Operations in the Extended Bench Casting Model

In the extended bench casting, six operational phases have been modeled. These are chopping, keycut excavation, maincut excavation, rehandling, walking and delays. A dragline spends certain portion of the allocated time to complete each operational task. It can be clearly observed from Figure 4.9 that the expert system has produced consistent results for every tested dragline.

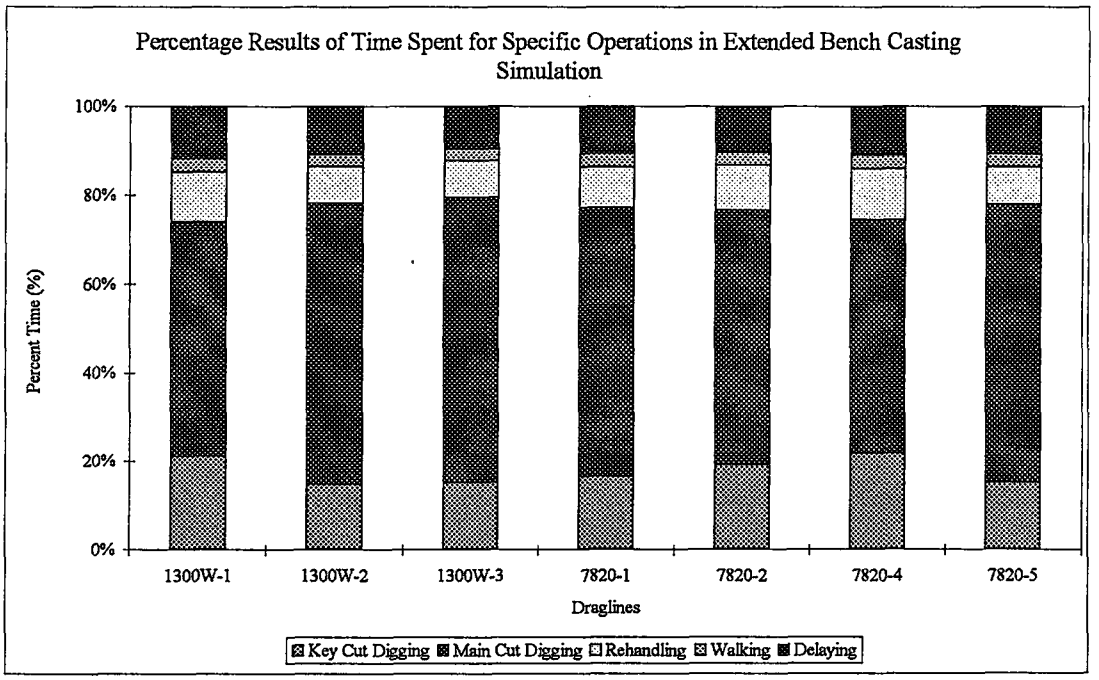


Figure 4.9. Decomposition of Total Time Spent for Completing Specific Tasks in Extended Bench Casting Simulation

Bucket Capacity vs. Total Stripping in One Slice Pullback Stripping Simulation with 1 Dragline

In this technique also, total stripping is not equal to the prime stripping because of rehandling. As revealed by Figure 4.10, the first dragline, the 1300W-1 has passed the required stripping barrier on the basis of total production but both draglines have failed because they could not meet the desired production on the basis of prime stripping rate.

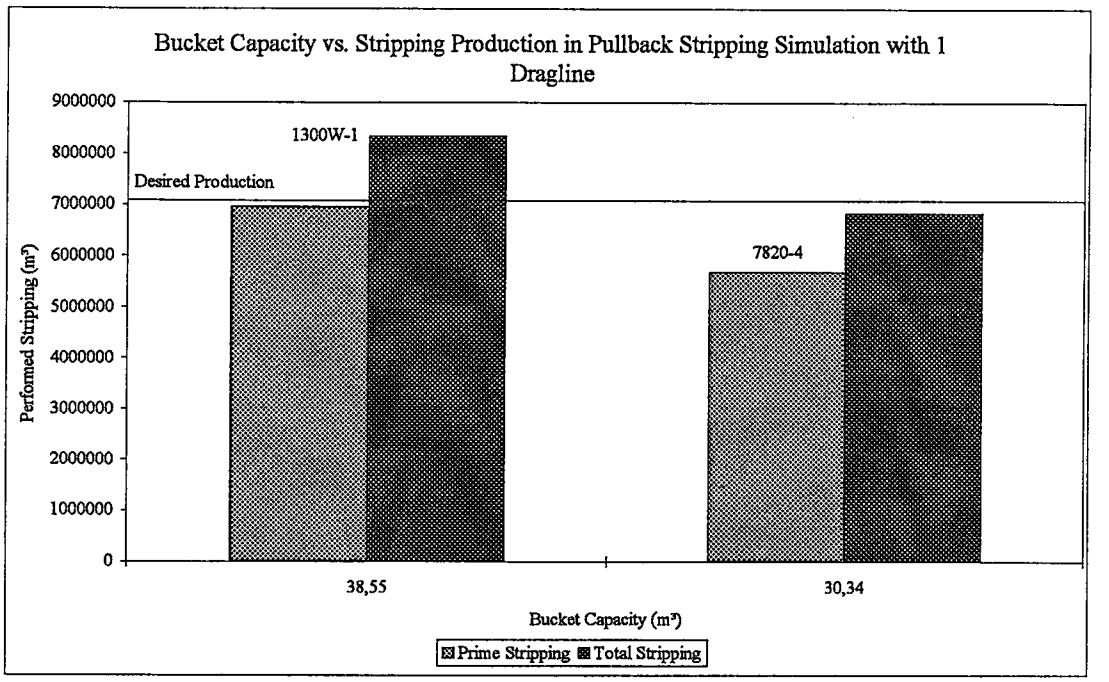


Figure 4.10. The Relation Between Bucket Capacity and Production Capability of Draglines in the One Slice One Dragline Pullback Stripping Model

Decomposition of Total Time Spent For Specific Operations in One Slice One Dragline Pullback Stripping Model

It can be clearly observed from Figure 4.11 that the expert system has produced consistent results for every tested dragline.

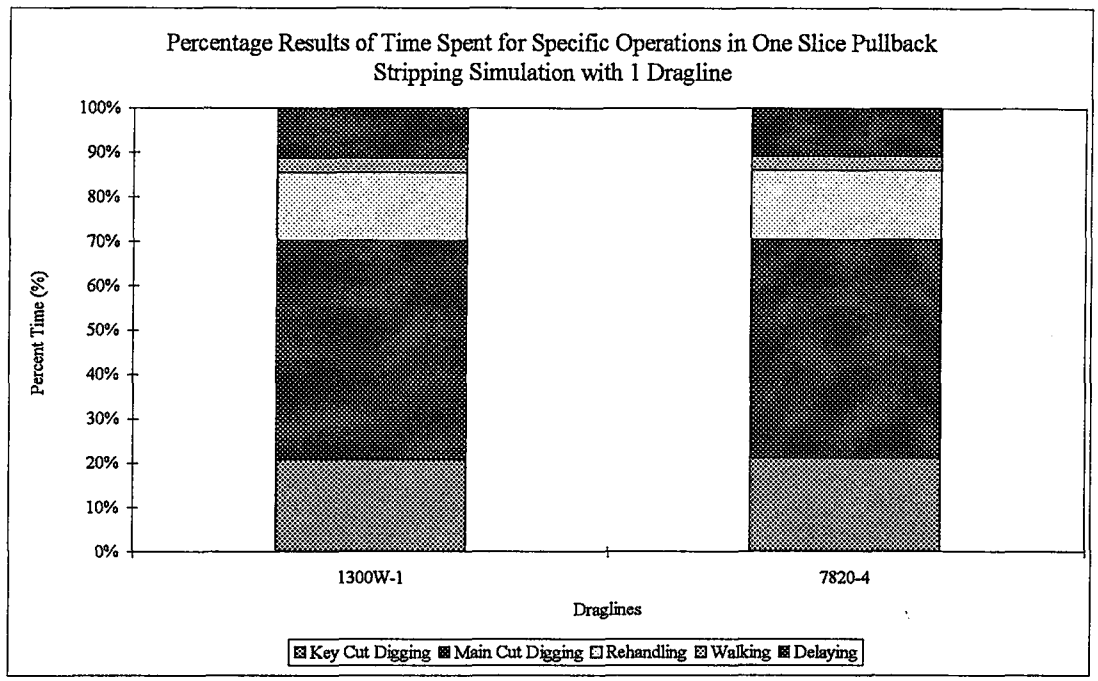


Figure 4.11. Decomposition of Total Time Spent for Completing Specific Tasks in the One Slice One Dragline Pullback Stripping Model

Bucket Capacity vs. Waiting Times of the Dependent Dragline in Pullback Stripping Simulation on 1 Slice with 2 Draglines

In techniques where two draglines are employed in the same pit, there always exists the problem of synchronization (Erickson, 1995d). In such systems the independent dragline sets the pace of the whole system and the linear advance of both draglines must be matched in order to maintain an optimum production level. In cases where the dependent dragline digs faster then it wastes its time by waiting for the independent dragline. In cases where the independent dragline digs faster then the total coal production is limited by the coal uncovering capability of the dependent one. In sample run #2, the first case has happened and the dependent draglines have

waited for the independent draglines. Figure 4.12 illustrates this case where the larger capacity dependent draglines have waited more than smaller capacity ones because they have finished their portions faster than smaller capacity ones.

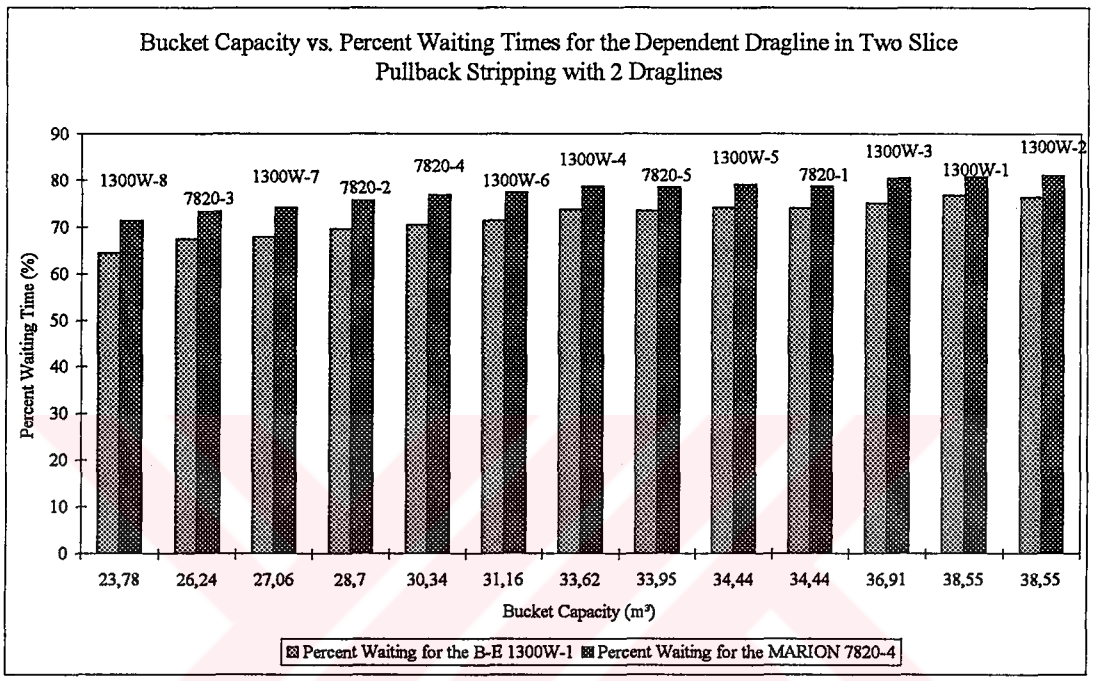


Figure 4.12. The Relation Between the Bucket Capacity and the Percent Waiting Time of Dependent Draglines in the One Slice Two Dragline Pullback Stripping Model

Cost of Stripping in Pullback Stripping Simulation on 1 Slice with 2 Draglines

As mentioned previously, the cost in terms of prime stripping is computed by considering the cost of total production and the prime volume of the waste

removed although removing the volume to be rehandled adds significantly to the total cost. This is done to clarify how rehandling effects the total cost. Because the coal is uncovered by the prime prime stripping and rehandling is caused by the nature of the method applied. Figure 4.13 shows the cost of effective stripping of tandem dragline systems. The figures of 400-500 US$/bank_m³ indicates that employing a dragline on the spoil side is a disastrous decision for this set of data and a dragline on the spoil side spends almost all of its time rehandling rather than excavating the highwall barrier. Erickson (1995d) declares that most mines in the USA won't use two dragline systems in pullback stripping. The results produced by the expert system support this assertion.

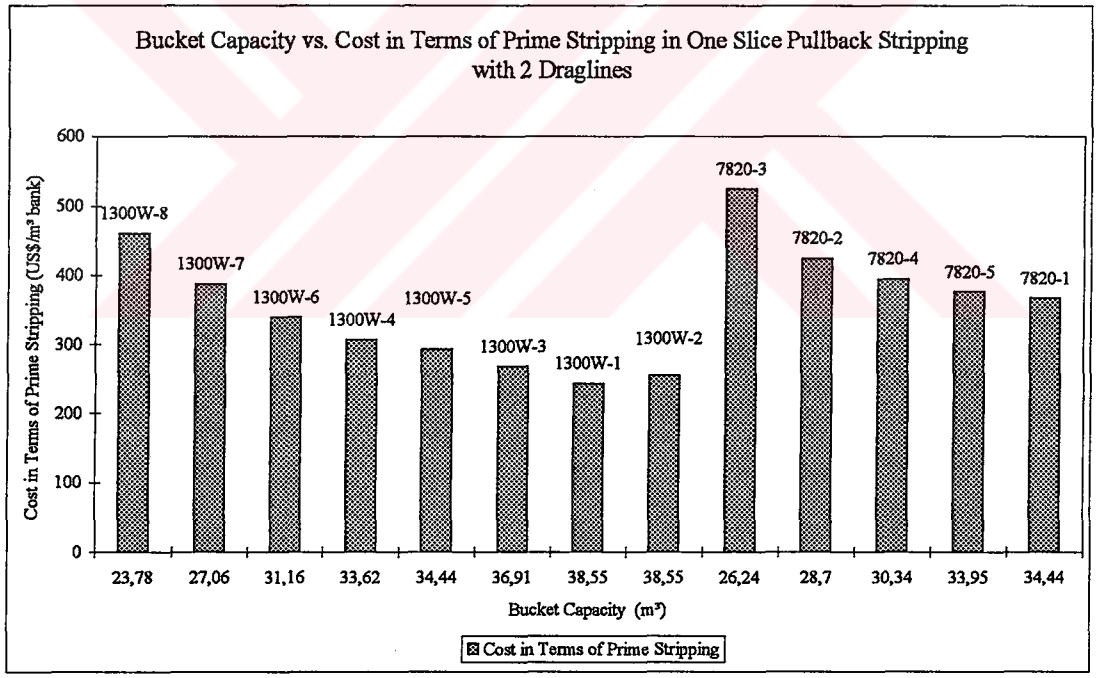


Figure 4.13. The Relation Between the Bucket Capacity and the Cost in Terms of Prime Stripping of the Dependent Draglines in the One Slice Two Dragline Pullback Stripping Model

Figure 4.14 illustrates the total cost of stripping of the dependent draglines employed on the spoil side. Although figures drop significantly due to inclusion of rehandling into the cost computations, it is still higher than 1 dragline systems. This result states that two dragline systems must be avoided wherever a single dragline can solve the stripping problems and they must be thought where the geometrical considerations set tighter constraints on stripping schemes.

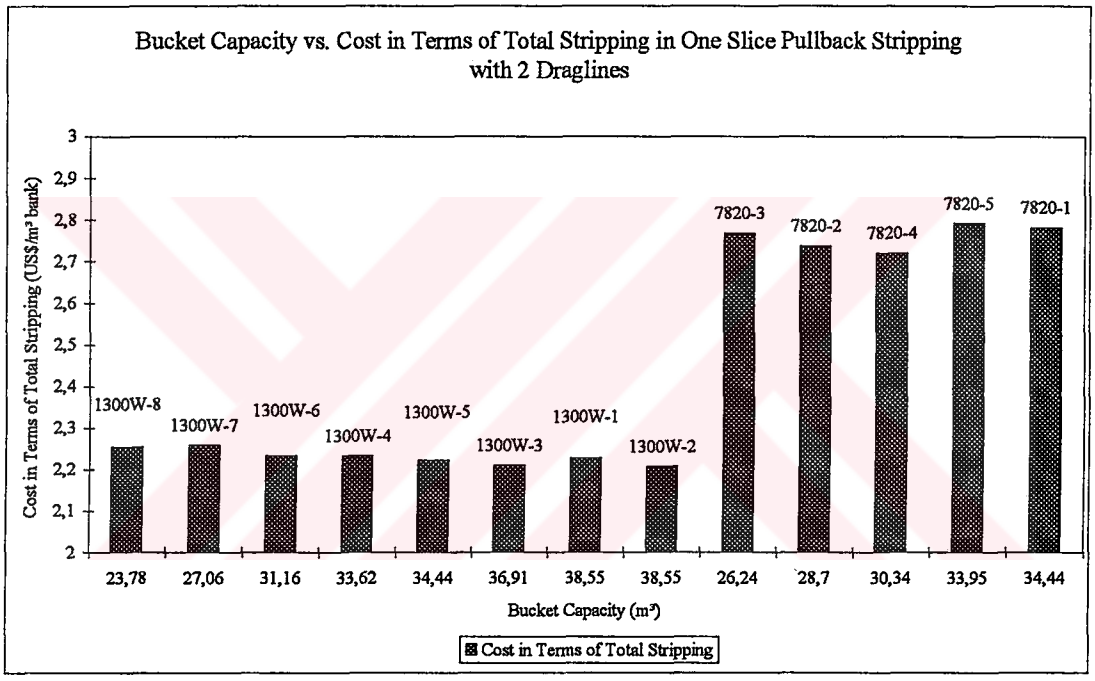


Figure 4.14. The Relation Between the Bucket Capacity and the Cost in Terms of Total Stripping of the Dependent Draglines in the One Slice Two Dragline Pullback Stripping Model

Bucket Capacity vs. Production Factor

For the sample run #2, the operating efficiency has been taken as 0.7. After analyzing the production figures in the extended bench casting model, it is seen that the production factor of draglines range between 220,000 to 235,000 bank m^3/m^3 of bucket capacity. Figure 4.15 illustrates that production factor of all draglines fluctuates around 225,000 m^3 that means it is producing consistent results.

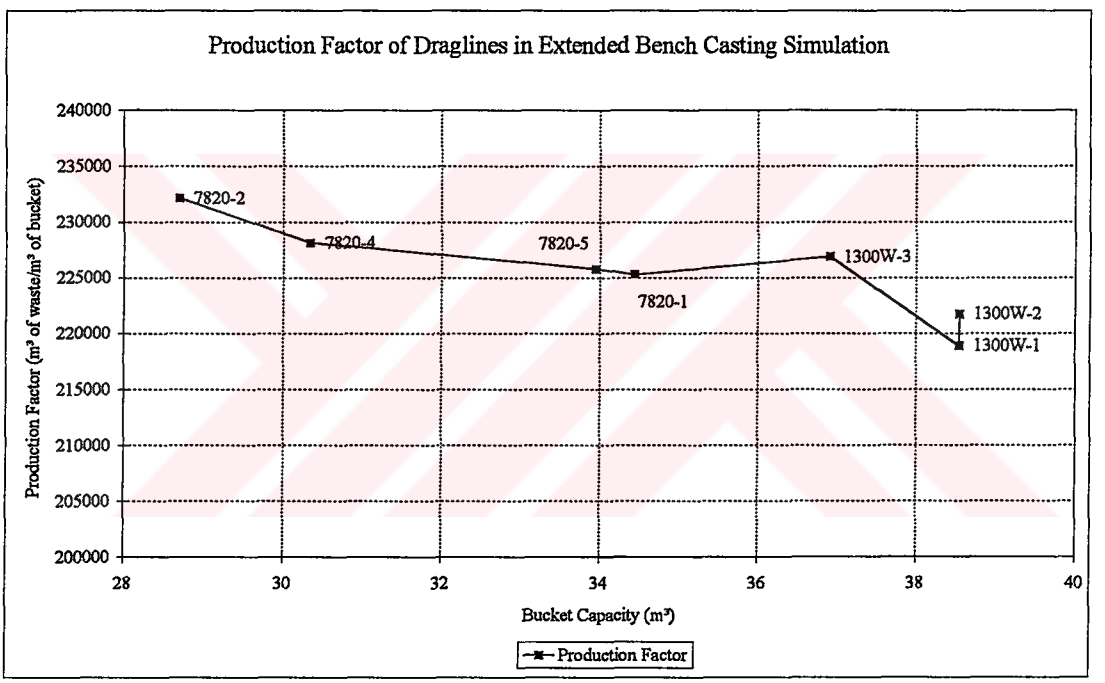


Figure 4.15. The Relation Between Bucket Capacity and Production Factor of Draglines in the Extended Bench Casting Simulation Model

Analysis of Cost Figures for the Sample Run #2

When the stripping cost figures for various stripping models are analyzed, it is observed that costs produced by the direct side casting model and the extended bench casting model are close to each other while other stripping models produce much higher cost figures. The closeness of the stripping cost is caused by the following reason. All draglines are members of the same series, Bucyrus-Erie 1300W family. The operating parameters vary among the members of a family but the variation is not of large-scale. Refer to Tables 4.14 and 4.15 where the operating radius and bucket capacity values are given. It can be observed that the longer operating radius draglines have met the requirements of the direct side casting geometry model and shorter ones have met those of the extended bench casting geometry model. However, there exists an inverse relationship between these parameters. The longer the operating radius the smaller the capacity. This is due to the swing inertia of draglines. If reach must be lengthened, then the bucket capacity must be sacrificed to keep the dragline in balance. Refer again to percent rehandle values of extended bench draglines in Table 4.15 where the values range between 10% to 15%. This reveals the fact that the draglines have spent most of their time in prime stripping rather than rehandling. If the rehandle percentage had been higher, the draglines would have spend more time for rehandling and the cost in terms of desired stripping would have been much higher than these given here.

It must be borne in mind that the draglines in the extended bench casting model are higher capacity ones compared to those in the direct side casting model and the least cost dragline comes from the extended bench model when the total cost of stripping is considered. However, the ultimate aim of the expert system is to select a dragline that exactly meets the desired stripping production and does not perform

rehandling. The reason for comparing draglines on the basis of desired stripping comes from the fact that both desired stripping that must be performed and prime stripping a dragline performs do not include rehandling. The stripping cost of a dragline whose prime stripping is closer to the desired volume will eventually be lower than another with a higher prime stripping and among the draglines given in Tables 4.14 and 4.15 the one whose prime stripping is the most closest to the desired stripping is the B-E 1300W-6.

Table 4.14. Combined Results of the Direct Side Casting Model

Dragline	1300W-4	1300W-5	1300W-6
Operating Radius (m)	81.7	78.9	86.0
Bucket Capacity (m^3)	33.62	34.44	31.16
Total Production (m^3)	7654571	7765094	7229430
Prime Production (m^3)	7654571	7765094	7229430
Yearly Total Owning & Operating Cost (US$)	3,948,011	3,968,804	3,904,924
Cost in Terms of Total Production (US$/$m^3$)	0.52011	0.51111	0.54014
Cost in Terms of Prime Production (US$/$m^3$)	0.52011	0.51111	0.54014
Cost in Terms of Desired Production (US$/$m^3$)	0.55272	0.55563	0.54669

Table 4.15. Combined Results of the Extended Bench Casting Model

Dragline	1300W-1	1300W-2	1300W-3
Operating Radius (m)	68.6	75.0	75.0
Bucket Capacity (m^3)	38.55	38.55	36.91
Total Production (m^3)	8437385	8547819	8373774
Prime Production (m^3)	7334750	7733535	7578207
Percent Rehandle (%)	15	10	10
Yearly Total Owning & Operating Cost (US$)	4,032,397	4,045,504	4,041,390
Cost in Terms of Total Production (US$/$m^3$)	0.47792	0.47328	0.48262
Cost in Terms of Prime Production (US$/$m^3$)	0.54980	0.52311	0.53329
Cost in Terms of Desired Production (US$/$m^3$)	0.56454	0.56637	0.56579

4.5. Sample Run #3

The third run has been performed for a severe operating environment characterized by a thick overburden, a medium coal production demand, a high scheduled working time and a medium operational efficiency. The draglines selected for testing were the MARION 8750 series which consists of 7 units. The input data and selected draglines are given in Table 4.16.

4.5.1. Results of Sample Run #3

After executing the expert system for the data given for sample run #2, the best dragline and stripping method pair has been concluded as the ***Marion 8750-1*** as the upper slice dragline and ***8750-2*** as the lower slice dragline and the ***Lower Slice Limited Extended Bench Casting*** method. The optimum selection and the cost of stripping from different aspects are given in Table 4.17.

4.5.2. Results of Pit Geometry and Range Diagramming Models

No draglines satisfied the requirements of the direct side casting geometry model. However, they all satisfied the extended bench geometry model. All but the 8750-1 satisfied the pullback casting on 1 slice with 1 dragline model and the same draglines in combination with all others satisfied pullback casting on 1 slice with 2 draglines model. Among two slice methods, none of them was successful in two slice direct side casting models, and limited extended bench with 1 dragline model. Two combinations have satisfied the limited extended bench with 2 draglines model and the

full extended bench with 2 dragline model. Lastly, 11 combinations have satisfied the 2 slice pullback stripping with two draglines geometry model. The results of the lower slice extended bench casting geometry model related to the best combination are presented in Table 4.18 and those related to all draglines are given in Appendix E.

Table 4.16. Basic Operating Parameters of Draglines in Sample Run #3

Model	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Working Weight (kg)	5080320	5307120	5692680	5896800	5715360	5806080	5896800
Boom Length (m)	91.4	102.1	102.1	109.7	102.1	109.7	102.1
Boom Angle (degrees)	35	36	33	30	36	30	32.5
Operating Radius (m)	83.8	91.4	94.5	103.6	91.4	103.6	102.1
Dumping Height (m)	39.0	45.7	40.2	40.5	45.7	40.5	40.2
Digging Depth (m)	45.7	45.7	45.7	61.0	45.7	61.0	45.7
Tub Radius (m)	24.4	24.4	24.4	24.4	24.4	24.4	24.4
Bearing Area (m^2)	467	467	467	467	467	467	467
Bearing Pressure (kPa)	108.79	113.65	121.90	126.27	122.39	124.33	126.27
Maximum Allowable Load (kg)	264449	215460	247212	204120	256284	181440	259006
Step Length (m)	2.13	2.13	2.13	2.13	2.13	2.13	2.13
Walking Speed (m/h)	0	0	0	0	0	0	0

Table 4.17. The Best Dragline and Stripping Method Pair for the Sample Run #3

Stripping Method	Lower Slice Limited Extended Bench Casting with 2 Draglines	
Upper Slice Dragline	8750-1	
Lower Slice Dragline	8750-2	
Cost in Terms of Total Stripping	0.56716	0.66457
Cost in Terms of Prime Stripping	0.56716	0.91610
Cost in Terms of Desired Stripping	1.08379	1.23405
Combined Cost	2.31784	

Table 4.18. Results of the Lower Slice Limited Extended Bench Casting with 2 Draglines Geometry Model for 8750-1 and 8750-2

Upper Slice Dragline	8750-1
Lower Slice Dragline	8750-2
Upper Slice Thickness (m)	21.70
Lower Slice Thickness (m)	18.30
Pit Width (m)	44.73
Upper Slice Keycut Upper Width (m)	26.73
Upper Slice Keycut Right Wall Angle (degrees)	62
Lower Slice Keycut Upper Width (m)	25.63
Lower Slice Keycut Right Wall Angle (degrees)	55
Effective Reach (m)	26.43
Height of Temporary Spoil Pile (m)	38.47
Area of Void Near the Lower Slice (m^2)	200.80
Area of Conical Part in Spoil Pile to Fill the Void (m^2)	200.80
Height of Limited Extended Bench (m)	24.30
Width of Limited Extended Bench (m)	54.47
Required Reach on Lower Slice (m)	70.10
Available Reach on Spoil Side (m)	73.10
Percent Rehandle (%)	17.88

4.5.3. Results of Production Simulation Models

The one slice 2 draglines pullback stripping model, lower slice limited and full extended bench casting models with 2 draglines, and two slice two dragline pullback casting model have produced dragline combinations that have met the required stripping production. The results of the simulation geometry and production simulation model related to the best combination are presented in Tables 4.19 and 4.20 and those related to all draglines are given in Appendix E.

Table 4.19. Results of the Lower Slice Limited Extended Bench Casting with 2 Draglines Simulation Geometry Model for 8750-1 and 8750-2

Upper Slice Dragline	8750-1
Lower Slice Dragline	8750-2
Upper Slice Bucket Capacity (m^3)	85.15
Lower Slice Bucket Capacity (m^3)	69.38
Upper Slice Set Length (m)	31.11
Upper Slice Setback Distance (m)	30.99
Lower Slice Set Length (m)	36.74
Lower Slice Setback Distance (m)	36.36
Upper Slice Keycut Right Wall Angle (degrees)	62
Lower Slice Keycut Right Wall Angle (degrees)	55
Upper Slice Keycut Volume (m^3)	9024
Upper Slice Maincut Volume (m^3)	21177
Lower Slice Keycut Volume (m^3)	8616
Lower Slice Maincut Volume (m^3)	21463
Rehandle Volume (m^3)	15985
Upper Slice Distance 1-2 (m)	11.24
Upper Slice Distance 2-3 (m)	21.68
Upper Slice Distance 1-3 (m)	18.54
Upper Slice Distance 4-1' (m)	50.91
Lower Slice Distance 1-2 (m)	28.82
Lower Slice Distance 2-3 (m)	23.91
Lower Slice Distance 1-3 (m)	37.45
Lower Slice Distance 4-1' (m)	67.15

Table 4.20. Results of the Lower Slice Limited Extended Bench Casting with 2 Draglines Production Simulation Model for 8750-1 and 8750-2

Upper Slice Dragline	8750-1
Lower Slice Dragline	8750-2
Average Upper Slice Keycut Cycle Time (s)	60.60816
Average Upper Slice Maincut Cycle Time (s)	60.59071
Average Lower Slice Keycut Cycle Time (s)	59.98937
Average Lower Slice Keycut Cycle Time (s)	59.99412
Average Fill Factor (.00)	0.90001
Total Time Spent for Upper Slice Keycut (s)	7186128
Total Time Spent for Upper Slice Maincut (s)	16781263
Total Time Spent for Upper Slice Walking (s)	1517340
Total Time Spent for Upper Slice Delays (s)	3315274
Total Time Spent for Lower Slice Keycut (s)	4969819
Total Time Spent for Lower Slice Maincut (s)	12339103
Total Time Spent for Lower Slice Rehandle (s)	6768062
Total Time Spent for Lower Slice Waiting (s)	116186
Total Time Spent for Lower Slice Walking (s)	1443432
Total Time Spent for Lower Slice Delays (s)	3180117
Total Scheduled Time (s)	28800000
Upper Slice Total Stripping Time (s)	28800005
Lower Slice Total Stripping Time (s)	28816720
Upper Slice X-Direction Walk (m)	22867
Lower Slice X-Direction Walk (m)	16131
Upper Slice Total Stripping (m^3)	22288437
Upper Slice Prime Stripping (m^3)	22288437
Upper Slice Desired Stripping (m^3)	11659094
Lower Slice Total Stripping (m^3)	18425322
Lower Slice Prime Stripping (m^3)	13244796
Lower Slice Desired Stripping (m^3)	9832324
Desired Stripping (m^3)	21428571

4.5.4. Results of the Stripping Cost Models

For this sample run case, only those models that have employed two draglines could satisfy the production requirement. Those draglines in specific models

have been subjected to the stripping cost determination. The results of the lower slice extended bench casting with two draglines cost model related to the best combination are presented in Table 4.21. The stripping cost results of the other stripping method models are presented in Appendix E.

Table 4.21. Results of the Limited Extended Bench Casting with 2 Draglines Stripping Cost Model for 8750-1 and 8750-2

Upper Slice Dragline	8750-1	
Lower Slice Dragline	8750-2	
Yearly Total Owning Cost (US$)	6,202,136	6,247,847
Yearly Total Operating Cost (US$)	6,433,893	5,885,751
Yearly Total Owning & Operating Cost (US$)	12,636,029	12,133,597
Hourly Owning & Operating Cost (US$/h)	1579.5036	1516.6997
Cost in Terms of Total Production (US$/bank m^3)	0.56716	0.66457
Cost in Terms of Prime Production (US$/ bank m^3)	0.56716	0.91610
Cost in Terms of Desired Production (US$/ bank m^3)	1.08379	1.23405
Combined Cost on the Basis of Desired Production (US$/$m^3$)	2.31784	

4.5.5. Discussion on the Results of Sample Run #3

Several analyses have been carried out on the outputs that the system has produced and compared to those in literature. They are given below.

Bucket Capacity vs. Cycle Time

It has been indicated that (Anonymous, 1993a), smaller capacity draglines perform a cycle faster than larger capacity ones. Although the cycle time of a dragline is around the industry standard of 60 s (Chironis, 1986), higher swing inertia of large capacity draglines force it to above this value. This fact is illustrated in Figure 4.16 where the cycle time increases with the bucket capacity. The data has been taken from the maincut cycle time of highwall side draglines in the one slice two dragline pullback stripping simulation model.

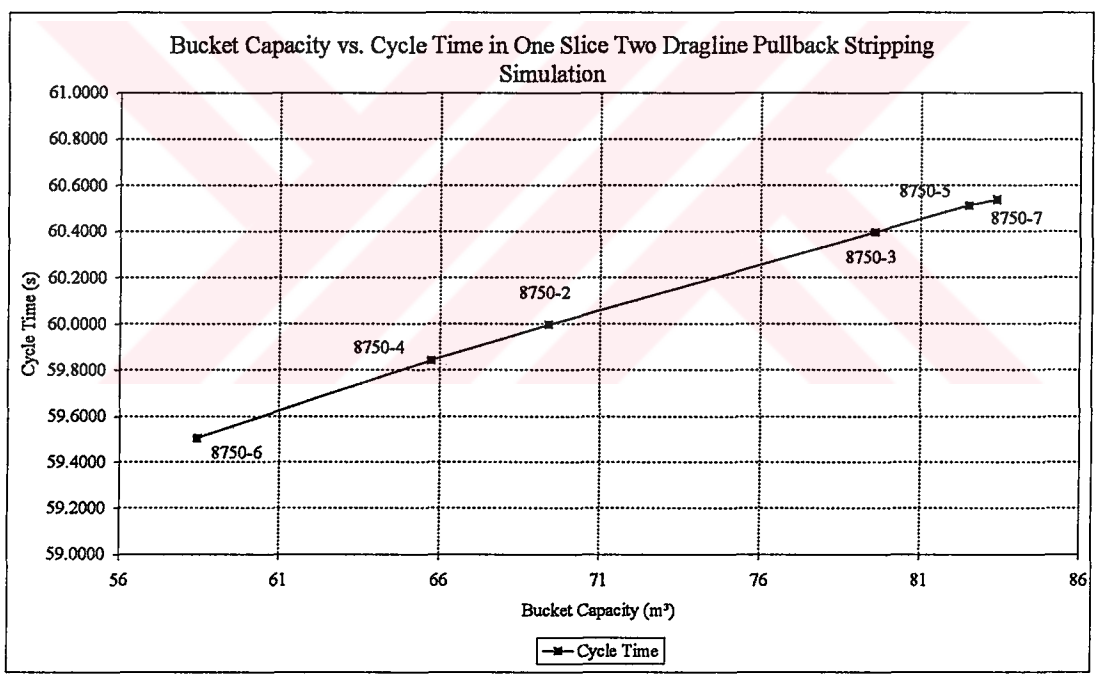


Figure 4.16. The Relation Between Bucket Capacity and Cycle Time of Draglines in One Slice Two Dragline Pullback Stripping Simulation Model

Bucket Capacity vs. Electricity Consumption

It has been stated that larger capacity draglines consume more power to spoil a cubic meter of waste than smaller capacity draglines (Anonymous, 1993a). The capacity of draglines is positively related with the working weight and the bucket capacity increases with the working weight. Figure 4.17 illustrates this assertion where the electricity consumption increases with the working weight. The data has been taken from the electricity consumption of spoil side draglines in the one slice two dragline pullback stripping simulation model.

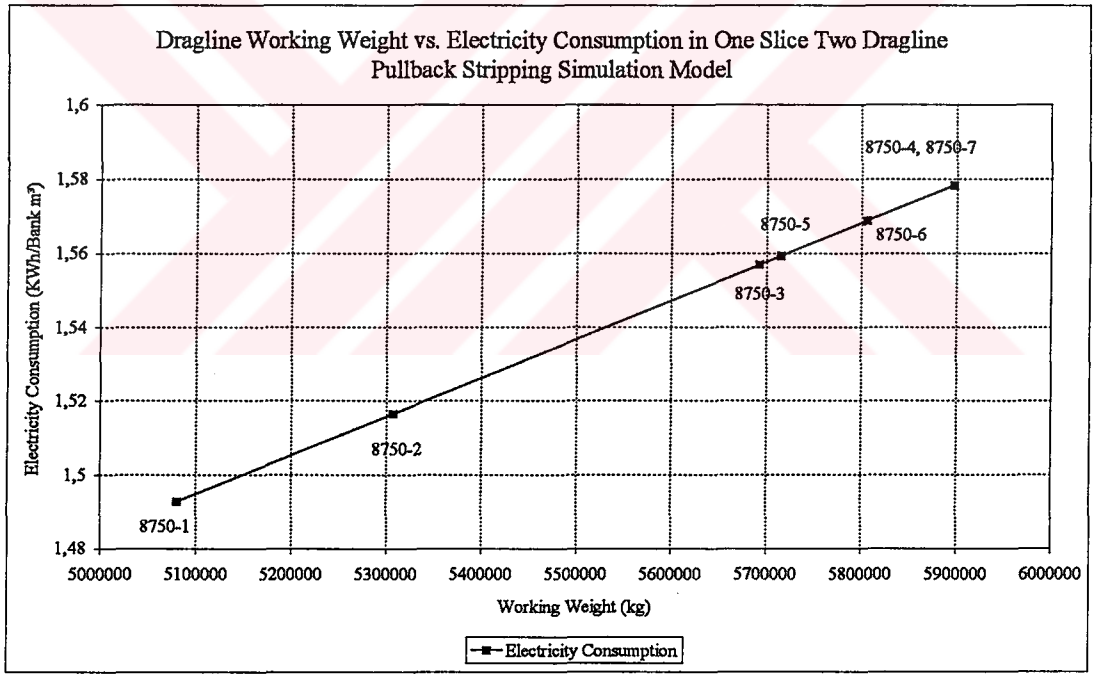


Figure 4.17. The Relation Between Working Weight and Electricity Consumption of Draglines in One Slice Two Dragline Pullback Stripping Simulation Model

Percent Walking Time

During simulation phases, percent time spent for walking is calculated between 1-5 % of the total time. The results obtained are similar to previous studies. Sadri and Lee (1982) simulated dragline operating schemes and indicated that total time spent for walking is around 2-3 % of the scheduled time. Figure 4.18 illustrates the similarity in walking times between the expert system and those mentioned previously. The data has been taken from the walking time of highwall side draglines in two slice two dragline pullback stripping simulation model.

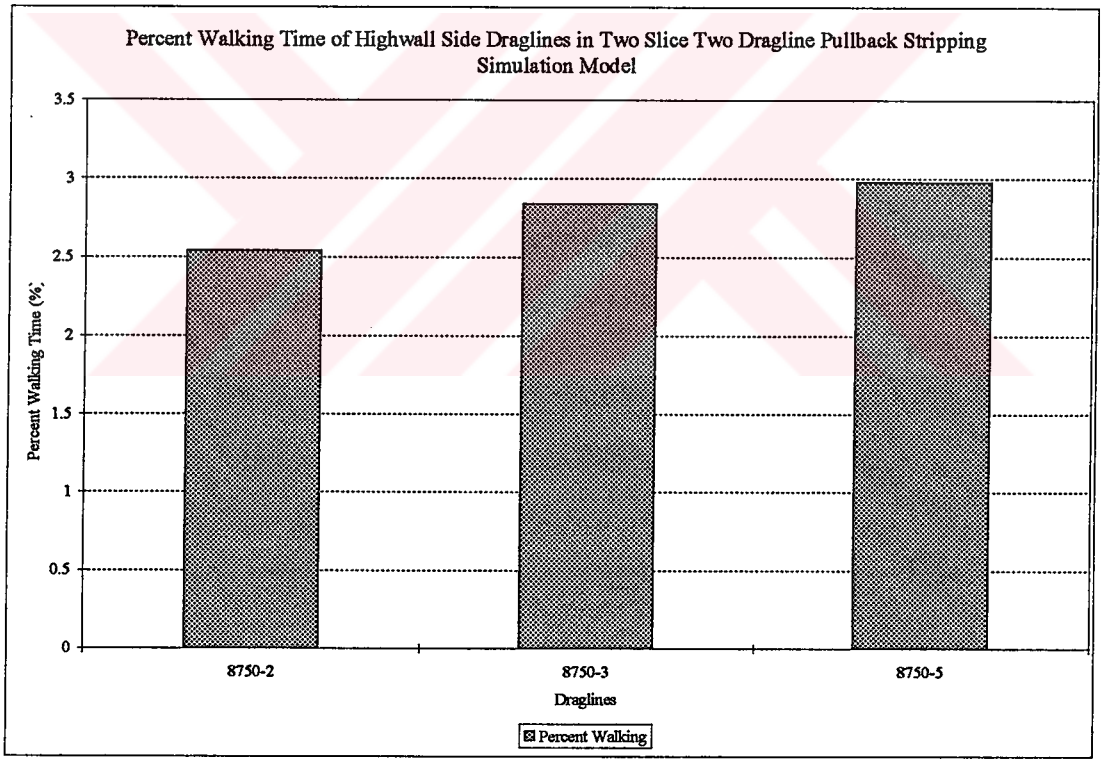


Figure 4.18. The Percent Walking Time of Highwall Side Draglines in Two Slice Two Dragline Pullback Stripping Simulation Model

4.6. Sample Run #4

The geometrical data gathered from Turkish Coal Enterprises (TKİ) Tunçbilek open pit mine has been used to show the applicability of the model. The current stripping method applied in TKİ's Tunçbilek open pit mine is the extended bench casting with 35% rehandling and a MARION 7820 is used in overburden removal operations. The available data did not cover most of the parameters used in production simulation and stripping cost calculations and only the geometrical analysis has been performed. The geometrical data characterizing the mine are given in Table 4.22. The coal thickness has been assumed as 7 m. The physical operating data of the dragline in the database and the one employed at Tunçbilek mine are given in Table 4.23.

Table 4.22. The Geometrical Data of Tunçbilek Open-Pit Mine

INPUT VARIABLES	*Sample Run #4*
Average Overburden Thickness (m)	25
Average Coal Seam Thickness (m)	7
Highwall Angle (degrees)	60
Coal Seam Bench Angle (degrees)	80
Spoil Pile Angle (degrees)	35
Swell Factor of the Waste (%)	40

After performing analyses with the simple side casting geometry module, the ***MARION 7820-4*** could not satisfy the necessary operating dimensions and failed to meet the required reach value. The expert system then switched to the extended bench geometry model to test the dragline. The ***MARION 7820-4*** satisfied the

geometrical requirements of this method. The expert system has produced results that are very close to actual ones. The actual and computed results are given in Table 4.24.

Table 4.23. Comparison of Actual and Catalog Operating Dimensions of the Dragline Employed in Tunçbilek Open-Pit Mine

Dragline Data Related to MARION 7820-4	Catalog Data	Actual Data
Working Weight (kg)	1,428,840	N/A
Boom Length (m)	71.6	76.2
Boom Angle (degrees)	32.5	32
Operating Radius (m)	67.1	67.0
Dumping Height (m)	25.9	29.2
Digging Depth (m)	41.8	25.0
Tub Radius (m)	15.2	N/A
Bearing Area (m^2)	182	N/A
Bearing Pressure (kPa)	78.33	N/A
Maximum Allowable Load (kg)	83,916	86,000
Step Length (m)	2.13	2.13
Walking Speed (m/h)	N/A	241

Table 4.24. Comparison of Actual Data from Tunçbilek Open-pit Mine and Computed Results in Extended Bench Casting Geometry Model

Dragline	Computed Data	Actual Data
Pit Width (m)	65.87	50.00
Required Reach (m)	82.12	N/A
Available Reach (m)	55.70	N/A
Bench Extension (m)	26.42	N/A
Keycut Upper Width (m)	51.37	N/A
Keycut Bottom Width (m)	22.50	N/A
Keycut Right Wall Angle (°)	60	N/A
Percent Rehandle (%)	32	35
Pit Geometry Model Result	PASS	-

4.7. Discussion on the Expert System

Apart from discussions on the results of the sample cases, the following comments are valid for the expert system.

1. During the sample runs, it has been observed that the use of a single equipment in two slice techniques was difficult and the dragline was mismatched for one of the slices. So two slice techniques employing one dragline did not produce working solutions in most times. This was caused by designing the required dragline dimensions for the upper slice. Humphrey (1990) indicates the same problem of mismatching dragline dimensions.

2. The developed dragline stripping models attempt to allocate the full thickness of the overburden for one slice. Hence, models applied for two slice cases produce no working dragline combinations where the overburden thickness is adequate for models applied on one slice. For instance, in Sample Run #1 where the average overburden thickness was 20 m, there has been produced no draglines by two slice techniques. Because all the upper slice draglines were capable to spoil all 20 m. thick strata and left no waste for the lower slice.

3. The direct side casting model produces no working dragline solutions when the overburden gets thicker than 40 m even with the largest capacity draglines as seen in Sample Run #3. Wolski and Prince (1986) state that after 45 m of depth dragline stripping becomes no more economical. This is because of inclusion of ever-increasing rates of rehandling as the the pit gets deeper. Switching to two-slice techniques produce working solutions, however the cost of stripping increases drastically in two-dragline cases.

4. After running the expert system for sample cases, it has been observed that the stripping cost of one dragline-one slice systems is about 0.50-0.60 US$/bank m^3. Lee (1988), after running his dragline simulator for a sample case, calculated the cost of stripping as 0.39 US$. Also, it is indicated that (Anonymous, 1993a) the cost of stripping must be between 0.33-0.52 US$/bank m^3 for normal operations. This shows that the developed expert system is producing reasonable solutions as far as the cost of stripping is concerned.

5. As could be seen from results of Sample Run #3 that, the cost of stripping one cubic meter of waste is 2.31784 US$ where the stripping method was lower slice limited extended bench casting with two draglines. The upper slice dragline was a MARION 8750-1 and the lower slice dragline was a MARION 8750-2. The cost was much higher than one dragline systems. There can be addressed two causes for this high cost. Firstly two dragline systems must be very carefully matched. In other words, rate of linear advance of both draglines must approximately be the same. The management will definitely experience problems if one of the draglines' stripping capacity is higher or lower than the portion left to it. The second and the less significant cause of the high cost is the inclusion of another dragline into the system. The extra dragline will contribute significantly to the total cost of stripping no matter how productive it works.

6. During the sample runs it has been observed that the owning cost of a dragline is nearly equal to or sometimes higher than the operating cost. This means that the mine management is under significant monetary load whether or not the dragline is allowed to strip. As Chironis (1980) states, this reveals the fact that a dragline must be worked continuously to make it pay off.

7. After performing numerous simulation runs, it has been observed that the deviation in value of output parameters was but a very small percentage. For instance, refer to Table E.37 in Appendix E where the production simulation outputs of two slice two dragline pullback stripping are presented. See the total stripping volume figures of the highwall side dragline. Since in this model combinations are produced, the stripping production of a highwall side dragline is simulated many times. This matter has been confirmed by Bandopadhyay and Sundararajan (1986) who after simulating dragline systems tens of times, indicated that the deviation in production stripping was less than 0.013%.

8. The expert system requires large computer storage area and long durations of time for execution. The most time-consuming procedure is the production simulation phase. Although the time and storage space required to execute one dragline cases are within allowable limits, two dragline cases where many dragline combinations exist demand excessive resources to execute. Table 4.25 gives the estimated time figures required to run pit geometry, production simulation and stripping cost models. The computer on which the tests were done had an INTEL 486DX-50 CPU. In Table 4.26 are given the required space to store the output files produced by these models.

   To notice the user about how long it would take to execute the expert system and how large a storage area would be needed for a case if all 245 draglines in the database were selected, tables 4.27 and 4.28 have been prepared. As it is clearly seen, such a case would require more than a month's time and approximately 370 Mbytes of storage space.

Table 4.25. Estimated Time to Execute Models in the Expert System (Max. 245 draglines, 6000 h of scheduled time)

Maximum Estimated Time Spent for Model Execution	Pit Geometry	Production Simulation	Stripping Cost
Direct Side Casting	Negligible	25 min.	Negligible
Extended Bench Casting	Negligible	25 min.	Negligible
One Slice One Dragline Pullback Stripping	Negligible	25 min.	Negligible
One Slice Two Dragline Pullback Stripping	10 min.	167 h.	10 min.
Two Slice One Dragline Direct Side Casting	Negligible	25 min.	Negligible
Two Slice Two Dragline Direct Side Casting	10 min.	167 h.	10 min.
Two Slice One Dragline Lower Slice Limited Extended Bench Casting	Negligible	25 min.	Negligible
Two Slice Two Dragline Lower Slice Limited Extended Bench Casting	10 min.	167 h	10 min.
Two Slice One Dragline Lower Slice Full Extended Bench Casting	Negligible	25 min.	Negligible
Two Slice Two Dragline Lower Slice Full Extended Bench Casting	10 min.	167 h	10 min.
Two Slice One Dragline Pullback Stripping	Negligible	25 min.	Negligible
Two Slice Two Dragline Pullback Stripping	10 min.	167 h	10 min.

Table 4.26. Estimated Storage Area to for Output Files Produced by the Models in the Expert System (Max. 245 draglines)

Maximum Estimated Storage Area for Output Files	Pit Geometry	Production Simulation	Stripping Cost
Direct Side Casting	204 byte 49 kB	312 byte 75 kB	80 byte 19 kB
Extended Bench Casting	360 byte 86 kB	366 byte 88 kB	80 byte 19 kB
One Slice One Dragline Pullback Stripping	539 byte 129 kB	521 byte 125 kB	80 byte 19 kB
One Slice Two Dragline Pullback Stripping	539 byte 31 MB	521 byte 30 MB	160 byte 9 MB
Two Slice One Dragline Direct Side Casting	412 byte 99 KB	622 byte 149 kB	80 byte 19 kB
Two Slice Two Dragline Direct Side Casting	413 byte 24 MB	623 byte 36 MB	160 byte 9 MB
Two Slice One Dragline Lower Slice Limited Extended Bench Casting	575 byte 138 kB	659 byte 158 kB	80 byte 19 kB
Two Slice Two Dragline Lower Slice Limited Extended Bench Casting	576 byte 33 MB	659 byte 38 MB	160 byte 9 MB
Two Slice One Dragline Lower Slice Full Extended Bench Casting	575 byte 138 kB	659 byte 158 kB	80 byte 19 kB
Two Slice Two Dragline Lower Slice Full Extended Bench Casting	576 byte 33 MB	659 byte 38 MB	160 byte 9 MB
Two Slice One Dragline Pullback Stripping	587 byte 140 kB	526 byte 126 kB	80 byte 19 kB
Two Slice Two Dragline Pullback Stripping	588 byte 34 MB	527 byte 30 MB	160 byte 9 MB

Table 4.27. Estimated Time to Execute the Expert System for 245 Draglines

Required Time to Execute the Geometry Modules	1 h
Required Time to Execute the Simulation Modules	838 h
Required Time to Execute the Cost Modules	1 h
Total Time to Execute the Expert System	840 h (35 days)

Table 4.28. Estimated Space to Store Output Files

Required Space to Save the Geometry Output Files	156 MB
Required Space to Save the Simulation Output Files	173 MB
Required Space to Save the Cost Output Files	45 MB
Total Time to Save All Output Files	374 MB

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1. Conclusions

In this study, an expert system has been developed for dragline-stripping method selection in surface coal mines. The dragline selection mechanism has been based on three basic criteria, namely; pit geometry and range diagramming analysis, production simulation and finally the stripping cost determination studies. Seven basic stripping techniques have been analysed and then modeled where the required pit dimensions have been translated into mathematical formulations within the domain of the pit geometry studies. These stripping techniques are: direct side casting, extended bench casting, pullback stripping, two slice direct side casting, lower slice limited and full extended bench casting and two slice pullback stripping. The production simulation studies have been done to estimate the production capability of a dragline employed in a particular stripping method. However, the possibility of employing two draglines in methods that are applied in two slices or on both sides of the pit led to the development of twelve production simulation models. Finally models that would be used to determine the cost of dragline stripping have been developed for each stripping method. Besides, the expert system has been equipped with numerous facility routines to ease the data entrance, choose the draglines for testing, manage the dragline database and provide the user with the outputs of pit design models.

After conducting sessions with the expert system and analysing and comparing the results with those published previouly, it has been concluded that the models have been producing meaningful and reasonable outcomes. Some critical conclusions are as follows;

1. A cut spoiling diagram in the direct side casting method that ignores keycut spoiling procedure may result in dumping the keycut waste onto highwall. For this reason, a keycut excavation and spoiling methodology has been developed in the study to place the keycut waste accurately in the empty pit.

2. Previous studies have been based on static bench extension formulations where the principles for switching to extended bench method has not been clear. However, deciding how wide an extended bench is required is of utmost importance in terms of minimizing the rehandle percentage. In the study, the need for switching to extended bench method has been defined and four extended bench building patterns have been generated with the rehandled area and percent rehandle formulated for each pattern.

3. Previous studies have ignored the pullback pad spoil pile building principles. However, availability of room on spoil side especially in deep overburden conditions is very important in determining whether a dragline can place all the waste on the pullback pad. For this reason, pit geometry models have been equipped with principles of building pullback pad spoil piles.

4. Simulation of dragline systems has been limited to one dragline applications in previous studies. However, simulation of two dragline systems has been unexplored. The cause of this is the complexity in dragline synchronization. The

two dragline simulation models in the expert system have been equipped with dragline synchronization procedures.

5. The stripping cost determining models have been equipped with three different cost methodology; cost in terms of total stripping, cost in terms of prime stripping and cost in terms of desired stripping where the ultimate dragline selection has been based on this item.

5.2. Recommendations for Further Research

The recommendations for further research are as follows:

1. The dragline selecting expert system has been designed for one flat-lying coal seam. Considering the existence of more than one coal seam that are not necessarily flat in surface mines, the pit geometry studies can be enlarged to equip the expert system with tools that cover such inconvenient cases.

2. The expert system has been designed for up to two draglines. In stripping methods like terrace mining that is applied in deep overburden situations however, employment of three draglines in the same pit is possible. The pit geometry and production simulation studies can be enlarged to allow the introduction of one more dragline into the stripping scheme.

3. The expert system has been designed for up to two slices. In deep overburden conditions, multi-slice mining may be required. The pit geometry studies can be extended towards multi-slice mining methods to cope with deep overburden cases.

4. The pit geometry and range diagramming studies have been designed on a two-dimensional space. Introducing a third dimension that is taken along the block length into the pit geometry studies will make the horizontal dimension calculations more precise.

5. The mechanism of the expert system is based on selecting the dragline that is producing at the lowest cost. However, in reality, the dragline declared as the most optimum one is actually the most optimum among other alternative draglines allowed for testing, not among all draglines in the database. Reaching the best dragline is only possible by allowing all draglines in the database to be tested by the expert system. This, however requires very large storing area for the generated data files and many hours of computer processing time. Stuart and Cobb (1988) complain the same problem of time-consuming iterations during pit optimization in the computer. They state that several draglines are processed for a range of pit configurations and this process is tedious. This inconvenience can be overcome by generating intelligent methods that would reduce the time required to execute the model and space needed to store the output files. Besides, the largest time-consuming process in an expert system session is the production simulation procedure due to the potential dragline combinations generated by pit geometry models. Cutting the time required for simulation by some percent may allow the introduction of extra draglines into the expert system.

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APPENDIX A

DRAGLINE DATABASE

A.1. The Dragline Database

The dragline database contains physical operating dimensions of draglines manufactured by the three dragline manufacturing companies, namely Marion of Indresco, Inc., Bucyrus-Erie Company and P&H-Page Company.

There have been embodied some 245 draglines in the database of which 104 belong to Bucyrus-Erie, 73 belong to Marion and 68 draglines belong to P&H-Page. The data related to the operating dimensions of Bucyrus-Erie, Marion and P&H-PAGE draglines are given in Tables A.1, A.2 and A.3, respectively. The collected data related to draglines of each manufacturer company have been compiled together and transferred into three computer files by using Borland PASCAL V.7.0. to be later processed by the expert system. The name of the database files are;

1. BE.DAT { Bucyrus-Erie Draglines }
2. MARIO.DAT {Marion Draglines}
3. PHPAGE.DAT { P&H-Page Draglines }

Table A.1. The Operating Dimensions of Bucyrus-Erie Draglines

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
380W-1	459293	42.7	40	35.1	18.9	22.9	9.1	66	69.93	36288	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-2	459293	42.7	35	37.2	16.2	22.9	9.1	66	69.93	34020	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-3	459293	42.7	30	39.3	13.1	22.9	9.1	66	69.93	32206	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-4	494265	51.8	40	42.1	25.0	30.5	9.1	66	75.25	29030	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-5	494265	51.8	35	44.8	21.3	30.5	9.1	66	75.25	27216	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-6	494265	51.8	30	47.2	18.0	30.5	9.1	66	75.25	25855	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-7	523296	61.0	40	49.1	31.7	38.1	9.1	66	79.67	22680	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-8	523296	61.0	35	52.4	27.4	38.1	9.1	66	79.67	21319	9.4	1.1	1.6	3.5	12.7	2.29	644
380W-9	523296	61.0	30	55.2	23.2	38.1	9.1	66	79.67	20412	9.4	1.1	1.6	3.5	12.7	2.29	644
480W-1	700812	53.3	40	46.9	21.9	24.4	11.0	95	74.10	37195	11.6	1.4	5.1	2.6	15.1	0.00	241
480W-2	700812	53.3	35	49.7	18.3	28.0	11.0	95	74.10	37195	11.6	1.4	5.1	2.6	15.1	0.00	241
480W-3	700812	53.3	30	52.1	14.3	32.0	11.0	95	74.10	37195	11.6	1.4	5.1	2.6	15.1	0.00	241
480W-4	721224	59.4	40	51.5	25.9	20.4	11.0	95	76.26	36288	11.6	1.4	5.1	2.6	15.1	2.24	241
480W-5	721224	59.4	35	54.6	21.6	25.9	11.0	95	76.26	34474	11.6	1.4	5.1	2.6	15.1	2.24	241
480W-6	721224	59.4	30	57.3	17.4	33.5	11.0	95	76.26	32659	11.6	1.4	5.1	2.6	15.1	2.24	241
480W-7	746172	65.5	40	56.1	32.6	21.3	11.0	95	78.90	31752	11.6	1.4	5.1	2.6	15.1	2.24	241
480W-8	746172	65.5	35	59.7	28.0	25.9	11.0	95	78.90	29938	11.6	1.4	5.1	2.6	15.1	2.24	241
480W-9	746172	65.5	30	62.8	23.2	35.1	11.0	95	78.90	28123	11.6	1.4	5.1	2.6	15.1	2.24	241
680W-1	1011528	57.9	34	51.2	24.4	45.7	11.9	111	91.11	70308	15.5	1.5	1.9	4.7	16.6	2.24	290
680W-2	1011528	57.9	30	53.3	21.0	48.8	11.9	111	91.11	65772	15.5	1.5	1.9	4.7	16.6	2.24	290
680W-3	1018332	68.6	40	55.5	36.3	48.8	11.9	111	91.73	56700	15.5	1.5	1.9	4.7	16.6	2.24	290
680W-4	1018332	68.6	34	60.0	30.8	48.8	11.9	111	91.73	54432	15.5	1.5	1.9	4.7	16.6	2.24	290
680W-5	1029672	79.2	40	63.7	42.7	57.9	11.9	111	92.75	47628	15.5	1.5	1.9	4.7	16.6	2.24	290
680W-6	1029672	79.2	34	68.6	36.6	57.9	11.9	111	92.75	43092	15.5	1.5	1.9	4.7	16.6	2.24	290
680W-7	1045548	89.9	34	77.4	44.8	57.9	11.9	111	94.18	36288	15.5	1.5	1.9	4.7	16.6	2.24	290

Table A.1. The Operating Dimensions of Bucyrus-Erie Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
1260W-1	1716876	69.2	31	65.5	25.6	39.6	16.8	221	77.78	90720	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-2	1755432	71.9	34	65.8	30.5	33.5	16.8	221	79.53	90720	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-3	1755432	71.9	30	68.6	25.9	38.1	16.8	221	79.53	88906	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-4	1764504	79.2	35	71.3	35.4	41.1	16.8	221	79.94	81648	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-5	1764504	79.2	30	75.0	30.5	45.7	16.8	221	79.94	74844	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-6	1766772	87.0	38	75.0	44.2	35.1	16.8	221	80.05	72576	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-7	1766772	87.0	30	81.7	35.7	45.7	16.8	221	80.05	62143	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-8	1769040	92.0	38	78.9	48.8	30.5	16.8	221	80.15	64411	15.8	2.7	5.2	5.2	23.5	2.18	241
1260W-9	1769040	92.0	30	86.0	38.1	53.3	16.8	221	80.15	54432	15.8	2.7	5.2	5.2	23.5	2.18	241
1300W-1	2109240	79.2	38	68.6	37.2	41.1	16.8	221	95.56	106596	17.4	2.7	5.2	5.2	23.5	2.18	241
1300W-2	2109240	79.2	30	75.0	28.0	50.3	16.8	221	95.56	106596	17.4	2.7	5.2	5.2	23.5	2.18	241
1300W-3	2154600	87.0	38	75.0	42.7	50.3	16.8	221	97.62	102060	17.4	2.7	5.2	5.2	23.5	2.18	241
1300W-4	2154600	87.0	30	81.7	32.6	59.4	16.8	221	97.62	92988	17.4	2.7	5.2	5.2	23.5	2.18	241
1300W-5	2154600	92.0	38	78.9	45.7	47.2	16.8	221	97.62	95256	17.4	2.7	5.2	5.2	23.5	2.18	241
1300W-6	2154600	92.0	30	86.0	35.1	61.0	16.8	221	97.62	86184	17.4	2.7	5.2	5.2	23.5	2.18	241
1300W-7	2222640	99.1	38	84.4	50.9	47.2	16.8	221	100.70	74844	17.4	2.7	5.2	5.2	23.5	2.18	241
1300W-8	2222640	99.1	30	92.0	39.6	61.0	16.8	221	100.70	65772	17.4	2.7	5.2	5.2	23.5	2.18	241
1350W-1	2677601	86.9	38	77.7	38.1	45.7	17.7	245	109.09	102060	20.1	2.4	7.6	4.4	24.8	2.59	225
1350W-2	2677601	86.9	30	84.4	28.0	51.8	17.7	245	109.09	95256	20.1	2.4	7.6	4.4	24.8	2.59	225
1350W-3	2743010	93.0	38	82.3	43.3	45.7	17.7	245	111.75	97524	20.1	2.4	7.6	4.4	24.8	2.59	225
1350W-4	2743010	93.0	30	89.6	32.6	51.8	17.7	245	111.75	90720	20.1	2.4	7.6	4.4	24.8	2.59	225
1350W-5	2770044	99.1	38	87.2	48.8	45.7	17.7	245	112.85	92988	20.1	2.4	7.6	4.4	24.8	2.59	225
1350W-6	2770044	99.1	30	94.8	37.2	51.8	17.7	245	112.85	83916	20.1	2.4	7.6	4.4	24.8	2.59	225
1360W-1	2829058	86.9	38	77.7	38.1	45.7	17.7	245	115.26	120204	20.1	2.4	7.6	4.4	24.8	2.59	225
1360W-2	2829058	86.9	30	84.4	28.0	51.8	17.7	245	115.26	115668	20.1	2.4	7.6	4.4	24.8	2.59	225

Table A.1. The Operating Dimensions of Bucyrus-Erie Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
1360W-3	2872785	93.0	38	82.3	41.8	45.7	17.7	245	117.04	117936	20.1	2.4	7.6	4.4	24.8	2.59	225
1360W-4	2872785	93.0	30	89.6	31.1	51.8	17.7	245	117.04	108864	20.1	2.4	7.6	4.4	24.8	2.59	225
1360W-5	2918009	99.1	38	87.2	45.7	45.7	17.7	245	118.88	113400	20.1	2.4	7.6	4.4	24.8	2.59	225
1360W-6	2918009	99.1	30	94.8	34.1	51.8	17.7	245	118.88	104328	20.1	2.4	7.6	4.4	24.8	2.59	225
1370W-1	2903494	86.9	38	77.7	38.1	29.0	19.4	294	98.69	138348	20.7	2.4	7.9	4.3	27.2	2.59	225
1370W-2	2903494	86.9	30	84.4	28.0	50.3	19.4	294	98.69	127008	20.7	2.4	7.9	4.3	27.2	2.59	225
1370W-3	3022790	94.5	38	83.8	42.7	33.5	19.4	294	102.74	129276	20.7	2.4	7.9	4.3	27.2	2.59	225
1370W-4	3022790	94.5	30	91.1	32.0	44.2	19.4	294	102.74	117936	20.7	2.4	7.9	4.3	27.2	2.59	225
1370W-5	3070872	97.5	38	86.3	44.8	35.1	19.4	294	104.37	127008	20.7	2.4	7.9	4.3	27.2	2.59	225
1370W-6	3070872	97.5	30	93.9	33.5	45.7	19.4	294	104.37	115668	20.7	2.4	7.9	4.3	27.2	2.59	225
1370W-7	3075408	99.1	38	87.5	45.7	48.8	19.4	294	104.53	129730	20.7	2.4	7.9	4.3	27.2	2.59	225
1570W-1	3685500	94.5	38	83.8	42.7	48.8	20.1	318	115.95	181440	21.4	2.4	7.9	4.3	28.0	2.59	225
1570W-2	3685500	94.5	30	91.1	32.6	61.0	20.1	318	115.95	170100	21.4	2.4	7.9	4.3	28.0	2.59	225
1570W-3	3730860	97.5	38	86.3	44.8	53.3	20.1	318	117.38	176904	21.4	2.4	7.9	4.3	28.0	2.59	225
1570W-4	3730860	97.5	30	93.9	34.4	61.0	20.1	318	117.38	163296	21.4	2.4	7.9	4.3	28.0	2.59	225
1570W-5	3776220	105.2	38	92.4	50.3	48.8	20.1	318	118.81	165564	21.4	2.4	7.9	4.3	28.0	2.59	225
1570W-6	3776220	105.2	30	100.6	39.6	61.0	20.1	318	118.81	142884	21.4	2.4	7.9	4.3	28.0	2.59	225
1570W-7	3753540	99.1	38	87.5	45.7	53.3	20.1	318	118.10	176904	21.4	2.4	7.9	4.3	28.0	2.59	225
1570WS-1	4740120	103.6	30	99.7	37.5	61.0	20.1	318	149.14	208656	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-2	4740120	103.6	34	96.0	42.7	61.0	20.1	318	149.14	219996	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-3	4740120	103.6	38	91.7	47.9	61.0	20.1	318	149.14	235872	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-4	4649400	109.7	30	105.2	41.1	61.0	20.1	318	146.28	183708	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-5	4649400	109.7	34	100.9	47.2	61.0	20.1	318	146.28	195048	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-6	4649400	109.7	38	96.6	53.0	61.0	20.1	318	146.28	208656	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-7	4558680	115.8	30	110.3	44.5	61.0	20.1	318	143.43	156492	25.8	2.9	8.3	4.7	28.0	2.18	214

Table A.1. The Operating Dimensions of Bucyrus-Erie Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
1570WS-8	4558680	115.8	34	106.1	51.2	61.0	20.1	318	143.43	172368	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-9	4558680	115.8	38	101.2	57.6	61.0	20.1	318	143.43	188244	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-10	4513320	121.9	30	115.5	48.2	61.0	20.1	318	142.00	142884	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-11	4513320	121.9	34	111.3	55.2	61.0	20.1	318	142.00	151956	25.8	2.9	8.3	4.7	28.0	2.18	214
1570WS-12	4513320	121.9	38	106.1	61.6	61.0	20.1	318	142.00	167832	25.8	2.9	8.3	4.7	28.0	2.18	214
2570W-1	5656392	103.6	30	100.6	36.0	51.8	22.6	400	141.57	235872	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-2	5656392	103.6	34	96.0	42.7	54.9	22.6	400	141.57	249480	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-3	5656392	103.6	38	92.7	47.2	45.7	22.6	400	141.57	265356	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-4	5692680	109.7	30	104.5	36.9	48.8	22.6	400	142.47	215460	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-5	5692680	109.7	34	100.9	45.1	45.7	22.6	400	142.47	229068	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-6	5692680	109.7	38	97.5	49.1	42.7	22.6	400	142.47	242676	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-7	5799276	115.8	30	111.3	39.9	51.4	22.6	400	145.14	210017	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-8	5799276	115.8	34	105.8	48.2	48.8	22.6	400	145.14	223625	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-9	5799276	115.8	38	102.1	53.0	45.7	22.6	400	145.14	237233	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-10	5996592	121.9	30	116.4	43.0	54.9	22.6	400	150.08	205027	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-11	5996592	121.9	34	110.9	51.8	51.8	22.6	400	150.08	218635	24.4	4.3	9.1	4.9	31.9	2.59	241
2570W-12	5996592	121.9	38	107.0	57.0	48.8	22.6	400	150.08	232243	24.4	4.3	9.1	4.9	31.9	2.59	241
2570WS-1	6305040	109.7	30	106.1	36.9	61.0	24.4	467	135.02	288036	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-2	6305040	109.7	35	100.9	44.5	61.0	24.4	467	135.02	299376	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-3	6305040	109.7	38	97.5	49.1	61.0	24.4	467	135.02	306180	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-4	6463800	115.8	30	111.3	39.9	61.0	24.4	467	138.42	274428	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-5	6463800	115.8	35	105.8	48.2	61.0	24.4	467	138.42	283500	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-6	6463800	115.8	38	102.1	53.0	61.0	24.4	467	138.42	290304	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-7	6622560	121.9	30	116.4	43.3	61.0	24.4	467	141.82	260820	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-8	6622560	121.9	35	110.9	51.8	61.0	24.4	467	141.82	272160	27.6	4.4	9.1	5.0	34.3	2.59	241

Table A.1. The Operating Dimensions of Bucyrus-Erie Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
2570WS-9	6622560	121.9	38	107.0	57.0	61.0	24.4	467	141.82	280325	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-10	6792660	128.0	30	121.9	46.3	67.1	24.4	467	145.46	244944	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-11	6792660	128.0	35	115.8	55.5	67.1	24.4	467	145.46	256284	27.6	4.4	9.1	5.0	34.3	2.59	241
2570WS-12	6792660	128.0	38	111.9	61.0	67.1	24.4	467	145.46	265356	27.6	4.4	9.1	5.0	34.3	2.59	241

Table A.2. The Operating Dimensions of Marion Draglines

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
7200-1	199017	30.5	39	27.4	13.6	11.2	7.3	42	47.35	18053	10.1	1.2	3.3	2.0	10.1	1.83	257
7200-2	209790	36.6	36	33.5	15.8	15.2	7.3	42	49.92	16012	10.1	1.2	3.3	2.0	10.1	1.83	257
7200-3	214326	41.1	33.5	38.1	17.8	18.4	7.3	42	51.00	13869	10.1	1.2	3.3	2.0	10.1	1.83	257
7250-1	498960	42.7	38	37.5	18.3	30.5	9.1	66	75.98	36288	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-2	498960	42.7	34	39.3	15.8	33.5	9.1	66	75.98	34020	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-3	498960	42.7	30	40.8	14.3	35.1	9.1	66	75.98	32659	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-4	498960	48.8	38	42.4	23.2	32.0	9.1	66	75.98	31752	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-5	498960	48.8	34	44.5	20.4	35.1	9.1	66	75.98	29938	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-6	498960	48.8	30	46.3	17.4	38.1	9.1	66	75.98	29030	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-7	498960	54.9	38	47.2	26.8	33.5	9.1	66	75.98	28577	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-8	498960	54.9	34	49.4	23.8	36.6	9.1	66	75.98	27216	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-9	498960	54.9	30	51.5	20.7	39.6	9.1	66	75.98	25855	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-10	498960	61.0	38	52.1	30.8	36.6	9.1	66	75.98	25855	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-11	498960	61.0	34	54.6	26.8	39.6	9.1	66	75.98	24494	11.0	1.2	3.0	2.4	13.9	1.83	0
7250-12	498960	61.0	30	56.7	23.2	44.2	9.1	66	75.98	22680	11.0	1.2	3.0	2.4	13.9	1.83	0
7450-1	680400	48.8	38	43.9	22.4	38.1	9.3	68	100.24	36288	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-2	680400	48.8	34	46.0	19.7	41.1	9.3	68	100.24	36288	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-3	680400	48.8	30	47.9	16.8	44.2	9.3	68	100.24	36288	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-4	680400	54.9	38	48.8	26.2	33.5	9.3	68	100.24	36288	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-5	680400	54.9	34	50.9	23.0	47.2	9.3	68	100.24	34020	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-6	680400	54.9	30	53.2	19.8	50.3	9.3	68	100.24	31752	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-7	680400	61.0	38	53.6	29.9	41.1	9.3	68	100.24	31752	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-8	680400	61.0	34	56.1	26.5	53.3	9.3	68	100.24	29484	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-9	680400	61.0	30	58.5	22.9	56.4	9.3	68	100.24	27216	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-10	680400	67.1	38	58.5	33.5	47.2	9.3	68	100.24	27216	11.9	1.4	4.9	3.0	14.0	1.83	0

Table A.2. The Operating Dimensions of Marion Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
7450-11	680400	67.1	34	61.3	29.9	61.0	9.3	68	100.24	24948	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-12	680400	67.1	30	63.7	25.9	64.0	9.3	68	100.24	24948	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-13	680400	73.2	38	63.1	37.5	53.3	9.3	68	100.24	24948	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-14	680400	73.2	34	66.1	33.2	57.9	9.3	68	100.24	22680	11.9	1.4	4.9	3.0	14.0	1.83	0
7450-15	680400	73.2	30	68.9	29.0	61.0	9.3	68	100.24	20412	11.9	1.4	4.9	3.0	14.0	1.83	0
7500-13R	771120	61.0	30	58.5	22.6	42.7	11.3	100	77.20	42638	12.1	1.3	4.9	2.8	15.6	1.88	0
7500-14R	703080	61.0	32	57.3	25.8	28.7	11.3	100	70.39	35381	12.1	1.3	4.9	2.8	15.6	1.88	0
7500-17	694008	61.0	36	55.2	25.8	27.4	11.3	100	69.48	38420	12.1	1.3	4.9	2.8	15.6	1.88	0
7500-18	771120	61.0	35	55.5	26.4	32.2	11.3	100	77.20	42638	12.1	1.3	4.9	2.8	15.6	1.88	0
7500-21R	793800	61.0	37	54.3	24.4	42.7	11.3	100	79.47	48989	12.1	1.3	4.9	2.8	15.6	1.88	0
7500-22	816480	54.9	30	53.3	16.8	36.6	11.3	100	81.74	48989	12.1	1.3	4.9	2.8	15.6	1.88	0
7620-3A	1206576	71.6	30.5	68.6	27.1	42.7	14.0	154	78.15	68040	16.3	1.5	5.6	3.6	19.5	2.13	0
7620-5A	1383480	91.4	32	83.8	38.4	46.9	14.0	154	89.61	49896	16.3	1.5	5.6	3.6	19.5	2.13	0
7620-8R	1428840	83.8	35	75.6	36.6	39.6	14.0	154	92.54	63504	16.3	1.5	5.6	3.6	19.5	2.13	0
7820-1	1750896	76.2	32	71.9	29.3	44.2	15.2	182	95.98	95256	16.3	2.2	6.2	4.1	21.6	2.13	0
7820-2	1406160	76.2	35	69.8	34.7	36.6	15.2	182	77.09	79380	16.3	2.2	6.2	4.1	21.6	2.13	0
7820-3	1778112	91.4	32	84.7	39.3	53.3	15.2	182	97.48	72576	16.3	2.2	6.2	4.1	21.6	2.13	0
7820-4	1428840	71.6	32.5	67.1	25.9	41.8	15.2	182	78.33	83916	16.3	2.2	6.2	4.1	21.6	2.13	0
7820-5	1791720	83.8	38	73.2	40.8	39.0	15.2	182	98.22	93895	16.3	2.2	6.2	4.1	21.6	2.13	0
8050-1	2744280	99.1	37	87.2	47.9	53.3	18.9	280	97.84	131544	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-2	2755620	99.1	37	87.2	47.9	53.3	18.9	280	98.25	131544	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-3	2880360	99.1	34.3	89.9	42.7	48.8	18.9	280	102.69	130637	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-4	2812320	99.1	34.3	89.9	42.7	48.8	18.9	280	100.27	127008	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-5	2789640	99.1	37	87.2	45.7	53.3	18.9	280	99.46	131544	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-6	2721600	76.2	30	74.1	25.0	47.2	18.9	280	97.03	136080	20.1	2.6	6.6	3.8	27.4	2.13	0

Table A.2. The Operating Dimensions of Marion Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
8050-7	2857680	83.8	38.5	73.8	38.1	51.8	18.9	280	101.89	145152	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-8	2789640	83.8	38.5	73.8	38.1	51.8	18.9	280	99.46	145152	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-9	2903040	99.1	31	93.0	36.3	55.2	18.9	280	103.50	115668	20.1	2.6	6.6	3.8	27.4	2.13	0
8050-10	2812320	99.1	40	83.8	48.8	51.8	18.9	280	100.27	136987	20.1	2.6	6.6	3.8	27.4	2.13	0
8200-1	3515400	99.1	35	89.0	41.1	48.8	19.8	308	114.03	163296	21.9	3.4	6.6	4.6	28.7	2.06	0
8200-2	3402000	99.1	38	86.0	45.1	45.7	19.8	308	110.35	165564	21.9	3.4	6.6	4.6	28.7	2.06	0
8200-3	3379320	91.4	35.8	82.3	39.6	36.6	19.8	308	109.62	172368	21.9	3.4	6.6	4.6	28.7	2.06	0
8200-4	3560760	106.7	33	97.5	42.7	48.8	19.8	308	115.50	136080	21.9	3.4	6.6	4.6	28.7	2.06	0
8200-5	3991680	106.7	36	94.5	42.7	44.2	19.8	308	129.48	151956	21.9	3.4	6.6	4.6	28.7	2.06	0
8200-6	3515400	99.1	35	89.0	41.1	48.8	19.8	308	114.03	163296	21.9	3.4	6.6	4.6	28.7	2.06	0
8500-1	4037040	106.7	37	93.3	45.7	61.0	19.8	308	130.95	158760	21.9	3.4	6.6	4.6	28.7	2.13	0
8500-2	4127760	99.1	34	90.2	39.6	48.8	19.8	308	133.90	172368	21.9	3.4	6.6	4.6	28.7	2.13	0
8500-3	3923640	109.7	30	102.7	42.7	61.0	19.8	308	127.27	124740	21.9	3.4	6.6	4.6	28.7	2.13	0
8750-1	5080320	91.4	35	83.8	39.0	45.7	24.4	467	108.79	264449	25.0	5.0	7.3	6.7	35.4	2.13	0
8750-2	5307120	102.1	36	91.4	45.7	45.7	24.4	467	113.65	215460	25.0	5.0	7.3	6.7	35.4	2.13	0
8750-3	5692680	102.1	33	94.5	40.2	45.7	24.4	467	121.90	247212	25.0	5.0	7.3	6.7	35.4	2.13	0
8750-4	5896800	109.7	30	103.6	40.5	61.0	24.4	467	126.27	204120	25.0	5.0	7.3	6.7	35.4	2.13	0
8750-5	5715360	102.1	36	91.4	45.7	45.7	24.4	467	122.39	256284	25.0	5.0	7.3	6.7	35.4	2.13	0
8750-6	5806080	109.7	30	103.6	40.5	61.0	24.4	467	124.33	181440	25.0	5.0	7.3	6.7	35.4	2.13	0
8750-7	5896800	102.1	32.5	102.1	40.2	45.7	24.4	467	126.27	259006	25.0	5.0	7.3	6.7	35.4	2.13	0
8950-1	6622560	94.5	33	88.7	37.8	48.8	27.4	591	112.05	351540	26.5	4.6	8.2	7.0	35.5	2.13	0
8950-2	7348320	94.5	33	89.0	36.6	50.3	27.4	591	124.33	412776	26.5	4.6	8.2	7.0	35.5	2.13	0
8950-3	7711200	109.7	31	103.6	36.6	45.7	27.4	591	130.47	283500	26.5	4.6	8.2	7.0	35.5	2.13	0

Table A.3. The Operating Dimensions of P&H-PAGE Draglines

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
2355-1	666338	42.7	30	39.9	20.1	33.5	0.0	54	17.54	45360	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-2	666338	42.7	35	38.1	23.2	32.0	0.0	54	17.54	45360	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-3	666338	42.7	40	35.7	26.2	30.5	0.0	54	17.54	45360	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-4	682668	48.8	30	45.4	23.2	33.5	0.0	54	17.97	40370	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-5	682668	48.8	35	43.0	26.8	32.0	0.0	54	17.97	42638	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-6	682668	48.8	40	40.5	30.2	30.5	0.0	54	17.97	45360	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-7	690379	54.9	30	50.6	26.2	39.6	0.0	54	18.18	32659	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-8	690379	54.9	35	47.9	30.2	38.1	0.0	54	18.18	34927	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-9	690379	54.9	40	45.1	34.1	36.6	0.0	54	18.18	36288	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-10	704441	61.0	30	55.8	29.3	39.6	0.0	54	18.55	27670	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-11	704441	61.0	35	53.0	33.8	38.1	0.0	54	18.55	28577	11.3	2.8	2.2	4.8	11.3	0.00	1540
2355-12	704441	61.0	40	49.7	38.1	36.6	0.0	54	18.55	30845	11.3	2.8	2.2	4.8	11.3	0.00	1540
732-1	856850	53.3	30	53.6	19.2	30.5	11.3	100	12.20	45360	12.3	1.2	6.2	3.0	15.7	2.13	0
732-2	866830	58.5	30	57.9	22.3	36.0	11.3	100	12.34	40824	12.3	1.2	6.2	3.0	15.7	2.13	0
732-3	876809	61.3	30	60.4	23.8	37.2	11.3	100	12.48	36288	12.3	1.2	6.2	3.0	15.7	2.13	0
732-4	886788	64.6	30	63.4	25.9	39.6	11.3	100	12.63	31752	12.3	1.2	6.2	3.0	15.7	2.13	0
732-5	896767	71.3	30	69.2	29.9	38.1	11.3	100	12.77	24948	12.3	1.2	6.2	3.0	15.7	2.13	0
736-1	1276430	59.4	30	59.7	21.0	31.7	12.5	123	14.80	65772	16.0	1.3	7.4	3.0	18.5	2.13	0
736-2	1274616	61.6	30	61.6	22.3	33.8	12.5	123	14.78	61236	16.0	1.3	7.4	3.0	18.5	2.13	0
736-3	1084104	63.4	30	63.1	23.8	35.7	12.5	123	12.57	56700	14.4	1.3	7.4	3.0	17.8	2.13	0
736-4	1062785	65.8	30	65.2	25.3	38.4	12.5	123	12.32	52164	14.4	1.3	7.4	3.0	17.8	2.13	0
736-5	1054166	68.6	30	67.7	26.8	41.1	12.5	123	12.22	47628	14.4	1.3	7.4	3.0	17.8	2.13	0
736-6	1053713	72.8	30	71.3	29.3	44.2	12.5	123	12.22	43092	14.4	1.3	7.4	3.0	17.8	2.13	0
736-7	1053259	78.3	30	76.2	32.6	44.8	12.5	123	12.21	38556	14.4	1.3	7.4	3.0	17.8	2.13	0
740-1	1689206	67.4	30	67.4	23.2	36.0	15.2	182	13.17	90720	17.4	1.3	8.0	3.6	21.0	1.98	0

Table A.3. The Operating Dimensions of P&H-PAGE Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
740-2	1696464	71.0	30	70.7	25.6	39.6	15.2	182	13.23	79380	17.1	1.3	8.0	3.6	21.0	1.98	0
740-3	1415232	68.0	30	68.0	25.6	38.1	13.7	148	13.62	68040	15.2	1.3	8.0	3.6	19.5	1.98	0
740-4	1704175	74.4	30	73.8	29.0	35.1	15.2	182	13.29	68040	17.1	1.3	8.0	3.6	21.0	1.98	0
740-5	1438819	72.8	30	72.2	29.0	39.6	13.7	148	13.85	56700	15.2	1.3	8.0	3.6	19.5	1.98	0
740-6	1712794	79.9	30	78.3	32.3	45.7	15.2	182	13.35	56700	17.1	1.3	8.0	3.6	21.0	1.98	0
740-7	1473293	81.1	30	79.2	34.1	51.8	13.7	148	14.18	40824	15.2	1.3	8.0	3.6	19.5	1.98	0
740-8	1730030	88.1	30	85.3	37.8	51.8	15.2	182	13.49	40824	17.1	1.3	8.0	3.6	21.0	1.98	0
752-1	2181816	82.3	30	82.3	29.9	47.2	17.1	229	13.56	108864	18.4	1.4	9.9	3.7	24.6	2.07	0
752-2	2170476	84.1	30	83.8	31.1	48.8	17.1	229	13.49	102060	18.4	1.4	9.9	3.7	24.6	2.07	0
752-3	1976335	75.3	30	76.2	26.8	42.1	17.1	229	12.28	102060	18.4	1.4	9.9	3.7	24.6	2.07	0
752-4	2180455	87.8	30	87.2	33.2	47.2	17.1	229	13.55	90720	18.4	1.4	9.9	3.7	24.6	2.07	0
752-5	2000376	78.9	30	79.6	29.0	45.7	17.1	229	12.43	90720	18.4	1.4	9.9	3.7	24.6	2.07	0
752-6	2197692	92.0	30	90.8	36.0	47.2	17.1	229	13.66	79380	18.4	1.4	9.9	3.7	24.6	2.07	0
752-7	2023963	83.8	30	83.8	32.0	50.3	17.1	229	12.58	79380	18.4	1.4	9.9	3.7	24.6	2.07	0
752-8	2211300	97.5	30	95.7	41.1	57.9	17.1	229	13.75	62143	18.4	1.4	9.9	3.7	24.6	2.07	0
757-1	4057452	97.8	30	97.5	35.1	51.8	21.3	358	16.14	181440	24.1	2.0	10.9	5.3	31.4	2.18	0
757-2	4055638	100.0	30	99.4	36.6	56.4	21.3	358	16.13	170100	24.1	2.0	10.9	5.3	31.4	2.18	0
757-3	3645583	90.8	30	91.4	32.0	51.5	21.3	358	14.50	170100	20.1	2.0	10.9	5.3	30.6	2.18	0
757-4	4052916	102.4	30	101.5	38.1	53.3	21.3	358	16.12	158760	24.1	2.0	10.9	5.3	31.4	2.18	0
757-5	3646037	95.1	30	95.1	34.4	55.8	21.3	358	14.50	158760	20.1	2.0	10.9	5.3	30.6	2.18	0
757-6	3646490	97.8	30	97.5	36.3	52.7	21.3	358	14.51	147420	20.1	2.0	10.9	5.3	30.6	2.18	0
757-7	3412433	101.5	30	100.6	38.7	62.5	18.7	276	17.59	136080	20.1	2.0	10.9	5.3	26.8	2.18	0
757-8	3421505	103.6	30	102.4	40.2	64.9	18.7	276	17.63	124740	20.1	2.0	10.9	5.3	26.8	2.18	0
757-9	3426948	106.7	30	105.2	42.1	68.3	18.7	276	17.66	113400	20.1	2.0	10.9	5.3	26.8	2.18	0
852-1	2218104	78.6	30	82.3	32.6	47.2	17.1	229	13.79	108864	18.4	1.4	12.6	6.5	24.6	2.07	0

Table A.3. The Operating Dimensions of P&H-PAGE Draglines (Continued)

Model	Working Weight (kg)	Boom Length (m)	Boom Angle (°)	Operating Radius (m)	Dumping Height (m)	Digging Depth (m)	Tub Radius (m)	Bearing Area (m^2)	Bearing Pressure (kPa)	Maximum Allowable Load (kg)	Clearance Radius (m)	Clearance Height (m)	Boom Foot Radius (m)	Boom Foot Height (m)	Distance Between Feet (m)	Step Length (m)	Walk Speed (m/hr)
852-2	2206764	80.5	30	83.8	34.1	47.2	17.1	229	13.72	102060	18.4	1.4	12.6	6.5	24.6	2.07	0
852-3	2012623	71.6	30	76.2	29.6	42.1	17.1	229	12.51	102060	18.4	1.4	12.6	6.5	24.6	2.07	0
852-4	2216743	84.4	30	87.2	36.3	42.7	17.1	229	13.78	90720	18.4	1.4	12.6	6.5	24.6	2.07	0
852-5	2036664	75.6	30	79.6	32.0	45.7	17.1	229	12.66	90720	18.4	1.4	12.6	6.5	24.6	2.07	0
852-6	2233980	88.4	30	90.8	39.0	45.7	17.1	229	13.89	79380	18.4	1.4	12.6	6.5	24.6	2.07	0
852-7	2060251	80.5	30	83.8	35.1	48.8	17.1	229	12.81	79380	18.4	1.4	12.6	6.5	24.6	2.07	0
852-8	2247588	94.2	30	95.7	44.2	57.9	17.1	229	13.97	62143	18.4	1.4	12.6	6.5	24.6	2.07	0
852LR-1	3015986	89.6	30	88.7	32.6	51.8	18.3	263	16.33	140616	21.2	1.8	9.4	5.2	26.7	2.19	0
852LR-2	3024151	92.7	30	91.1	34.4	54.9	18.3	263	16.37	129276	21.2	1.8	9.4	5.2	26.7	2.19	0
852LR-3	3034584	95.4	30	93.6	36.3	57.9	18.3	263	16.43	117936	21.2	1.8	9.4	5.2	26.7	2.19	0
852LR-4	3045017	98.1	30	96.0	38.1	61.0	18.3	263	16.49	106596	21.2	1.8	9.4	5.2	26.7	2.19	0
852LR-5	3050460	100.3	30	97.8	39.6	63.7	18.3	263	16.52	99792	21.2	1.8	9.4	5.2	26.7	2.19	0
9100-1	6051024	99.4	30	101.5	35.4	52.7	25.6	515	16.72	272160	0.0	2.1	14.3	6.1	0.0	2.13	0
9100-2	5883192	89.0	30	93.0	30.2	43.9	25.6	515	16.25	272160	0.0	2.1	14.3	6.1	0.0	2.13	0
9100-3	5964840	110.6	30	111.3	41.8	64.0	25.6	515	16.48	226800	0.0	2.1	14.3	6.1	0.0	2.13	0
9100-4	5942160	97.8	30	100.3	35.4	53.0	25.6	515	16.42	226800	0.0	2.1	14.3	6.1	0.0	2.13	0
9100-5	5955768	124.7	30	123.1	50.3	78.6	25.6	515	16.45	181440	0.0	2.1	14.3	6.1	0.0	2.13	0
9100-6	5869584	106.4	30	108.2	41.1	62.5	25.6	515	16.22	181440	0.0	2.1	14.3	6.1	0.0	2.13	0

A.2. The Module to Initially Choose Draglines for Testing

The purpose of the developed expert system is to determine the applicability of draglines for a surface coal mine. For testing process, however, as many draglines as possible can be picked. The purpose of developing this preliminary selection process is twofold: First, the dragline database has been split into three data files and it has been aimed to present all draglines in the database to the user at the time of selection. Second, it has been planned to ease the initial dragline picking process and give the user immediate visual feedback of what he/she has chosen as the potential draglines that would be tested.

The initial dragline selection module is a stand-alone, executable, menu-driven and user-friendly program written in Borland PASCAL V.7.0. It houses all 245 draglines in the database and the user-selected draglines are written to a file called "*DRAGLINE.DAT*" to be later processed by the geometry, simulation and stripping cost modules.

A.2.1. The Initial Dragline Selection Program

The dragline selection program is a two-layer module. In the upper layer is found the main menu for selecting one of the three dragline groups. In the lower layer however, are placed the records of dragline manufacturers. In every menu, the user is restricted to utilize only a few keys in the keyboard. Below are given the menus and description of associated keys allowed to use in each menu.

Upper Layer

The main menu is illustrated in Figure A.1. It is used to direct the control to one of the dragline groups. The keys that are allowed and descriptions are given in Table A.4.

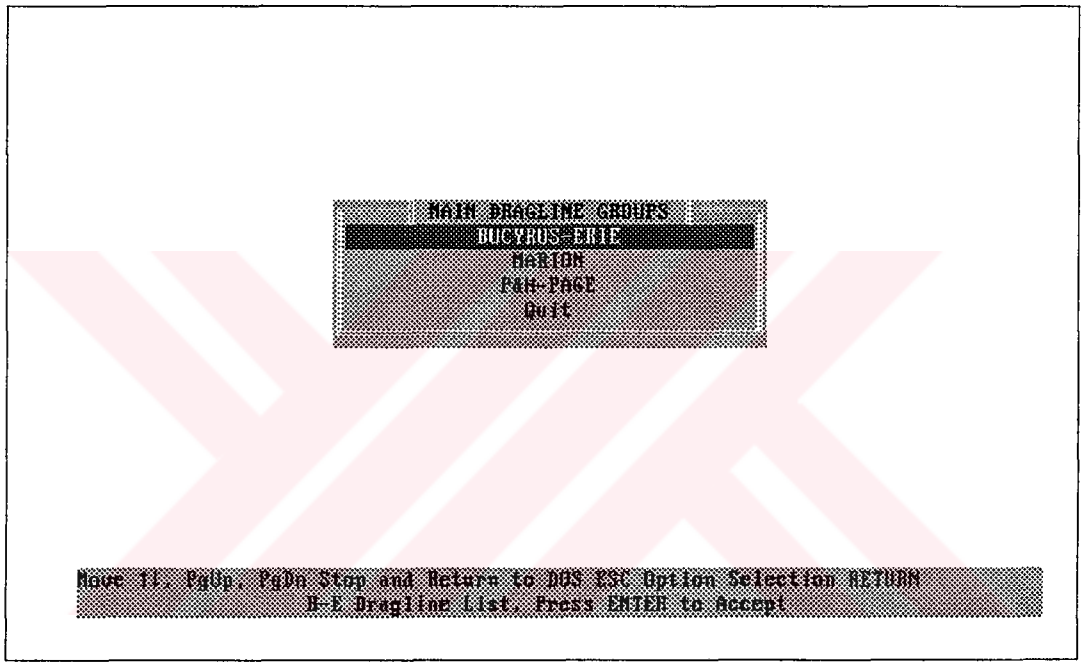

Figure A.1. The Main Menu of Dragline Group Selection in the Upper Layer

Lower Layer

In the lower layer are placed the records of specific dragline groups. An illustrative view related to the Bucyrus-Erie draglines is presented in Figure A.2. In

this menu, the user can choose any draglines for testing by the expert system. The keys that are allowed and descriptions are given in Table A.5.

Table A.4. The Description of the Keys in the Main Menu

Keys	*Description*
↑,↓	Scrolling up or down through the main menu
PgUp	Jump to the top line in the main menu
PgDn	Jump to the bottom line in the main menu
ESCape	Leave the program
RETURN	Go to the selected dragline group

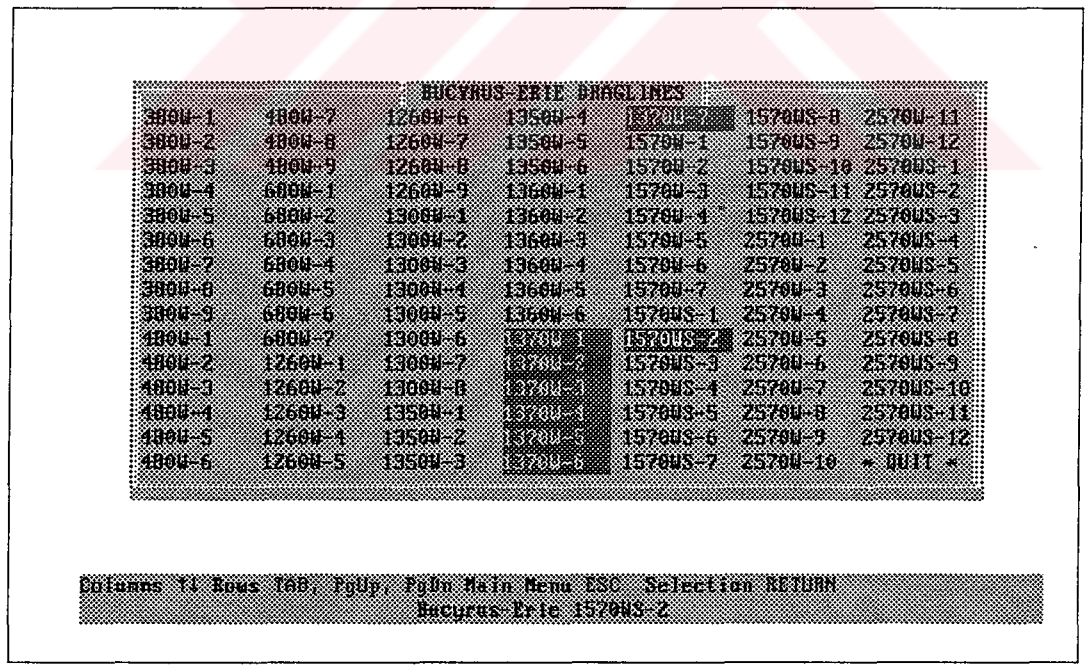

Figure A.2. The Menu of Dragline Selection in the Lower Layer

Table A.5. The Description of the Keys in the Dragline Choosing Menu

Keys	*Description*
↑,↓	Scrolling up or down through the dragline records
TAB	Move rowwise through the dragline records
PgUp	Jump to the top record in the dragline group
PgDn	Jump to the bottom record in the dragline group
ESCape	Return to the Main Menu
RETURN	Mark a dragline for selection that has not been marked before or Mark a previously selected dragline for rejection

A.3. The Dragline Database Managing Module

The purpose of this module is to permit the user to access, analyze and modify the operational dimensions of a dragline in the database.

This module is also a stand-alone, executable, menu-driven and user-friendly program written in Borland PASCAL V.7.0. It houses the data related to the working dimensions of all the draglines in the database.

A.3.1. The Module for Dragline Database Managing

The dragline database manager module is a three-layer program. In the upper layer is found the main menu for selecting one of the three dragline groups. In the intermediate layer are placed the draglines manufactured by companies and in the bottom layer are placed the working dimensions of a specific dragline. Again in this program, the user is restricted to utilize only a few keys in the keyboard in each menu. Below are given the menus and description of associated keys allowed to use in each menu.

Upper Layer

The main menu is illustrated in Figure A.3. It is used to direct the control to one of the dragline groups. The keys that are allowed and descriptions are given in Table A.6.

Table A.6. The Description of the Keys in the Main Menu

Keys	***Description***
↑,↓	Scrolling up or down through the main menu
PgUp	Jump to the top line in the main menu
PgDn	Jump to the bottom line in the main menu
ESCape	Leave the program
RETURN	Go to the selected dragline group

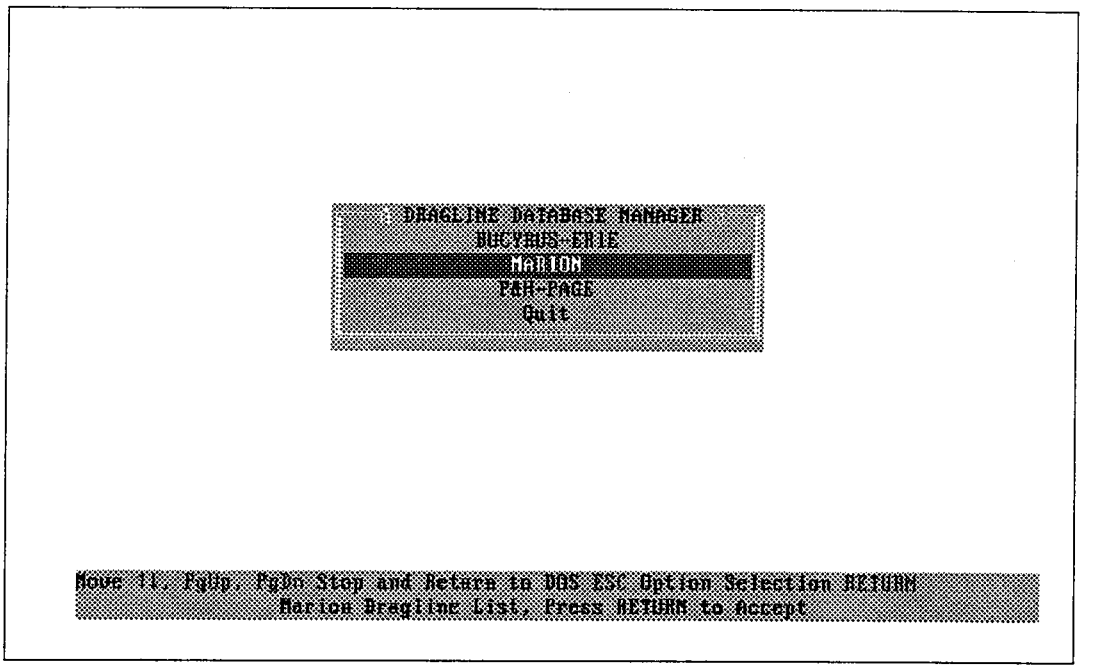

Figure A.3. The Main Menu of Dragline Database Manager

Intermediate Layer

In the intermediate layer are placed the draglines in a specific group. An illustrative view related to the Marion draglines is presented in Figure A.4. In this menu, the user can choose any one dragline whose operating dimensions are to be modified. The keys that are allowed and descriptions are given in Table A.7.

Table A.7. The Description of the Keys in the Dragline Selection Menu

Keys	*Description*
↑,↓	Scrolling up or down through the dragline records
TAB	Move rowwise through the dragline records
PgUp	Jump to the top record in the dragline group
PgDn	Jump to the bottom record in the dragline group
ESCape	Return to the Main Menu
RETURN	Select a dragline whose operating dimensions are to be modified

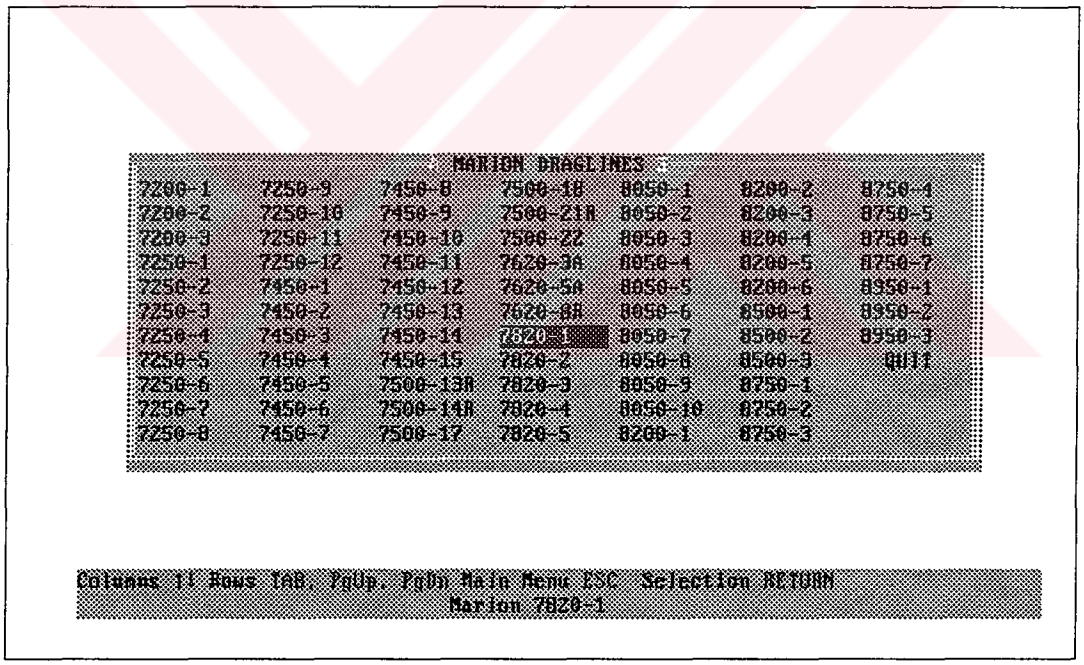

Figure A.4. The Dragline Selection Menu in the Intermediate Layer

Bottom Layer

The bottom layer is where the records related to dragline operating dimensions are accessed, modified and saved, if necessary. In case the data entered is out of allowable range for a particular record then the user is warned to correct the data. An illustrative view is given in Figure A.5 and a list of allowable keys are given in Table A.8.

Table A.8. The Description of the Keys in the Record Modification Menu

Keys	*Description*
↑,↓,RETURN	Scrolling up or down through the operating dimension records
INSert	Toggle between INSERT/OVERWRITE modes
HOME	Go to the beginning of a line
END	Go to the end of a line
TAB	Move rowwise through the dragline records
PgUp	Jump to the top record of operating dimensions
PgDn	Jump to the bottom record of operating dimensions
ESCape	Return to the Dragline Group Menu
F1	Prompt for saving the modified records

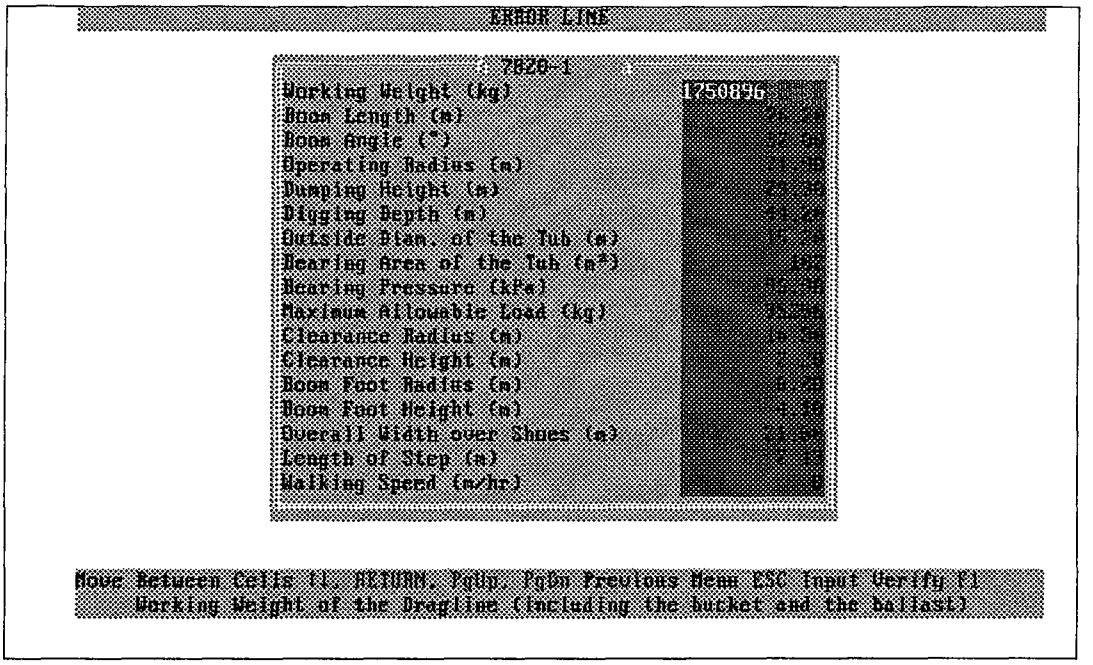

Figure A.5. The Operating Dimension Modification Menu in the Bottom Layer

APPENDIX B

DERIVED FORMULATIONS RELATED TO PIT DIMENSIONS IN STRIPPING GEOMETRY MODELS

B.1. General

Within the scope of the thesis, a number of dragline stripping methods have been included into the developed expert system whose primary objective is to find the best dragline-stripping method combination among the alternative dragline stripping methods. However, the applicability of a stripping method is only possible when there exists a particular dragline that completely satisfies the geometrical requirements of that specific stripping method. For this reason, the geometrical analysis of every stripping method included into the expert system has been done in detail and those parameters that have to be satisfied by draglines have been extracted and formulated. These formulation are used by the expert system to compare the available dragline dimensions to the required pit dimensions and draglines satisfying the required dimensions are allowed to be employed in those stripping methods.

The formulations related to specific pit dimensions of each stripping method are given in the following sections.

B.2. Direct Side Casting Geometry Model

In the direct side casting geometry model, the following pit dimensions have been analyzed and translated into mathematical formulations; unexcavated and spoiled advance bench dimensions; unexcavated and spoiled keycut dimensions, pit width, required operating radius and finally required reach. Since the inclusion of chopdown changes the stripping scheme, some pit dimensions have been formulated twice to cope with the negative effect of chopdown. The respective dimensions with or without inclusion of chopdown in the direct side casting method are given in Figures B.1 and B.2.

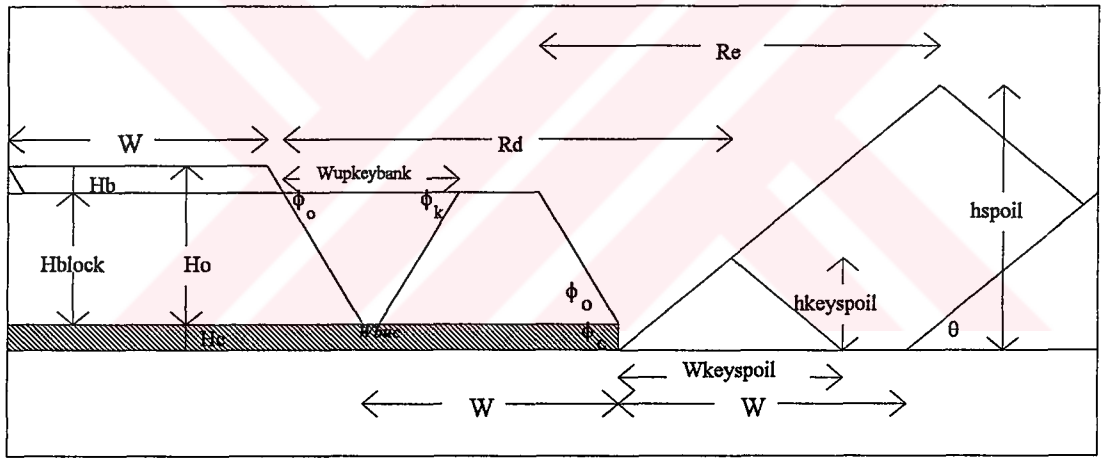

Figure B.1. Pit Dimensions in Direct Side Casting Model When Chopping is Done

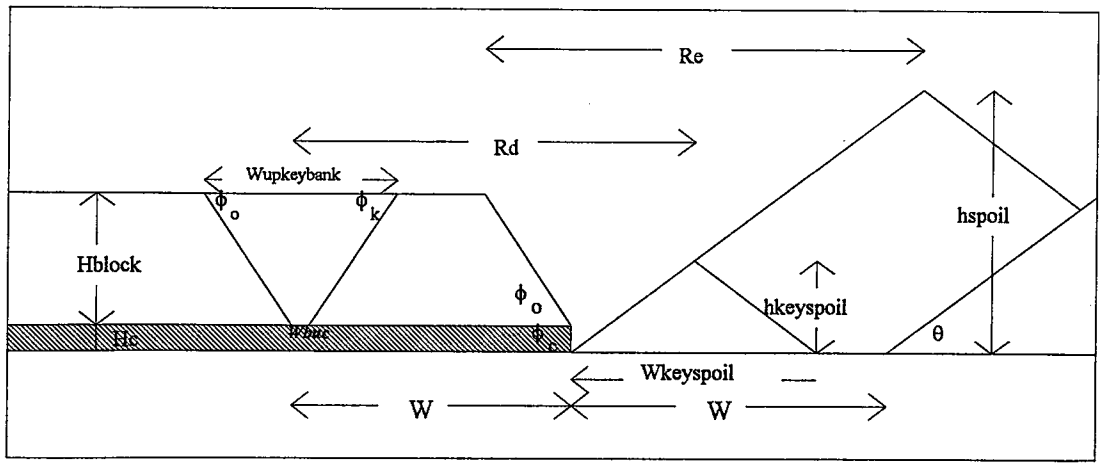

Figure B.2. Pit Dimensions in Direct Side Casting Model When No Chopping is Done

Area of Unexcavated and Spoiled Advance Bench:

Area of the waste in the unexcavated and spoiled advance bench is given in Equation B.1.

$$A_{chop} = H_b * W$$
$$A_{chopspoil} = H_b * W * fs \qquad \text{(B.1)}$$

Dimensions of Unexcavated and Spoiled Keycut:

Area and dimensions of the waste in the unexcavated and spoiled keycut are given in Equation B.2.

$$
\begin{aligned}
A_{keycut} &= \frac{1}{2} * H_{block}^2 * (\cot\Phi_o + \cot\Phi_k) + H_{block} * W_{buc} \\
A_{keyspoil} &= A_{keycut} * fs \Rightarrow (NoChopping) \\
A_{keyspoil} &= A_{keycut} * fs + A_{chopspoil} \Rightarrow (Chopping) \\
W_{upkeybank} &= H_{block} * (\cot\Phi_o + \cot\Phi_k) + W_{buc} \\
W_{keyspoil} &= \sqrt{\frac{4 * A_{keyspoil}}{\tan\theta}} \\
h_{keyspoil} &= \frac{A_{keyspoil} + \frac{W^2}{4} * \tan\theta}{W}
\end{aligned}
\tag{B.2}
$$

Pit Width:

The formulations related to the width of the pit with and without chopdown are given in Equation B.3.

$$
\begin{aligned}
W &= R_d + \frac{W_{buc}}{2} - h_{keyspoil} * \cot\theta - H_c * \cot\Phi_c \Rightarrow (No\ Chopping) \\
W &= R_d - H_{block} * \cot\Phi_o - H_c * \cot\Phi_c - h_{keyspoil} * \cot\theta \Rightarrow (Chopping)
\end{aligned}
\tag{B.3}
$$

Required Operating Radius:

The formulations related to the required operating radius with and without chopdown are given in Equation B.4.

$$R_d = W + H_c * \cot\Phi_c + h_{keyspoil} * \cot\theta \Rightarrow (NoChopping)$$
$$R_d = W + H_{block} * \cot\Phi_o + H_c * \cot\Phi_c + h_{keyspoil} * \cot\theta \Rightarrow (Chopping) \quad \text{(B.4)}$$

Required Reach:

The required dumping radius (reach) is given in Equation B.5.

$$R_e = H_{block} * \cot\Phi_o + H_c * \cot\Phi_c + h_{spoil} * \cot\theta \quad \text{(B.5)}$$

B.3. Extended Bench Casting Geometry Model

In the extended bench casting geometry model, four bench extension patterns have been identified. In each pattern, the area of the extended bench, area of the part to be rehandled and rehandle percentage have been formulized. Besides the width of the pit has been formulized when chopdown is or is not performed.

Pit Width

The formulations related to the width of the pit are given in Equation B.6. The dimensions used in pit width calculations with and without chopping are given in Figure B.3 and B.4.

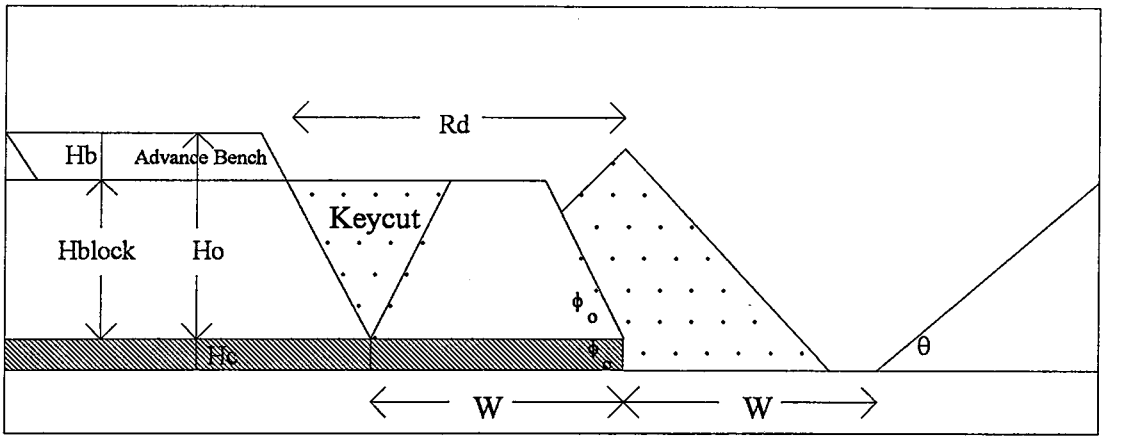

Figure B.3. Determination of the Pit Width When Chopping is Done

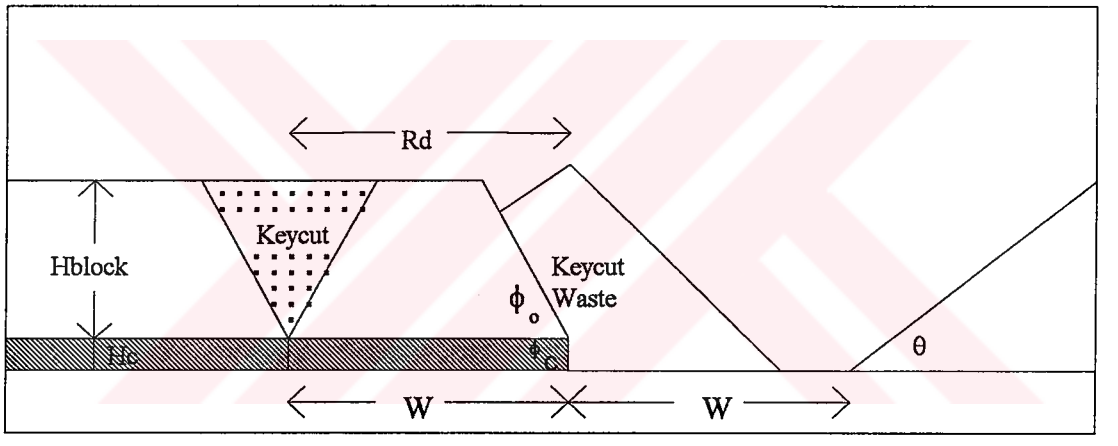

Figure B.4. Determination of the Pit Width When No Chopping is Done

$$W = R_d + \frac{W_{buc}}{2} - H_c * \cot \Phi_c \Rightarrow \textit{No Chopping}$$
$$W = R_d - H_{block} * \cot \Phi_o - H_c * \cot \Phi_c \Rightarrow \textit{Chopping} \qquad \text{(B.6)}$$

First Bench Extension Pattern:

In the first bench extension pattern, the bench extends into the empty pit and its base is larger than the pit. Figure B.5 illustrates the parameters used in calculations and the area to be rehandled is given in Figure B.6. The formulations related to the area of the extended bench are given in Equation B.7 and those related to area to be rehandled and rehandle percentage are given in Equations B.8 and B.9.

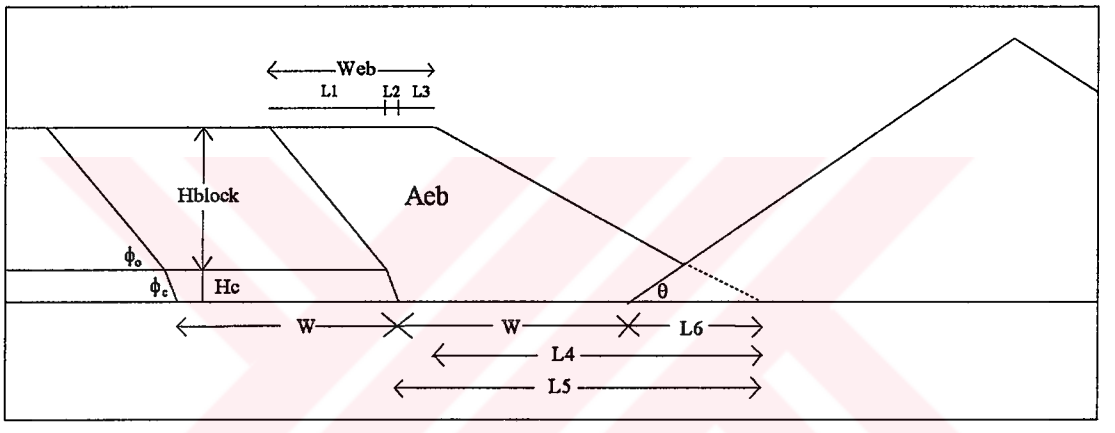

Figure B.5. Parameters Used in the First Bench Extension Pattern

Second Bench Extension Pattern:

In the second bench extension pattern, the bench extends into the empty pit and its base is narrower than the pit. Figure B.7 illustrates the parameters used in calculations and the area to be rehandled by the dragline is given in Figure B.8. The area of the extended bench is given in Equation B.10 and that related to the area to be rehandled is given in Equation B.11.

$$
\begin{aligned}
L_1 &= H_{block} * \cot \Phi_o \\
L_2 &= H_c * \cot \Phi_c \\
L_3 &= W_{eb} - (L_1 + L_2) \\
L_4 &= (H_{block} + H_c) * \cot \theta \\
L_5 &= W_{eb} + (H_{block} + H_c) * \cot \theta - (H_{block} * \cot \Phi_o + H_c * \cot \Phi_c) \\
L_6 &= L_5 - W
\end{aligned}
\tag{B.7}
$$

$$
\begin{aligned}
A_{eb} = {} & \frac{1}{2} * H_{block}^2 * \cot \Phi_o + H_{block} * H_c * \cot \Phi_c + \frac{1}{2} * H_c^2 * \cot \Phi_c \\
& + (H_{block} + H_c) * (W_{eb} - H_{block} * \cot \Phi_o - H_c * \cot \Phi_c) \\
& + \frac{1}{2} * (H_{block} + H_c)^2 * \cot \theta - \frac{1}{4} * L_6^2 * \tan \theta
\end{aligned}
$$

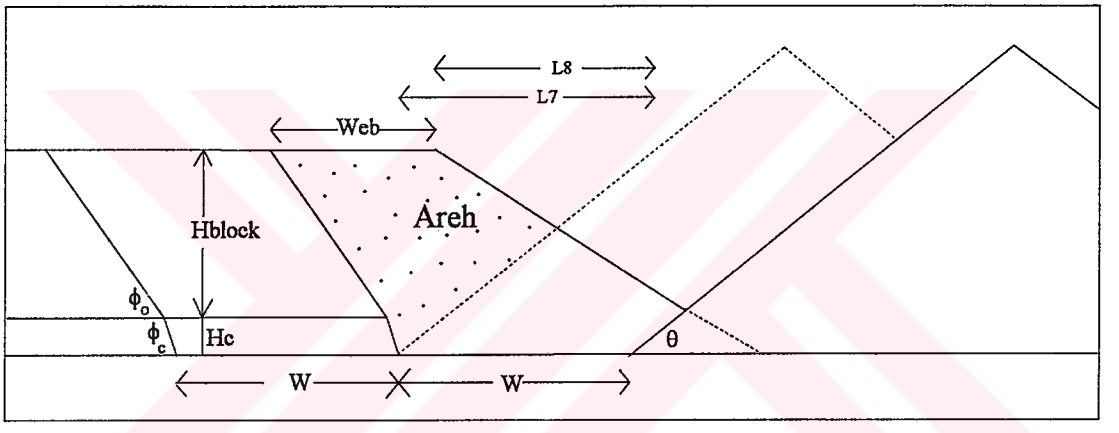

Figure B.6. Area to be Rehandled by the Dragline in the First Geometry Pattern

$$
\begin{aligned}
L_7 &= (H_{block} + H_c) * \cot \theta \\
L_8 &= L_7 + L_1 + L_2 - W_{eb}
\end{aligned}
$$

$$
\begin{aligned}
A_{reh} = {} & \frac{1}{2} * H_{block}^2 * \cot \Phi_o + H_{block} * H_c * \cot \Phi_c \\
& + \frac{1}{2} * H_c^2 * \cot \Phi + \frac{1}{2} * (H_{block} + H_c)^2 * \cot \theta - \frac{1}{4} * L_8{}^2 * \tan \theta
\end{aligned}
\tag{B.8}
$$

$$
p_{reh} = \frac{A_{reh}}{W * H_{block} * fs} * 100 \tag{B.9}
$$

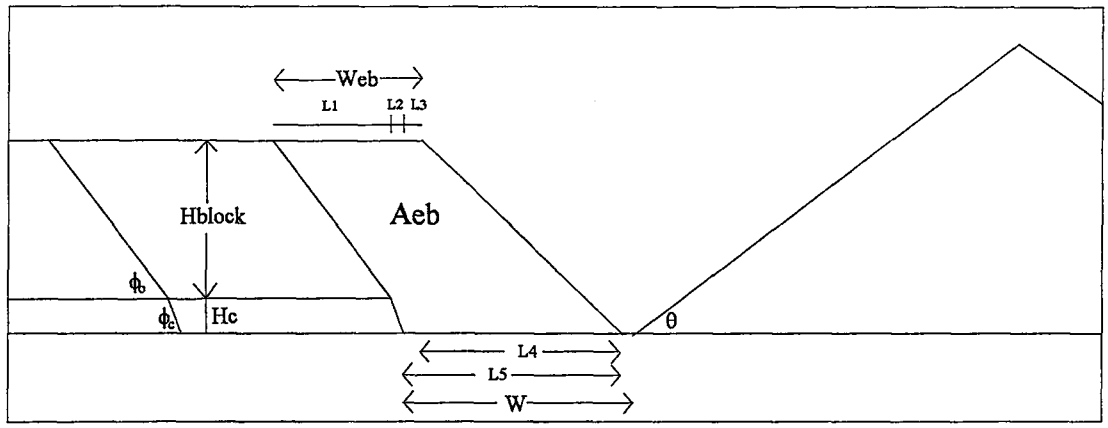

Figure B.7. Parameters Used in the Second Geometry Pattern

$$A_{eb} = \frac{1}{2} * H_{block}^2 * \cot\Phi_o + H_{block} * H_c * \cot\Phi_c + \frac{1}{2} * H_c^2 * \cot\Phi_c$$
$$+ (H_{block} + H_c) * (W_{eb} - H_{block} * \cot\Phi_o - H_c * \cot\Phi_c) \qquad \text{(B.10)}$$
$$+ \frac{1}{2} * (H_{block} + H_c)^2 * \cot\theta$$

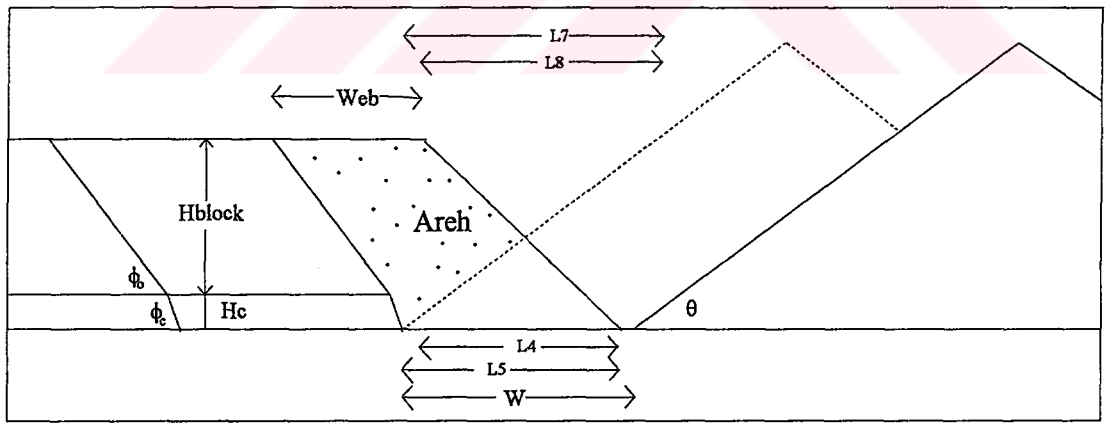

Figure B.8. Area to be Rehandled by the Dragline in the Second Geometry Pattern

$$L_7 = (H_{block} + H_c) * \cot\theta$$

$$L_8 = L_7 + L_1 + L_2 - W_{eb}$$

$$A_{reh} = \frac{1}{2} * H_{block}^2 * \cot\Phi_o + H_{block} * H_c * \cot\Phi_c + \frac{1}{2} * H_c^2 * \cot\Phi_c + \frac{1}{2} * (H_{block} + H_c)^2 * \cot\theta - \frac{1}{4} * L_8^2 * \tan\theta \quad \text{(B.11)}$$

Third Bench Extension Pattern:

In the third bench extension pattern, the bench does not extend into the empty pit but its base is larger than the pit. Figure B.9 illustrates the parameters used in calculations and the area of the extended bench is formulized in Equation B.12. The area to be rehandled by the dragline is given in Figure B.10 and Equation B.13.

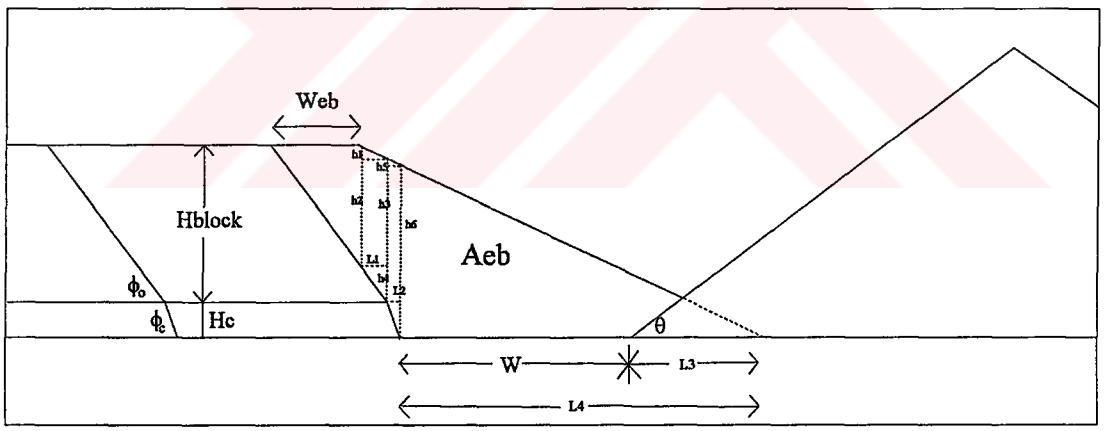

Figure B.9. Parameters Used in the Third Geometry Pattern

$$h_7 = h_1 + h_2$$
$$h_8 = h_3 + h_4 + h_5$$
$$h_9 = H_c + h_6$$
$$h_4 = H_{block} - h_7$$
$$h_7 = W_{eb} * \tan \Phi_o$$
$$L_1 = h_4 * \cot \Phi_o$$
$$h_1 = L_1 * \tan \theta$$
$$h_2 = h_7 - h_1 \Rightarrow h_2 = W_{eb} * \tan \Phi_o - L_1 * \tan \theta \qquad \text{(B.12)}$$
$$L_2 = H_c * \cot \Phi_c$$
$$h_5 = L_2 * \tan \theta$$
$$h_6 = H_{block} - (h_1 + h_5)$$
$$h_3 = h_6 - h_4$$
$$L_4 = h_9 * \tan \theta$$
$$A_{eb} = \frac{1}{2} * W_{eb} * h_7 + \frac{(h_7 + h_8)}{2} * L_1 + \frac{(h_8 + h_9)}{2} * L_2 + \frac{1}{2} * h_9 * L_4 - \frac{1}{4} * L_3^2 * \tan \theta$$

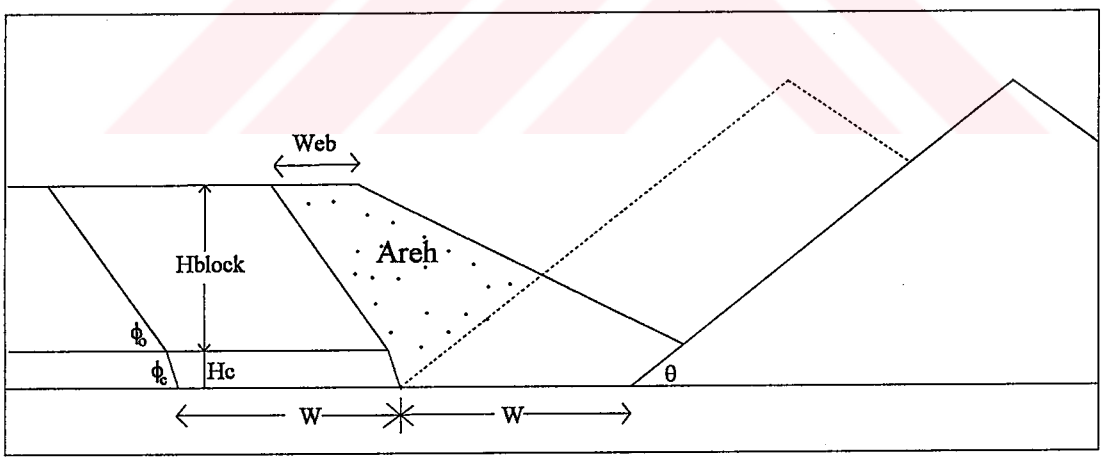

Figure B.10. Area to be Rehandled by the Dragline in the Third Geometry Pattern

$$A_{reh} = \frac{1}{2} * W_{eb} * h_7 + \frac{(h_7 + h_8)}{2} * L_1 + \frac{(h_8 + h_9)}{2} * L_2 + \frac{1}{2} * h_9 * L_4 - \frac{1}{4} * L_4^2 * \tan\theta \qquad \text{(B.13)}$$

Fourth Bench Extension Pattern:

In the fourth bench extension pattern, the bench does not extend into the empty pit and its base is narrower than the pit. Figure B.11 illustrates the parameters used in calculations and the area of the extended bench is formulized in Equation B.14. The area to be rehandled by the dragline is given in Figure B.12 and Equation B.15.

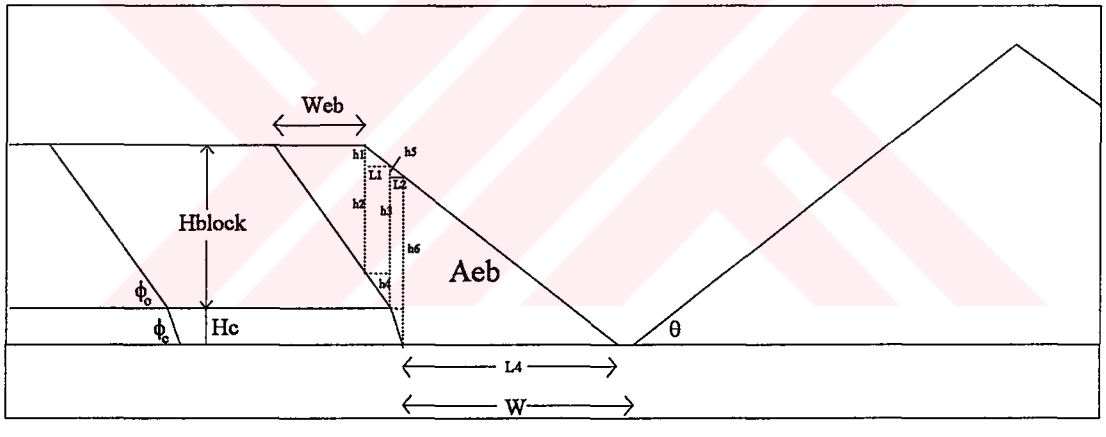

Figure B.11. Parameters Used in the Fourth Geometry Pattern

$$h_7 = h_1 + h_2$$
$$h_8 = h_3 + h_4 + h_5$$
$$h_9 = H_c + h_6$$
$$h_4 = H_{block} - h_7$$
$$h_7 = W_{eb} * \tan\Phi_o$$
$$L_1 = h_4 * \cot\Phi_o$$
$$h_1 = L_1 * \tan\theta$$
$$h_2 = h_7 - h_1 \Rightarrow h_2 = W_{eb} * \tan\Phi_o - L_1 * \tan\theta \qquad \text{(B.14)}$$
$$L_2 = H_c * \cot\Phi_c$$
$$h_5 = L_2 * \tan\theta$$
$$h_6 = H_{block} - (h_1 + h_5)$$
$$h_3 = h_6 - h_4$$
$$L_4 = h_9 * \tan\theta$$
$$A_{eb} = \frac{1}{2} * W_{eb} * h_7 + \frac{(h_7 + h_8)}{2} * L_1 + \frac{(h_8 + h_9)}{2} * L_2 + \frac{1}{2} * h_9 * L_4$$

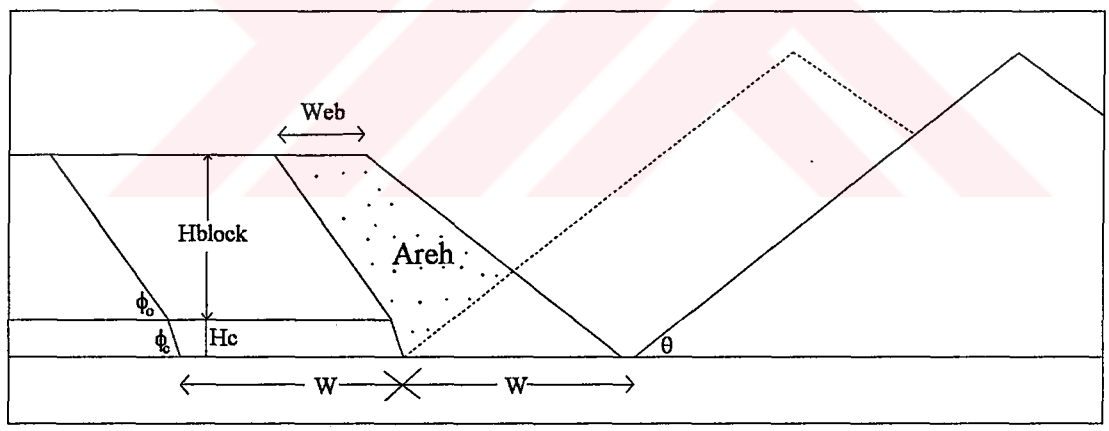

Figure B.12. Area to be Rehandled by the Dragline in the Fourth Geometry Pattern

$$A_{reh} = \frac{1}{2} * W_{eb} * h_7 + \frac{(h_7 + h_8)}{2} * L_1 + \frac{(h_8 + h_9)}{2} * L_2 + \frac{1}{2} * h_9 * L_4 - \frac{1}{4} * L_4^2 * \tan\theta \qquad \text{(B.15)}$$

B.4. One Slice Pullback Stripping Geometry Model

In the one slice pullback stripping geometry model, the width of the pit has been formulized according to whether chopdown is performed or not. Besides, the height of the temporary spoil pile in the pit with respect to the relative length of the effective dragline dumping radius, the area of the highwall barrier, the area to be rehandled and the rehandle percentage, the width and height of the pullback pad, the required dumping radius on the spoil side and finally the dimensions of the spoil pile built on the pullback pad have been formulized.

Pit Width:

Determination of the pit width with and without inclusion of chopdown is given in Equation B.16 and illustrated in Figures B.13 and B.14.

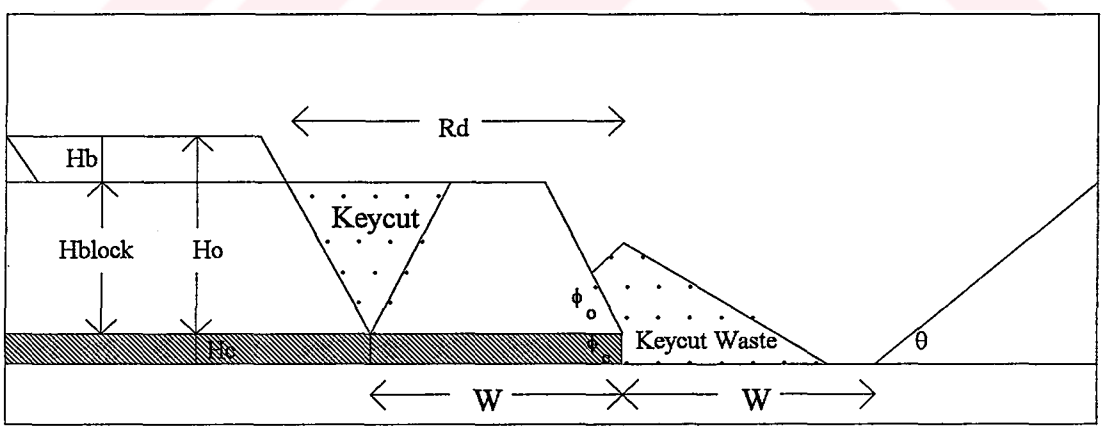

Figure B.13. Determination of the Pit Width Where Chopping is Experienced

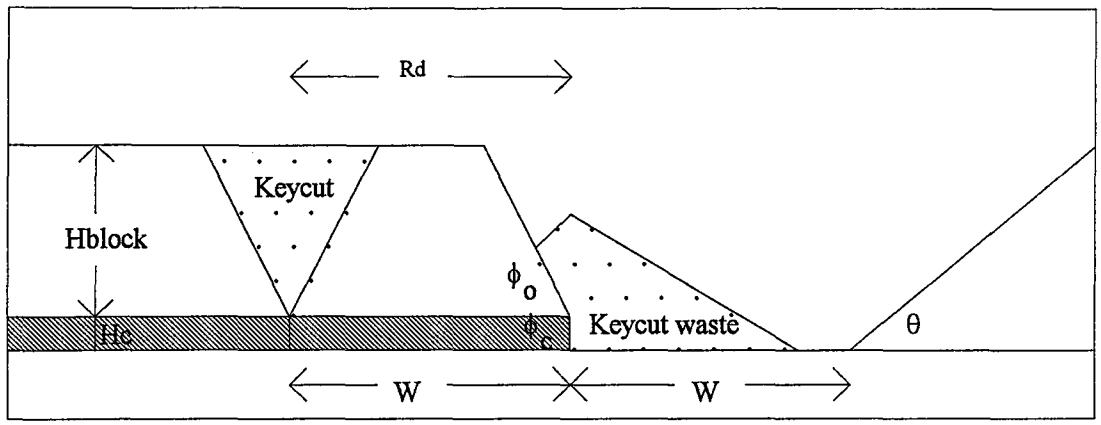

Figure B.14. Determination of the Pit Width Where No Chopping is Experienced

$$W = R_d + \frac{W_{buc}}{2} - H_c{*}\cot\Phi_c \Rightarrow \textit{No Chopping}$$
$$W = R_d - H_{block}{*}\cot\Phi_o - H_c{*}\cot\Phi_c \Rightarrow \textit{Chopping} \qquad \text{(B.16)}$$

Height of the Temporary Spoil Pile in the Empty Pit:

The exist two patterns related to the formation of the temporary spoil pile in the empty pit. Figure B.15 shows the first pattern where the effective dragline dumping radius is shorter than the pit width and the height of the temporary spoil pile is formulized in Equation B.17. The second pattern where the effective dragline dumping radius is longer than the pit width is given in Figure B.16. and the height of the temporary spoil pile is formulized in Equation B.18.

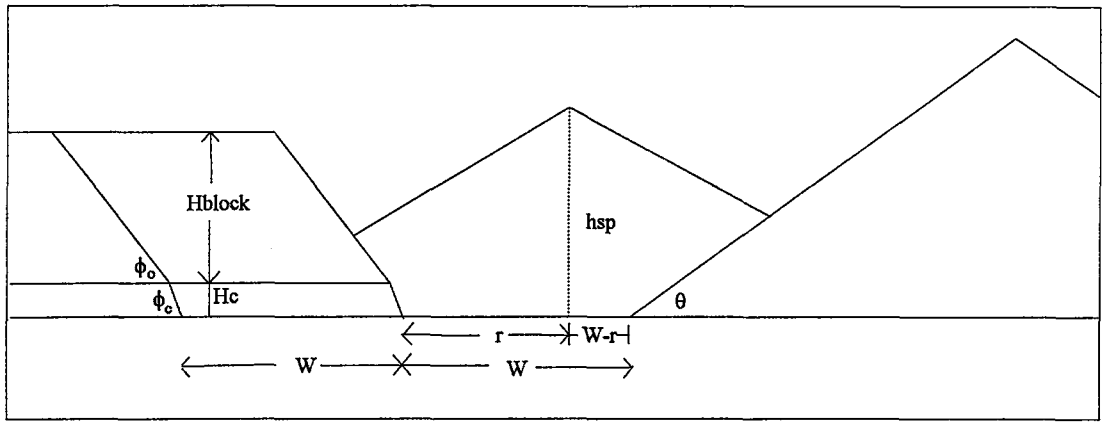

Figure B.15. The First Alternative where the Effective Dumping Radius is Shorter than the Pit Width (r<W)

$$\sigma = (W - r)$$

$$\lambda = \frac{\sin\theta * \sin\Phi_o}{\sin(180 - \theta - \Phi_o)}$$

$$\gamma = \cot\theta + \cot\Phi_c$$

$$\infty = \cot\theta + \cot\Phi_o$$

$$h_{sp} = \frac{-b + \sqrt{b^2 - 4*a*c}}{2*a}$$

where

$$a = \frac{3*\cot\theta}{4} + \frac{\lambda*fs*\cot^2\theta}{2} - \frac{\lambda*\cot^2\theta}{2} \qquad \text{(B.17)}$$

$$b = \frac{\sigma}{2} + \lambda*r*\cot\theta + \lambda*\gamma*H_c*\cot\theta$$
$$-\lambda*r*fs*\cot\theta - \lambda*\gamma*H_c*\cot\theta*fs - Hc*\cot\theta$$

$$c = r*H_c + \frac{H_c^2*\gamma}{2} - \frac{\sigma^2*\tan\theta}{4} - \frac{\lambda*r^2}{2} - \frac{\lambda*H_c^2*\gamma^2}{2} - \lambda*r*\gamma*H_c$$
$$-H_{block}*W*fs + \frac{\lambda*fs*r^2}{2} + \frac{\lambda*H_c^2*\gamma^2*fs}{2} + \lambda*r*\gamma*H_c*fs$$

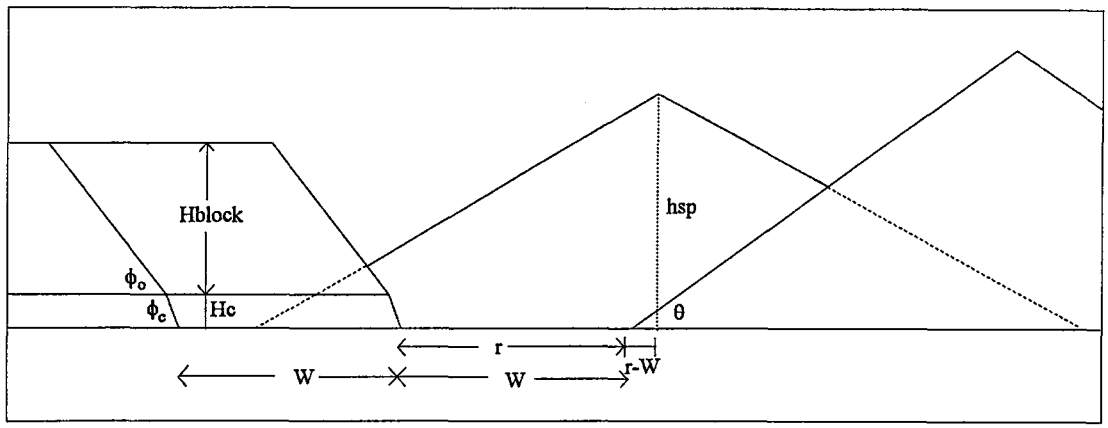

Figure B.16. The Second Alternative where the Effective Dumping Radius is Shorter than the Pit Width (r>W)

$$\sigma = (r - W)$$

$$\lambda = \frac{\sin\theta * \sin\Phi_o}{\sin(180 - \theta - \Phi_o)}$$

$$\gamma = \cot\theta + \cot\Phi_c$$

$$\infty = \cot\theta + \cot\Phi_o$$

$$h_{sp} = \frac{-b + \sqrt{b^2 - 4*a*c}}{2*a}$$

and

$$a = \frac{3*\cot\theta}{4} + \frac{\lambda*fs*\cot^2\theta}{2} - \frac{\lambda*\cot^2\theta}{2} \qquad \text{(B.18)}$$

$$b = \lambda*r*\cot\theta + \lambda*\gamma*H_c*\cot\theta - \lambda*r*fs*\cot\theta$$

$$-\frac{\sigma}{2} - \lambda*\gamma*H_c*\cot\theta*fs - H_c*\cot\theta$$

$$c = r*H_c + \frac{H_c^2*\gamma}{2} - \frac{\sigma^2*\tan\theta}{4} - \frac{\lambda*r^2}{2} - \frac{\lambda*H_c^2*\gamma^2}{2} - \lambda*r*\gamma*H_c$$

$$-H_{block}*W*fs + \frac{\lambda*fs*r^2}{2} + \frac{\lambda*H_c^2*\gamma^2*fs}{2} + \lambda*r*\gamma*H_c*fs$$

Area of the Highwall Barrier

The area of the highwall barrier is illustrated in Figure B.17 and the area is given in Equation B.19.

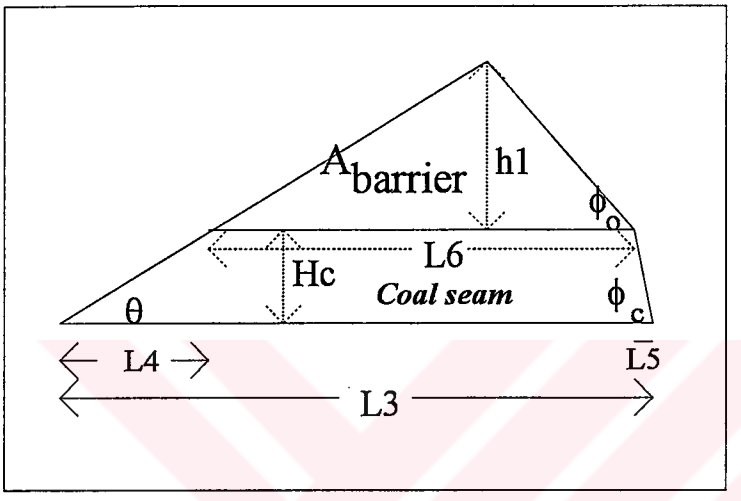

Figure B.17. The Area of the Highwall Side Barrier

$$
\begin{aligned}
L_3 &= h_{sp} * \cot\theta - r \\
L_4 &= H_c * \cot\theta \\
L_5 &= H_c * \cot\Phi_c \\
L_6 &= h_{sp} * \cot\theta - r - H_c * (\cot\theta + \cot\Phi_c) \\
h_1 &= L_6 * \lambda \\
A_{barrier} &= \left[h_{sp} * \cot\theta - r - H_c * (\cot\theta + \cot\Phi_c) \right]^2 * \frac{\lambda}{2}
\end{aligned}
\qquad \text{(B.19)}
$$

Parameters of the Spoil Side Pullback Pad:

Figure B.18 shows the parameters used in formulating the width and height of the pullback pad built on the spoil side and Equation B.20 gives formulas of the width and height of the pullback pad.

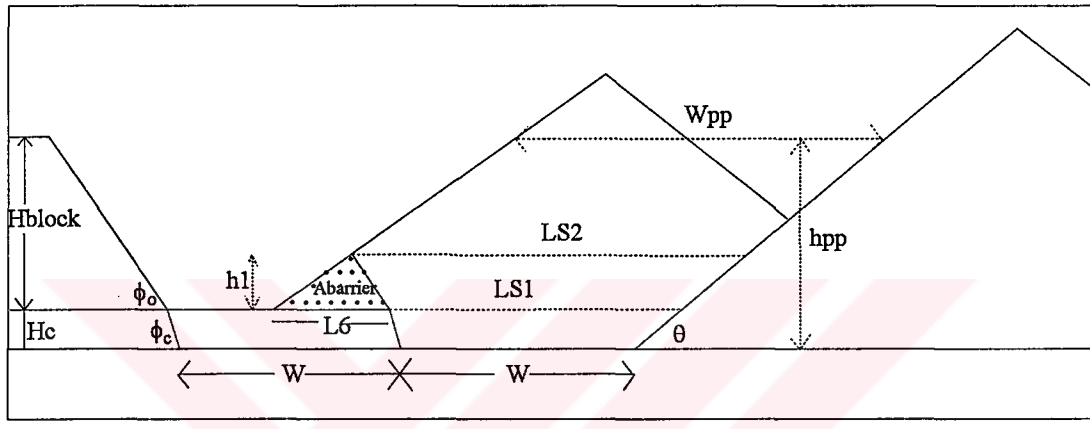

Figure B.18. Decomposition of the Pullback Pad into its Dimensional Components

$$h_{pp} = \frac{(H_{block}*W - A_{barrier})*fs + (H_c + h_1)*[W + H_c*\gamma + h_1*\infty]}{W + H_c*\gamma + h_1*\infty} + \frac{-W*h_1 - H_c*h_1*\gamma - \frac{1}{2}*h_1^2*\infty - H_c*W - \frac{1}{2}*H_c^2*\gamma}{W + H_c*\gamma + h_1*\infty}$$

$$W_{pp} = W + H_c*(\cot\theta + \cot\Phi_c) + h_1*(\cot\theta + \cot\Phi_o) \qquad \text{(B.20)}$$

Area to be Rehandled and Rehandle Percentage:

Figure B.19 shows the parameters used in formulating the area to be rehandled and Equation B.21 gives the formulas related to the area to be rehandled and rehandle percentage.

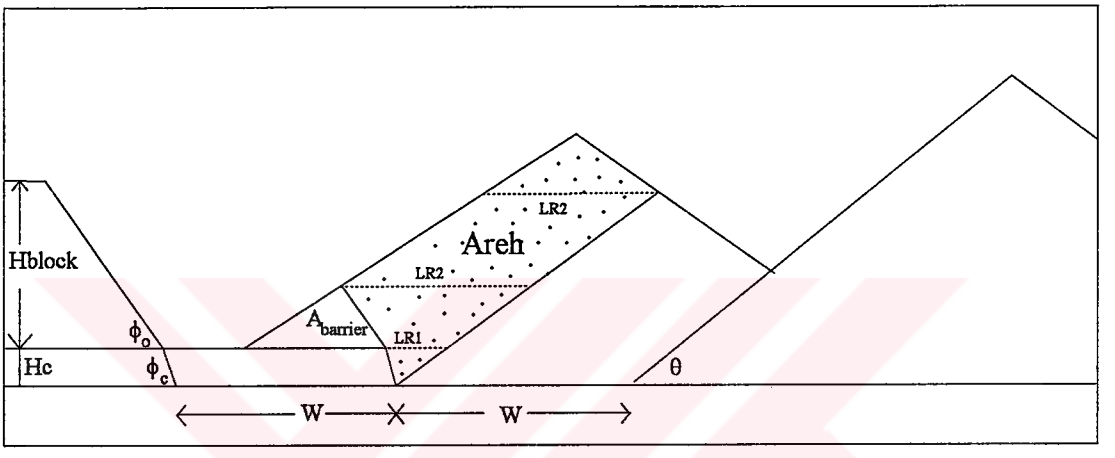

Figure B.19. Parameters Used in the Formulation of Area to be Rehandled

$$
\begin{aligned}
LR_1 &= H_c{*}(\cot\theta + \cot\Phi_c) \\
LR_2 &= LR_1 + h_1{*}(\cot\theta + \cot\Phi_o) \\
A_{reh} &= \frac{1}{2}{*}H_c^2{*}\gamma + H_c{*}\gamma{*}h_1 + \frac{1}{2}{*}h_1^2{*}\infty \\
&\quad + \left[(h_{pp} - (H_c + h_1)){*}(H_c{*}\gamma + h_1{*}\infty)\right] + \frac{1}{16}{*}LS_2^2{*}\tan\theta \\
p_{reh} &= \frac{A_{reh}}{H_{block}{*}W{*}fs}{*}100
\end{aligned}
\qquad \text{(B.21)}
$$

Dimensions Required on Spoil Side:

The required dumping radius on spoil side is illustrated in Figure B.20 and given in Equation B.22. The parameters used in formulating the spoil pile built on pullback pad are given in Figure B.21 and the formulas related to these parameters are given in the following formulas (Equations B.23 to B.26).

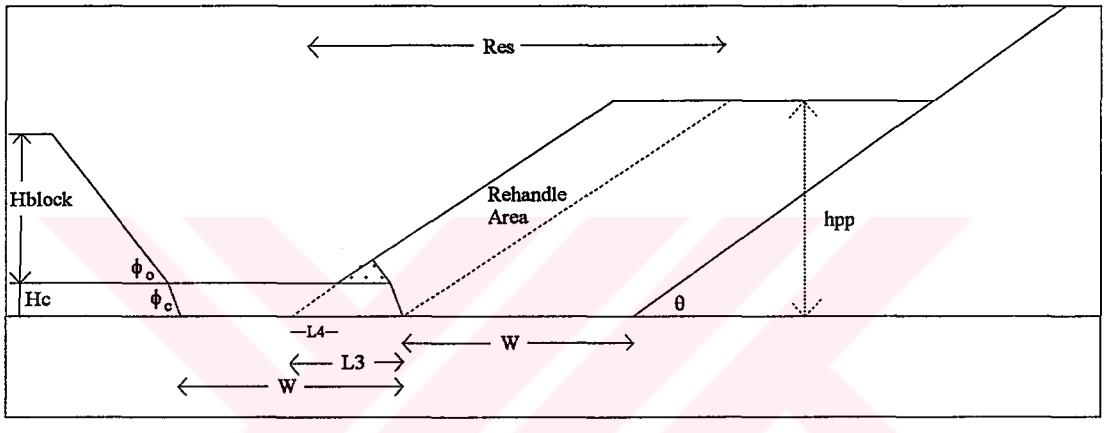

Figure B.20. Required Dumping Radius for the Dragline Employed on Spoil Side

$$L3 = h_{sp} * \cot\theta - r$$
$$L4 = H_c * \cot\theta \qquad \text{(B.22)}$$
$$R_{es} = h_{pp} * \cot\theta + L3 - L4$$

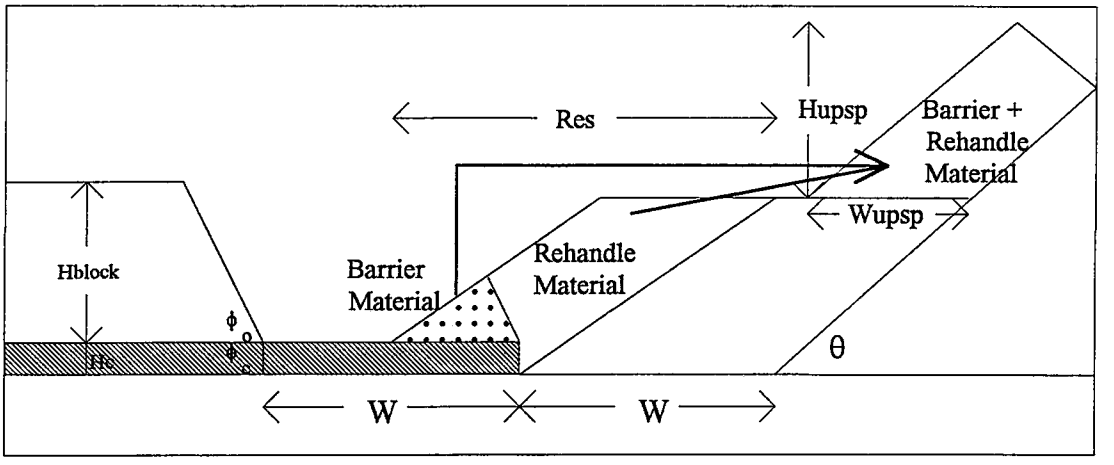

Figure B.21. Parameters Used in Formulation of the Upper Spoil Pile from Rehandle and Barrier Materials on Pullback Pad

According to the way the upper spoil pile is placed, the following relation (Equation B.23) can be derived for the area of upper spoil.

$$A_{upsp} = W_{upsp} H_{upsp} - \frac{W_{upsp}^2}{4} * \tan\theta \qquad \text{(B.23)}$$

At the same time the height of the upper rehandle spoil pile is given with the following formula (Equation B.24),

$$H_{upsp} = \sqrt{(A_{upsp} + A_{barrier} * fs) * \tan\theta} \qquad \text{(B.24)}$$

Since it is assumed that the dragline could dump higher than the crest of the upper rehandle pile then the following inequality (Equation B.25) must satisfy,

$$H_{upsp}^2 >= (A_{upsp} + A_{barrier} * fs) * \tan\theta \tag{B.25}$$

Then, the base width of the upper rehandle pile is calculated with the following discriminant (Equation B.26);

$$W_{upsp} = \frac{H_{upsp} - \sqrt{H_{upsp}^2 - 4*(\frac{\tan\theta}{4})*(A_{upsp} + A_{barrier} * fs)}}{2*\frac{\tan\theta}{4}} \tag{B.26}$$

B.5. Two Slice Direct Side Casting Geometry Model

In the two slice direct side casting geometry model, the width of the pit has been formulized according to whether chopdown is performed or not. Other formulized parameters are the required operating radius and reach for draglines employed on the upper and lower slices.

Pit Width:

Determination of the pit width with and without inclusion of chopdown is given in equation B.27 and illustrated in Figures B.22 and B.23.

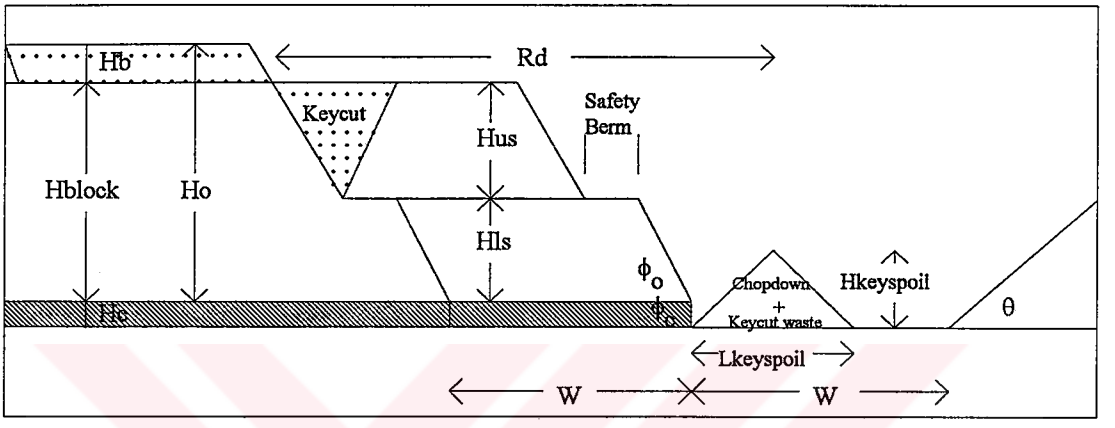

Figure B.22. Determination of the Pit Width Where Chopping is Experienced

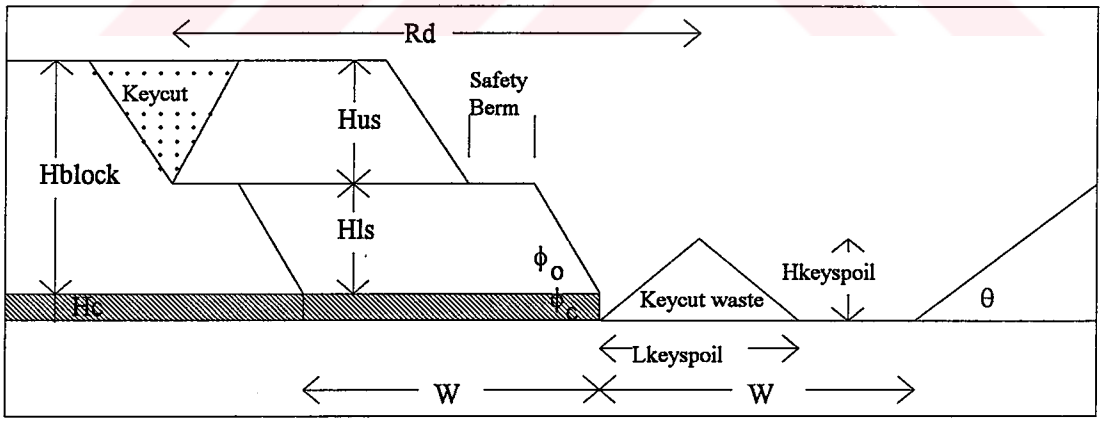

Figure B.23. Determination of the Pit Width Where No Chopping is Experienced

$$W = R_d - H_{US}*\cot\Phi_o - W_{Berm} - H_{LS}*\cot\Phi_o - H_c*\cot\Phi_c - h_{keyspoil}*\cot\theta \quad (Chopping)$$

$$W = R_d + \frac{W_{buc}}{2} - W_{Berm} - H_{LS}*\cot\Phi_o - H_c*\cot\Phi_c - h_{keyspoil}*\cot\theta \quad (No\ Chopping) \qquad (B.27)$$

Required Operating Radius and Reach on the Upper Slice:

Figure B.24 illustrates the parameters used in formulating the required operating radius and reach on the upper slice and Equation B.28 gives the formulations related to these parameters.

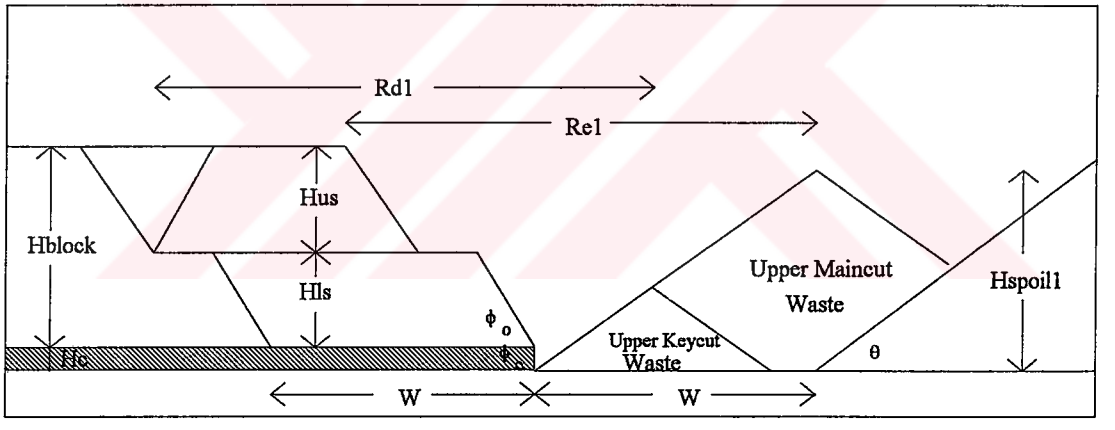

Figure B.24. Parameters Used in the Calculation of Required Upper Slice Dragline Dimensions

$$R_{d1} = W + W_{Berm} + H_{LS}{*}\cot\Phi_o + H_c{*}\cot\Phi_c + h_{keyspoil}{*}\cot\theta$$
$$R_{e1} = H_{US}{*}\cot\Phi_o + W_{Berm} + H_{LS}{*}\cot\Phi_o + H_c{*}\cot\Phi_c + H_{spoil1}{*}\cot\theta \quad \text{(B.28)}$$

Required Operating Radius and Reach on the Lower Slice:

Figure B.25 illustrates the parameters used in formulating the required operating radius and reach on the lower slice and Equation B.29 gives the formulations related to these parameters.

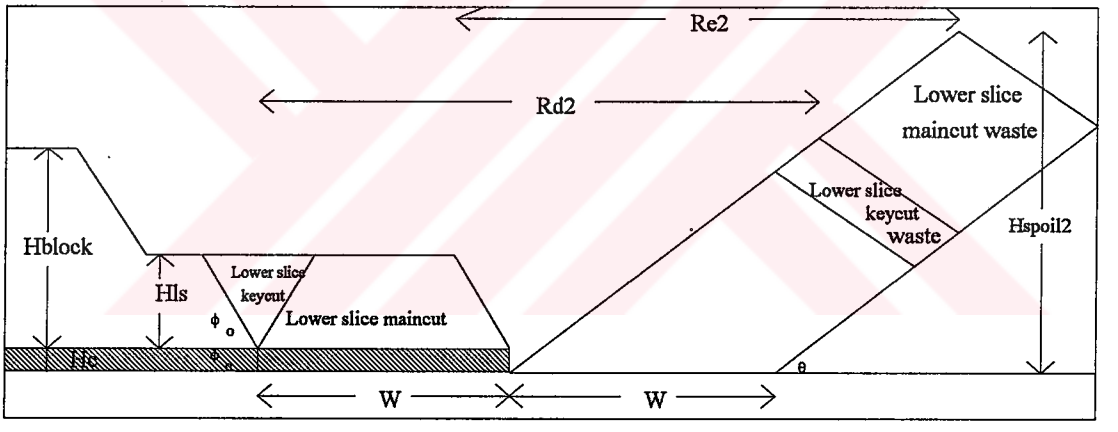

Figure B.25. Parameters Used in the Calculation of Required Lower Slice Dragline Dimensions

$$R_{d2} = W + H_c{*}\cot\Phi_c + H_{spoil2}{*}\cot\theta$$
$$R_{e2} = H_{LS}{*}\cot\Phi_o + H_c{*}\cot\Phi_c + H_{spoil2}{*}\cot\theta \quad \text{(B.29)}$$

B.6. Lower Slice Extended Bench Casting Geometry Model

In the lower slice extended bench casting geometry model the pit width, height of temporary spoil pile in the empty pit, area of hollow sections in the pit, height of the extended bench, width of the extended bench, area to be rehandled and rehandle percentage and the required operating radius and reach for the dragline employed on the lower slice have been formulized.

Pit Width:

Determination of the pit width with and without inclusion of chopdown is illustrated in Figures B.26 and B.27 and is given in equation B.30.

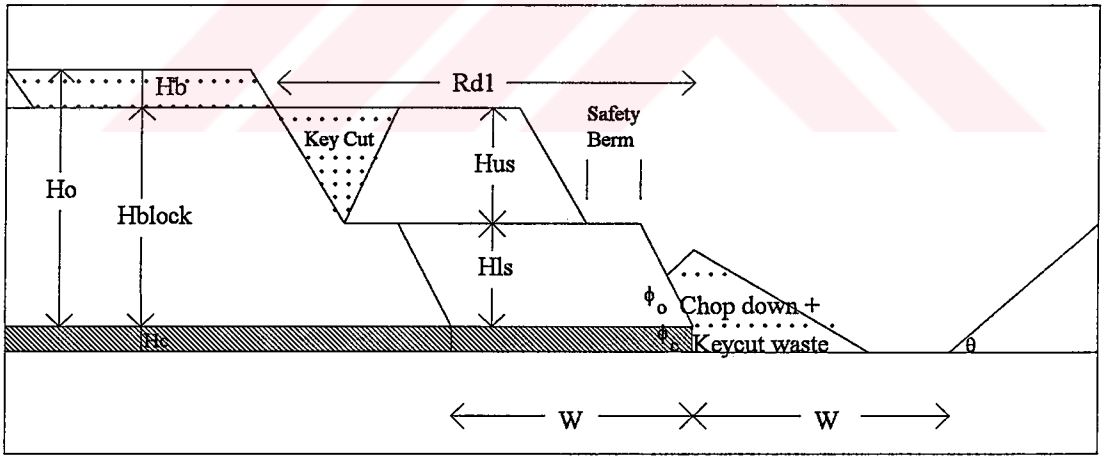

Figure B.26. Optimal Pit Width Determination Where Chopping is Experienced

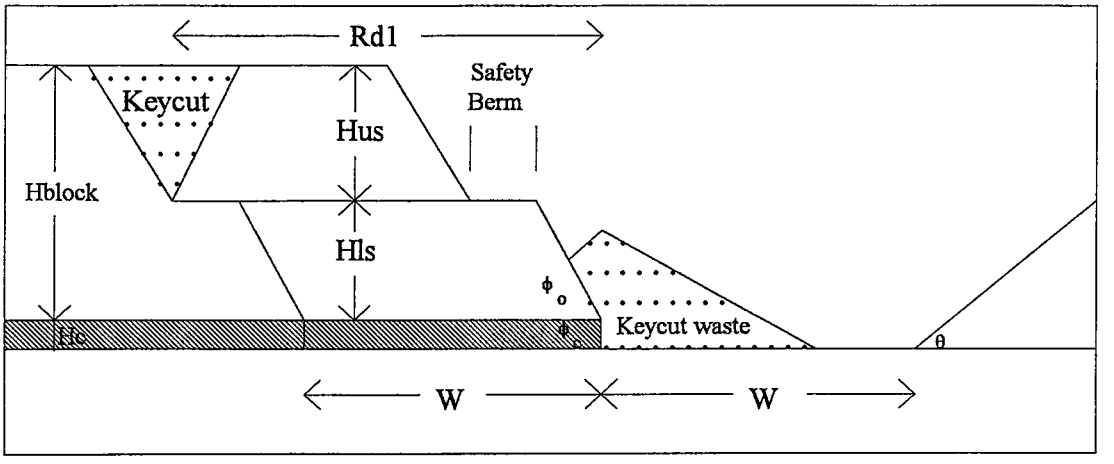

Figure B.27. Optimal Pit Width Determination Where No Chopping is Experienced

$$W = R_{d1} - H_{US}*\cot\Phi_o - W_{Berm} - H_{LS}*\cot\Phi_o - H_c*\cot\Phi_c \quad (Chopping)$$
$$W = R_{d1} + \frac{W_{buc}}{2} - W_{Berm} - H_{LS}*\cot\Phi_o - H_c*\cot\Phi_c \quad (No\ Chopping) \qquad (B.30)$$

Height of the Temporary Spoil Pile in the Empty Pit:

The first pattern where the effective reach of upper slice dragline is shorter than the pit width is given in Figure B.28. The formulations regarding the height of temporary spoil pile is given in Equation B.31.

The second pattern where the effective reach of upper slice dragline is larger than the pit width is given in Figure B.29. The formulations regarding the height of temporary spoil pile is given in Equation B.32.

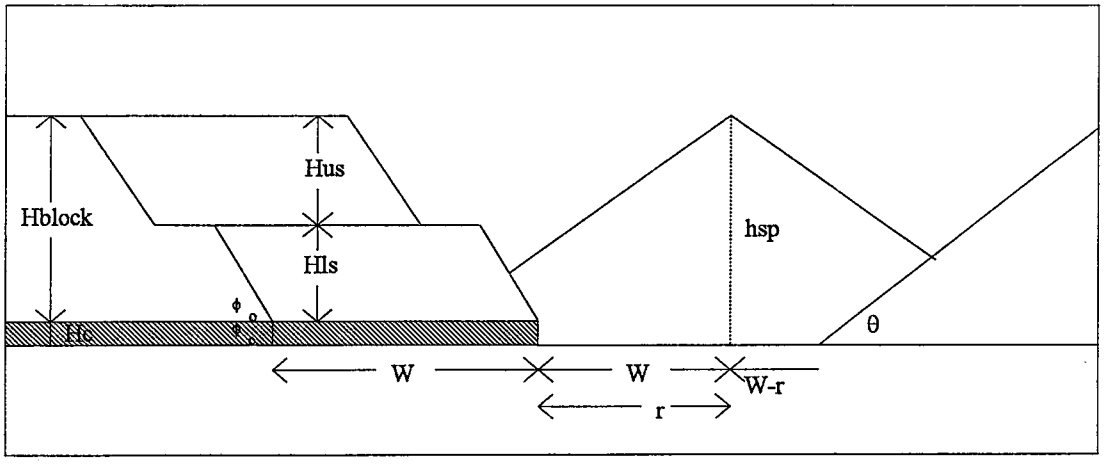

Figure B.28. The First Alternative where the Effective Dumping Radius is Shorter than the Pit Width (r<W)

$$\sigma = (W - r)$$

$$\lambda = \frac{\sin\theta * \sin\Phi_o}{\sin(180 - \theta - \Phi_o)}$$

$$\gamma = \cot\theta + \cot\Phi_c$$

$$\infty = \cot\theta + \cot\Phi_o$$

$$h_{sp} = \frac{-b + \sqrt{b^2 - 4*a*c}}{2*a}$$

and (B.31)

$$a = \frac{3*\cot\theta}{4} - \frac{\lambda*\cot^2\theta}{2}$$

$$b = \frac{\sigma}{2} + \lambda*r*\cot\theta + \lambda*\gamma*H_c*\cot\theta - H_c*\cot\theta$$

$$c = r*Hc + \frac{H_c^2*\gamma}{2} - \frac{\sigma^2*\tan\theta}{4} - \frac{\lambda*r^2}{2} - \frac{\lambda*H_c^2*\gamma}{2}$$
$$-\lambda*r*\gamma*H_c - H_{US}*W*fs$$

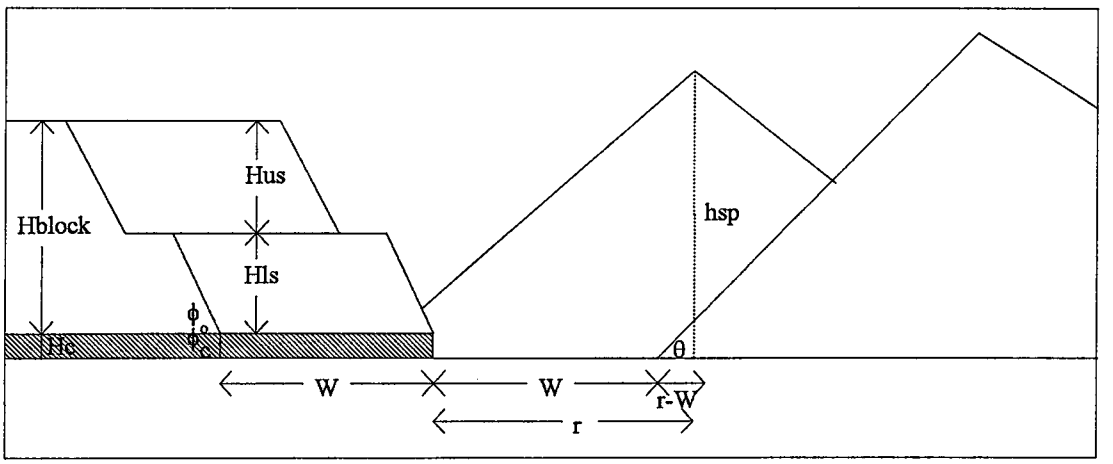

Figure B.29. The Second Alternative where the Effective Dumping Radius is Larger than the Pit Width (r>W)

$$\sigma = (r - W)$$

$$\lambda = \frac{\sin\theta * \sin\Phi_o}{\sin(180 - \theta - \Phi_o)}$$

$$\gamma = \cot\theta + \cot\Phi_c$$

$$\infty = \cot\theta + \cot\Phi_o$$

$$h_{sp} = \frac{-b + \sqrt{b^2 - 4*a*c}}{2*a}$$

and (B.32)

$$a = \frac{3*\cot\theta}{4} - \frac{\lambda*\cot^2\theta}{2}$$

$$b = \lambda*r*\cot\theta + \lambda*\gamma*H_c*\cot\theta - \frac{\sigma}{2} - H_c*\cot\theta$$

$$c = r*H_c + \frac{H_c^2*\gamma}{2} - \frac{\sigma^2*\tan\theta}{4} - \frac{\lambda*r^2}{2} - \frac{\lambda*H_c^2*\gamma}{2} - \lambda*r*\gamma*H_c - H_{US}*W*fs$$

Area of Hollow Section between Upper Slice Spoil and the Lower Slice:

When building a limited extended bench near the lower slice the area of void part and the conical upper part have to be equal to each other ($A_{d1} = A_{upsp}$). The area, height and base width of the conical upper part in the spoil pile are illustrated in Figure B.30 and formulated in Equation B.33.

Construction of a full extended bench in the model occurs as filling the hollow parts that are located in both sides of the spoiled upper slice waste by moving a part of spoiled material located at top of the pile into both sides as illustrated in Figure B.31. The formulations relating to the area calculations of the hollow sections on both sides of the temporary spoil pile in the pit are given in Equation B.34.

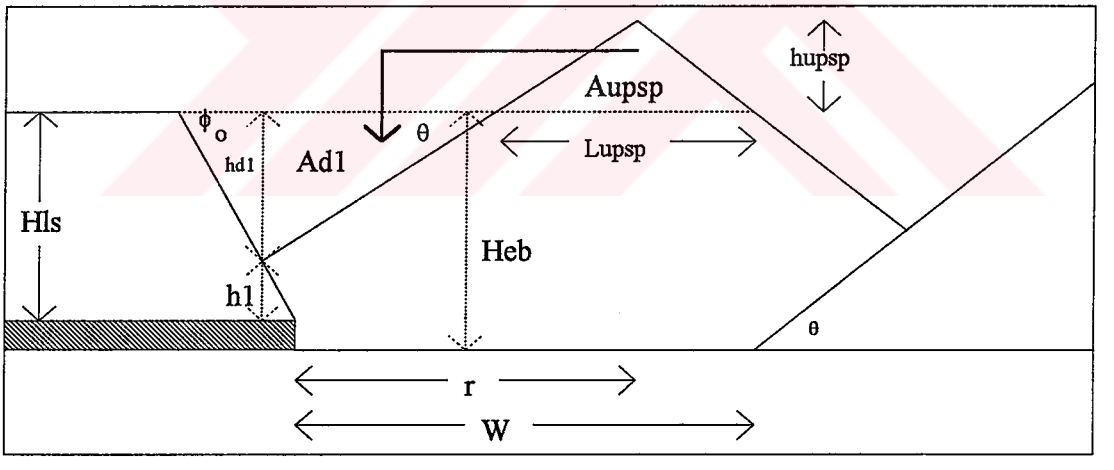

Figure B.30. Related Dimensions of the Void Area and Spoiled Waste When a Limited Extended Bench is Built

$$
\begin{aligned}
h_{d1} &= H_{LS} - h_1 \\
h_{d1} &= H_{LS} + \lambda^* \alpha - \lambda^* h_{sp}^* \cot\theta \\
A_{d1} &= \frac{1}{2}^* h_{d1}^{2\,*} (\cot\theta + \cot\Phi_o) \\
A_{upsp} &= A_{d1} \quad \textit{must satisfy!} \\
h_{upsp} &= \frac{L_{upsp}}{2}^* \tan\theta \\
A_{upsp} &= \frac{1}{4}^* L_{upsp}^{2\,*} \tan\theta \\
L_{upsp} &= \sqrt{\frac{4^* A_{upsp}}{\tan\theta}}
\end{aligned}
\qquad \text{(B.33)}
$$

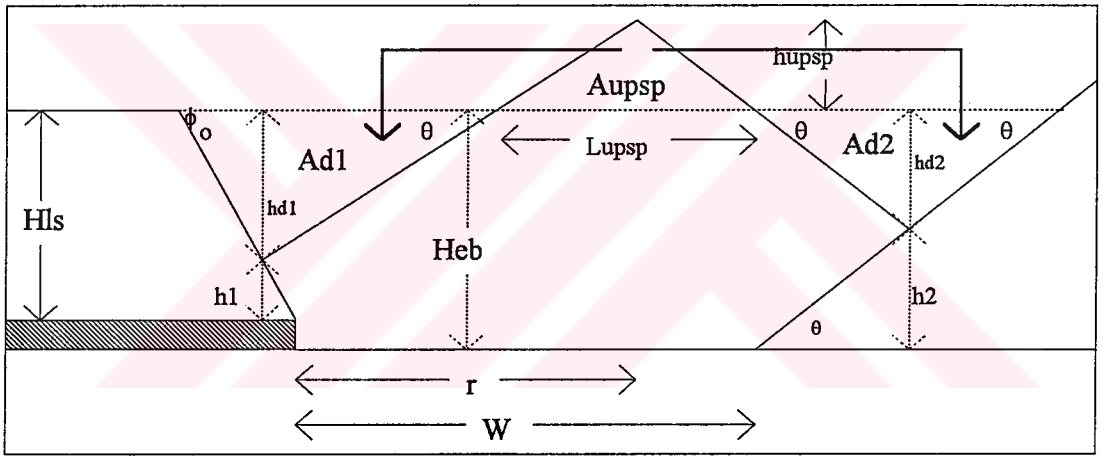

Figure B.31. Related Dimensions of the Void Areas and Spoiled Waste When a Full Extended Bench is Built

$$
\begin{aligned}
h_{d2} &= (H_{LS} + H_c) - h_2 \\
A_{d2} &= \left[(H_{LS} + H_c) - h_2\right]^2 * \cot\theta \\
h_{d1} &= H_{LS} - h_1 \\
h_{d1} &= H_{LS} + \lambda * \alpha - \lambda * h_{sp} * \cot\theta \\
A_{d1} &= \frac{1}{2} * h_{d1}^2 * (\cot\theta + \cot\Phi_o) \\
A_{upsp} &= A_{d1} + A_{d2} \quad \textit{must satisfy}! \\
L_{upsp} &= \sqrt{\frac{4 * A_{upsp}}{\tan\theta}} \\
h_{upsp} &= \frac{L_{upsp}}{2} * \tan\theta \\
A_{upsp} &= \frac{1}{4} * L_{upsp}^2 * \tan\theta
\end{aligned}
\qquad \text{(B.34)}
$$

Height of the Extended Bench:

It is obvious that the height of the extended bench can be derived by two alternative ways. The following formula (Equation B.35) represents the calculation of the extended bench height,

$$
\begin{aligned}
H_{eb} &= H_{LS} + H_c \\
&\textit{or} \\
H_{eb} &= h_{sp} - h_{upsp}
\end{aligned}
\qquad \text{(B.35)}
$$

Width of Lower Slice Extended Bench:

The width of the lower slice limited extended bench can be calculated by the aid of previously derived relations between pit dimensions. Figure B.32 illustrates the parameters used in formulating the width of the extended bench and Equation B.36 represents the formulation of the lower slice extended bench width.

$$W_{eb} = h_{d1}*(\cot\theta + \cot\Phi_o) + L_{upsp} \qquad \text{(B.36)}$$

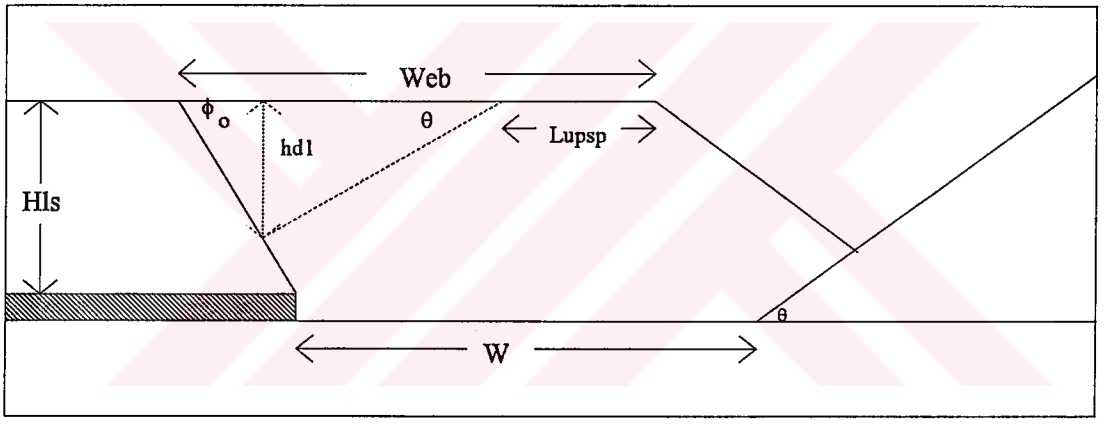

Figure B.32. The Width of the Lower Slice Limited Extended Bench

The width of the lower slice full extended bench is illustrated in Figure B.33 and given in Equation B.37.

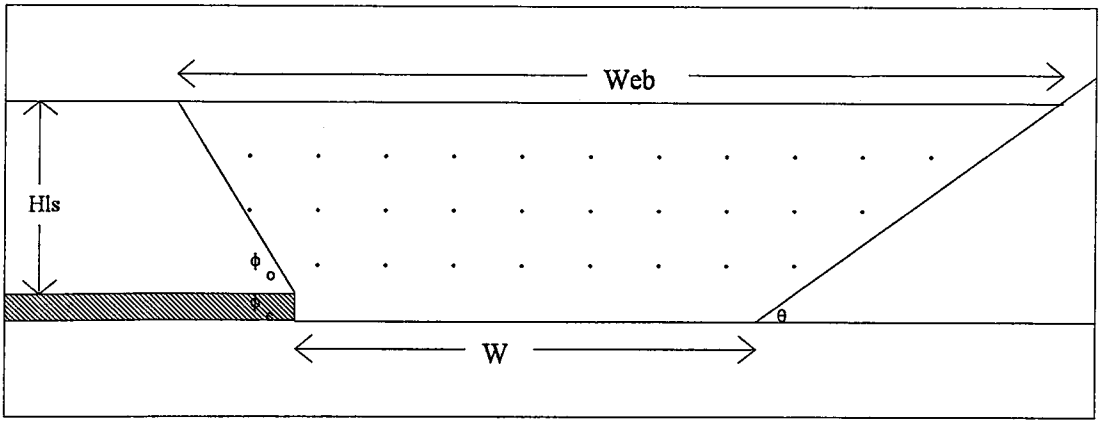

Figure B.33. The Width of the Lower Slice Full Extended Bench

$$W_{eb} = W + H_{LS}*(\cot\theta + \cot\Phi_o) + H_c*(\cot\theta + \cot\Phi_c) \quad \text{(B.37)}$$

Area to be Rehandled and Rehandle Percentage:

The area of the material to be rehandled in the lower slice limited extended bench casting geometry model and the rehandle percentage are given in Equation B.38 and illustrated in Figure B.34.

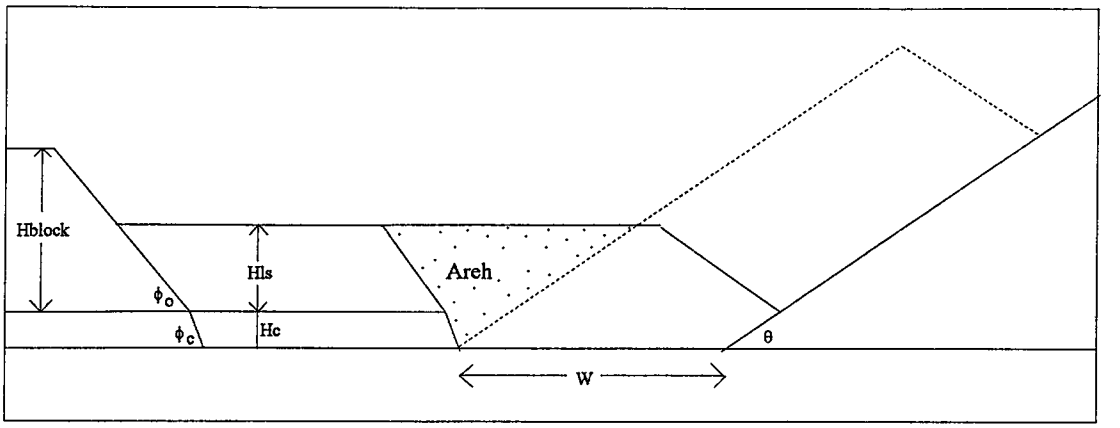

Figure B.34. Area of the Material That Must Be Rehandled in the Lower Slice Limited Extended Bench

$$A_{reh} = \frac{1}{2} * H_{LS}^2 * \cot \Phi_o + \frac{2 * H_{LS} + H_c}{2} * (H_c * \cot \Phi_c) + \frac{1}{2} * (H_{LS} + H_c)^2 * \cot \theta \quad \text{(B.38)}$$

$$p_{reh} = \frac{A_{reh}}{H_o * W * fs} * 100$$

The area of the material to be rehandled in the lower slice full extended bench casting geometry model is given in Equation B.39 and illustrated in Figure B.35.

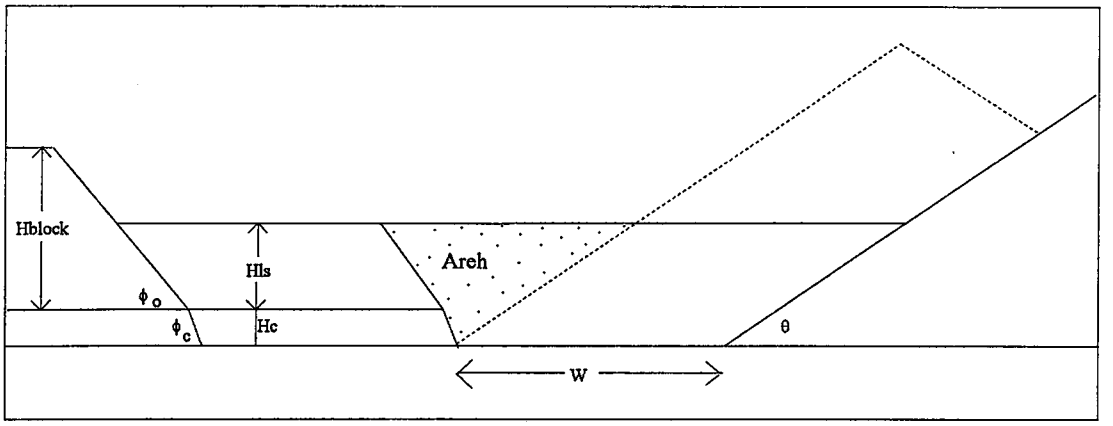

Figure B.35. Area of the Material That Must Be Rehandled in the Lower Slice Full Extended Bench

$$A_{reh} = \frac{1}{2} * H_{LS}^2 * \cot \Phi_o + \frac{2 * H_{LS} + H_c}{2} * (H_c * \cot \Phi_c) + \frac{1}{2} * (H_{LS} + H_c)^2 * \cot \theta \quad \text{(B.39)}$$

Required Dimensions for the Dragline Employed on the Lower Slice:

Required operating dimensions of the dragline employed on the lower slice for the limited bench extensions are given in the Equation B.40 and illustrated in Figure B.36.

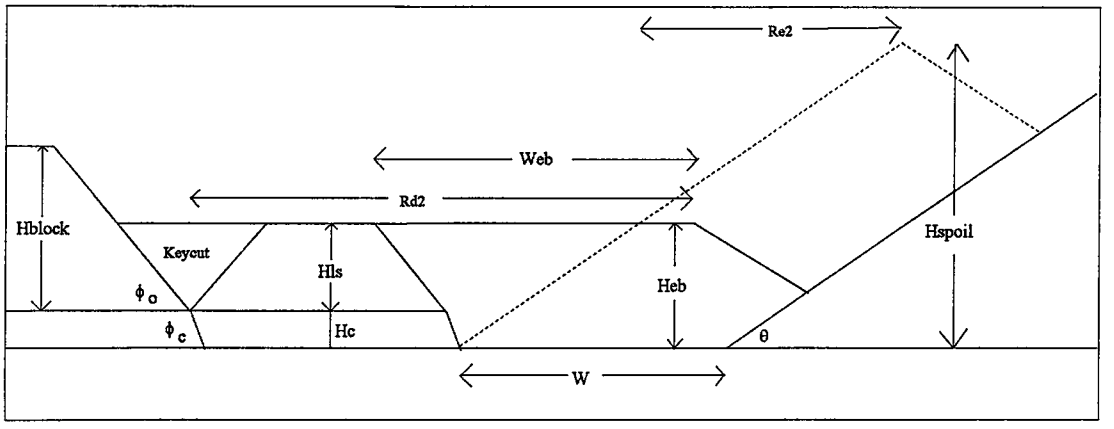

Figure B.36. Required Dimensions in the Lower Slice Limited Extended Bench

$$R_{d2} = W + W_{eb} - H_{LS} * \cot \Phi_o$$
$$R_{e2} = (H_{spoil} - H_{eb}) * \cot \theta \qquad \text{(B.40)}$$

Required operating dimensions of the dragline employed on the lower slice for the full bench extensions are given in the Equation B.41 and illustrated in Figure B.37.

$$R_{d2} = W + W_{eb} - H_{LS} * \cot \Phi_o$$
$$R_{e2} = (H_{spoil} - H_{eb}) * \cot \theta \qquad \text{(B.41)}$$

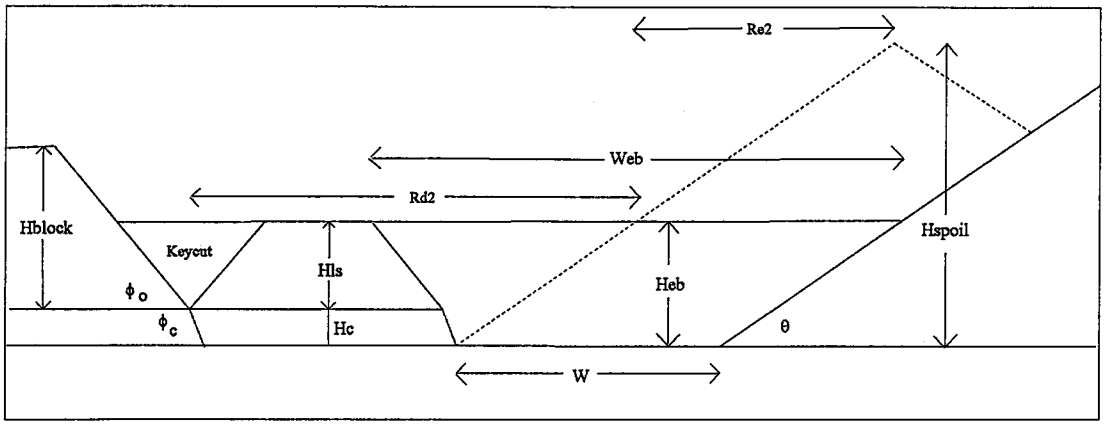

Figure B.37. Required Dimensions in the Lower Slice Full Extended Bench

B.7. Two Slice Pullback Stripping Geometry Model

In the two slice pullback stripping geometry model the pit width, height of temporary spoil pile in the empty pit, height and width of pullback pad, area to be rehandled and rehandle percentage and the required dumping radius on spoil side and dimensions of the spoil pile built on the pullback pad have been formulized.

Pit Width:

Determination of the pit width with and without inclusion of chop down is given in Equation B.41 and illustrated in Figures B.38 and B.39.

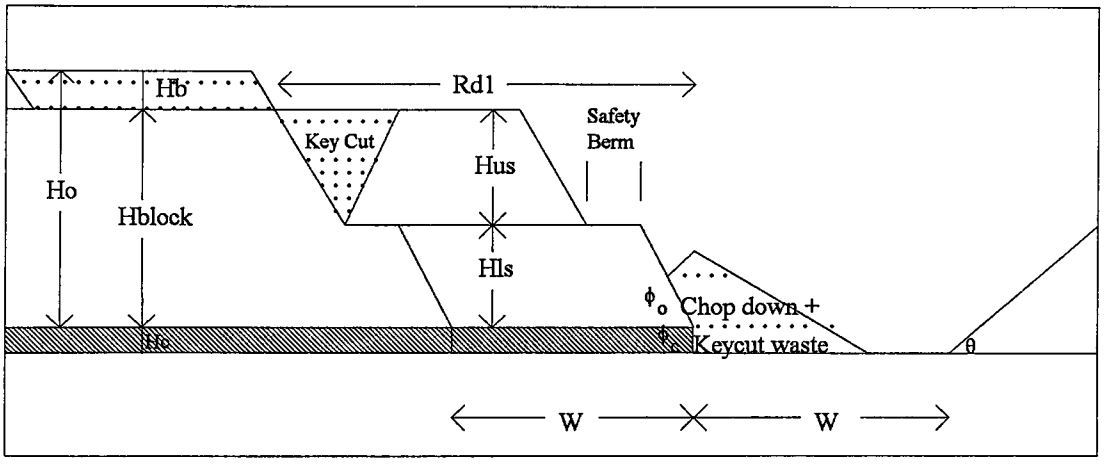

Figure B.38. Pit Width Determination Where Chopping is Experienced

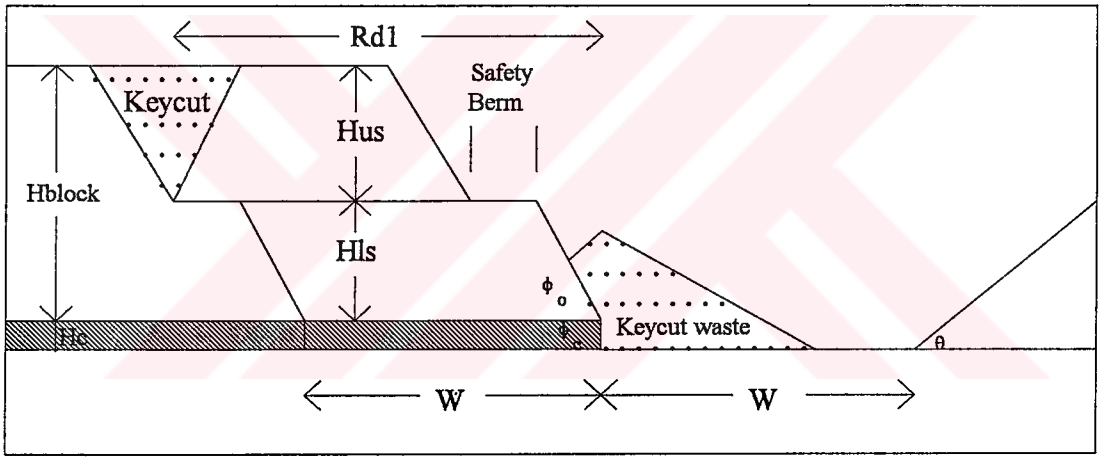

Figure B.39. Pit Width Determination Where No Chopping is Experienced

$$W = R_{d1} - H_{US}*\cot\Phi_o - W_{Berm} - H_{LS}*\cot\Phi_o - H_c*\cot\Phi_c \quad (Chopping)$$

$$W = R_{d1} + \frac{W_{buc}}{2} - W_{Berm} - H_{LS}*\cot\Phi_o - H_c*\cot\Phi_c \quad (No\ Chopping) \qquad (B.41)$$

Height of Temporary Spoil Pile in the Pit:

The first pattern where the effective reach of upper slice dragline is shorter than the pit width is given in Figure B.40. The formulations regarding the height of temporary spoil pile is given in Equation B.42.

The second pattern where the effective reach of upper slice dragline is larger than the pit width is given in Figure B.41. The formulations regarding the height of temporary spoil pile is given in Equation B.43.

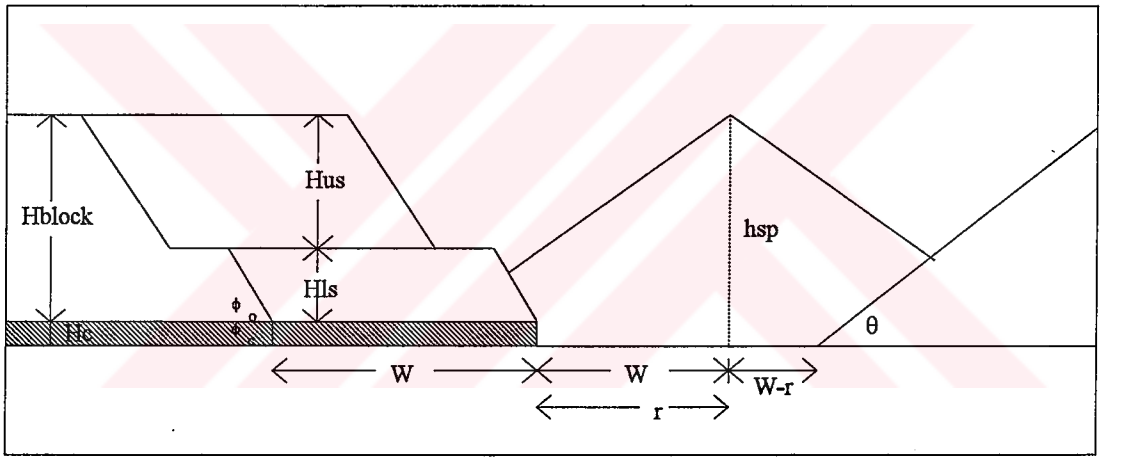

Figure B.40. The First Alternative where the Effective Dumping Radius is Shorter than the Pit Width (r<W)

$$\sigma = (W - r)$$

$$\lambda = \frac{\sin\theta * \sin\Phi_o}{\sin(180 - \theta - \Phi_o)}$$

$$\gamma = \cot\theta + \cot\Phi_c$$

$$\infty = \cot\theta + \cot\Phi_o$$

$$h_{sp} = \frac{-b + \sqrt{b^2 - 4*a*c}}{2*a}$$

and (B.42)

$$a = \frac{3*\cot\theta}{4} - \frac{\lambda*\cot^2\theta}{2}$$

$$b = \frac{\sigma}{2} + \lambda*r*\cot\theta + \lambda*\gamma*H_c*\cot\theta - H_c*\cot\theta$$

$$c = r*Hc + \frac{H_c^2*\gamma}{2} - \frac{\sigma^2*\tan\theta}{4} - \frac{\lambda*r^2}{2} - \frac{\lambda*H_c^2*\gamma}{2}$$
$$-\lambda*r*\gamma*H_c - H_{US}*W*fs$$

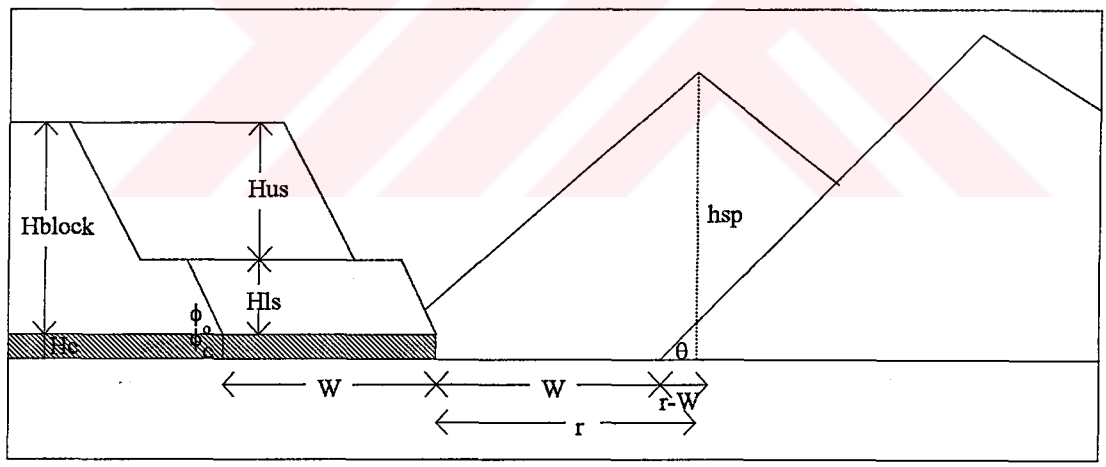

Figure B.41. The Second Alternative where the Effective Dumping Radius is Larger than the Pit Width (r>W)

$$\sigma = (r - W)$$

$$\lambda = \frac{\sin\theta * \sin\Phi_o}{\sin(180 - \theta - \Phi_o)}$$

$$\gamma = \cot\theta + \cot\Phi_c$$

$$\infty = \cot\theta + \cot\Phi_o$$

$$h_{sp} = \frac{-b + \sqrt{b^2 - 4*a*c}}{2*a}$$

and (B.43)

$$a = \frac{3*\cot\theta}{4} - \frac{\lambda*\cot^2\theta}{2}$$

$$b = \lambda*r*\cot\theta + \lambda*\gamma*H_c*\cot\theta - \frac{\sigma}{2} - H_c*\cot\theta$$

$$c = r*H_c + \frac{H_c^2*\gamma}{2} - \frac{\sigma^2*\tan\theta}{4} - \frac{\lambda*r^2}{2} - \frac{\lambda*H_c^2*\gamma}{2} - \lambda*r*\gamma*H_c - H_{US}*W*fs$$

Height and Width of Pullback Pad:

The height and width of the pullback pad are illustrated in Figure B.42 and formulated in Equation B.44.

$$LS1 = W + Hc*\gamma$$

$$LS2 = W + Hc*(\cot\theta + \cot\Phi c) + h1*(\cot\theta + \cot\Phi o)$$

$$h_{pp} = \frac{H_{US}*W*fs - Hc*W - \frac{1}{2}*H_c^2*\gamma - W*h_1 - H_c*h_1*\gamma}{W + H_c*\gamma + h_1*\infty} + \frac{+(H_c + h_1)*[W + H_c*\gamma + h_1*\infty] - \frac{1}{2}*h_1^2*\infty}{W + H_c*\gamma + h_1*\infty} \quad \text{(B.44)}$$

$$W_{pp} = W + H_c*(\cot\theta + \cot\Phi_c) + h_1*(\cot\theta + \cot\Phi_o)$$

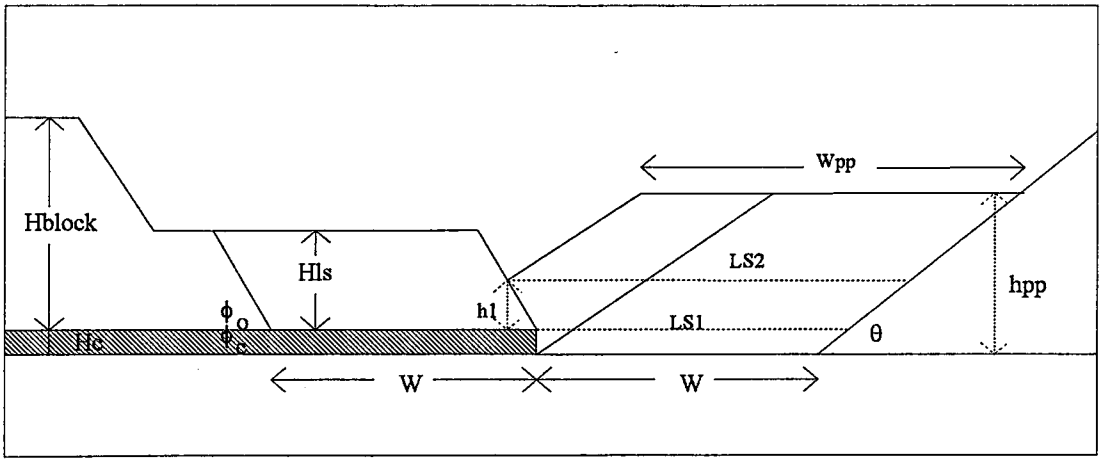

Figure B.42. Parameters Used in Formulating the Height and Width of the Pullback Pad

Area of Material to be Rehandled and Rehandle Percentage:

The area of the material to be rehandled in the pullback pad and the rehandle percentage are formulated in Equation B.45 and illustrated in Figure B.43.

$$
\begin{aligned}
LR_1 &= H_c{*}(\cot\theta + \cot\Phi_c) \\
LR_2 &= LR_1 + h_1{*}(\cot\theta + \cot\Phi_o) \\
A_{reh} &= \frac{1}{2}{*}H_c^2{*}\gamma + H_c{*}\gamma{*}h_1 + \frac{1}{2}{*}h_1^2{*}\infty \\
&\quad + \left[(h_{pp} - (H_c + h_1)){*}(H_c{*}\gamma + h_1{*}\infty)\right] + \frac{1}{16}{*}LS_2^2{*}\tan\theta \\
p_{reh} &= \frac{A_{reh}}{H_o{*}W{*}fs}{*}100
\end{aligned}
\qquad \text{(B.45)}
$$

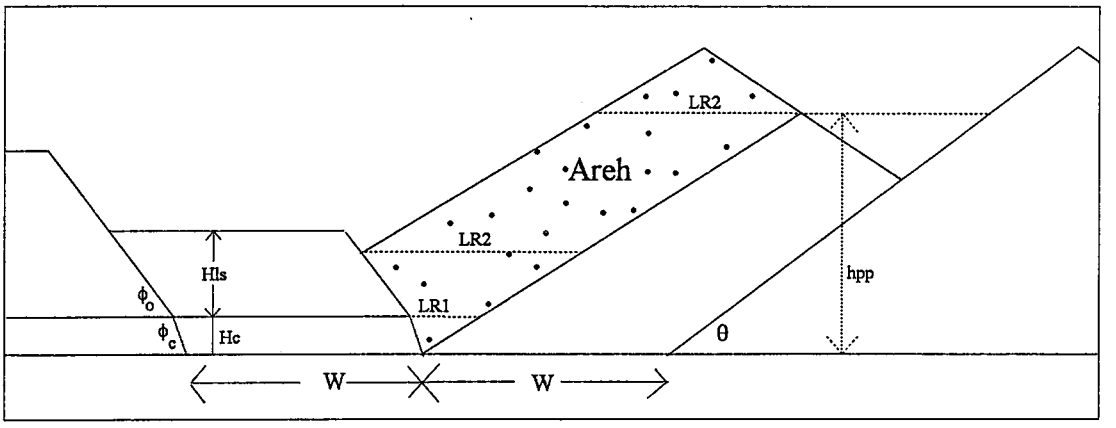

Figure B.43. Area of Material to be Rehandled in the Two Slice Pullback Stripping Geometry Model

Required Dumping Radius on Spoil Side:

The required dumping radius for the dragline employed on the spoil side is illustrated in Figure B.44 and given in Equation B.46.

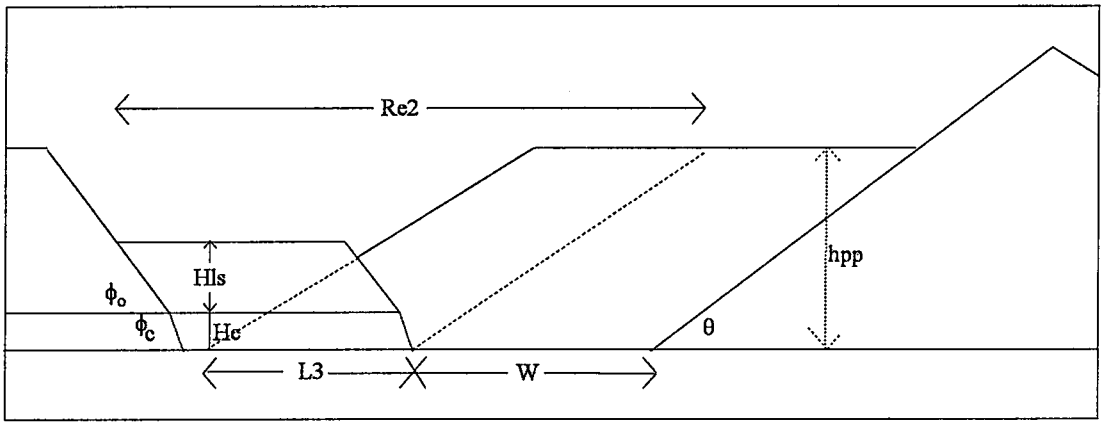

Figure B.44. Required Dumping Radius on the Spoil Side

$$R_{e2} = h_{pp}*\cot\theta + H_c*\cot\Phi_c + H_{LS}*\cot\Phi_o + W - L_3 \quad \text{(B.46)}$$

Dimensions of the Spoil Pile Constructed on Pullback Pad:

The logic embedded in the model is to build an upper spoil pile on the leveled pad. In this method, the spoil pile formed by rehandle and lower slice materials leans against previous spoil pile. But this criterion is limited with the dumping height of the dragline. Figure B.45 illustrates the parameters used in the formulation of pullback pad spoil pile.

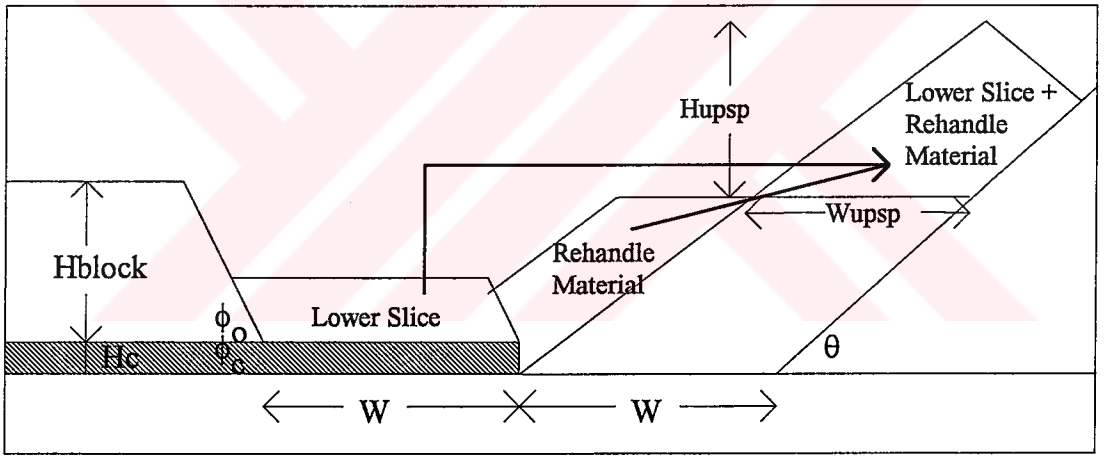

Figure B.45. Dimensions of the Spoil Pile Constructed on Pullback Pad

According to the way the upper spoil pile is placed, the following formula (Equation B.47) can be derived for the area of upper spoil.

$$A_{upsp} = W_{upsp} * H_{upsp} - \frac{W_{upsp}^2}{4} * \tan\theta \quad \text{(B.47)}$$

At the same time the height of the upper rehandle spoil pile is given with the following formula (Equation B.48),

$$H_{upsp} = \sqrt{(A_{upsp} + A_{lowerslice} * fs) * \tan\theta} \quad \text{(B.48)}$$

Since it is assumed that the dragline could dump higher than the peak of the upper rehandle pile, then the following inequality must satisfy (Equation B.49),

$$H_{upsp}^2 \geq (A_{upsp} + A_{lowerslice} * fs) * \tan\theta \quad \text{(B.49)}$$

Then the base width of the upper rehandle pile is calculated with the following discriminant (Equation B.50),

$$W_{upsp} = \frac{H_{upsp} + \sqrt{H_{upsp}^2 - 4 * (\frac{\tan\theta}{4}) * (A_{upsp} + A_{lowerslice} * fs)}}{2 * \frac{\tan\theta}{4}} \quad \text{(B.50)}$$

APPENDIX C

CONTROL OF RANDOM NUMBER GENERATORS IN THE EXPERT SYSTEM

C.1. Control of the Normal Distribution Random Number Generator

The production simulation modules in the expert system have been equipped with random number generators to produce random numbers from a specific statistical distribution. For estimating the cycle time values of draglines, a normal random number generator has been coded into the production simulation models of the expert system. Validation of the normal random number generator has been done in the following way: 1500 normally distributed random numbers with a mean of 60 and a standard deviation of 5 were generated by both the expert system and a commercially available statistical analysis package, STATGRAPHICS V.5. (STSC Inc, 1991). The 1500 numbers generated by the expert system were tested by STATGRAPHICS to fit in a distribution and it has been proved that the expert system has been producing random numbers from the normal distribution. The results of the distribution fitting process are given in Table C.1. Besides, histograms related to the 1500 normally distributed random numbers generated by the expert system and the commercial program are presented in Figures C.1 and C.2 respectively.

Table C.1. The Results of the Distribution Fitting Tests on the 1500 Normally Distributed Random Numbers

Mean of the Stream Generated by the Expert System	60
Standard Deviation of the Stream Generated by the Expert System	5
Mean of the Stream After Distribution Fitting	59.9793
Standard Deviation of the Stream After Distribution Fitting	5.00716

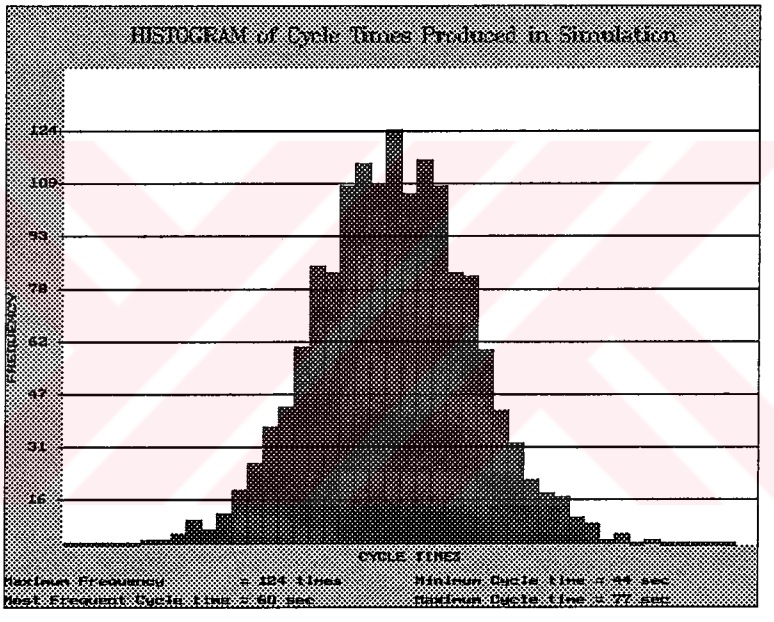

Figure C.1. The Histogram of 1500 Normally Distributed Random Numbers Generated by the Expert System ($\mu = 60$, $\sigma = 5$)

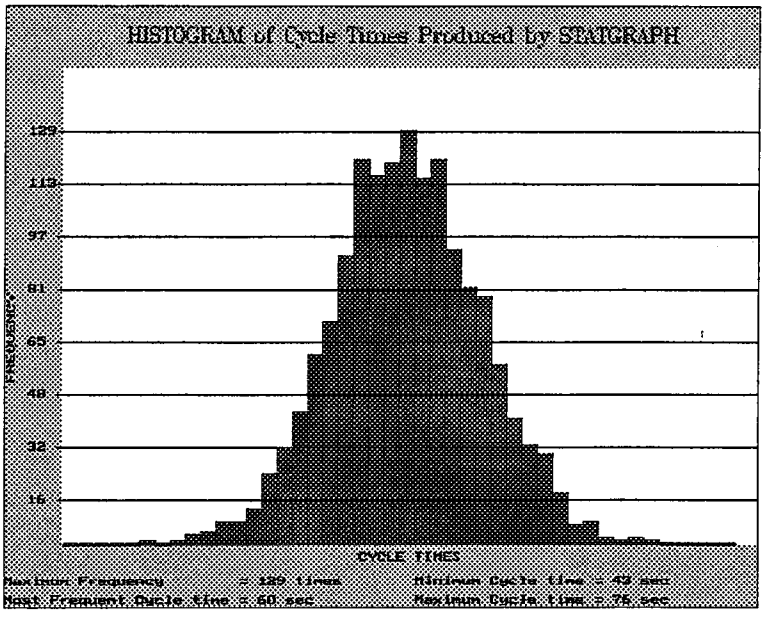

Figure C.2. The Histogram of 1500 Normally Distributed Random Numbers Generated by the Commercial Program ($\mu = 60$, $\sigma = 5$)

C.2. Control of the Uniform Distribution Random Number Generator

For estimating the delaying of draglines, the random number generator of the Borland PASCAL V.7.0. compiler has been used in the production simulation models of the expert system. Validation of the uniform random number generator has been done in the same way: 1500 uniformly distributed random numbers with a lower limit of 0 and an upper limit of 100 were generated by both the expert system and STATGRAPHICS V.5.. The 1500 uniform numbers generated by the expert system were tested to fit in a distribution and it has been proved that the expert system has been producing random numbers from the uniform distribution. The results of the distribution fitting process are given in Table C.2. Besides, histograms related to the

1500 uniformly distributed random numbers generated by the expert system and the commercial program are presented in Figures C.3 and C.4 respectively.

Table C.2. The Results of the Distribution Fitting Tests on the 1500 Uniformly Distributed Random Numbers

Lower Limit of the Stream Generated by the Expert System	0
Upper Limit of the Stream Generated by the Expert System	100
Lower limit of the Stream After Distribution Fitting	0
Upper Limit of the Stream After Distribution Fitting	100

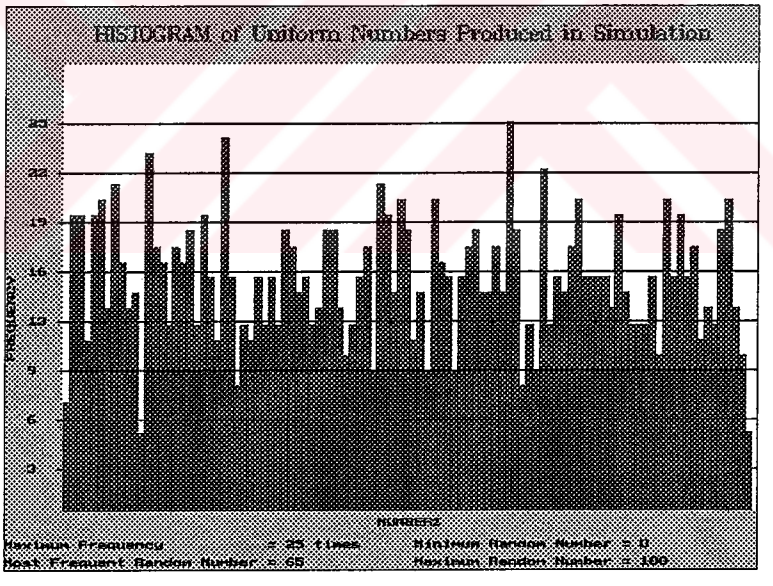

Figure C.3. The Histogram of 1500 Uniformly Distributed Random Numbers Generated by the Expert System (Lower Limit = 0, Upper Limit = 100)

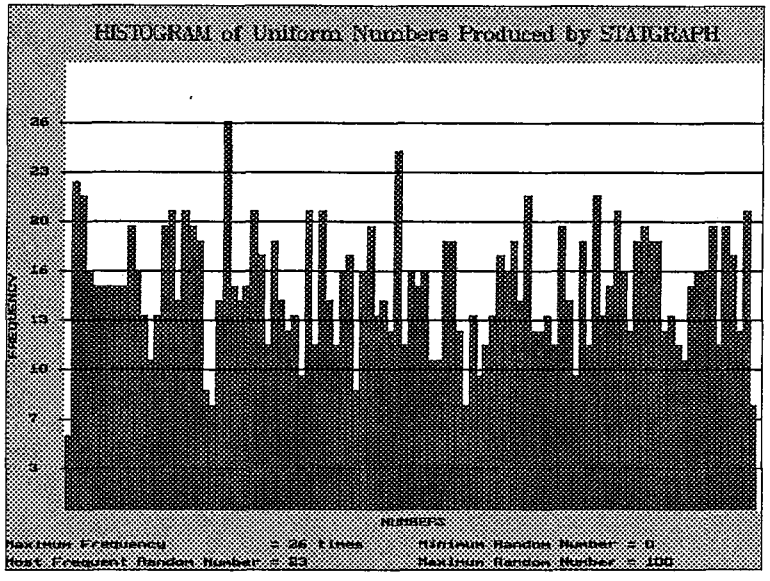

Figure C.4. The Histogram of 1500 Uniformly Distributed Random Numbers Generated by the Commercial Program (Lower Limit = 0, Upper Limit = 100)

APPENDIX D

DERIVED FORMULATIONS RELATED TO BLOCK DIMENSIONS AND WALKING DISTANCES IN PRODUCTION SIMULATION MODELS

D.1. General

To estimate the production capability of draglines, production simulation models have been developed for every stripping method included into the expert system. Development of the simulation models however, are dependent on the determination of the block volumes and walking distances. For this purpose, simulation geometry studies have been performed prior to the development of production simulation models to determine the block dimensions and walking distances for each stripping method and the formulations related to specific pit dimensions of each stripping method are given in the following sections.

D.2. Direct Side Casting Simulation Geometry Model

In the direct side casting simulation geometry model, the following block dimensions have been determined and translated into mathematical formulations; advance bench dimensions; keycut and maincut block dimensions, distance between sitting points with and without inclusion of chopdown into the stripping scheme.

Dimensions of the Advance Bench:

The dimensions used in the determination of the volume of advance bench block are presented in Figure D.1 and advance bench block volumes are given in Equation D.1.

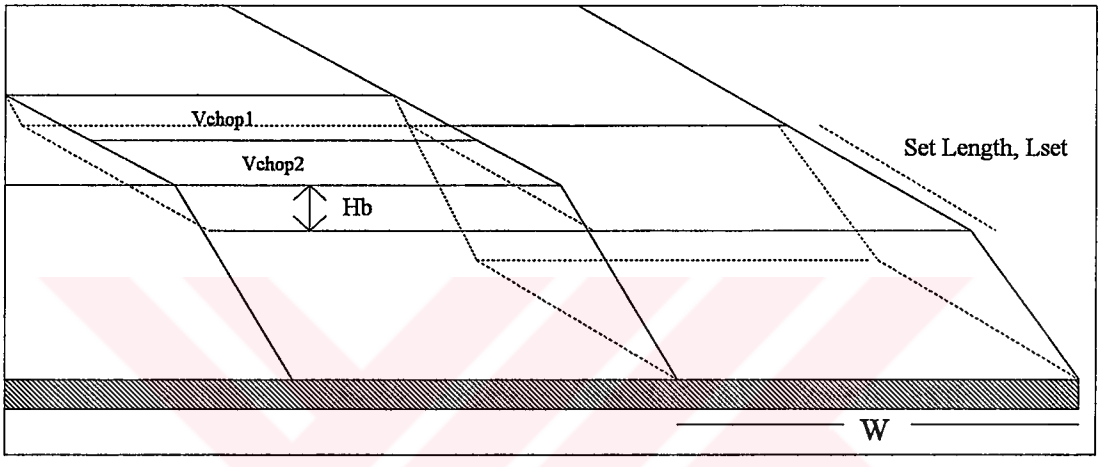

Figure D.1. Volume of the Advance Bench Blocks

$$
\begin{aligned}
V_{chopcut} &= W * L_{set} * H_b \\
V_{chop1} &= 1.25 * Diameter_{tub} * W * H_b \\
V_{chop2} &= V_{chopcut} - V_{chop1}
\end{aligned}
\qquad \text{(D.1)}
$$

Dimensions of Keycut and Maincut Blocks:

The dimensions used in the determination of the keycut and maincut volumes are presented in Figures D.2 and D.3 and block volumes are given in Equation D.2.

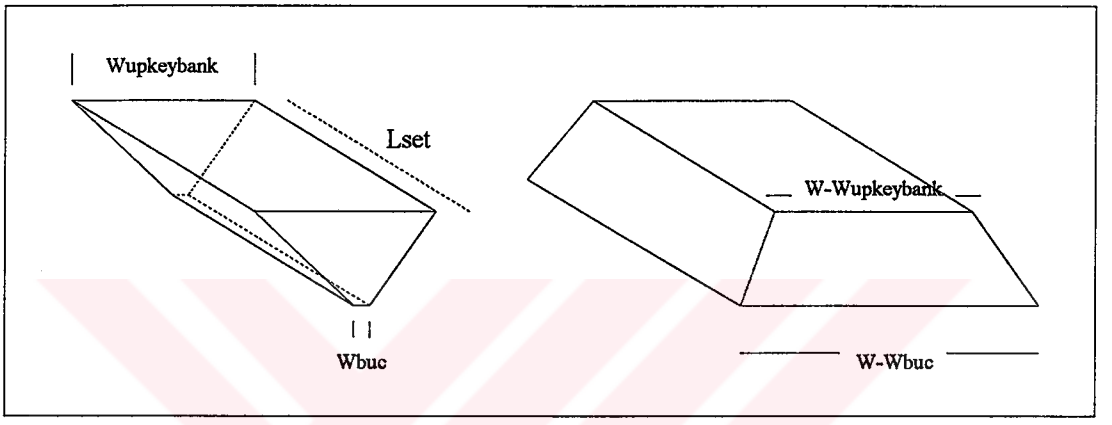

Figure D.2. Dimensions of Keycut and Maincut Blocks

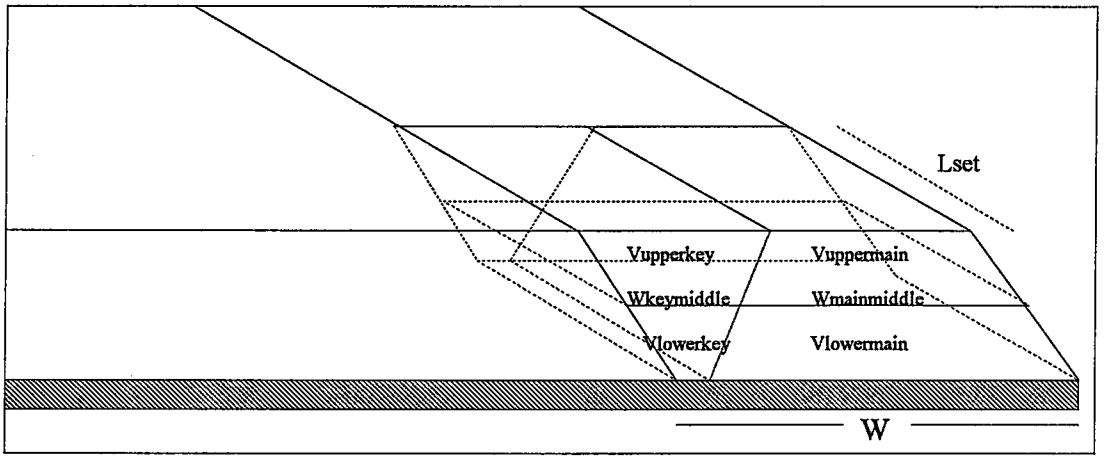

Figure D.3. Volume of Keycut and Maincut Blocks

$$
\begin{aligned}
W_{keymiddle} &= W_{upkeybank} - \frac{1}{2} * H_{block} * (\cot\Phi_o + \cot\Phi_k) \\
V_{upperkey} &= \frac{1}{4} * L_{set} * H_{block} * (W_{upkeybank} + W_{keymiddle}) \\
V_{lowerkey} &= \frac{1}{4} * L_{set} * H_{block} * (W_{buc} + W_{keymiddle}) \\
W_{mainmiddle} &= W - W_{keymiddle} \\
V_{uppermain} &= \frac{1}{4} * L_{set} * H_{block} * (W - W_{upkeybank} + W_{mainmiddle}) \\
V_{lowermain} &= \frac{1}{4} * L_{set} * H_{block} * (W + W_{mainmiddle} - W_{buc})
\end{aligned}
\qquad \text{(D.2)}
$$

Distances Between Sitting Points When No Chopping is Done:

The distances between sitting points when chopdown is not included into the stripping scheme are illustrated in Figure D.4 and given in Equation D.3.

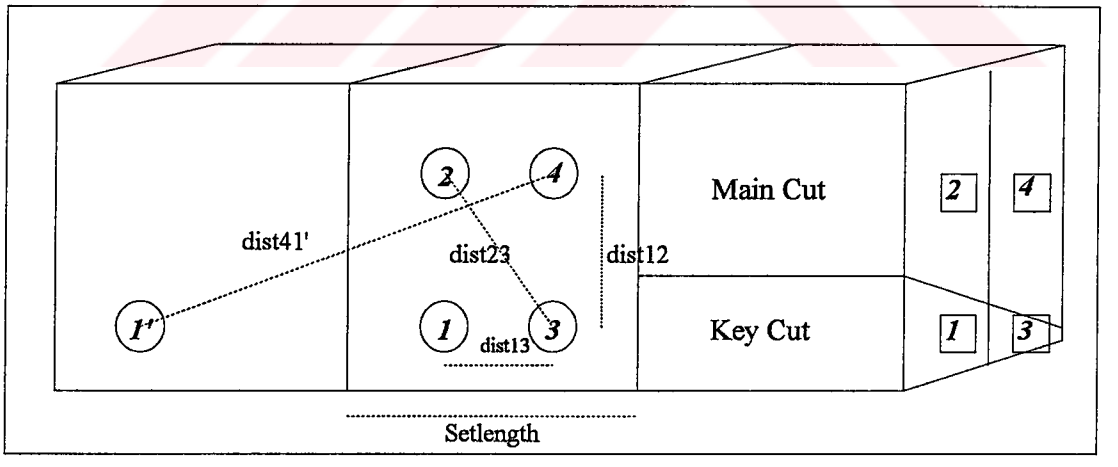

Figure D.4. Distances between Sitting Points within the Slice When No Chopping is Done

$$
\begin{aligned}
dist_{12} &= W - 0.75*Diameter_{tub} - H_{block}*\cot\Phi_o - \frac{1}{2}*W_{buc} \\
dist_{13} &= Diameter_{tub} \\
dist_{23} &= \sqrt{dist^2_{12} + dist^2_{13}} \\
dist_{41'} &= \sqrt{dist^2_{12} + (dist_{13} + L_{set})^2}
\end{aligned}
\tag{D.3}
$$

Distances between Sitting Points When Chopping is Done:

The distances between sitting points when chopdown is done are illustrated in Figure D.5 and given in Equation D.4.

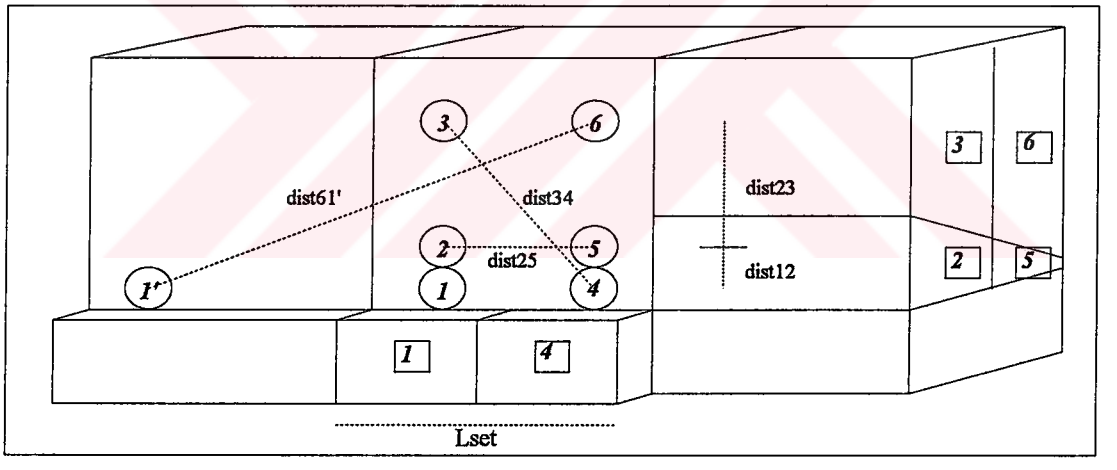

Figure D.5. Distances between Sitting Points within the Slice When Chopping is Done

$$
\begin{aligned}
dist_{12} &= H_{block} * \cot\Phi_o + \frac{1}{2} * W_{buc} \\
dist_{23} &= W - 0.75 * Diameter_{tub} - H_{block} * \cot\Phi_o - \frac{1}{2} * W_{buc} \\
dist_{25} &= Diameter_{tub} \\
dist_{34} &= \sqrt{(dist_{12} + dist_{23})^2 + dist^2_{25}} \\
dist_{61'} &= \sqrt{(dist_{12} + dist_{23})^2 + (dist_{25} + L_{set})^2}
\end{aligned}
\tag{D.4}
$$

D.3. Extended Bench Casting Simulation Geometry Model

The difference of this simulation geometry model from the direct side casting simulation geometry model is in the volume of the rehandled part in the extended bench. Besides, distances to walk within the slice have been formulated.

Dimensions of the Rehandled Part in the Extended Bench:

The dimensions used in the determination of the rehandle volume are presented in Figure D.6 and the rehandle volume is given in Equation D.5.

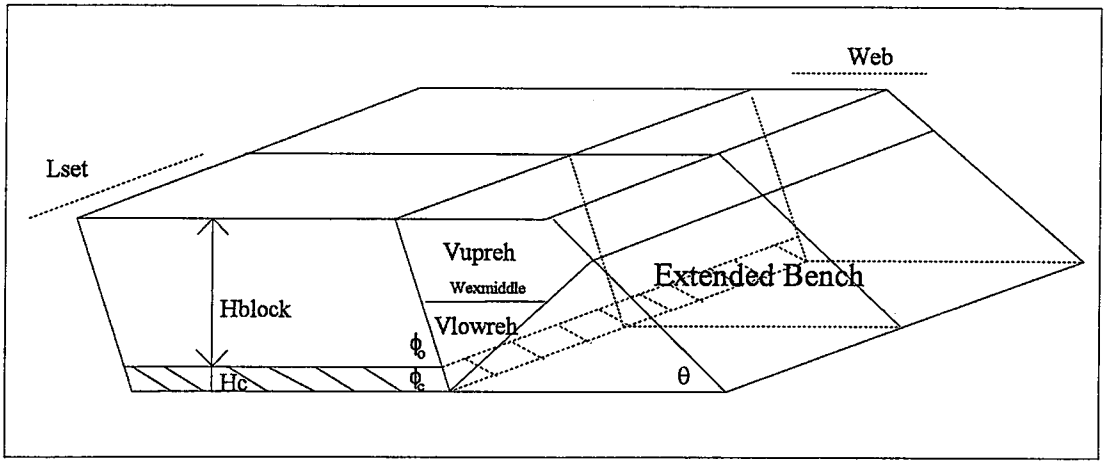

Figure D.6. Dimensions of the Rehandle Volume in the Extended Bench

$$
\begin{aligned}
W_{rehmiddle} &= W_{eb} + \frac{1}{2} * H_{block} * (\cot\theta - \cot\Phi_o) \\
&\quad if\ (W_{rehmiddle} - \frac{1}{2} * H_{block} * \cot\Phi_o - H_c * \cot\Phi_c) \\
&\quad \langle (\frac{1}{2} * H_{block} + H_c) * \cot\theta \\
then\, V_{upreh} &= \frac{1}{4} * (W_{eb} + W_{rehmiddle}) * H_{block} * L_{set} \qquad \text{(D.5)} \\
else\, V_{upreh} &= (\frac{1}{4} * (W_{eb} + W_{rehmiddle}) * H_{block} \\
&\quad - \frac{1}{4} * ((W_{rehmiddle} - \frac{1}{2} * H_{block} * \cot\Phi_o - H_c * \cot\Phi_c) \\
&\quad - (\frac{1}{2} * H_{block} + H_c) * \cot\theta)^2 * \tan\theta) * L_{set}
\end{aligned}
$$

Distances Between Sitting Points When No Chopping is Done:

The distances between sitting points when chopdown is not included into the stripping scheme are illustrated in Figure D.7 and given in Equation D.6.

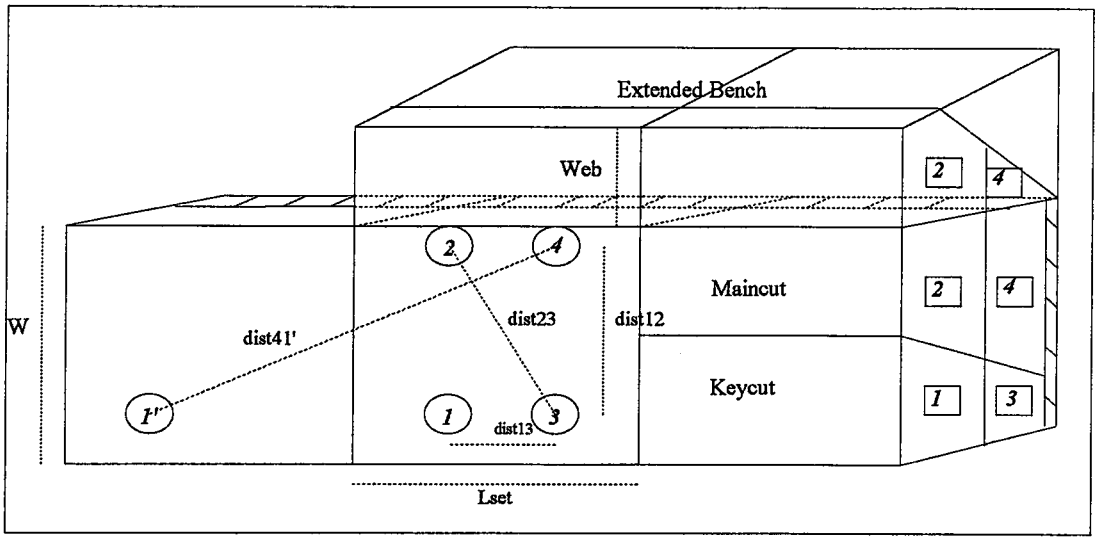

Figure D.7. Distances Between Sitting Points within the Slice When No Chopping is Done

$$
\begin{aligned}
dist_{12} &= W + W_{eb} - 0.75 * Diameter_{tub} - H_{block} * \cot\Phi_o - \frac{1}{2} * W_{buc} \\
dist_{13} &= Diameter_{tub} \\
dist_{23} &= \sqrt{dist^2 12 + dist^2 13} \\
dist_{41'} &= \sqrt{dist^2 12 + (dist_{13} + L_{set})^2}
\end{aligned}
\tag{D.6}
$$

Distances Between Sitting Points When Chopping is Done:

The distances between sitting points when chopdown is done are illustrated in Figure D.8 and given in Equation D.7.

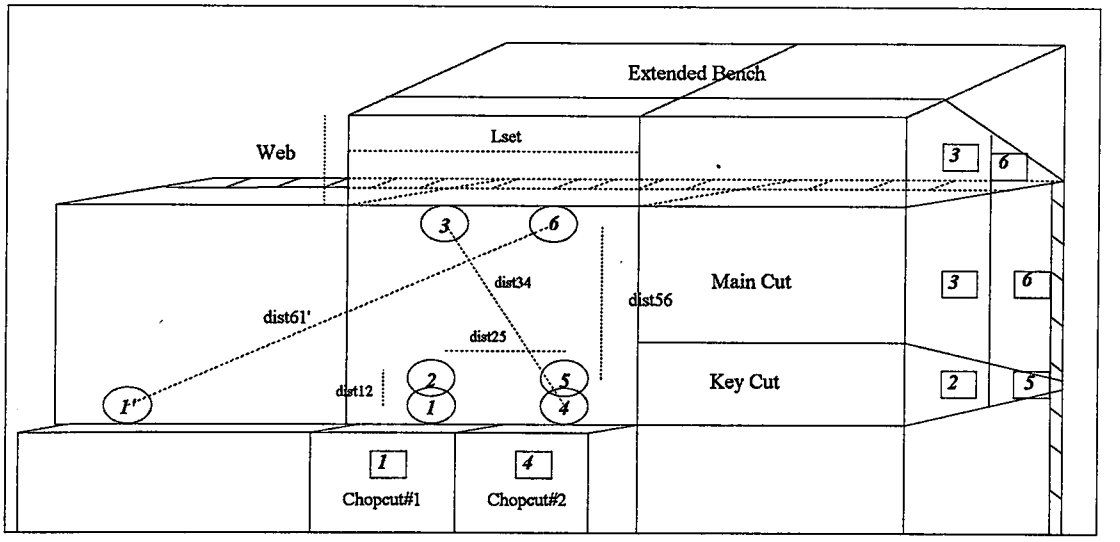

Figure D.8. Distances Between Sitting Points within the Slice When Chopping is Done

$$
\begin{aligned}
dist_{12} &= H_{block} * \cot\Phi_o + \frac{1}{2} * W_{buc} \\
dist_{23} &= W + W_{eb} - 0.75 * Diameter_{tub} - H_{block} * \cot\Phi_o - \frac{1}{2} * W_{buc} \\
dist_{25} &= Diameter_{tub} \\
dist_{34} &= \sqrt{(dist_{12} + dist_{23})^2 + dist^2_{25}} \\
dist_{61'} &= \sqrt{(dist_{12} + dist_{23})^2 + (dist_{25} + L_{set})^2}
\end{aligned}
\tag{D.7}
$$

D.4. Pullback Stripping Simulation Geometry Model

In the pullback stripping simulation geometry model, both the highwall and spoil side block dimensions have been formulized. Highwall side parameters include only the volume of the maincut. However, spoil side parameters include the setback distance, set length, rehandle volume in the pullback pad, distance between sitting points and finally the deadheading distance between highwall and spoil sides.

Dimensions of the Main Cut:

The dimensions used in formulizing the maincut volume are presented in Figure D.9 and the maincut volume is given in Equation D.8.

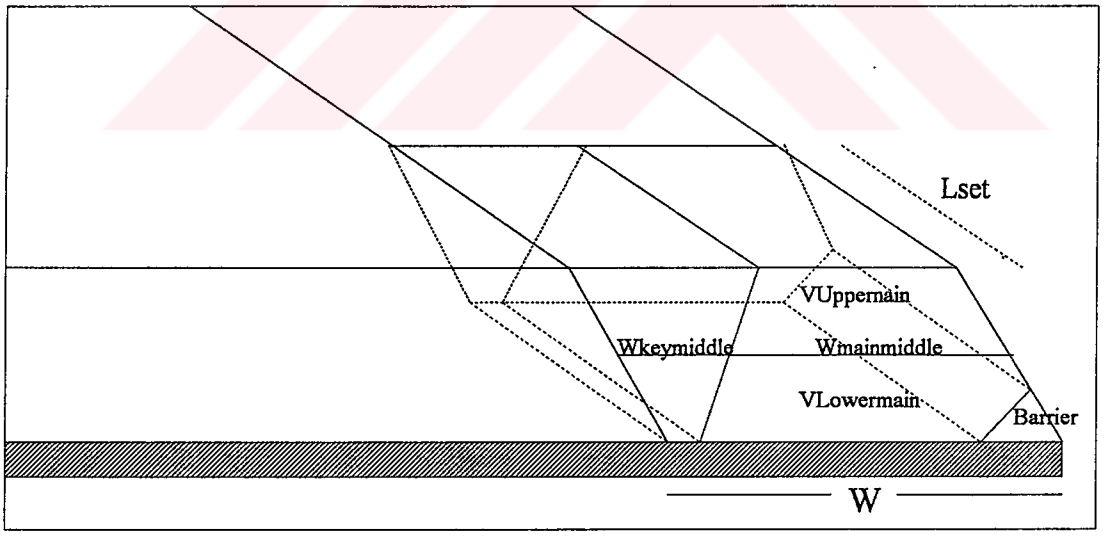

Figure D.9. Main Cut and Its Components in Pullback Stripping Simulation Geometry Model

$$W_{mainmiddle} = W - W_{upkeybank} + \frac{1}{2} * H_{block} * (\cot\Phi_o + \cot\Phi_k)$$

$$\text{if } h_1 \leq \frac{1}{2} * H_{block} \text{ then}$$

$$V_{uppermain} = \frac{1}{4} * L_{set} * H_{block} * (W - W_{upkeybank} + W_{mainmiddle})$$

$$V_{lowermain} = (\frac{1}{4} * H_{block} * (W - W_{buc} + W_{mainmiddle}) - A_{barrier}) * L_{set}$$

$$\text{if } h_1 \rangle \frac{1}{2} * H_{block} \text{ then} \qquad \text{(D.8)}$$

$$V_{uppermain} = (\frac{1}{4} * H_{block} * (W - W_{upkeybank} + W_{mainmiddle}) - (h_1 - \frac{1}{2} * H_{block})^2 * \cot\Phi_o) * L_{set}$$

$$V_{lowermain} = (\frac{1}{4} * H_{block} * (W - W_{buc} + W_{mainmiddle}) - (A_{barrier} - (\frac{1}{2} * H_{block})^2 * \cot\Phi_o)) * L_{set}$$

Spoil Side Setback Distance:

The spoil side setback distance is illustrated in Figure D.10 and given in Equation D.9.

$$L_{ppsb} = W_{pp} - W + \frac{3}{4} * Diameter_{tub} \qquad \text{(D.9)}$$

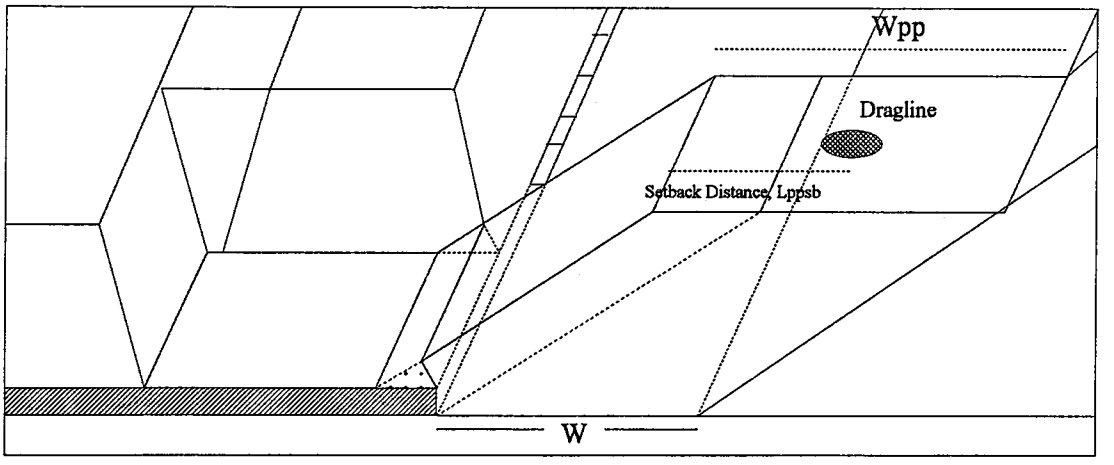

Figure D.10. Setback Distance on Spoil Side

Spoil Side Set Length:

The spoil side set length is illustrated in Figure D.11 and given in Equation D.10.

$$L_{spoilset} = \frac{1}{2} * \sqrt{R_d^2 - (R_d - L_6)^2} \qquad \text{(D.10)}$$

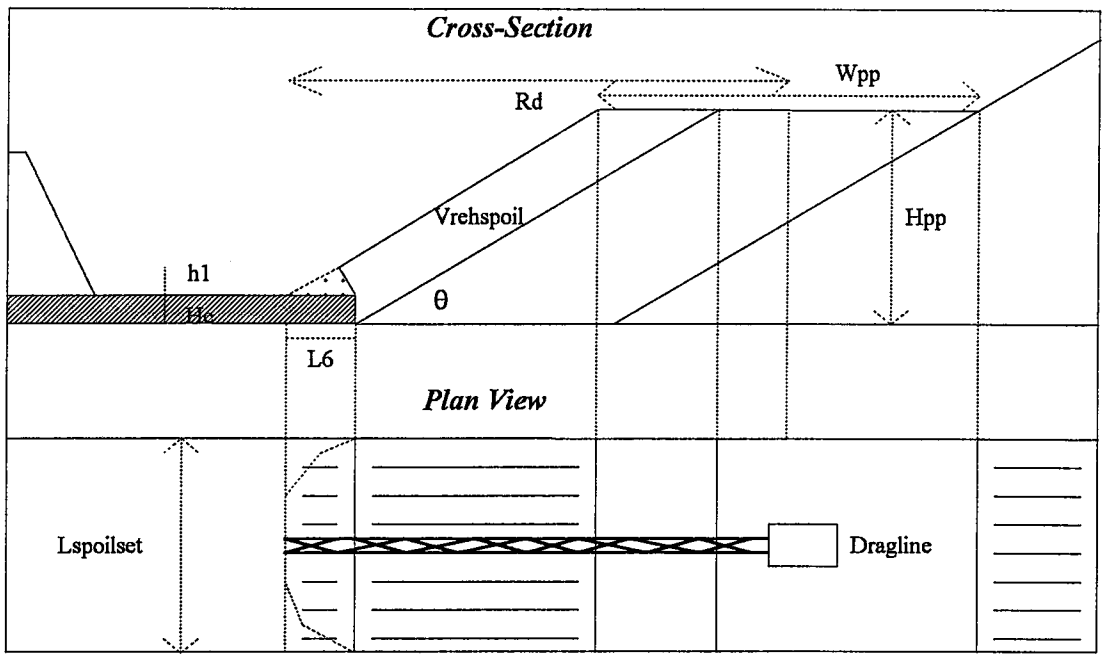

Figure D.11. Set Length Determination on Spoil Side

Volume of the Rehandle Material on Spoil Side:

The rehandle volume in the pullback pad is illustrated in Figure D.11 and given in Equation D.11.

$$V_{rehspoil} = (\frac{1}{2} * H_c^2 * \gamma + H_c * \gamma * h_1 + \frac{1}{2} * h_1^2 * \infty + ((h_{pp} - (H_c + h_1)) * (H_c * \gamma + h_1 * \infty)) + \frac{1}{16} * W_{pp}^2 * \tan\theta) * L_{spoilset} \quad \text{(D.11)}$$

Distances between Sitting Points on Spoil Side:

The distance between sitting points on the spoil side is illustrated in Figure D.12 and given in Equation D.12.

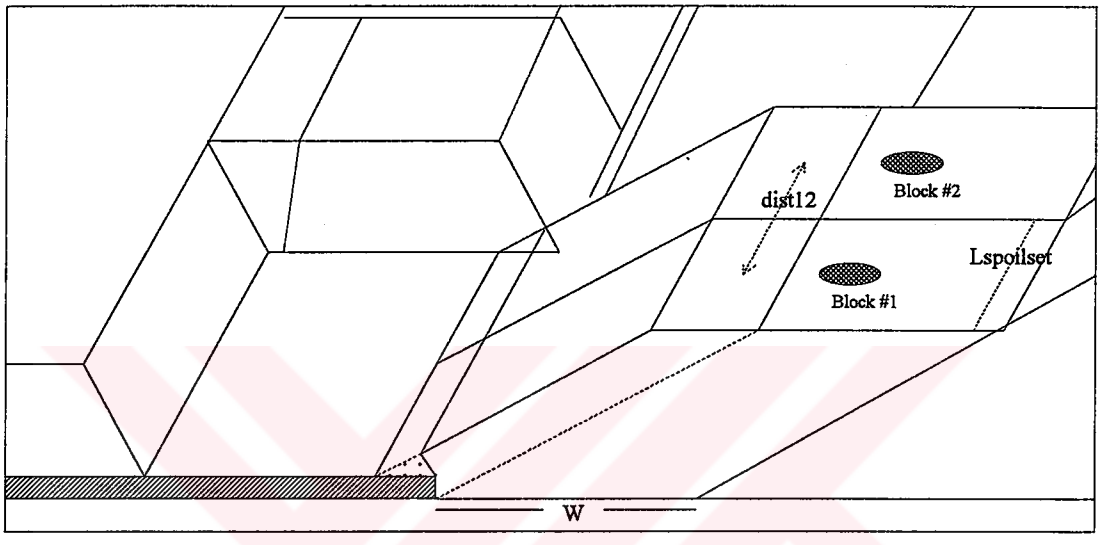

Figure D.12. The Distance Between Sitting Points on Spoil Side

$$dist12 = L_{spoilset} = \sqrt{R_d^2 - (R_d - L_6)^2} \tag{D.12}$$

Geometrical Formulation of Distance between Highwall and Spoil Sides:

The deadheading distance between highwall and spoil sides are illustrated in Figure D.13 and given in Equation D.13.

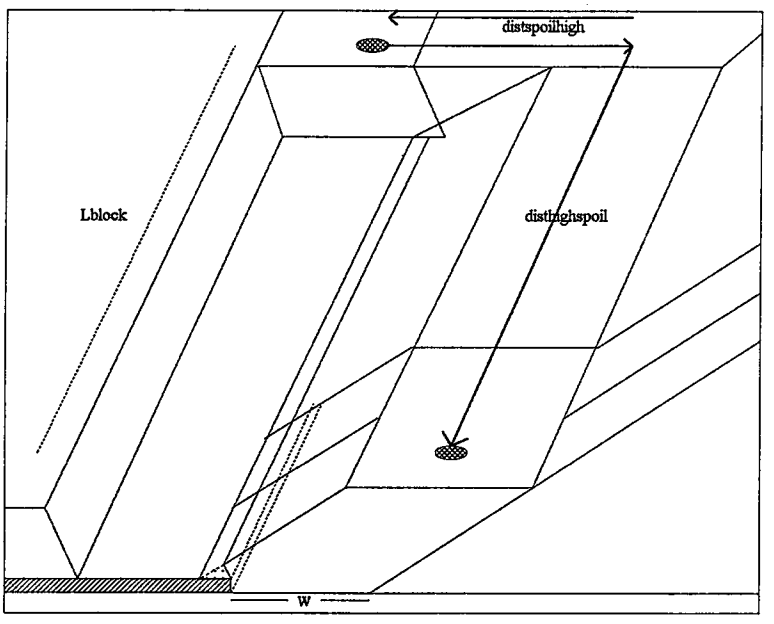

Figure D.13. The Walking Distance Between Highwall and Spoil Sides

$$
\begin{aligned}
dist_{highspoil} &= L_{block} + W + H_c * \cot\Phi_c \\
&\quad - \frac{1}{2} * W_{buc} + H_{pp} * \cot\theta + \frac{3}{4} * Diameter_{tub} \\
dist_{spoilhigh} &= W + H_c * \cot\Phi_c - \frac{1}{2} * W_{buc} \\
&\quad + H_{pp} * \cot\theta + \frac{3}{4} * Diameter_{tub}
\end{aligned}
\qquad \text{(D.13)}
$$

D.5. Two Slice Direct Side Casting Simulation Geometry Model

In the two slice direct side casting simulation geometry model, both the upper and lower slice keycut and maincut block dimensions and the deadheading distance between either blocks have been formulized.

Dimensions of Upper and Lower Slice Keycut and Maincut:

The dimensions used in formulizing the upper and lower slice keycut and maincut volumes are illustrated in Figure D.14. Upper slice keycut and maincut volumes are given in Equation D.14 and lower slice keycut and maincut volumes are given in Equation D.15.

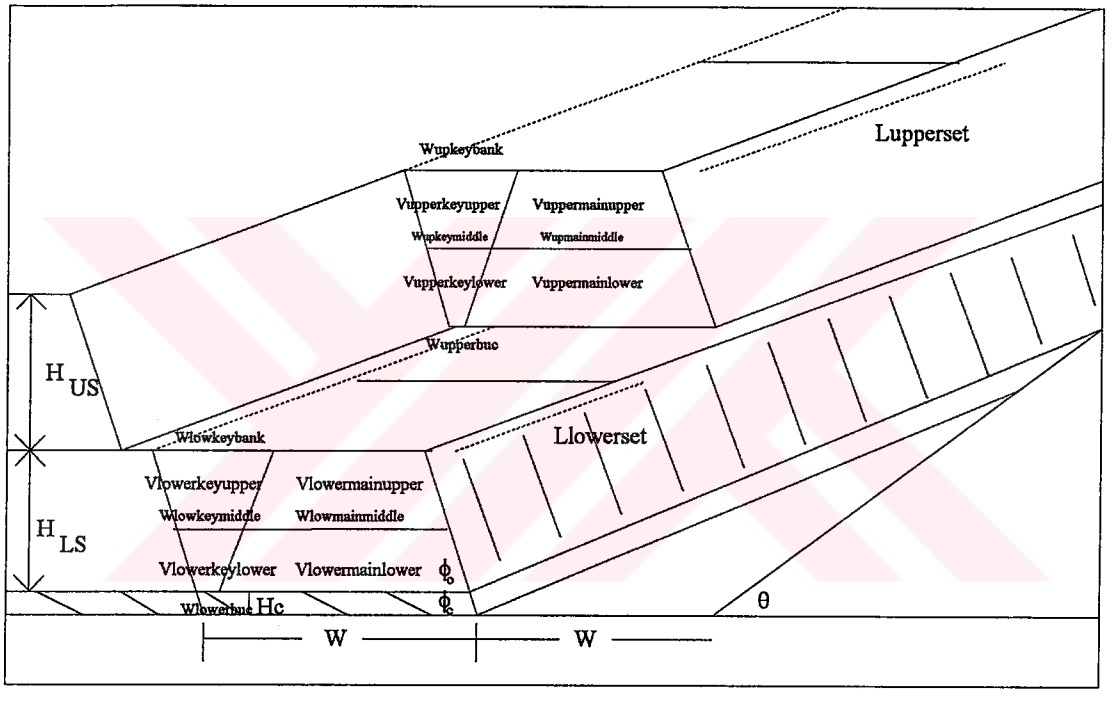

Figure D.14. Dimensions of Upper and Lower Slice Keycut and Maincut Blocks

$$W_{upkeymiddle} = W_{upkeybank} - \frac{1}{2} * H_{US} * (\cot\Phi_o + \cot\Phi_{upperk})$$

$$V_{upperkeyupper} = \frac{1}{4} * L_{upperset} * H_{US} * (W_{upkeybank} + W_{upkeymiddle})$$

$$V_{upperkeylower} = \frac{1}{4} * L_{upperset} * H_{US} * (W_{upperbuc} + W_{upkeymiddle})$$

$$W_{upmainmiddle} = W - W_{upkeymiddle} \qquad \text{(D.14)}$$

$$V_{uppermainupper} = \frac{1}{4} * L_{upperset} * H_{US} * (W - W_{upkeybank} + W_{upmainmiddle})$$

$$V_{uppermainlower} = \frac{1}{4} * L_{upperset} * H_{US} * (W + W_{upmainmiddle} - W_{upperbuc})$$

$$W_{lowkeymiddle} = W_{lowkeybank} - \frac{1}{2} * H_{LS} * (\cot\Phi_o + \cot\Phi_{lowerk})$$

$$V_{lowerkeyupper} = \frac{1}{4} * L_{lowerset} * H_{LS} * (W_{lowkeybank} + W_{lowkeymiddle})$$

$$V_{lowerkeylower} = \frac{1}{4} * L_{lowerset} * H_{LS} * (W_{lowerbuc} + W_{lowkeymiddle})$$

$$W_{lowmainmiddle} = W - W_{lowkeymiddle} \qquad \text{(D.15)}$$

$$V_{lowermainupper} = \frac{1}{4} * L_{lowerset} * H_{LS} * (W - W_{lowkeybank} + W_{lowmainmiddle})$$

$$V_{lowermainlower} = \frac{1}{4} * L_{lowerset} * H_{LS} * (W + W_{lowmainmiddle} - W_{lowerbuc})$$

Geometrical Formulation of Walking Distances between Upper and Lower Slices:

The deadheading distance between upper and lower blocks are illustrated in Figure D.15 and given in Equation D.16.

$$dist_{upperlower} = L_{block} - \frac{H_{US}}{\cos 10^{o}} + \frac{H_{US}}{\sin 10^{o}}$$
$$dist_{lowerupper} = L_{block} + \frac{H_{US}}{\sin 10^{o}} \qquad \text{(D.16)}$$

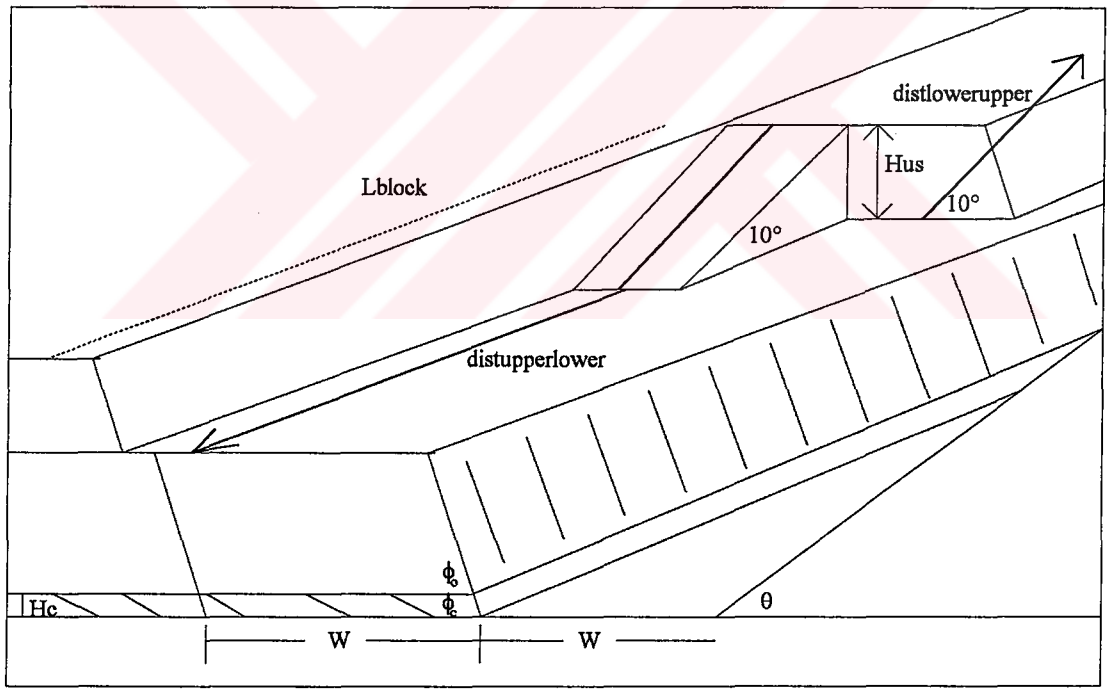

Figure D.15. The Walking Distance Between Upper and Lower Slices

D.6. Lower Slice Extended Bench Casting Simulation Geometry Model

The difference between the lower slice extended bench casting simulation geometry model and the two slice direct side casting simulation geometry model is caused from the rehandle volumes in the former models.

Volume of the Part to be Rehandled in Lower Slice Limited Extended Bench Casting Method:

The dimensions used in the formulation of the rehandle volume are illustrated in Figure D.16 and the volume to be rehandled in the lower slice limited extended bench casting method is given in Equation D.17.

$$W_{rehmiddle} = H_c*(\cot\Phi_c + \cot\theta) + \frac{1}{2}*H_{LS}*(\cot\Phi_o + \cot\theta)$$

$$V_{totreh} = (\frac{1}{2}*H_{LS}^2*\cot\Phi_o + \frac{2*H_{LS}+H_c}{2}*(H_c*\cot\Phi_c) + \frac{1}{2}*(H_{LS}+H_c)^2*\cot\theta)*L_{lowerset}$$

$$V_{lowreh} = (\frac{1}{2}*H_c^2*(\cot\Phi_c + \cot\theta) + \frac{1}{4}*H_{LS}*(W_{rehmiddle} + H_c*(\cot\Phi_c + \cot\theta)))*L_{lowerset} \quad \text{(D.17)}$$

$$V_{upreh} = V_{totreh} - V_{lowreh}$$

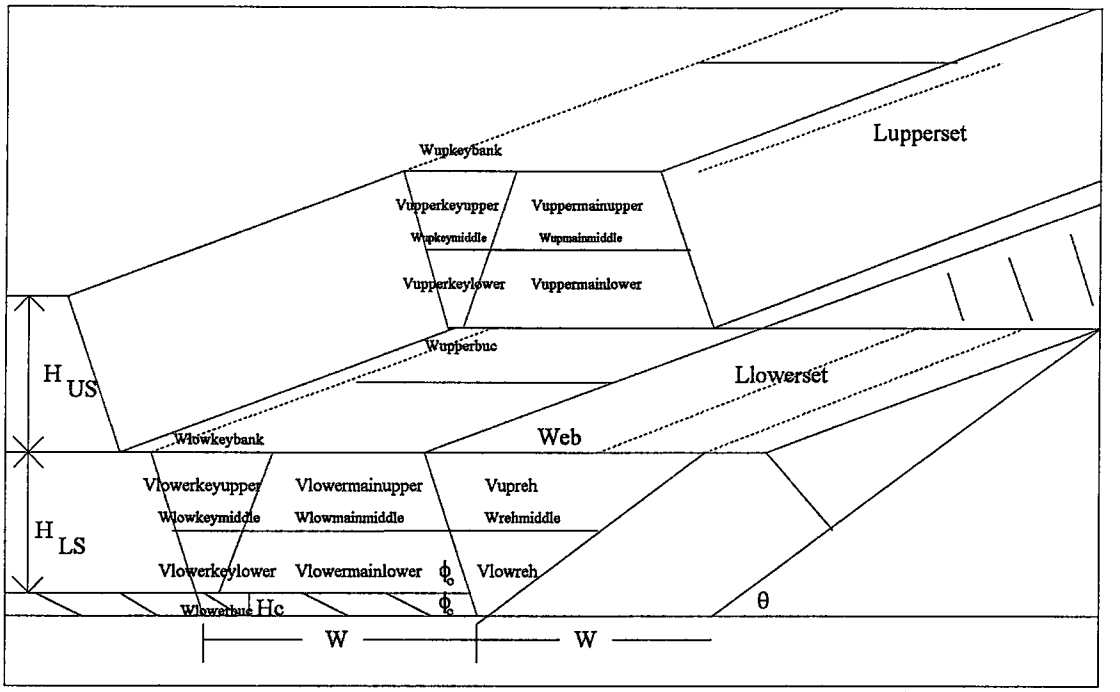

Figure D.16. Dimensions of Upper and Lower Slice Keycut and Maincut Blocks and Part to be Rehandled in Lower Slice Limited Extended Bench Method

Volume of the Part to be Rehandled in Lower Slice Full Extended Bench Casting Method:

The dimensions used in the formulation of the rehandle volume are illustrated in Figure D.17 and the volume to be rehandled in the lower slice full extended bench casting method is given in Equation D.18.

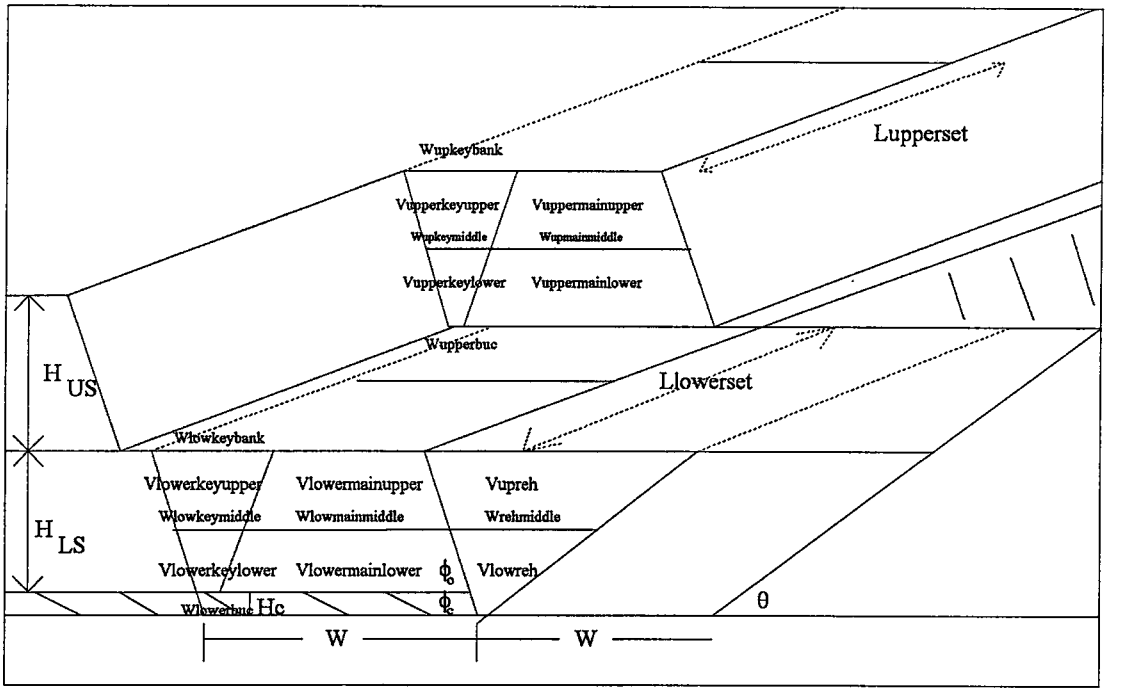

Figure D.17. Dimensions of Upper and Lower Slice Keycut and Maincut Blocks and Part to be Rehandled in Lower Slice Full Extended Bench Method

$$W_{rehmiddle} = H_c * (\cot\Phi_c + \cot\theta) + \frac{1}{2} * H_{LS} * (\cot\Phi_o + \cot\theta)$$

$$V_{totreh} = \left(\frac{1}{2} * H_{LS}^2 * \cot\Phi_o + \frac{2*H_{LS} + H_c}{2} * (H_c * \cot\Phi_c)\right) + \frac{1}{2} * (H_{LS} + H_c)^2 * \cot\theta) * L_{lowerset}$$

$$V_{lowreh} = \left(\frac{1}{2} * H_c^2 * (\cot\Phi_c + \cot\theta)\right) + \frac{1}{4} * H_{LS} * (W_{rehmiddle} + H_c * (\cot\Phi_c + \cot\theta))) * L_{lowerset} \quad \text{(D.18)}$$

$$V_{upreh} = V_{totreh} - V_{lowreh}$$

Distances between Sitting Points on the Lower Slice Extended Bench Methods:

The dimensions used in the formulation of the distance between sitting points are illustrated in Figure D.18 and the formulas related to the distances between sitting points are given in Equation D.19.

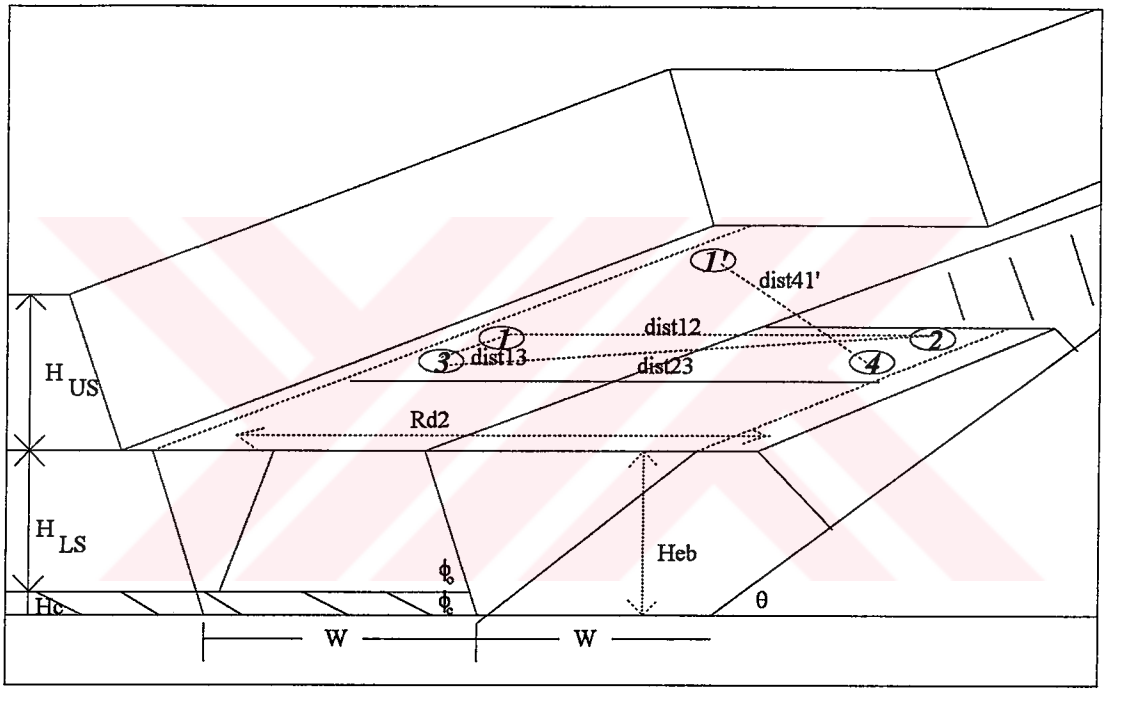

Figure D.18. Distances between Sitting Points on the Lower Slice in Lower Slice Extended Bench Methods

$$
\begin{aligned}
dist_{12} &= R_{d2} - W_{eb} + H_{eb} * \cot\theta + H_{LS} * \cot\Phi_o + H_c * \cot\Phi_c \\
dist_{13} &= Diameter_{tub} \\
dist_{23} &= \sqrt{dist^2_{12} + dist^2_{13}} \\
dist_{41'} &= \sqrt{dist^2_{12} + (dist_{13} + L_{lowerset})^2}
\end{aligned}
\tag{D.19}
$$

D.7. Two Slice Pullback Stripping Simulation Geometry Model

In the two slice pullback stripping simulation geometry model, spoil side setback distance, set length, rehandle volume in the pullback pad and the distance between sitting points have been formulized.

Spoil Side Setback Distance:

The spoil side setback distance is illustrated in Figure D.19 and given in Equation D.20.

$$
L_{ppsb} = H_c * (\cot\theta + \cot\Phi_c) + h_1 * (\cot\theta + \cot\Phi_o) + \frac{3}{4} * Diameter_{tub} \tag{D.20}
$$

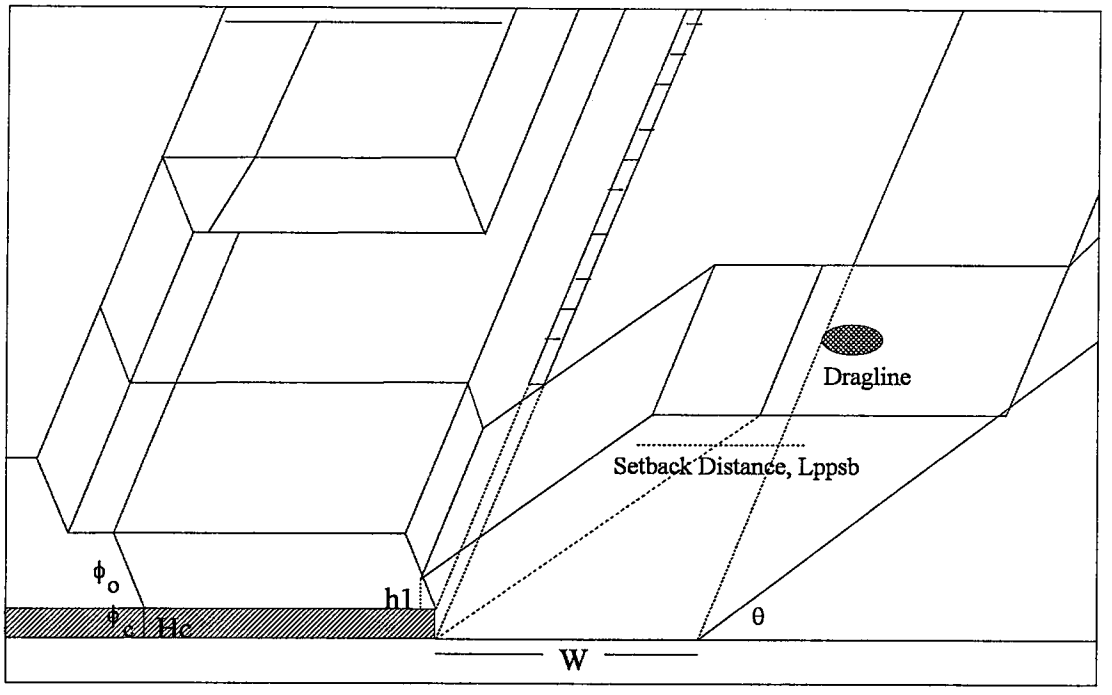

Figure D.19. Setback Distance on Spoil Side

Spoil Side Set Length:

The spoil side set length is illustrated in Figure D.20 and given in Equation D.21.

$$L_{spoilset} = \frac{1}{2} * \sqrt{R_d^2 - (R_d - (W + (H_{LS} - h_1) * \cot \Phi_o)^2} \qquad \text{(D.21)}$$

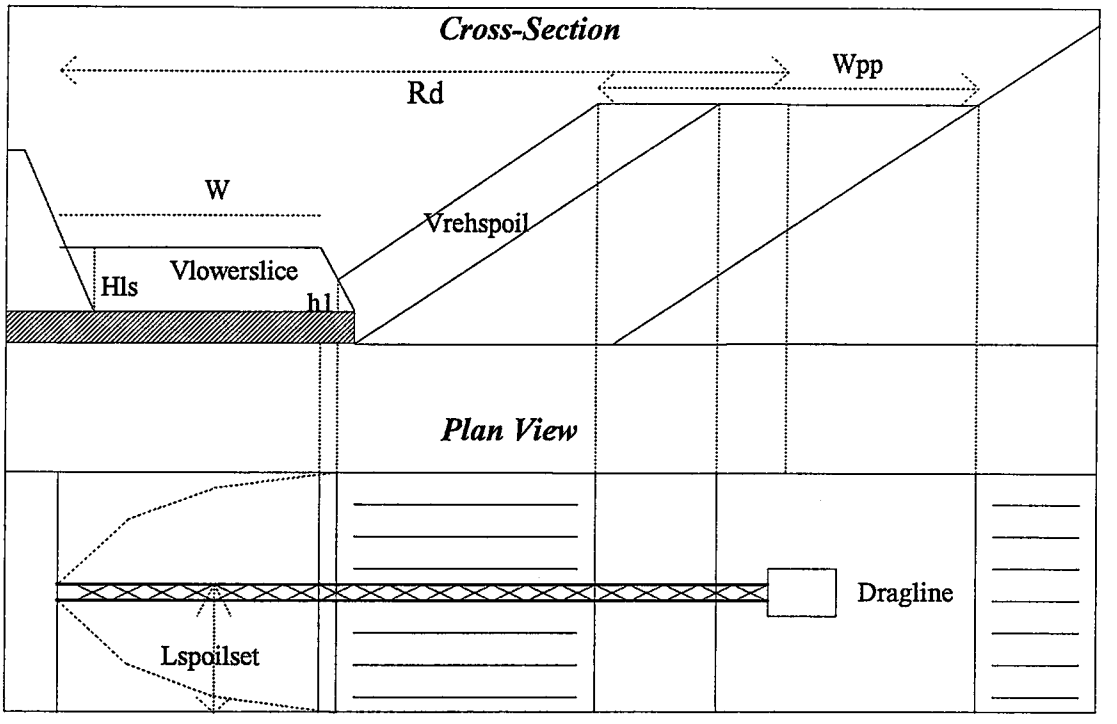

Figure D.20. Set Length Determination on Spoil Side

Volume of the Lower Slice and the Rehandle Material

The dimensions used in formulizing the volumes of the lower slice and the rehandle part in the pullback pad are illustrated in Figure D.20 and they are given in Equation D.22.

$$
\begin{aligned}
V_{lowerslice} &= H_{LS} * W * L_{spoilset} \\
V_{rehspoil} &= \left(\frac{1}{2} * H_c^2 * \gamma + H_c * \gamma * h_1 + \frac{1}{2} * h_1^2 * \infty\right) \\
&\quad + \left((H_{pp} - (H_c + h_1)) * (H_c * \gamma + h_1 * \infty)\right) \\
&\quad + \frac{1}{16} * W_{pp}^2 * \tan\theta) * L_{spoilset}
\end{aligned}
\qquad \text{(D.22)}
$$

Distances between Sitting Points on Spoil Side:

The distance between sitting points on the pullback pad is illustrated in Figure D.21 and given in Equation D.23.

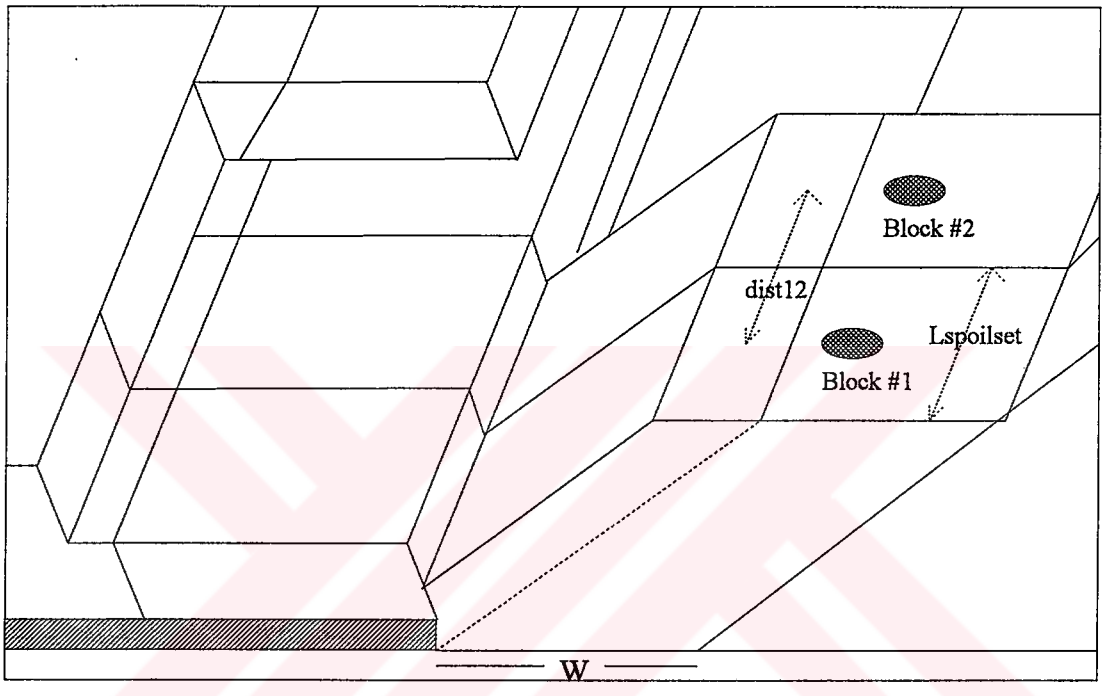

Figure D.21. Walking Distance between Sitting Points on Spoil Side

$$dist_{12} = L_{spoilset} = \sqrt{R_d^2 - (R_d - (W + (H_{LS} - h_1) * \cot \Phi_o))^2} \qquad \text{(D.23)}$$

APPENDIX E

THE RESULTS OF THE SAMPLE RUNS PERFORMED TO VALIDATE THE EXPERT SYSTEM

E.1. General

Validation of the expert system has been done by running three sample cases where the overburden thickness have gradually been increased from the first to the third runs. The purpose of performing sample runs is to analyze the operating procedure of the expert system, compare the important output parameters to those published in the literature to extract identical and conflicting points between the expert system and the previous studies.

The expert system performs the best dragline selection procedure on three bases; by analyzing the pit geometry that the dragline works in, by simulating the likely stripping production of a dragline employed in a particular stripping method and by determining the cost of stripping. During the sample runs, significant output parameters related to the best dragline-stripping method pair of each sample run have been analyzed and presented in the form of figures, charts and tables. Here, all the output parameters of each sample run related to pit geometry, production simulation and stripping cost aspects are given.

E.2. Sample Run #1

In sample run #1, seven draglines of the BUCYRUS-ERIE 1370W series have been tested. The results of the dragline selection aspects are given below.

E.2.1. Results of Pit Geometry and Range Diagramming Models

Only the direct side casting geometry model has been applied. The pit geometry results are given in Table E.1.

Table E.1. Results of the Direct Side Casting Geometry Model

Dragline	Pit Width (m)	Available Operating Radius (m)	Required Operating Radius (m)	Avail. Reach (m)	Required Reach (m)	Keycut Upper Width (m)	Keycut Right Wall Angle (°)	Pit Geometry Model Result
1370W-1	59.5	77.7	77.7	63.1	50.9	23.1	60	PASS
1370W-2	66.2	84.4	84.4	69.8	52.6	23.1	60	PASS
1370W-3	65.6	83.8	83.8	69.3	52.4	23.1	60	PASS
1370W-4	72.9	91.1	91.1	76.5	54.2	23.1	60	PASS
1370W-5	68.1	86.3	86.3	71.7	53.0	23.1	60	PASS
1370W-6	75.7	93.9	93.9	79.3	54.9	23.1	60	PASS
1370W-7	69.3	87.5	87.5	72.9	53.3	23.1	60	PASS

E.2.2. Results of Production Simulation Models

The simulation geometry results and production simulation results of all seven draglines are given in Tables E.2 and E.3.

Table E.2. Results of the Direct Side Casting Simulation Geometry Model

Dragline	1370W-1	1370W-2	1370W-3	1370W-4	1370W-5	1370W-6	1370W-7
Bucket Capacity (m^3)	51.14	46.95	47.79	43.59	46.95	42.76	47.95
Set Length (m)	28.99	32.39	31.98	37.15	33.32	39.95	33.94
Setback Distance (m)	28.71	32.01	31.82	33.95	32.98	33.95	33.56
Keycut Volume (m^3)	6694	7480	7386	8579	7695	9226	7838
Maincut Volume (m^3)	27803	35406	34578	45587	37689	51260	39202
Distance 1-2 (m)	33.41	40.11	39.51	46.81	42.01	49.61	43.21
Distance 2-3 (m)	38.34	44.55	44.01	50.67	46.27	53.26	47.36
Distance 1-3 (m)	18.82	19.40	19.40	19.40	19.40	19.40	19.40
Distance 4-1' (m)	58.32	65.50	64.82	73.41	67.41	77.35	68.64

Table E.3. Results of the Direct Side Casting Production Simulation Model

Dragline	1370W-1	1370W-2	1370W-3	1370W-4	1370W-5	1370W-6	1370W-7
Average Keycut Cycle Time (s)	59.12708	58.90946	58.93669	58.65908	58.88879	58.61334	58.93820
Average Maincut Cycle Time (s)	59.11993	58.86196	58.92631	58.66665	58.87295	58.60804	58.93493
Average Fill Factor (.00)	0.94998	0.95006	0.94998	0.94999	0.95000	0.95002	0.95000
Time Spent for Keycut (s)	2917094	2676257	2640010	2384726	2561780	2327419	2475227
Time Spent for Maincut (s)	12049647	12564614	12308821	12634274	12480418	12893768	12317518
Time Spent for Walking (s)	836945	699663	712362	580981	683118	544666	684009
Time Spent for Delaying (s)	4003348	3860414	4169483	4201214	4094336	4101607	4329396
Percent Time for Keycut Excavation (%)	14.73	13.52	13.31	12.04	12.92	11.71	12.50
Percent Time for Maincut Excavation (%)	60.84	63.45	62.07	63.81	62.97	64.90	62.19
Percent Time for Walking (%)	4.22	3.53	3.59	2.93	3.45	2.74	3.45
Percent Time for Delaying (%)	20.21	19.50	21.03	21.22	20.66	20.64	21.86
Total Stripping Time (s)	19807034	19800949	19830677	19801195	19819652	19867459	19806151
Scheduled Time (s)	19800000	19800000	19800000	19800000	19800000	19800000	19800000
Total Walked Distance (m)	43681	38434	38630	31926	37207	30030	36882
Total Production (m^3)	9246959	8682060	8658519	7971725	8567560	7931586	8597341
Prime Production (m^3)	9246959	8682060	8658519	7971725	8567560	7931586	8597341
Desired Production (m^3)	8928571	8928571	8928571	8928571	8928571	8928571	8928571
Simulation Result	PASSED	FAILED	FAILED	FAILED	FAILED	FAILED	FAILED

E.2.3. Results of the Stripping Cost Models

The results of the stripping cost analyses in the direct side casting model are given in Table E.4.

Table E.4. Results of the Direct Side Casting Stripping Cost Model

Dragline	1370W-1
Purchase Price (US$)	17,500,000
Options and Extras (US$)	875,000
Freight (US$)	1,624,080
Trail Cable (US$)	49,213
Ballast (US$)	57,154
Erection (US$)	3,008,020
Total Price (US$)	23,113,466
Yearly Depreciation Cost (US$)	856,054
Yearly Investment Cost (US$)	1,198,760
Yearly ITI Cost (US$)	2,157,257
Yearly Total Owning Cost (US$)	3,013,311
Yearly Maintenance & Supply Cost (US$)	1,403,380
Electricity Consumption (KWh/BCM)	1.28544
Yearly Electricity Cost (US$)	1,188,637
Yearly Labor Cost (US$)	50,000
Yearly Total Operating Cost (US$)	2,642,017
Yearly Total Owning & Operating Cost (US$)	5,655,328
Hourly Owning & Operating Cost (US$/hr)	1028.24153
Cost in Terms of Total Production (US$/bank m^3)	0.61159
Cost in Terms of Prime Production (US$/bank m^3)	0.61159
Cost in Terms of Desired Production (US$/ bank m^3)	0.63340

E.3. Sample Run #2

In the second sample run, five MARION 7820 series draglines and eight BUCYRUS-ERIE 1300W series draglines have been chosen for testing. The results of the dragline selection procedures are given below.

E.3.1. Results of Pit Geometry and Range Diagramming Models

The initially chosen draglines have passed the pit geometry criteria of the following stripping methods: direct side casting, extended bench casting, one slice pullback stripping with one and two draglines and finally the two slice pullback stripping with two draglines. The pit geometry results of these stripping methods are given in Tables E.5 to E.9.

Table E.5. Results of the Direct Side Casting Geometry Model

Dragline	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-3
Pit Width (m)	57.3	55.0	61.4	59.8	67.4	60.1
Available Operating Radius (m)	81.7	78.9	86.0	84.4	92.0	84.7
Required Operating Radius (m)	81.7	78.9	86.0	84.4	92.0	84.7
Available Reach (m)	69.1	66.3	73.4	71.8	79.4	73.3
Required Reach (m)	65.7	65.1	66.7	66.3	68.2	66.3
Keycut Upper Width (m)	33.9	32.6	34.6	34.6	34.6	34.6
Keycut Right Wall Angle (°)	61	63	60	60	60	60
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS

Table E.6. Results of the Extended Bench Casting Geometry Model

Dragline	1300W-1	1300W-2	1300W-3	7820-1	7820-2	7820-4	7820-5
Pit Width (m)	68.6	75.0	75.0	71.9	69.8	67.1	73.2
Required Reach (m)	68.48	70.08	70.08	69.30	68.78	68.10	69.63
Available Reach (m)	56.0	62.4	62.4	60.5	58.4	55.7	61.8
Bench Extension (m)	12.48	7.68	7.68	8.80	10.38	12.40	7.83
Keycut Upper Width (m)	36.94	28.24	28.24	30.68	34.64	36.84	28.24
Keycut Bottom Width (m)	2.3	0.0	0.0	0.0	0.0	2.2	0.0
Keycut Right Wall Angle (°)	60	70	70	66	60	60	70
Percent Rehandle (%)	15	10	10	12	13	15	11
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.7. Results of the One Slice One Dragline Pullback Stripping Geometry Model

Highwall Side Dragline	1300W-1	7820-4
Spoil Side Dragline	1300W-1	7820-4
Pit Width (m)	50.75	49.25
Keycut Upper Width (m)	30.05	29.44
Keycut Right Wall Angle (°)	67	68
Effective Reach (m)	38.15	37.85
Area of the Barrier on Highwall Side (m^2)	0.15	0.10
Height of Temporary Spoil Pile (m)	52.88	52.36
Height of Pullback Pad (m)	35.91	35.87
Width of Pullback Pad (m)	56.97	55.33
Required Reach on Spoil Side (m)	31.31	31.15
Available Reach on Spoil Side (m)	56.0	55.7
Height of Spoil Pile on Pullback Pad (m)	15.64	15.47
Width of Spoil Pile on Pullback Pad (m)	23.29	23.02
Percent Rehandle (%)	21.94	21.69
Pit Geometry Model Result	PASS	PASS

E.3.2. Results of Production Simulation Models

The simulation geometry and production simulation results of the direct side casting, extended bench casting, one slice one dragline pullback casting, one slice two dragline pullback casting and two slice two dragline pullback casting models are given below in Tables E.10 to E.19.

Table E.8. Results of the One Slice Two Dragline Pullback Stripping Geometry Model

Highwall Side Dragline	1300W-1												
Spoil Side Dragline	1300W-1	1300W-2	1300W-3	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-1	7820-2	7820-3	7820-4	7820-5
Pit Width (m)	50.75	50.75	50.75	50.75	50.75	50.75	50.75	50.75	50.75	50.75	50.75	50.75	50.75
Keycut Upper Width (m)	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05
Keycut Right Wall Angle (°)	67	67	67	67	67	67	67	67	67	67	67	67	67
Effective Reach (m)	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15
Area of the Barrier on Highwall Side (m²)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Height of Temporary Spoil Pile (m)	52.88	52.88	52.88	52.88	52.88	52.88	52.88	52.88	52.88	52.88	52.88	52.88	52.88
Height of Pullback Pad (m)	35.91	35.91	35.91	35.91	35.91	35.91	35.91	35.91	35.91	35.91	35.91	35.91	35.91
Width of Pullback Pad (m)	56.97	56.97	56.97	56.97	56.97	56.97	56.97	56.97	56.97	56.97	56.97	56.97	56.97
Required Reach on Spoil Side (m)	31.31	31.31	31.31	31.31	31.31	31.31	31.31	31.31	31.31	31.31	31.31	31.31	31.31
Available Reach on Spoil Side (m)	56.0	62.4	62.4	69.1	66.3	73.4	71.8	79.4	60.5	58.4	73.3	55.7	61.8
Height of Spoil Pile on Pullback Pad (m)	15.64	15.64	15.64	15.64	15.64	15.64	15.64	15.64	15.64	15.64	15.64	15.64	15.64
Width of Spoil Pile on Pullback Pad (m)	23.29	23.29	23.29	23.29	23.29	23.29	23.29	23.29	23.29	23.29	23.29	23.29	23.29
Percent Rehandle (%)	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94	21.94
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.8. Results of the One Slice Two Dragline Pullback Stripping Geometry Model (Continued)

Highwall Side Dragline	7820-4												
Spoil Side Dragline	1300W-1	1300W-2	1300W-3	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-1	7820-2	7820-3	7820-4	7820-5
Pit Width (m)	49.25	49.25	49.25	49.25	49.25	49.25	49.25	49.25	49.25	49.25	49.25	49.25	49.25
Keycut Upper Width (m)	29.44	29.44	29.44	29.44	29.44	29.44	29.44	29.44	29.44	29.44	29.44	29.44	29.44
Keycut Right Wall Angle (°)	68	68	68	68	68	68	68	68	68	68	68	68	68
Effective Reach (m)	37.85	37.85	37.85	37.85	37.85	37.85	37.85	37.85	37.85	37.85	37.85	37.85	37.85
Area of the Barrier on Highwall Side (m^2)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Height of Temporary Spoil Pile (m)	52.36	52.36	52.36	52.36	52.36	52.36	52.36	52.36	52.36	52.36	52.36	52.36	52.36
Height of Pullback Pad (m)	35.87	35.87	35.87	35.87	35.87	35.87	35.87	35.87	35.87	35.87	35.87	35.87	35.87
Width of Pullback Pad (m)	55.33	55.33	55.33	55.33	55.33	55.33	55.33	55.33	55.33	55.33	55.33	55.33	55.33
Required Reach on Spoil Side (m)	31.15	31.15	31.15	31.15	31.15	31.15	31.15	31.15	31.15	31.15	31.15	31.15	31.15
Available Reach on Spoil Side (m)	56.0	62.4	62.4	69.1	66.3	73.4	71.8	79.4	60.5	58.4	73.3	55.7	61.8
Height of Spoil Pile on Pullback Pad (m)	15.47	15.47	15.47	15.47	15.47	15.47	15.47	15.47	15.47	15.47	15.47	15.47	15.47
Width of Spoil Pile on Pullback Pad (m)	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02
Percent Rehandle (%)	21.69	21.69	21.69	21.69	21.69	21.69	21.69	21.69	21.69	21.69	21.69	21.69	21.69
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.9. Results of the Two Slice Two Dragline Pullback Stripping Geometry Model

Highwall Side Dragline	1300W-1					7820-1	7820-4					
Spoil Side Dragline	1300W-4	1300W-6	1300W-7	1300W-8	7820-3	1300W-8	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-3
Pit Width (m)	45.75	45.75	45.75	45.75	45.75	49.05	44.25	44.25	44.25	44.25	44.25	44.25
Keycut Upper Width (m)	27.2	27.2	27.2	27.2	27.2	29.15	26.18	26.18	26.18	26.18	26.18	26.18
Keycut Right Wall Angle (°)	69	69	69	69	69	68	71	71	71	71	71	71
Effective Reach (m)	33.15	33.15	33.15	33.15	33.15	37.65	32.85	32.85	32.85	32.85	32.85	32.85
Height Spoil Pile Toe Rises on Highwall (m)	1.53	1.53	1.53	1.53	1.53	0.27	1.47	1.47	1.47	1.47	1.47	1.47
Upper Slice Height (m)	28.3	28.3	28.3	28.3	28.3	29.7	28.4	28.4	28.4	28.4	28.4	28.4
Lower Slice Height (m)	1.7	1.7	1.7	1.7	1.7	0.3	1.6	1.6	1.6	1.6	1.6	1.6
Height of Temporary Spoil Pile (m)	48.72	48.72	48.72	48.72	48.72	51.96	48.26	48.26	48.26	48.26	48.26	48.26
Height of Pullback Pad (m)	32.79	32.79	32.79	32.79	32.79	35.58	32.8	32.8	32.8	32.8	32.8	32.8
Width of Pullback Pad (m)	53.48	53.48	53.48	53.48	53.48	55.0	51.9	51.9	51.9	51.9	51.9	51.9
Required Reach on Spoil Side (m)	67.05	67.05	67.05	67.05	67.05	73.66	65.58	65.58	65.58	65.58	65.58	65.58
Available Reach on Spoil Side (m)	69.1	73.4	71.8	79.4	73.3	79.4	69.1	66.3	73.4	71.8	79.4	73.3
Height of Spoil Pile on Pullback Pad (m)	16.45	16.45	16.45	16.45	16.45	15.25	16.37	16.37	16.37	16.37	16.37	16.37
Width of Spoil Pile on Pullback Pad (m)	24.56	24.56	24.56	24.56	24.56	22.67	24.43	24.43	24.43	24.43	24.43	24.43
Percent Rehandle (%)	25.26	25.26	25.26	25.26	25.26	21.57	25.16	25.16	25.16	25.16	25.16	25.16
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.10. Results of the Direct Side Casting Simulation Geometry Model

Dragline	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-3
Bucket Capacity (m^3)	33.62	34.44	31.16	27.06	23.78	26.24
Set Length (m)	26.0	24.54	28.11	27.35	32.6	28.1
Setback Distance (m)	25.7	24.36	27.89	27.05	29.4	26.6
Keycut Volume (m^3)	13238	12002	14607	14213	16939	14601
Maincut Volume (m^3)	31477	28498	37170	34852	48972	36058
Distance 1-2 (m)	27.42	25.09	31.47	29.87	37.47	31.37
Distance 2-3 (m)	32.15	29.65	35.68	34.27	41.07	34.86
Distance 1-3 (m)	16.8	15.79	16.8	16.8	16.8	15.2
Distance 4-1' (m)	50.82	47.5	54.84	53.31	62.01	53.47

Table E.11. Results of the Direct Side Casting Production Simulation Model

Dragline	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-3
Average Keycut Cycle Time (s)	59.0214	59.19932	58.38719	57.26688	56.26183	57.03856
Average Maincut Cycle Time (s)	58.9878	59.18708	58.38594	57.27904	56.27606	57.02889
Average Fill Factor (.00)	0.9500	0.95001	0.95002	0.94998	0.94999	0.95002
Time Spent for Keycut (s)	5574984	5549285	5363389	5482044	4871318	5460985
Time Spent for Maincut (s)	13227956	13131720	13598319	13431305	14024444	13433268
Time Spent for Walking (s)	437595	465378	379620	349367	268797	371052
Time Spent for Delaying (s)	2421150	2472658	2293382	2383194	2440725	2344812
Percent Time for Keycut Excavation (%)	25.74	25.67	24.79	25.33	22.55	25.27
Percent Time for Maincut Excavation (%)	61.07	60.74	62.85	62.05	64.91	62.16
Percent Time for Walking (%)	2.02	2.15	1.75	1.61	1.24	1.72
Percent Time for Delaying (%)	11.18	11.44	10.6	11.01	11.30	10.85
Total Stripping Time (s)	21661685	21619040	21634710	21645910	21605284	21610117
Scheduled Time (s)	21600000	21600000	21600000	21600000	21600000	21600000
Total Walked Distance (m)	23514	24345	21363	19100	15347	18463
Total Production (m^3)	7654571	7765094	7229430	6383329	5704352	6210350
Prime Production (m^3)	7654571	7765094	7229430	6383329	5704352	6210450
Desired Production (m^3)	7142857	7142857	7142857	7142857	7142857	7142857
Result	PASS	PASS	PASS	FAIL	FAIL	FAIL

Table E.12. Results of the Extended Bench Casting Simulation Geometry Model

Dragline	1300W-1	1300W-2	1300W-3	7820-1	7820-2	7820-4	7820-5
Bucket Capacity (m^3)	38.55	38.55	36.91	34.44	28.7	30.34	33.95
Set Length (m)	19.45	22.66	22.66	21.08	20.04	18.56	21.62
Setback Distance (m)	19.15	22.34	22.34	20.82	19.76	18.54	21.58
Keycut Volume (m^3)	11447	9597	9597	9698	10413	10867	9156
Maincut Volume (m^3)	28577	41379	41379	35763	31551	26487	38312
Rehandle Volume (m^3)	7999	7114	7114	7129	7429	7606	6858
Distance 1-2 (m)	50.01	52.76	52.76	51.98	51.46	49.68	52.31
Distance 2-3 (m)	51.11	54.52	54.52	53.60	52.84	50.84	54.10
Distance 1-3 (m)	10.58	13.78	13.78	13.07	12.01	10.79	13.83
Distance 4-1' (m)	58.33	64.11	64.11	62.19	60.62	57.70	63.19

Table E.13. Results of the Extended Bench Casting Production Simulation Model

Dragline	1300W-1	1300W-2	1300W-3	7820-1	7820-2	7820-4	7820-5
Average Keycut Cycle Time (s)	60.10364	60.14140	59.74300	59.18583	57.73951	58.16625	59.09386
Average Maincut Cycle Time (s)	60.11188	60.10145	59.75266	59.19556	57.73615	58.17756	59.07227
Average Fill Factor (.00)	0.94999	0.95001	0.95002	0.94999	0.94999	0.95001	0.95000
Time Spent for Keycut (s)	4583984	3195193	3243925	3572516	4113247	4696634	3260681
Time Spent for Maincut (s)	11427619	13688496	13932076	13124889	12445990	11411688	13581293
Time Spent for Rehandle (s)	2409414	1777590	1804146	1970993	2203115	2467384	1829541
Time Spent for Walking (s)	658931	576773	563532	632088	575112	636468	618720
Time Spent for Delaying (s)	2546392	2362287	2076304	2317941	2285948	2406203	2330330
Percent Time for Keycut Excavation (%)	21.20	14.79	15.00	16.53	19.02	21.75	15.08
Percent Time for Maincut Excavation (%)	52.84	63.37	64.44	60.71	57.56	52.79	62.81
Percent Time for Rehandling (%)	11.14	8.23	8.34	9.11	10.19	11.41	8.46
Percent Time for Walking (%)	3.05	2.67	2.61	2.92	2.66	2.94	2.86
Percent Time for Delaying (%)	11.77	10.94	9.60	10.72	10.57	11.13	10.78
Total Stripping Time (s)	21626340	21600339	21619983	21617827	21623413	21618377	21620564
Scheduled Time (s)	21600000	21600000	21600000	21600000	21600000	21600000	21600000
Total Walked Distance (m)	38272	34006	33226	33454	30231	33314	32228
Total Production (m^3)	8437385	8547819	8373774	7758994	6662599	6920886	7664997
Prime Production (m^3)	7334750	7733535	7578207	6940168	5880472	6002371	6913677
Total Rehandling (m^3)	1102635	814284	795567	818826	782127	918515	751320
Desired Production (m^3)	7142857	7142857	7142857	7142857	7142857	7142857	7142857
Result	PASS	PASS	PASS	FAIL	FAIL	FAIL	FAIL

Table E.14. Results of the One Slice One Dragline Pullback Stripping Simulation Geometry Model

Dragline	1300W-1	7820-4
Bucket Capacity (m^3)	38.55	30.34
Highwall Side Set Length (m)	19.45	18.56
Setback Distance (m)	19.15	18.54
Spoil Side Set Length (m)	9.48	8.34
Keycut Volume (m^3)	8768	8195
Maincut Volume (m^3)	20842	19223
Rehandle Volume (m^3)	4212	3556
Distance 1-2 (m)	20.83	20.53
Distance 2-3 (m)	23.37	23.20
Distance 1-3 (m)	10.58	10.79
Distance 4-1' (m)	36.55	35.82

Table E.15. Results of the One Slice One Dragline Pullback Stripping Production Simulation Model

Dragline	1300W-1	7820-4
Average Keycut Cycle Time (s)	60.10391	58.17106
Average Maincut Cycle Time (s)	60.10186	58.18189
Average Rehandling Cycle Time (s)	72.08981	71.64687
Average Fill Factor (.00)	0.95000	0.95001
Time Spent for Keycut (s)	4493068	4558924
Time Spent for Maincut (s)	10659545	10662995
Time Spent for Rehandle (s)	3313398	3366086
Time Spent for Walking (s)	680783	650628
Time Spent for Delaying (s)	2460283	2368998
Percent Time for Keycut Excavation (%)	20.79	21.10
Percent Time for Maincut Excavation (%)	49.33	49.35
Percent Time for Rehandling (%)	15.33	15.58
Percent Time for Walking (%)	3.15	3.01
Percent Time for Delaying (%)	11.39	10.96
Total Stripping Time (s)	21607077	21607631
Scheduled Time (s)	21600000	21600000
Total Walked Distance (m)	34044	28985
Total Production (m^3)	8340777	6826527
Prime Production (m^3)	6953727	5679961
Total Rehandling (m^3)	1387050	1146566
Desired Production (m^3)	7142857	7142857
Result	FAIL	FAIL

Table E.16. Results of the One Slice Two Dragline Pullback Stripping Simulation Geometry Model

Highwall Side Dragline	1300W-1												
Spoil Side Dragline	1300W-1	1300W-2	1300W-3	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-1	7820-2	7820-3	7820-4	7820-5
High. Side Bucket Capacity (m³)	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55
Spoil Side Bucket Capacity (m³)	38.55	38.55	36.91	33.62	34.44	31.16	27.06	23.78	34.44	28.70	26.24	30.34	33.95
Highwall Side Set Length (m)	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.45
Setback Distance (m)	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15	19.15
Spoil Side Set Length (m)	9.48	9.91	9.91	10.35	10.17	10.62	10.52	10.99	9.71	9.56	10.54	9.38	9.79
Keycut Volume (m³)	8768	8768	8768	8768	8768	8768	8768	8768	8768	8768	8768	8768	8768
Maincut Volume (m³)	20842	20842	20842	20842	20842	20842	20842	20842	20842	20842	20842	20842	20842
Rehandle Volume (m³)	4212	4405	4405	4598	4518	4718	4674	4880	4312	4248	4682	4165	4351
Distance 1-2 (m)	20.83	20.83	20.83	20.83	20.83	20.83	20.83	20.83	20.83	20.83	20.83	20.83	20.83
Distance 2-3 (m)	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37
Distance 1-3 (m)	10.58	10.58	10.58	10.58	10.58	10.58	10.58	10.58	10.58	10.58	10.58	10.58	10.58
Distance 4-1' (m)	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55	36.55

Table E.16. Results of the One Slice Two Dragline Pullback Stripping Simulation Geometry Model (Continued)

Highwall Side Dragline	7820-4												
Spoil Side Dragline	1300W-1	1300W-2	1300W-3	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-1	7820-2	7820-3	7820-4	7820-5
High. Side Bucket Capacity (m³)	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34
Spoil Side Bucket Capacity (m³)	38.55	38.55	36.91	33.62	34.44	31.16	27.06	23.78	34.44	28.70	26.24	30.34	33.95
Highwall Side Set Length (m)	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56
Setback Distance (m)	18.54	18.54	18.54	18.54	18.54	18.54	18.54	18.54	18.54	18.54	18.54	18.54	18.54
Spoil Side Set Length (m)	8.44	8.82	8.82	9.21	9.05	9.45	9.36	9.77	8.64	8.51	9.38	8.34	8.72
Keycut Volume (m³)	8195	8195	8195	8195	8195	8195	8195	8195	8195	8195	8195	8195	8195
Maincut Volume (m³)	19223	19223	19223	19223	19223	19223	19223	19223	19223	19223	19223	19223	19223
Rehandle Volume (m³)	3596	3761	3761	3926	3858	4028	3990	4167	3682	3628	3997	3556	3715
Distance 1-2 (m)	20.53	20.53	20.53	20.53	20.53	20.53	20.53	20.53	20.53	20.53	20.53	20.53	20.53
Distance 2-3 (m)	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20
Distance 1-3 (m)	10.79	10.79	10.79	10.79	10.79	10.79	10.79	10.79	10.79	10.79	10.79	10.79	10.79
Distance 4-1' (m)	35.82	35.82	35.82	35.82	35.82	35.82	35.82	35.82	35.82	35.82	35.82	35.82	35.82

Table E.17. Results of the One Slice Two Dragline Pullback Stripping Production Simulation Model

Highwall Side Dragline	1300W-1												
Spoil Side Dragline	1300W-1	1300W-2	1300W-3	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-1	7820-2	7820-3	7820-4	7820-5
Av. Keycut Cycle Time (s)	60.09788	60.09647	60.10398	60.11728	60.12597	60.09248	60.11481	60.11423	60.09730	60.10228	60.11404	60.11198	60.11565
Av. Maincut Cycle Time (s)	60.1142	60.11329	60.11503	60.10524	60.10452	60.11218	60.11415	60.11058	60.11593	60.10153	60.11105	60.11443	60.10877
Av. Rehandle Cycle Time (s)	72.31757	72.31757	72.19525	71.93341	72.00087	71.72117	71.32918	70.97250	71.99192	71.49235	71.24404	71.64687	71.96075
Average Fill Factor (.00)	0.95001	0.95001	0.94999	0.95003	0.94999	0.95002	0.95000	0.94999	0.94999	0.95002	0.94998	0.95000	0.95000
Time Spent for Keycut (s)	5504666	5471242	5563284	5506562	5532310	5510660	5474836	5488008	5485021	5491485	5550028	5529941	5487296
H.S. Time for Maincut (s)	13051213	12986153	13187435	13047405	13120096	13076082	12985919	12985928	12986904	13027067	13168348	13095809	13002850
H.S. Time for Walking (s)	584769	581606	590898	584769	587736	585692	581606	582280	582280	583649	589779	587290	582725
H.S. Time for Delaying (s)	2475469	2566371	2260112	2478608	2386703	2435895	2563748	2558081	2559648	2521433	2329122	2389030	2534402
S.S. Time for Rehandle (s)	4368314	4339573	4581050	4915141	4838542	5258649	5898030	6633145	4805782	5633657	6144137	5400358	4857008
S.S. Time for Maincut (s)	37886	36409	36574	34133	35228	32884	32525	30173	36398	35647	33013	36783	35667
S.S. Time for Waiting (s)	16562258	16499890	16218479	15915054	16019492	15428506	14635281	13924057	15986909	15045760	14596572	15215188	15884052
S.S. Time for Walking (s)	145399	156118	158663	150461	153855	146784	147067	141411	169800	151536	157800	155760	168000
S.S. Time for Delaying (s)	502259	573383	606964	602555	579728	741507	893207	885511	614963	757034	705755	793981	662546
Total Scheduled Time (s)	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000
H.S. Total Strip. Time (s)	21616116	21605373	21601729	21617344	21626845	21608330	21606109	21614297	21613852	21623634	21637277	21602070	21607274
S.S. Total Strip. Time (s)	21616116	21605373	21601729	21617344	21626845	21608330	21606109	21614297	21613852	21623634	21637277	21602070	21607274
H.S. X-Direction Walk (m)	5562	5523	5620	5562	5582	5562	5523	5543	5543	5543	5601	5582	5543
S. S. X-Direction Walk (m)	5508	5473	5562	5506	5533	5512	5471	5493	5494	5489	5544	5532	5485
H.S. Total Stripping (m^3)	8499218	8454440	8587939	8498521	8543125	8513609	8454467	8461289	8460457	8484115	8573289	8530528	8468798
H.S. Prime Stripping (m^3)	8499218	8454440	8587939	8498521	8543125	8513609	8454467	8461289	8460457	8484115	8573289	8530528	8468798
H.S. Desired Stripping (m^3)	7134771	7134309	7134620	7134023	7134219	7134238	7136544	7136825	7133865	7134289	7142857	7134183	7133885
S. S. Total Stripping (m^3)	1863598	1850320	1880191	1858492	1868121	1858299	1842376	1847647	1856124	1851288	1866608	1866621	1852212
S.S. Prime Stripping (m^3)	16066	15155	14763	12752	13400	11538	10058	8482	13930	11761	9833	12779	13582
S.S. Desired Stripping (m^3)	13430	12755	12239	10693	11171	9667	8493	7143	11694	9873	8189	10646	11424
Desired Stripping (m^3)	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857
Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.17. Results of the One Slice Two Dragline Pullback Stripping Production Simulation Model (Continued)

Highwall Side Dragline	7820-4												
Spoil Side Dragline	1300W-1	1300W-2	1300W-3	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-1	7820-2	7820-3	7820-4	7820-5
Av. Keycut Cycle Time (s)	58.16459	58.18353	58.17408	58.15616	58.18060	58.16708	58.17702	58.17265	58.18911	58.17373	58.16695	58.16542	58.16572
Av. Maincut Cycle Time (s)	58.18802	58.17447	58.18207	58.18568	58.17021	58.19123	58.17084	58.18982	58.17171	58.17063	58.17789	58.17799	58.18949
Av. Rehandle Cycle Time (s)	72.31757	72.31757	72.19525	71.93341	72.00087	71.72117	71.32918	70.97250	71.99192	71.49235	71.24404	71.64687	71.96075
Average Fill Factor (.00)	0.94999	0.95002	0.94998	0.95003	0.94998	0.95000	0.95001	0.94998	0.95002	0.95001	0.94998	0.95003	0.94998
Time Spent for Keycut (s)	5618815	5514984	5513740	5526463	5558167	5558388	5573300	5507167	5581557	5551635	5595312	5577191	5528011
H.S. Time for Maincut (s)	13139902	12912289	12883897	12938632	13014886	13018368	13036550	12885108	13067169	12963442	13069838	13069163	12917602
H.S. Time for Walking (s)	561312	551268	550788	552480	555684	555684	556896	550272	557892	554208	558624	557892	552000
H.S. Time for Delaying (s)	2299400	2625680	2656285	2582715	2485893	2486764	2441689	2667855	2419418	2546101	2389133	2404654	2614271
S.S. Time for Rehandle (s)	3553049	3476972	3613430	3929393	3872448	4219259	4791691	5300697	3878890	4534151	4941082	4334773	3896724
S.S. Time for Maincut (s)	36189	33610	33316	31889	32774	31413	30531	28924	34297	33791	30654	34709	33424
S.S. Time for Waiting (s)	17449863	17481956	17371564	16978555	17079077	16729226	16004038	15410964	16991489	16328928	15822183	16595888	16977132
S.S. Time for Walking (s)	138392	129633	129633	124628	127381	122126	123627	117120	141240	142824	130680	146256	138864
S.S. Time for Delaying (s)	441937	482050	456766	535816	502950	517179	658549	752696	580119	575692	688308	497275	565741
Total Scheduled Time (s)	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000
H.S. Total Strip. Time (s)	21619429	21604222	21604709	21600290	21614630	21619203	21608435	21610402	21626036	21615386	21612907	21608900	21611885
S.S. Total Strip. Time (s)	21619429	21604222	21604709	21600290	21614630	21619203	21608435	21610402	21626036	21615386	21612907	21608900	21611885
H.S. X-Direction Walk (m)	4713	4620	4620	4639	4658	4658	4676	4620	4676	4658	4695	4676	4639
S. S. X-Direction Walk (m)	4665	4570	4570	4586	4606	4611	4624	4574	4621	4604	4642	4622	4584
H.S. Total Stripping (m^3)	6988672	6865201	6853571	6879262	6920285	6920364	6933896	6851592	6947640	6898716	6954076	6947357	6871293
H.S. Prime Stripping (m^3)	6988672	6865201	6853571	6879262	6920285	6920364	6933896	6851592	6947640	6898716	6954076	6947357	6871293
H.S. Desired Stripping (m^3)	6988672	6865201	6853571	6879262	6920285	6920364	6933896	6851592	6947640	6898716	6954076	6947357	6871293
S.S. Total Stripping (m^3)	1518218	1485865	1485226	1487992	1495111	1494286	1496359	1478022	1501042	1492091	1501718	1499477	1488296
S.S. Prime Stripping (m^3)	15199	14246	13639	11959	12476	10860	9536	7949	13126	11101	9279	12018	12711
S.S. Desired Stripping (m^3)	15199	14246	13639	11959	12476	10860	9536	7949	13126	11101	9279	12018	12711
Desired Stripping (m^3)	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857
Result	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL

Table E.18. Results of the Two Slice Two Dragline Pullback Stripping Simulation Geometry Model

Highwall Side Dragline	1300W-1					7820-1	7820-4					
Spoil Side Dragline	1300W-4	1300W-6	1300W-7	1300W-8	7820-3	1300W-8	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-3
Highwall Side Bucket Capacity (m^3)	38.55	38.55	38.55	38.55	38.55	34.44	30.34	30.34	30.34	30.34	30.34	30.34
Spoil Side Bucket Capacity (m^3)	33.62	31.16	27.06	23.78	26.24	23.78	33.62	34.44	31.16	27.06	23.78	26.24
Highwall Side Set Length (m)	20.31	20.31	20.31	20.31	20.31	21.22	19.40	19.40	19.40	19.40	19.40	19.40
Setback Distance (m)	19.99	19.99	19.99	19.99	19.99	20.98	19.30	19.30	19.30	19.30	19.30	19.30
Spoil Side Set Length (m)	18.46	19.13	18.88	20.02	18.93	20.36	18.27	17.83	18.92	18.68	19.80	18.73
Keycut Volume (m^3)	7817	7817	7817	7817	7817	9186	7209	7209	7209	7209	7209	7209
Maincut Volume (m^3)	18479	18479	18479	18479	18479	21735	17168	17168	17168	17168	17168	17168
Rehandle Volume (m^3)	8031	8322	8215	8711	8235	8509	7685	7501	7959	7858	8327	7877
Distance 1-2 (m)	16.82	16.82	16.82	16.82	16.82	20.51	16.46	16.46	16.46	16.46	16.46	16.46
Distance 2-3 (m)	20.33	20.33	20.33	20.33	20.33	24.40	20.11	20.11	20.11	20.11	20.11	20.11
Distance 1-3 (m)	11.42	11.42	11.42	11.42	11.42	13.22	11.55	11.55	11.55	11.55	11.55	11.55
Distance 4-1' (m)	35.91	35.91	35.91	35.91	35.91	40.09	35.05	35.05	35.05	35.05	35.05	35.05

Table E.19. Results of the Two Slice Two Dragline Pullback Stripping Production Simulation Model

Highwall Side Dragline	1300W-1					7820-1	7820-4					
Spoil Side Dragline	1300W-4	1300W-6	1300W-7	1300W-8	7820-3	1300W-8	1300W-4	1300W-5	1300W-6	1300W-7	1300W-8	7820-3
Av. Keycut Cycle Time (s)	60.09609	60.09302	60.09533	60.11690	60.11149	59.17240	58.18349	58.17518	58.18396	58.19280	58.17865	58.17464
Av. Maincut Cycle Time (s)	60.11371	60.10667	60.11362	60.10653	60.10434	59.19741	58.17497	58.18598	58.17744	58.17230	58.17211	58.17159
Av. Rehandle Cycle Time (s)	71.93341	71.72117	71.32918	70.97250	71.24404	70.97250	71.93341	72.00088	71.72117	71.32918	70.97250	71.24404
Average Fill Factor (.00)	0.94999	0.95001	0.95000	0.95000	0.95000	0.95001	0.95000	0.95000	0.94999	0.95000	0.95000	0.94999
Time Spent for Keycut (s)	5513636	5525192	5542352	5561655	5492747	5538123	5532202	5511808	5494428	5489327	5492530	5472313
High. Side Total Time for Maincut (s)	13010291	13024815	13051509	13090362	12942928	13089080	13121015	13079393	13057344	13028734	13056264	13009844
High. Side Total Time for Walking (s)	583833	584855	586289	588104	581224	569196	556356	554808	552852	552000	552852	550896
High. Side Total Time for Delaying (s)	2505446	2471181	2430731	2365931	2593056	2425231	2391851	2454257	2522728	2545911	2500617	2572181
Spoil Side Total Time for Rehandle (s)	5644509	6053494	6877537	7713434	7000194	5939008	4609580	4494729	4879984	5528110	6197312	5655572
Spoil Side Total Time for Maincut (s)	1349541	1448384	1642254	1839915	1673028	284464	1041889	1013142	1101521	1243798	1394020	1274655
Spoil Side Total Time for Waiting (s)	13571203	13025639	11749416	10669207	11610958	14412523	15112723	15206037	14771918	13807097	12929252	13575435
Spoil Side Total Time for Walking (s)	133180	140034	142512	134664	151404	106161	113774	116057	118141	119793	113184	127872
Spoil Side Total Time for Delaying (s)	914773	938493	1199161	1248832	1174371	879473	723458	770301	755789	917175	968495	971700
Total Scheduled Time (s)	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000	21600000
High. Side Total Stripping Time (s)	21613206	21606043	21610881	21606052	21609955	21621630	21601424	2100266	21627352	21615973	21602262	21605235
Spoil Side Total Stripping Time (s)	21613206	21606043	21610881	21606052	21609955	21621630	21601424	2100266	21627352	21615973	21602262	21605235
Highwall Side X-Direction Walk (m)	6519	6539	6559	6580	6499	5285	5508	5489	5470	5470	5470	5450
Spoil Side X-Direction Walk (m)	6461	6485	6514	6528	6455	5233	5463	5439	5412	5418	5425	5394
Highwall Side Total Stripping (m^3)	8484582	8498110	8516880	8543229	8444953	7742828	6949092	6925225	6911073	6898700	6910981	6886454
Highwall Side Prime Stripping (m^3)	8484582	8498110	8516880	8543229	8444953	7742828	6949092	6925225	6911073	6898700	6910981	6886454
Highwall Side Desired Stripping (m^3)	6759734	6760599	6760281	6761758	6760341	7098645	6783449	6782899	6784270	6783968	6785369	6784024
Spoil Side Total Stripping (m^3)	2624497	2632902	2644565	2648686	2620219	1725237	2121824	2112915	2101197	2102890	2104466	2093040
Spoil Side Prime Stripping (m^3)	506552	507933	510076	510564	505338	78795	390655	389138	386478	386564	386459	384486
Spoil Side Desired Stripping (m^3)	406062	406114	406095	406183	406098	71703	382166	382135	382212	382195	382274	382199
Desired Stripping (m^3)	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857	7142857
Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

E.3.3. Results of the Stripping Cost Models

The draglines employed in the direct side casting, extended bench casting, one slice two dragline pullback stripping and two slice two dragline pullback stripping models have satisfied the desired production requirement. The stripping cost results of draglines employed in above-mentioned techniques are given in Tables E.20 to E.23.

Table E.20. Results of the Direct Side Casting Stripping Cost Model

Dragline	1300W-4	1300W-5	1300W-6
Yearly Total Owning Cost (US$)	2,052,390	2,052,390	2,052,390
Yearly Total Operating Cost (US$)	1,895,621	1,916,413	1,852,534
Yearly Total Owning & Operating Cost (US$)	3,948,011	3,968,804	3,904,924
Hourly Owning & Operating Cost (US$/hr)	658.00184	661.46728	650.82075
Cost in Terms of Total Production (US$/bank m^3)	0.52011	0.51111	0.54014
Cost in Terms of Prime Production (US$/bank m^3)	0.52011	0.51111	0.54014
Cost in Terms of Desired Production (US$/ bank m^3)	0.55272	0.55563	0.54669

Table E.21. Results of the Extended Bench Casting Stripping Cost Model

Dragline	1300W-1	1300W-2	1300W-3
Yearly Total Owning Cost (US$)	2,042,335	2,042,335	2,052,390
Yearly Total Operating Cost (US$)	1,990,061	2,003,169	1,989,000
Yearly Total Owning & Operating Cost (US$)	4,032,397	4,045,504	4,041,390
Hourly Owning & Operating Cost (US$/hr)	672.06609	674.25064	673.56503
Cost in Terms of Total Production (US$/bank m^3)	0.47792	0.47328	0.48262
Cost in Terms of Prime Production (US$/bank m^3)	0.54977	0.52311	0.53329
Cost in Terms of Desired Production (US$/ bank m^3)	0.56454	0.56637	0.56579

Table E.22. Results of the One Slice Two Dragline Pullback Stripping Cost Model

Highwall & Spoil Side Draglines	1300W-1	1300W-1	1300W-1	1300W-2	1300W-1	1300W-3	1300W-1	1300W-4	1300W-1	1300W-5	1300W-1	1300W-6
Yearly Total Owning Cost (US$)	2,042,335	2,042,335	2,042,335	2,042,335	2,042,335	2,052,390	2,042,335	2,052,390	2,042,335	2,052,390	2,042,335	2,052,390
Yearly Total Operating Cost (US$)	1,995,641	1,209,060	2,006,124	1,211,496	2,007,931	1,214,625	1,997,318	1,212,037	2,002,612	1,213,186	1,999,108	1,212,014
Yearly Total Owning & Operating Cost (US$)	4,037,976	3,251,395	4,048,459	3,253,831	4,050,266	3,267,015	4,039,653	3,264,428	4,044,947	3,265,576	4,041,444	3,264,405
Hourly Owning & Operating Cost (US$/hr)	672.9959	541.8991	674.7432	542.30511	675.04429	544.50253	673.27546	544.07125	674.1578	544.26265	673.57392	544.06742
Cost in Terms of Total Production (US$/bank m³)	0.47593	1.75072	0.47225	1.73288	0.47162	1.7376	0.47534	1.75649	0.47347	1.74805	0.4747	1.75666
Cost in Terms of Prime Production (US$/bank m³)	0.56596	202.3774	0.47225	214.7035	0.47162	221.2975	0.47534	255.9934	0.47347	243.6997	0.4747	282.9264
Cost in Terms of Desired Production (US$/ bank m³)	0.56596	242.0952	0.56749	253.71636	0.56769	266.93565	0.56625	305.28726	0.56698	292.32497	0.56649	337.66873
Combined Cost in Terms of Desired Production (US$/m³)	242.66118		254.28385		267.50334		305.85351		292.89195		338.23522	

Table E.22. Results of the One Slice Two Dragline Pullback Stripping Cost Model (Continued)

Highwall & Spoil Side Draglines	1300W-1	1300W-7	1300W-1	1300W-8	1300W-1	7820-1	1300W-1	7820-2	1300W-1	7820-3	1300W-1	7820-4	1300W-1	7820-5
Yearly Total Owning Cost (US$)	2,042,335	2,066,542	2,042,335	2,066,542	2,042,335	2,696,296	2,042,335	2,624,595	2,042,335	2,701,956	2,042,335	2,629,313	2,042,335	2,704,787
Yearly Total Operating Cost (US$)	1,992,089	1,214,335	1,992,899	1,214,968	1,992,800	1,578,520	1,995,608	1,557,793	2,006,192	1,581,317	2,001,117	1,560,823	1,993,790	1,580,462
Yearly Total Owning & Operating Cost (US$)	4,034,424	3,280,876	4,035,234	3,281,509	4,035,135	4,274,816	4,037,943	4,182,388	4,048,527	4,283,274	4,043,452	4,190,136	4,036,125	4,285,248
Hourly Owning & Operating Cost (US$/hr)	672.404	546.81274	672.53895	546.91825	672.52248	712.46934	672.99049	697.06475	674.75448	713.87892	673.9086	698.356	672.68749	714.20807
Cost in Terms of Total Production (US$/bank m³)	0.47719	1.78079	0.47691	1.77605	0.47694	2.30309	0.47594	2.25918	0.47223	2.29468	0.4740	2.24477	0.47659	2.31358
Cost in Terms of Prime Production (US$/bank m³)	0.47719	326.1957	0.47691	386.8792	0.47694	306.8784	0.47594	355.6150	0.47223	435.6019	0.4740	327.8923	0.47659	315.5094
Cost in Terms of Desired Production (US$/ bank m³)	0.56532	386.30676	0.56541	459.42547	0.56563	365.54745	0.56599	423.62384	0.56730	523.03729	0.56677	393.5943	0.56577	375.09466
Combined Cost in Terms of Desired Production (US$/m³)	386.87208		459.99088		366.11308		424.18983		523.60459		394.16107		375.66043	

Table E.23. Results of the Two Slice Two Dragline Pullback Stripping Cost Model

Highwall & Spoil Side Draglines	1300W-1	1300W-4	1300W-1	1300W-6	1300W-1	1300W-7	1300W-1	1300W-8	1300W-1	7820-3	7820-1	1300W-8
Yearly Total Owning Cost (US$)	2,042,335	2,052,390	2,042,335	2,052,390	2,042,335	2,066,542	2,042,335	2,066,542	2,042,335	2,701,956	2,696,296	2,066,542
Yearly Total Operating Cost (US$)	1,995,663	1,303,385	1,997,269	1,304,387	1,999,497	1,310,675	2,002,624	1,311,170	1,990,960	1,667,783	2,252,260	1,200,267
Yearly Total Owning & Operating Cost (US$)	4,037,998	3,355,775	4,039,604	3,356,778	4,041,832	3,377,217	4,044,959	3,377,711	4,033,295	4,369,740	4,948,556	3,266,808
Hourly Owning & Operating Cost (US$/hr)	672.99972	559.2959	673.26732	559.46295	673.63862	562.86942	674.15984	562.9519	672.21579	728.28994	824.75934	544.4681
Cost in Terms of Total Production (US$/bank m³)	0.47592	1.27864	0.47535	1.27493	0.47457	1.27704	0.47347	1.27524	0.4776	1.6677	0.63911	1.89354
Cost in Terms of Prime Production (US$/bank m³)	0.47592	6.62474	0.47535	6.60870	0.47457	6.6210	0.47347	6.61565	0.4776	8.64716	0.63911	41.4596
Cost in Terms of Desired Production (US$/ bank m³)	0.59736	8.2642	0.59752	8.26561	0.59788	8.31633	0.59821	8.31573	0.59661	10.7603	0.69711	45.55996
Combined Cost in Terms of Desired Production (US$/m³)	8.86156		8.86313		8.91421		8.91394		11.35691		46.25708	

Table E.23. Results of the Two Slice Two Dragline Pullback Stripping Cost Model (Continued)

Highwall & Spoil Side Draglines	7820-4	1300W-4	7820-4	1300W-5	7820-4	1300W-6	7820-4	1300W-7	7820-4	1300W-8	7820-4	7820-3
Yearly Total Owning Cost (US$)	2,629,313	2,052,390	2,629,313	2,052,390	2,629,313	2,052,390	2,629,313	2,066,542	2,629,313	2,066,542	2,629,313	2,701,956
Yearly Total Operating Cost (US$)	2,125,397	1,243,440	2,122,746	1,242,378	2,121,174	1,240,980	2,119,800	1,245,622	2,121,164	1,245,811	2,118,439	1,607,297
Yearly Total Owning & Operating Cost (US$)	4,754,710	3,295,830	4,752,059	3,294,768	4,750,487	3,293,371	4,749,112	3,312,163	4,750,476	3,312,353	4,747,752	4,309,253
Hourly Owning & Operating Cost (US$/hr)	792.45164	549.30508	792.00977	549.12801	791.74776	548.89511	791.5187	552.02721	791.74607	552.05875	791.29197	718.2089
Cost in Terms of Total Production (US$/bank m³)	0.68422	1.5533	0.6862	1.55935	0.68737	1.56738	0.68841	1.57505	0.68738	1.57396	0.68943	2.05885
Cost in Terms of Prime Production (US$/bank m³)	0.68422	8.43668	0.6862	8.4668	0.68737	8.52150	0.68841	8.56821	0.68738	8.57103	0.68943	11.2078
Cost in Terms of Desired Production (US$/ bank m³)	0.70093	8.62408	0.70059	8.622	0.70022	8.6166	0.70005	8.66615	0.70011	8.66486	0.69984	11.27491
Combined Cost in Terms of Desired Production (US$/m³)	9.32501		9.32259		9.31682		9.3662		9.36496		11.97475	

E.4. Sample Run #3

In the third sample run, seven MARION 8750 series draglines have been chosen for testing. The results of the dragline selection procedures are given below.

E.4.1. Results of Pit Geometry and Range Diagramming Models

The initially chosen draglines have passed the pit geometry criteria of the following stripping methods: extended bench casting, one slice one dragline pullback stripping, one slice two dragline pullback stripping, lower slice limited extended bench casting with 2 draglines, lower slice full extended bench casting with 2 draglines and finally two slice two dragline pullback stripping. The pit geometry results of these stripping methods are given in Tables E.24 to E.29.

Table E.24. Results of the Extended Bench Casting Geometry Model

Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Pit Width (m)	83.80	91.40	94.50	103.60	91.40	103.60	102.10
Required Reach (m)	104.42	106.32	107.09	109.37	106.32	109.37	108.99
Available Reach (m)	65.50	73.10	76.20	85.30	73.10	85.30	83.80
Bench Extension (m)	38.92	33.32	30.89	24.07	33.32	24.07	25.19
Keycut Upper Width (m)	67.02	62.12	60.22	53.00	62.12	53.00	54.99
Keycut Bottom Width (m)	11.0	6.1	4.2	0.0	6.1	0.0	0.0
Keycut Right Wall Angle (°)	55	55	55	58	55	58	56
Percent Rehandle (%)	29	25	23	18	25	18	19
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.25. Results of the One Slice One Dragline Pullback Stripping Geometry Model

Highwall Side Dragline	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Spoil Side Dragline	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Pit Width (m)	62.33	65.43	74.53	62.33	74.53	73.03
Keycut Upper Width (m)	37.24	38.73	44.17	37.24	44.17	43.36
Keycut Right Wall Angle (°)	77	75	68	77	68	69
Effective Reach (m)	44.03	47.13	56.23	44.03	56.23	54.73
Area of the Barrier on Highwall Side (m^2)	41.61	31.53	9.22	41.64	9.22	12.06
Height of Temporary Spoil Pile (m)	62.99	64.55	68.89	62.99	68.89	68.20
Height of Pullback Pad (m)	42.67	43.83	47.09	42.67	47.09	46.57
Width of Pullback Pad (m)	81.29	82.85	87.19	81.29	87.19	86.50
Required Reach on Spoil Side (m)	55.63	55.25	53.75	55.63	53.75	54.03
Available Reach on Spoil Side (m)	73.10	76.20	85.30	73.10	85.30	83.80
Height of Spoil Pile on Pullback Pad (m)	27.14	26.39	23.44	27.14	23.44	24.01
Width of Spoil Pile on Pullback Pad (m)	49.63	48.20	42.55	49.63	42.55	43.64
Percent Rehandle (%)	32.08	30.27	24.84	32.08	24.84	25.75
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS

Table E.26. Results of the One Slice Two Dragline Pullback Stripping Geometry Model

Highwall Side Dragline	8750-2							8750-3						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Pit Width (m)	62.33	62.33	62.33	62.33	62.33	62.33	62.33	65.43	65.43	65.43	65.43	65.43	65.43	65.43
Keycut Upper Width (m)	37.34	37.34	37.34	37.34	37.34	37.34	37.34	38.73	38.73	38.73	38.73	38.73	38.73	38.73
Keycut Right Wall Angle (°)	77	77	77	77	77	77	77	75	75	75	75	75	75	75
Effective Reach (m)	44.03	44.03	44.03	44.03	44.03	44.03	44.03	47.13	47.13	47.13	47.13	47.13	47.13	47.13
Area of Barrier on Highwall Side (m²)	41.64	41.64	41.64	41.64	41.64	41.64	41.64	31.53	31.53	31.53	31.53	31.53	31.53	31.53
Height of Temporary Spoil Pile (m)	62.99	62.99	62.99	62.99	62.99	62.99	62.99	64.55	64.55	64.55	64.55	64.55	64.55	64.55
Height of Pullback Pad (m)	42.67	42.67	42.67	42.67	42.67	42.67	42.67	43.83	43.83	43.83	43.83	43.83	43.83	43.83
Width of Pullback Pad (m)	81.29	81.29	81.29	81.29	81.29	81.29	81.29	82.85	82.85	82.85	82.85	82.85	82.85	82.85
Required Reach on Spoil Side (m)	55.63	55.63	55.63	55.63	55.63	55.63	55.63	55.25	55.25	55.25	55.25	55.25	55.25	55.25
Available Reach on Spoil Side (m)	65.50	73.10	76.20	85.30	73.10	85.30	83.30	65.50	73.10	76.20	85.30	83.30	85.30	83.30
Height of Spoil Pile on Pullback Pad (m)	27.14	27.14	27.14	27.14	27.14	27.14	27.14	26.39	26.39	26.39	26.39	26.39	26.39	26.39
Width of Spoil Pile on Pullback Pad (m)	49.63	49.63	49.63	49.63	49.63	49.63	49.63	48.20	48.20	48.20	48.20	48.20	48.20	48.20
Percent Rehandle (%)	32.08	32.08	32.08	32.08	32.08	32.08	32.08	30.27	30.27	30.27	30.27	30.27	30.27	30.27
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.26. Results of the One Slice Two Dragline Pullback Stripping Geometry Model (Continued)

Highwall Side Dragline	8750-4							8750-5						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Pit Width (m)	74.53	74.53	74.53	74.53	74.53	74.53	74.53	62.33	62.33	62.33	62.33	62.33	62.33	62.33
Keycut Upper Width (m)	44.17	44.17	44.17	44.17	44.17	44.17	44.17	37.24	37.24	37.24	37.24	37.24	37.24	37.24
Keycut Right Wall Angle (°)	68	68	68	68	68	68	68	77	77	77	77	77	77	77
Effective Reach (m)	56.23	56.23	56.23	56.23	56.23	56.23	56.23	44.03	44.03	44.03	44.03	44.03	44.03	44.03
Area of Barrier on Highwall Side (m²)	9.22	9.22	9.22	9.22	9.22	9.22	9.22	41.64	41.64	41.64	41.64	41.64	41.64	41.64
Height of Temporary Spoil Pile (m)	68.89	68.89	68.89	68.89	68.89	68.89	68.89	62.99	62.99	62.99	62.99	62.99	62.99	62.99
Height of Pullback Pad (m)	47.09	47.09	47.09	47.09	47.09	47.09	47.09	42.67	42.67	42.67	42.67	42.67	42.67	42.67
Width of Pullback Pad (m)	87.19	87.19	87.19	87.19	87.19	87.19	87.19	81.29	81.29	81.29	81.29	81.29	81.29	81.29
Required Reach on Spoil Side (m)	53.75	53.75	53.75	53.75	53.75	53.75	53.75	55.63	55.63	55.63	55.63	55.63	55.63	55.63
Available Reach on Spoil Side (m)	65.50	73.10	76.20	85.30	73.10	85.30	83.30	65.50	73.10	76.20	85.30	83.30	85.30	83.30
Height of Spoil Pile on Pullback Pad (m)	23.44	23.44	23.44	23.44	23.44	23.44	23.44	27.14	27.14	27.14	27.14	27.14	27.14	27.14
Width of Spoil Pile on Pullback Pad (m)	42.55	42.55	42.55	42.55	42.55	42.55	42.55	49.63	49.63	49.63	49.63	49.63	49.63	49.63
Percent Rehandle (%)	24.84	24.84	24.84	24.84	24.84	24.84	24.84	32.08	32.08	32.08	32.08	32.08	32.08	32.08
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.26. Results of the One Slice Two Dragline Pullback Stripping Geometry Model (Continued)

Highwall Side Dragline	8750-6							8750-7						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Pit Width (m)	74.53	74.53	74.53	74.53	74.53	74.53	74.53	73.03	73.03	73.03	73.03	73.03	73.03	73.03
Keycut Upper Width (m)	44.17	44.17	44.17	44.17	44.17	44.17	44.17	43.36	43.36	43.36	43.36	43.36	43.36	43.36
Keycut Right Wall Angle (°)	68	68	68	68	68	68	68	69	69	69	69	69	69	69
Effective Reach (m)	56.23	56.23	56.23	56.23	56.23	56.23	56.23	54.73	54.73	54.73	54.73	54.73	54.73	54.73
Area of Barrier on Highwall Side (m²)	9.22	9.22	9.22	9.22	9.22	9.22	9.22	12.06	12.06	12.06	12.06	12.06	12.06	12.06
Height of Temporary Spoil Pile (m)	68.89	68.89	68.89	68.89	68.89	68.89	68.89	68.20	68.20	68.20	68.20	68.20	68.20	68.20
Height of Pullback Pad (m)	47.09	47.09	47.09	47.09	47.09	47.09	47.09	46.57	46.57	46.57	46.57	46.57	46.57	46.57
Width of Pullback Pad (m)	87.19	87.19	87.19	87.19	87.19	87.19	87.19	86.50	86.50	86.50	86.50	86.50	86.50	86.50
Required Reach on Spoil Side (m)	53.75	53.75	53.75	53.75	53.75	53.75	53.75	54.03	54.03	54.03	54.03	54.03	54.03	54.03
Available Reach on Spoil Side (m)	65.50	73.10	76.20	85.30	73.10	85.30	83.30	65.50	73.10	76.20	85.30	83.30	85.30	83.30
Height of Spoil Pile on Pullback Pad (m)	23.44	23.44	23.44	23.44	23.44	23.44	23.44	24.01	24.01	24.01	24.01	24.01	24.01	24.01
Width of Spoil Pile on Pullback Pad (m)	42.55	42.55	42.55	42.55	42.55	42.55	42.55	43.64	43.64	43.64	43.64	43.64	43.64	43.64
Percent Rehandle (%)	24.84	24.84	24.84	24.84	24.84	24.84	24.84	25.75	25.75	25.75	25.75	25.75	25.75	25.75
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.27. Results of the Lower Slice Limited Extended Bench Casting with 2 Draglines Geometry Model

Upper Slice Dragline	8750-1	8750-1
Lower Slice Dragline	8750-2	8750-5
Upper Slice Thickness (m)	21.70	21.70
Lower Slice Thickness (m)	18.30	18.30
Pit Width (m)	44.73	44.73
Upper Slice Keycut Upper Width (m)	26.73	26.73
Upper Slice Keycut Right Wall Angle (°)	62	62
Lower Slice Keycut Upper Width (m)	25.63	25.63
Lower Slice Keycut Right Wall Angle (°)	55	55
Effective Reach (m)	26.43	26.43
Height of Temporary Spoil Pile (m)	38.47	38.47
Area of Void Near the Lower Slice (m^2)	200.80	200.80
Area of Conical Part in Spoil Pile to Fill the Void (m^2)	200.80	200.80
Height of Limited Extended Bench (m)	24.30	24.30
Width of Limited Extended Bench (m)	54.47	54.47
Required Reach on Lower Slice (m)	70.10	70.10
Available Reach on Spoil Side (m)	73.10	73.10
Percent Rehandle (%)	17.88	17.88
Pit Geometry Model Result	PASS	PASS

Table E.28. Results of the Lower Slice Full Extended Bench Casting with 2 Draglines Geometry Model

Upper Slice Dragline	8750-1	8750-1
Lower Slice Dragline	8750-2	8750-5
Upper Slice Thickness (m)	23.20	23.20
Lower Slice Thickness (m)	16.80	16.80
Pit Width (m)	44.73	44.73
Upper Slice Keycut Upper Width (m)	26.57	26.57
Upper Slice Keycut Right Wall Angle (°)	66	66
Lower Slice Keycut Upper Width (m)	23.53	23.53
Lower Slice Keycut Right Wall Angle (°)	55	55
Effective Reach (m)	26.43	26.43
Height of Temporary Spoil Pile (m)	40.03	40.03
Area of Void Near the Lower Slice (m^2)	142.65	142.65
Area of Void Near the Previous Spoil Pile Slice (m^2)	142.43	142.43
Area of Conical Part in Spoil Pile to Fill the Voids (m^2)	285.08	285.08
Height of Limited Extended Bench (m)	23.15	23.15
Width of Limited Extended Bench (m)	79.66	79.66
Required Reach on Lower Slice (m)	68.94	68.94
Available Reach on Spoil Side (m)	73.10	73.10
Percent Rehandle (%)	15.60	15.60
Pit Geometry Model Result	PASS	PASS

Table E.29. Results of the Two Slice Two Dragline Pullback Stripping Geometry Model

Highwall Side Dragline	8750-2				8750-3			8750-5			
Spoil Side Dragline	8750-3	8750-4	8750-6	8750-7	8750-4	8750-6	8750-7	8750-3	8750-4	8750-6	8750-7
Pit Width (m)	52.33	52.33	52.33	52.33	55.43	55.43	55.43	52.33	52.33	52.33	52.33
Keycut Upper Width (m)	31.05	31.05	31.05	31.05	32.96	32.96	32.96	31.05	31.05	31.05	31.05
Keycut Right Wall Angle (°)	76	76	76	76	74	74	74	76	76	76	76
Effective Reach (m)	34.03	34.03	34.03	34.03	37.13	37.13	37.13	34.03	34.03	34.03	34.03
Height of Upper Slice (m)	32.70	32.70	32.70	32.70	33.40	33.40	33.40	32.70	32.70	32.70	32.70
Height of Upper Slice (m)	7.30	7.30	7.30	7.30	6.60	6.60	6.60	7.30	7.30	7.30	7.30
Height of Temporary Spoil Pile (m)	52.39	52.39	52.39	52.39	54.37	54.37	54.37	52.39	52.39	52.39	52.39
Height of Pullback Pad (m)	34.71	34.71	34.71	34.71	36.20	36.20	36.20	34.71	34.71	34.71	34.71
Width of Pullback Pad (m)	70.69	70.69	70.69	70.69	72.67	72.67	72.67	70.69	70.69	70.69	70.69
Required Reach on Spoil Side (m)	74.87	74.87	74.87	74.87	80.08	80.08	80.08	74.87	74.87	74.87	74.87
Available Reach on Spoil Side (m)	76.20	85.30	85.30	83.80	85.30	85.30	83.80	76.20	85.30	85.30	83.80
Height of Spoil Pile on Pullback Pad (m)	23.80	23.80	23.80	23.80	23.61	23.61	23.61	23.80	23.80	23.80	23.80
Width of Spoil Pile on Pullback Pad (m)	43.24	43.24	43.24	43.24	42.88	42.88	42.88	43.24	43.24	43.24	43.24
Percent Rehandle (%)	35.36	35.36	35.36	35.36	33.41	33.41	33.41	35.36	35.36	35.36	35.36
Pit Geometry Model Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

E.4.2. Results of Production Simulation Models

After production simulation, one slice two dragline pullback stripping, lower slice limited extended bench casting with two draglines, lower slice full extended bench casting with two draglines and two slice two dragline pullback casting models have proved successful. The simulation geometry and production simulation results of each of them are presented in Tables E.30 to E.37.

E.4.3. Results of Stripping Cost Models

For the sample run #3, only those models that have employed two draglines have satisfied the desired production. The stripping cost results of each of them are presented in Tables E.38 to E.41.

Table E.30. Results of the One Slice Two Dragline Pullback Stripping Simulation Geometry Model

Highwall Side Dragline	8750-2							8750-3						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
H.S. Buc.Capacity (m³)	69.38	69.38	69.38	69.38	69.38	69.38	69.38	79.60	79.60	79.60	79.60	79.60	79.60	79.60
S.S. Buc. Capacity (m³)	85.15	69.38	79.60	65.73	82.52	58.42	83.40	85.15	69.38	79.60	65.73	82.52	58.42	83.40
H. Side Set Length (m)	25.78	25.78	25.78	25.78	25.78	25.78	25.78	27.42	27.42	27.42	27.42	27.42	27.42	27.42
Setback Distance (m)	25.62	25.62	25.62	25.62	25.62	25.62	25.62	27.08	27.08	27.08	27.08	27.08	27.08	27.08
S. Side Set Length (m)	43.04	45.10	45.91	48.21	45.10	48.21	47.84	40.35	42.26	43.01	45.15	42.26	45.15	44.80
Keycut Volume (m³)	19203	19203	19203	19203	19203	19203	19203	21234	21234	21234	21234	21234	21234	21234
Maincut Volume (m³)	44003	44003	44003	44003	44003	44003	44003	49658	49658	49658	49658	49658	49658	49658
Rehandle Volume (m³)	46817	49049	49931	52434	49049	52434	52029	43475	45528	46339	48642	45528	48642	48270
Distance 1-2 (m)	16.03	16.03	16.03	16.03	16.03	16.03	16.03	19.03	19.03	19.03	19.03	19.03	19.03	19.03
Distance 2-3 (m)	20.75	20.75	20.75	20.75	20.75	20.75	20.75	24.09	24.09	24.09	24.09	24.09	24.09	24.09
Distance 1-3 (m)	13.18	13.18	13.18	13.18	13.18	13.18	13.18	14.64	14.64	14.64	14.64	14.64	14.64	14.64
Distance 4-1' (m)	42.12	42.12	42.12	42.12	42.12	42.12	42.12	46.20	46.20	46.20	46.20	46.20	46.20	46.20

Table E.30. Results of the One Slice Two Dragline Pullback Stripping Simulation Geometry Model (Continued)

Highwall Side Dragline	8750-4							8750-5						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
H.S. Buc Capacity (m³)	65.73	65.73	65.73	65.73	65.73	65.73	65.73	82.52	82.52	82.52	82.52	82.52	82.52	82.52
S.S. Buc Capacity (m³)	85.15	69.38	79.60	65.73	82.52	58.42	83.40	85.15	69.38	79.60	65.73	82.52	58.42	83.40
H. Side Set Length (m)	31.88	31.88	31.88	31.88	31.88	31.88	31.88	25.78	25.78	25.78	25.78	25.78	25.78	25.78
Setback Distance (m)	31.72	31.72	31.72	31.72	31.72	31.72	31.72	25.62	25.62	25.62	25.62	25.62	25.62	25.62
S. Side Set Length (m)	30.12	31.50	32.04	33.60	31.50	33.60	33.35	43.04	45.10	45.91	48.21	45.10	48.21	47.84
Keycut Volume (m³)	28162	28162	28162	28162	28162	28162	28162	19203	19203	19203	19203	19203	19203	19203
Maincut Volume (m³)	66589	66589	66589	66589	66589	66589	66589	44003	44003	44003	44003	44003	44003	44003
Rehandle Volume (m³)	30335	31726	32276	33840	31726	33840	33587	46817	49049	49931	52434	49049	52434	52029
Distance 1-2 (m)	28.23	28.23	28.23	28.23	28.23	28.23	28.23	16.03	16.03	16.03	16.03	16.03	16.03	16.03
Distance 2-3 (m)	34.18	34.18	34.18	34.18	34.18	34.18	34.18	20.75	20.75	20.75	20.75	20.75	20.75	20.75
Distance 1-3 (m)	19.28	19.28	19.28	19.28	19.28	19.28	19.28	13.18	13.18	13.18	13.18	13.18	13.18	13.18
Distance 4-1' (m)	58.43	58.43	58.43	58.43	58.43	58.43	58.43	42.12	42.12	42.12	42.12	42.12	42.12	42.12

Table E.30. Results of the One Slice Two Dragline Pullback Stripping Simulation Geometry Model (Continued)

Highwall Side Dragline	8750-6							8750-7						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
H.S. Buc Capacity (m³)	58.42	58.42	58.42	58.42	58.42	58.42	58.42	83.40	83.40	83.40	83.40	83.40	83.40	83.40
S.S. Buc Capacity (m³)	85.15	69.38	79.60	65.73	82.52	58.42	83.40	85.15	69.38	79.60	65.73	82.52	58.42	83.40
H. Side Set Length (m)	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.11	31.11	31.11	31.11	31.11	31.11	31.11
Setback Distance (m)	31.72	31.72	31.72	31.72	31.72	31.72	31.72	30.99	30.99	30.99	30.99	30.99	30.99	30.99
S. Side Set Length (m)	30.12	31.50	32.04	33.60	31.50	33.60	33.35	32.13	33.61	34.20	35.86	33.61	35.86	35.59
Keycut Volume (m³)	28162	28162	28162	28162	28162	28162	28162	26982	26982	26982	26982	26982	26982	26982
Maincut Volume (m³)	66589	66589	66589	66589	66589	66589	66589	63532	63532	63532	63532	63532	63532	63532
Rehandle Volume (m³)	30335	31726	32276	33840	31726	33840	33587	32866	34381	34980	36681	34381	36681	36406
Distance 1-2 (m)	28.23	28.23	28.23	28.23	28.23	28.23	28.23	26.73	26.73	26.73	26.73	26.73	26.73	26.73
Distance 2-3 (m)	34.18	34.18	34.18	34.18	34.18	34.18	34.18	32.53	32.53	32.53	32.53	32.53	32.53	32.53
Distance 1-3 (m)	19.28	19.28	19.28	19.28	19.28	19.28	19.28	18.54	18.54	18.54	18.54	18.54	18.54	18.54
Distance 4-1' (m)	58.43	58.43	58.43	58.43	58.43	58.43	58.43	56.39	56.39	56.39	56.39	56.39	56.39	56.39

Table E.31. Results of the One Slice Two Dragline Pullback Stripping Production Simulation Model

Highwall Side Dragline	8750-2							8750-3						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Av. Key Cyc. Time (s)	60.0117	60.01169	60.00340	59.99809	59.98939	60.00682	59.99433	60.40132	60.39290	60.39951	60.38745	60.39820	60.38405	60.38983
Av. Main Cyc. Time (s)	59.9954	59.99235	59.99213	59.99465	59.99440	59.99427	59.99900	60.39405	60.39538	60.39643	60.39528	60.39572	60.39697	60.40170
Av. Reh Cyc Time (s)	73.7821	73.98400	74.40989	73.84089	74.50586	73.49626	74.53802	74.58892	73.99846	74.39983	73.85039	74.49667	73.50212	74.53587
Average Fill Factor (.00)	0.90002	0.90000	0.89998	0.90001	0.90002	0.90000	0.899998	0.90001	0.90000	0.899999	0.90000	0.90001	0.90001	0.89998
S.S. Waiting Time (s)	18909591	16967027	18275134	16029125	18503610	14536132	18764807	18221731	16185957	17684831	15314946	17961138	14001710	18379361
Scheduled Time (s)	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000
H.S. Total. Stripping (m³)	19084853	18940433	19115773	19193495	19148086	19067288	19242808	21725650	21695566	21549258	21725931	21654712	21654552	21669936
H.S. Prime. Stripping (m³)	19084853	18940433	19115773	19193495	19148086	19067288	19242808	21725650	21695566	21549258	21725931	21654712	21654552	21669936
H.S. Desir. Stripping (m³)	19084853	18940433	19115773	19193495	19148086	19067288	19242808	21173563	21173231	21174382	21173862	21173729	21173586	21172948
S.S. Total Stripping (m³)	6492195	6457725	6498332	6537378	6497744	6495628	6529464	6858124	6832209	6811719	6850681	6833943	6812565	6837663
S.S. Prime Stripping (m³)	325160	322512	325758	326444	325850	324047	327404	267587	266154	264659	265693	267321	263627	266099
S.S. Desir. Stripping (m³)	325160	322512	325758	326444	325850	324047	327404	261061	260704	260504	259915	261863	259297	260371
Desired Stripping (m³)	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571
Result	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.31. Results of the One Slice Two Dragline Pullback Stripping Production Simulation Model (Continued)

Highwall Side Dragline	8750-4							8750-5						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Av. Key Cyc. Time (s)	59.83860	59.83960	59.83370	59.83844	59.84320	59.84841	59.83929	60.49628	60.49878	60.51567	60.49969	60.50811	60.49416	60.50683
Av. Main Cyc. Time (s)	59.84230	59.83954	59.84290	59.84833	59.83974	59.83465	59.84337	60.50977	60.49286	60.49439	60.50119	60.50458	60.50432	60.49654
Av. Reh Cyc Time (s)	74.57821	74.00858	74.39107	73.82312	74.49523	73.50351	74.52708	74.58471	74.00796	74.39711	73.84238	74.49724	73.50086	74.53186
Average Fill Factor (.00)	0.90001	0.89999	0.90001	0.89999	0.90001	0.90000	0.90000	0.89999	0.90001	0.90001	0.89999	0.89999	0.90000	0.90002
S.S. Waiting Time (s)	22112812	20583869	21279300	20111975	21774560	19022140	21846790	17339409	14761943	16486595	13981197	17008122	12943387	17225873
Scheduled Time (s)	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000
H.S. Total. Stripping (m^3)	18114146	18209828	18161732	18161483	18229865	17972098	18208554	22224520	22287314	22173737	22223645	22128708	22319646	22238136
H.S. Prime. Stripping (m^3)	18114146	18209828	18161732	18161483	18229865	17972098	18208554	22224520	22287314	22173737	22223645	22128708	22319646	22238136
H.S. Desir. Stripping (m^3)	18114146	18209828	18161732	18161483	18229865	17972098	18208554	21084656	21084289	21082885	21083841	21083445	21084461	21084377
S.S. Total Stripping (m^3)	4481622	4521142	4526328	4518397	4546514	4465900	4510167	7543681	7559639	7542885	7552852	7524174	7591902	7577078
S.S. Prime Stripping (m^3)	58933	61180	59461	60802	62805	58498	59698	377763	377817	378606	377762	377552	378686	379726
S.S. Desir. Stripping (m^3)	58933	61180	59461	60802	62805	58498	59698	359602	258829	359118	357338	360429	356396	359530
Desired Stripping (m^3)	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571
Result	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.31. Results of the One Slice Two Dragline Pullback Stripping Production Simulation Model (Continued)

Highwall Side Dragline	8750-6							8750-7						
Spoil Side Dragline	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7	8750-1	8750-2	8750-3	8750-4	8750-5	8750-6	8750-7
Av. Key Cyc. Time (s)	59.50674	59.49495	59.49669	59.49664	59.49486	59.50132	59.49164	60.53529	60.52537	60.55311	60.54050	60.54076	60.53301	60.54578
Av. Main Cyc. Time (s)	59.50355	59.49767	59.50307	59.49801	59.50268	59.49967	59.49657	60.53598	60.53265	60.52855	60.53494	60.52831	60.52727	60.52967
Av. Reh Cyc Time (s)	74.58244	74.00596	74.40246	73.85109	74.49855	73.50076	74.55457	74.59101	73.99870	74.38441	73.83410	74.49824	73.50943	74.52015
Average Fill Factor (.00)	0.89998	0.90001	0.89999	0.90001	0.90001	0.90000	0.90001	0.89998	0.90001	0.90000	0.89999	0.90001	0.90000	0.90001
S.S. Waiting Time (s)	22740627	21444693	22270951	20979668	22434439	20011157	22595330	19740077	17855024	19278898	17512502	19815417	16099687	19662816
Scheduled Time (s)	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000
H.S. Total. Stripping (m^3)	16263124	16215864	16500447	16358451	16405708	16310573	16121329	22837672	22564822	22766975	22746245	22202878	22565625	22474766
H.S. Prime. Stripping (m^3)	16263124	16215864	16500447	16358451	16405708	16310573	16121329	22837672	22564822	22766975	22746245	22202878	22565625	22474766
H.S. Desir. Stripping (m^3)	16263124	16215864	16500447	16358451	16405708	16310573	16121329	21342584	21341730	21342236	21342062	21342056	21342449	21342352
S.S. Total Stripping (m^3)	4028416	4024262	4092716	4064142	4073037	4036903	3983859	5929078	5839030	5915879	5900634	5766076	5846926	5830185
S.S. Prime Stripping (m^3)	53006	54609	53704	54659	56134	52753	52677	97953	95450	96707	97128	97756	97604	95291
S.S. Desir. Stripping (m^3)	53006	54609	53704	54659	56134	52753	52677	91495	90445	90645	91252	93793	92604	90432
Desired Stripping (m^3)	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571
Result	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.32. Results of the Lower Slice Limited Extended Bench Casting with 2 Draglines Simulation Geometry Model

Upper Slice Dragline	8750-1	
Lower Slice Dragline	8750-2	8750-5
Upper Slice Bucket Capacity (m^3)	85.15	85.15
Lower Slice Bucket Capacity (m^3)	69.38	82.85
Upper Slice Set Length (m)	31.11	31.11
Upper Slice Setback Distance (m)	30.99	30.99
Lower Slice Set Length (m)	36.74	36.74
Lower Slice Setback Distance (m)	36.36	36.36
Upper Slice Keycut Right Wall Angle (°)	62	62
Lower Slice Keycut Right Wall Angle (°)	55	55
Upper Slice Keycut Volume (m^3)	9024	9024
Upper Slice Maincut Volume (m^3)	21177	21177
Lower Slice Keycut Volume (m^3)	8616	8616
Lower Slice Maincut Volume (m^3)	21463	21463
Rehandle Volume (m^3)	15985	15985
Upper Slice Distance 1-2 (m)	11.24	11.24
Upper Slice Distance 2-3 (m)	21.68	21.68
Upper Slice Distance 1-3 (m)	18.54	18.54
Upper Slice Distance 4-1' (m)	50.91	50.91
Lower Slice Distance 1-2 (m)	28.82	28.82
Lower Slice Distance 2-3 (m)	23.91	23.91
Lower Slice Distance 1-3 (m)	37.45	37.45
Lower Slice Distance 4-1' (m)	67.15	67.15

Table E.33. Results of the Lower Slice Limited Extended Bench Casting with 2 Draglines Production Simulation Model

Upper Slice Dragline	8750-1	
Lower Slice Dragline	8750-2	8750-5
Average Upper Slice Keycut Cycle Time (s)	60.60816	60.62838
Average Upper Slice Maincut Cycle Time (s)	60.59071	60.38502
Average Lower Slice Keycut Cycle Time (s)	59.98937	60.81132
Average Lower Slice Keycut Cycle Time (s)	59.99412	60.31061
Average Fill Factor (.00)	0.90001	0.89760
Total Time Spent for Upper Slice Keycut (s)	7186128	7233390
Total Time Spent for Upper Slice Maincut (s)	16781263	16819462
Total Time Spent for Upper Slice Walking (s)	1517340	1521948
Total Time Spent for Upper Slice Delays (s)	3315274	3226458
Total Time Spent for Lower Slice Keycut (s)	4969819	4942136
Total Time Spent for Lower Slice Maincut (s)	12339103	12131615
Total Time Spent for Lower Slice Rehandle (s)	6768062	6737766
Total Time Spent for Lower Slice Waiting (s)	116186	108556
Total Time Spent for Lower Slice Walking (s)	1443432	1680168
Total Time Spent for Lower Slice Delays (s)	3180117	3207496
Total Scheduled Time (s)	28800000	28800000
Upper Slice Total Stripping Time (s)	28800005	28801259
Lower Slice Total Stripping Time (s)	28816720	28807736
Upper Slice X-Direction Walk (m)	22867	22930
Lower Slice X-Direction Walk (m)	16131	18776
Upper Slice Total Stripping (m^3)	22288437	22359314
Upper Slice Prime Stripping (m^3)	22288437	22359314
Upper Slice Desired Stripping (m^3)	11659094	11659094
Lower Slice Total Stripping (m^3)	18425322	21466093
Lower Slice Prime Stripping (m^3)	13244796	15432492
Lower Slice Desired Stripping (m^3)	9832324	9832324
Desired Stripping (m^3)	21428571	21428571
Result	PASS	PASS

Table E.34. Results of the Lower Slice Full Extended Bench Casting with 2 Draglines Simulation Geometry Model

Upper Slice Dragline	8750-1	
Lower Slice Dragline	8750-2	8750-5
Upper Slice Bucket Capacity (m^3)	85.15	85.15
Lower Slice Bucket Capacity (m^3)	69.38	82.85
Upper Slice Set Length (m)	30.34	30.34
Upper Slice Setback Distance (m)	30.26	30.26
Lower Slice Set Length (m)	37.51	37.51
Lower Slice Setback Distance (m)	37.09	37.09
Upper Slice Keycut Right Wall Angle (°)	66	66
Lower Slice Keycut Right Wall Angle (°)	55	55
Upper Slice Keycut Volume (m^3)	9354	9354
Upper Slice Maincut Volume (m^3)	22138	22138
Lower Slice Keycut Volume (m^3)	7413	7413
Lower Slice Maincut Volume (m^3)	20778	20778
Rehandle Volume (m^3)	14243	14243
Upper Slice Distance 1-2 (m)	10.19	10.19
Upper Slice Distance 2-3 (m)	20.52	20.52
Upper Slice Distance 1-3 (m)	17.81	17.81
Upper Slice Distance 4-1' (m)	49.22	49.22
Lower Slice Distance 1-2 (m)	26.50	26.50
Lower Slice Distance 2-3 (m)	36.02	36.02
Lower Slice Distance 1-3 (m)	24.40	24.40
Lower Slice Distance 4-1' (m)	67.35	67.35

Table E.35. Results of the Lower Slice Full Extended Bench Casting with 2 Draglines Production Simulation Model

Upper Slice Dragline	8750-1	
Lower Slice Dragline	8750-2	8750-5
Average Upper Slice Keycut Cycle Time (s)	60.50709	60.94701
Average Upper Slice Maincut Cycle Time (s)	60.64784	60.53371
Average Lower Slice Keycut Cycle Time (s)	59.90927	60.46753
Average Lower Slice Keycut Cycle Time (s)	60.05724	60.45435
Average Fill Factor (.00)	0.89699	0.89754
Total Time Spent for Upper Slice Keycut (s)	7106497	7253486
Total Time Spent for Upper Slice Maincut (s)	16880538	16932974
Total Time Spent for Upper Slice Walking (s)	1423956	1438152
Total Time Spent for Upper Slice Delays (s)	3396166	3180941
Total Time Spent for Lower Slice Keycut (s)	4619484	4562094
Total Time Spent for Lower Slice Maincut (s)	12846267	12738554
Total Time Spent for Lower Slice Rehandle (s)	6496068	6430312
Total Time Spent for Lower Slice Waiting (s)	116549	125677
Total Time Spent for Lower Slice Walking (s)	1463868	1709400
Total Time Spent for Lower Slice Delays (s)	3271799	3245917
Total Scheduled Time (s)	28800000	28800000
Upper Slice Total Stripping Time (s)	28807157	28805553
Lower Slice Total Stripping Time (s)	28814035	28811954
Upper Slice X-Direction Walk (m)	21301	21514
Lower Slice X-Direction Walk (m)	17668	20632
Upper Slice Total Stripping (m^3)	22202935	22423497
Upper Slice Prime Stripping (m^3)	22202935	22423497
Upper Slice Desired Stripping (m^3)	12465820	12465820
Lower Slice Total Stripping (m^3)	18285697	21362145
Lower Slice Prime Stripping (m^3)	13331974	15572178
Lower Slice Desired Stripping (m^3)	9026973	9026973
Desired Stripping (m^3)	21428571	21428571
Result	PASS	PASS

Table E.36. Results of the Two Slice Two Dragline Pullback Stripping Simulation Geometry Model

Highwall Side Dragline	8750-2				8750-3			8750-5			
Spoil Side Dragline	8750-3	8750-4	8750-6	8750-7	8750-4	8750-6	8750-7	8750-3	8750-4	8750-6	8750-7
Highwall Side Bucket Capacity (m^3)	69.38	69.38	69.38	69.38	79.60	79.60	79.60	82.52	82.52	82.52	82.52
Spoil Side Bucket Capacity (m^3)	79.60	65.73	58.42	83.40	65.73	58.42	83.40	79.60	65.73	58.42	83.40
Highwall Side Set Length (m)	29.42	29.42	29.42	29.42	30.60	30.60	30.60	29.42	29.42	29.42	29.42
Setback Distance (m)	29.28	29.28	29.28	29.28	30.50	30.50	30.50	29.28	29.28	29.28	29.28
Spoil Side Set Length (m)	21.73	23.19	23.19	22.95	23.50	23.50	23.26	21.73	23.19	23.19	22.95
Keycut Volume (m^3)	14935	14935	14935	14935	16845	16845	16845	14935	14935	14935	14935
Maincut Volume (m^3)	35411	35411	35411	35411	39810	39810	39810	35411	35411	35411	35411
Rehandle Volume (m^3)	17885	19082	19082	18890	19771	19771	19568	17885	19082	19082	18890
Lower Slice Volume (m^3)	8303	8859	8859	8769	8598	8598	8510	8303	8856	8856	8769
Distance 1-2 (m)	11.14	11.14	11.14	11.14	13.75	13.75	13.75	11.14	11.14	11.14	11.14
Distance 2-3 (m)	20.19	20.19	20.19	20.19	22.69	22.69	22.69	20.19	20.19	20.19	20.19
Distance 1-3 (m)	16.84	16.84	16.84	16.84	18.06	18.06	18.06	16.84	16.84	16.84	16.84
Distance 4-1' (m)	47.58	47.58	47.58	47.58	50.56	50.56	50.56	47.58	47.58	47.58	47.58

Table E.37. Results of the Two Slice Two Dragline Pullback Stripping Production Simulation Model

Highwall Side Dragline	8750-2				8750-3			8750-5			
Spoil Side Dragline	8750-3	8750-4	8750-6	8750-7	8750-4	8750-6	8750-7	8750-3	8750-4	8750-6	8750-7
Av. Keycut Cycle Time (s)	60.22439	60.10638	59.86941	60.08897	60.10977	60.39364	60.41632	60.37476	60.71146	60.40407	60.47935
Av. Maincut Cycle Time (s)	59.86482	60.25381	59.91677	60.05822	60.63226	60.42473	60.40635	60.49018	60.41063	60.49251	60.68843
Av. Rehandle Cycle Time (s)	74.33592	73.84041	73.33205	74.67200	73.80812	73.36249	74.44291	74.32143	73.62298	73.39648	74.65091
Average Fill Factor (.00)	0.89800	0.89777	0.89833	0.89660	0.89737	0.89768	0.89820	0.89753	0.89728	0.89979	0.89700
High. Side TotalTime for Keycut (s)	7400613	7384609	7337775	7364144	7263965	7390973	7363179	7296833	7387613	7341209	7356829
High. Side Total Time for Maincut (s)	17387138	17459866	17371369	17479403	17342644	17445588	17362778	17297105	17326253	17333102	17358468
High. Side Total Time for Walking (s)	732588	732588	733500	733800	817860	825696	823188	859428	861684	862896	860640
High. Side Total Time for Delaying (s)	3292900	3264480	3373741	3226328	3397335	3149543	3254662	3347550	3228242	3286670	3236233
Spoil Side Total Time for Rehandle (s)	9322054	11289270	12615483	9034593	12106778	13596178	9616237	11055659	13240063	14839016	10612920
Spoil Side Total Time for Maincut (s)	5947138	7122392	7986422	5716188	7104958	8049352	5752055	6959856	8381607	9364646	6712287
Spoil Side Total Time for Waiting (s)	11317483	7830505	5237019	11831708	6918711	4106825	11145597	8253534	4091778	1122869	8768730
Spoil Side Total Time for Walking (s)	241440	243036	243552	246132	250776	253356	255420	283680	286380	286896	289476
Spoil Side Total Time for Delaying (s)	1985125	2356339	2733908	1975054	2440581	2806088	2034498	2248186	2803963	3210450	2428757
Total Scheduled Time (s)	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000	28800000
High. Side Total Stripping Time (s)	28813240	28841543	28816384	28803675	28821804	28811800	28803807	28800916	28803792	28823877	28812170
Spoil Side Total Stripping Time (s)	28813240	28841543	28816384	28803675	28821804	28811800	28803807	28800916	28803792	28823877	28812170
Highwall Side X-Direction Walk (m)	11003	11003	11033	11033	11506	11628	11597	12915	12945	12974	12945
Spoil Side X-Direction Walk (m)	10932	10921	10945	10949	11422	11539	11514	12844	12869	12892	12877
Highwall Side Total Stripping (m^3)	18914661	18915040	18926183	18939183	21398400	21597948	21525888	22179380	22249928	22276838	22211827
Highwall Side Prime Stripping (m^3)	18914661	18915040	18926183	18939183	21398400	21597948	21525888	22179380	22249928	22276838	22211827
Highwall Side Desired Stripping (m^3)	17552482	17554972	17554972	17554572	17934429	17934429	17933983	17552482	17554972	17554972	17554572
Spoil Side Total Stripping (m^3)	10818428	10801698	10821614	10834397	11265032	11378802	11362527	12710228	12727529	12748413	12742307
Spoil Side Prime Stripping (m^3)	4189950	4183028	4190215	4196233	4189262	4231317	4225972	4922623	4928226	4936346	4934444
Spoil Side Desired Stripping (m^3)	3918444	3919000	3919000	3918911	3543929	3543926	3543841	3918444	3919000	3919000	3918911
Desired Stripping (m^3)	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571	21428571
Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Table E.38. Results of the One Slice Two Dragline Pullback Stripping Cost Model

Highwall & Spoil Side Draglines	8750-3	8750-1	8750-3	8750-2	8750-3	8750-3	8750-3	8750-4	8750-3	8750-5	8750-3	8750-6	8750-3	8750-7
Yearly Total Owning Cost (US$)	6,325,555	6,202,136	6,325,555	6,247,847	6,325,555	6,325,555	6,325,555	6,366,694	6,325,555	6,330,126	6,325,555	6,348,410	6,325,555	6,366,694
Yearly Total Operating Cost (US$)	6,483,557	4,122,016	6,494,594	4,152,991	6,503,360	4,192,625	6,516,891	4,221,258	6,459,083	4,182,123	6,486,826	4,205,275	6,470,136	4,207,406
Yearly Total Owning & Operating Cost (US$)	12,809,112	10,324,152	12,820,149	10,400,838	12,828,915	10,518,179	12,842,446	10,587,953	12,784,638	10,512,249	12,812,381	10,553,686	12,795,691	10,574,101
Hourly Owning & Operating Cost (US$/hr)	1601.1390	1290.5190	1602.5186	1300.1047	1603.6144	1314.7724	1605.3057	1323.4941	1598.0797	1314.0311	1601.5477	1319.2107	1599.4614	1321.7626
Cost in Terms of Total Production (US$/bank m³)	0.59500	1.52001	0.59356	1.52246	0.59242	1.54401	0.59068	1.54549	0.59824	1.56227	0.59458	1.54904	0.59677	1.56350
Cost in Terms of Prime Production (US$/bank m³)	0.59500	38.5824	0.59356	39.0783	0.59242	39.7424	0.59068	39.8503	0.59824	39.3244	0.59458	40.0326	0.59677	39.7375
Cost in Terms of Desired Production (US$/ bank m³)	0.60498	39.50335	0.60550	39.94730	0.60589	40.27384	0.60652	40.69551	0.60380	40.27675	0.60511	40.62380	0.60432	40.61712
Combined Cost in Terms of Desired Production (US$/m³)	40.10832		40.55280		40.87973		41.30203		40.88056		41.22890		41.22144	

Table E.38. Results of the One Slice Two Dragline Pullback Stripping Cost Model (Continued)

Highwall & Spoil Side Draglines	8750-5	8750-1	8750-5	8750-2	8750-5	8750-3	8750-5	8750-4	8750-5	8750-5	8750-5	8750-6	8750-5	8750-7
Yearly Total Owning Cost (US$)	6,622,847	6,202,136	6,622,847	6,247,847	6,330,126	6,325,555	6,330,126	6,366,694	6,330,126	6,330,126	6,330,126	6,348,410	6,330,126	6,366,694
Yearly Total Operating Cost (US$)	6,607,892	4,239,809	6,622,847	4,274,993	6,632,785	4,324,338	6,623,684	4,344,846	6,617,626	4,317,855	6,622,642	4,333,884	6,580,532	4,329,436
Yearly Total Owning & Operating Cost (US$)	12,938,018	10,441,945	12,952,973	10,522,839	12,962,911	10,649,893	12,953,810	10,711,541	12,947,752	10,647,981	12,952,768	10,682,294	12,910,658	10,696,131
Hourly Owning & Operating Cost (US$/hr)	1617.2522	1305.2431	1619.1216	1315.3549	1620.3638	1331.2367	1619.2262	1338.9426	1618.4690	1330.9976	1619.0960	1335.2868	1613.8323	1337.0163
Cost in Terms of Total Production (US$/bank m³)	0.58052	1.37734	0.5787	1.37804	0.57750	1.39064	0.57860	1.40314	0.57934	0.40117	0.57873	1.3995	0.58389	1.41928
Cost in Terms of Prime Production (US$/bank m³)	0.58052	27.6415	0.5787	27.8517	0.57750	28.1292	0.57860	28.3553	0.57934	28.2027	0.57873	28.0884	0.58389	28.16802
Cost in Terms of Desired Production (US$/ bank m³)	0.61365	28.96419	0.61434	29.2677	0.61481	29.7393	0.61438	29.98973	0.61413	29.5678	0.61437	29.94082	0.61234	29.7765
Combined Cost in Terms of Desired Production (US$/m³)	29.57785		29.88207		30.35408		30.60411		30.18191		30.55519		30.38883	

Table E.38. Results of the One Slice Two Dragline Pullback Stripping Cost Model (Continued)

Highwall & Spoil Side Draglines	8750-7	8750-1	8750-7	8750-2	8750-7	8750-3	8750-7	8750-4	8750-7	8750-5	8750-7	8750-6	8750-7	8750-7
Yearly Total Owning Cost (US$)	6,366,694	6,202,136	6,366,694	6,247,847	6,366,694	6,325,555	6,366,694	6,366,694	6,366,694	6,330,126	6,366,694	6,348,410	6,366,694	6,366,694
Yearly Total Operating Cost (US$)	6,701,209	3,982,473	6,718,801	4,010,579	6,708,476	4,045,265	6,751,306	4,080,057	6,708,495	4,048,145	6,701,261	4,053,442	6,690,060	4,064,737
Yearly Total Owning & Operating Cost (US$)	13,067,903	10,184,609	13,085,495	10,258,425	13,075,170	10,370,820	13,118,000	10,446,751	13,075,189	10,378,271	13,067,955	10,401,853	13,056,755	10,431,431
Hourly Owning & Operating Cost (US$/hr)	1633.4880	1273.0761	1635.6869	1282.3031	1634.3963	1296.3525	1639.7500	1305.8439	1634.3987	1297.2839	1633.4944	1300.2316	1632.0944	1303.9289
Cost in Terms of Total Production (US$/bank m^3)	0.57912	1.73878	0.57705	1.74093	0.57826	1.7680	0.57328	1.75395	0.57826	1.76816	0.57912	1.77957	0.58044	1.78039
Cost in Terms of Prime Production (US$/bank m^3)	0.57912	103.9744	0.57705	107.4743	0.57826	107.2396	.057328	107.5565	0.57826	106.16505	0.57912	106.5720	0.58044	109.4661
Cost in Terms of Desired Production (US$/ bank m^3)	0.61231	108.8807	0.61312	111.41926	0.61264	111.18822	0.61466	113.87944	0.61264	110.75528	0.61231	114.14244	0.61180	112.6839
Combined Cost in Terms of Desired Production (US$/$m^3$)	109.49301		112.03238		111.80086		114.49411		111.36792		114.75474		113.29568	

Table E.39. Results of the Lower Slice Limited Extended Bench Casting with 2 Draglines Stripping Cost Model

Upper & Lower Slice Draglines	8750-1	8750-2	8750-1	8750-5
Yearly Total Owning Cost (US$)	6,202,136	6,247,847	6,202,136	6,330,126
Yearly Total Operating Cost (US$)	6,433,893	5,885,751	6,445,820	6,479,933
Yearly Total Owning & Operating Cost (US$)	12,636,029	12,133,597	12,647,956	12,810,059
Hourly Owning & Operating Cost (US$/hr)	1579.5036	1516.6997	1580.9945	1601.2574
Cost in Terms of Total Production (US$/bank m³)	0.56716	0.66457	0.56567	0.59676
Cost in Terms of Prime Production (US$/bank m³)	0.56716	0.9161	0.56567	0.8301
Cost in Terms of Desired Production (US$/ bank m³)	1.08379	1.23405	1.08481	1.30285
Combined Cost in Terms of Desired Production (US$/m³)	2.31784		2.38767	

Table E.40. Results of the Lower Slice Full Extended Bench Casting with 2 Draglines Stripping Cost Model

Upper & Lower Slice Draglines	8750-1	8750-2	8750-1	8750-5
Yearly Total Owning Cost (US$)	6,202,136	6,247,847	6,202,136	6,330,126
Yearly Total Operating Cost (US$)	6,422,477	5,889,986	6,455,401	6,463,726
Yearly Total Owning & Operating Cost (US$)	12,624,612	12,137,833	12,657,537	12,793,852
Hourly Owning & Operating Cost (US$/hr)	1578.0766	1517.2291	1582.1921	1599.2315
Cost in Terms of Total Production (US$/bank m³)	0.56860	0.66379	0.56448	0.59890
Cost in Terms of Prime Production (US$/bank m³)	0.56860	0.91043	0.56448	0.82158
Cost in Terms of Desired Production (US$/ bank m³)	1.01274	1.34462	1.01538	1.41729
Combined Cost in Terms of Desired Production (US$/m³)	2.35736		2.43267	

Table E.41. Results of the Two Slice Two Dragline Pullback Stripping Cost Model

Highwall & Spoil Side Draglines	8750-2	8750-3	8750-2	8750-4	8750-2	8750-6	8750-2	8750-7	8750-3	8750-4	8750-3	8750-6	8750-3	8750-7
Yearly Total Owning Cost (US$)	6,247,847	6,325,555	6,247,847	6,366,695	6,247,847	6,348,410	6,247,847	6,366,694	6,325,555	6,366,694	6,325,555	6,348,410	6,325,555	6,366,694
Yearly Total Operating Cost (US$)	5,985,367	4,816,313	5,985,425	4,844,763	5,987,115	4,834,086	5,989,086	4,849,924	6,463,415	4,917,885	6,494,480	4,921,490	6,483,262	4,933,271
Yearly Total Owning & Operating Cost (US$)	12,233,214	11,141,869	12,233,271	11,211,458	12,234,961	11,182,496	12,236,933	11,216,618	12,788,969	11,284,579	12,820,035	11,269,900	12,808,817	11,299,966
Hourly Owning & Operating Cost (US$/hr)	1529.1517	1392.7336	1529.1589	1401.4322	1529.3701	1397.8120	1529.6166	1402.0773	1598.6112	1410.5724	1602.5044	1408.7378	1601.1021	1412.4957
Cost in Terms of Total Production (US$/bank m³)	0.64676	1.02990	0.64675	1.03793	0.64646	1.03335	0.64612	1.03528	0.59766	1.00174	0.59358	0.99043	0.59504	0.99449
Cost in Terms of Prime Production (US$/bank m³)	0.64676	2.65920	0.64675	2.68022	0.64646	2.66872	0.64612	2.67302	0.59766	2.69369	0.59358	2.66345	0.59504	2.67393
Cost in Terms of Desired Production (US$/ bank m³)	0.69695	2.84344	0.69686	2.86080	0.69695	2.85341	0.69708	2.86218	0.71310	3.18420	0.71483	3.18006	0.71422	3.18862
Combined Cost in Terms of Desired Production (US$/m³)	3.54039		3.55765		3.55036		3.55926		3.89730		3.89489		3.90284	

Table E.41. Results of the Two Slice Two Dragline Pullback Stripping Cost Model (Continued)

Highwall & Spoil Side Draglines	8750-5	8750-3	8750-5	8750-4	8750-5	8750-6	8750-5	8750-7
Yearly Total Owning Cost (US$)	6,330,126	6,325,555	6,330,126	6,366,695	6,330,126	6,348,410	6,330,126	6,366,694
Yearly Total Operating Cost (US$)	6,591,148	5,110,831	6,602,148	5,148,690	6,606,343	5,136,337	6,596,207	5,151,023
Yearly Total Owning & Operating Cost (US$)	12,921,274	11,436,386	12,932,274	11,515,385	12,936,469	11,484,747	12,926,333	11,517,717
Hourly Owning & Operating Cost (US$/hr)	1615.1592	1429.5482	1616.5342	1439.4231	1617.0587	1435.5934	1615.7916	1439.7146
Cost in Terms of Total Production (US$/bank m³)	0.58258	0.89978	0.58123	0.90476	0.58071	0.90088	0.58196	0.90390
Cost in Terms of Prime Production (US$/bank m³)	0.58258	2.3232	0.58123	2.33662	0.58071	2.32657	0.58196	2.33415
Cost in Terms of Desired Production (US$/ bank m³)	0.73615	2.91860	0.73667	2.93835	0.73691	2.93053	0.73635	2.93901
Combined Cost in Terms of Desired Production (US$/m³)	3.65475		3.67502		3.66744		3.67536	

VITA

Bülent Erdem was born in Konya, 1965. He received his B.Sc. and M.Sc. degrees from the Mining Engineering Department of Middle East Technical University in 1987 and 1990 respectively. He has been working as a research assistant in the Mining Engineering Department of Cumhuriyet University, Sivas. His main areas of interest are surface mining, equipment selection in surface mines, computer programming and expert system development.