OPEN PIT OPTIMIZATION:
A COMPARATIVE STUDY ON THE APPLICATION OF
MOVING CONE AND LERCHS-GROSSMANN METHODS

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ABSTRACT

This engineering report compares Moving Cone and Lerchs-Grossmann optimization methods for an ultimate pit limit design. The ultimate pit limit of a gold deposit is determined by the two different methods to show what impact each method can make on the overall economics of the project.

Each block is assigned a value which represents the economic significance of the block if it is mined and processed. An economic block model consisting of 129,500 blocks, or 70 x 74 x 25 blocks in X, Y, and Z direction respectively, is used as the model framework. The economic value calculations for each block included grade, metallurgical recoveries, mining and extraction costs, commodity price (assumed constant at US$400.00/tr.oz), and the block values are expressed in US dollar. Ore, waste, and air block are defined as blocks with positive, negative, and zero economic value respectively.

Two open pit design software packages that are common in the mining industry are used for the purpose of this report: The Moving Cone (M720V1) and Lerchs-Grossmann (M720V3) programs of Medsystem developed by Mintec, Inc. of Tucson, Arizona, and the Three-D Whittle Open Pit Optimization Software (Three-D) from Whittle Programming Pty. Ltd. of Melbourne, Australia.

Bench by bench comparison of results coming from these software packages demonstrate how each pit limit method differs from one another. The significant
difference between Lerchs-Grossmann and Moving Cone method is that Lerchs-Grossmann technique mined more material with slightly higher overall economic profits than Moving Cone. The Lerchs-Grossmann method using Three-D mined 2,835 ore blocks with undiscounted net profits of $50,671,500. The Moving Cone method using Medsystem mined 2,518 ore blocks with economic return of $49,965,088. The Lerchs-Grossmann method using Medsystem mined 2,860 ore blocks with economic return of $50,787,904.
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CHAPTER 1
INTRODUCTION

Mining activity in broader perspective is an integrated operation of engineering and non-engineering activities. Engineering activities are exploration, development, construction, production, processing, and metallurgy. Non-engineering activities are financing, administration, legal, and marketing. Like many business activities, mining activities also based on common economic factors such as demand and supply, profit maximization, and economies of scale. In fact, the economic value of a mining project is the most important aspect of the overall activities unless other specific factors need to be considered.

Economic value of a mining project can be affected by many factors. Changes in market, technological advances, economic growth, political stability, and others are factors that can affect the economic value of a mining project. These factors can be strongly dependent among each others and become more complicated to the whole mining operation. For example, a relation between market changes and technological advances can be shown in a mineral supply process diagram presented as Figure 1.1. Market factors such as commodity price, demand and supply, bilateral and multilateral agreements between countries, and market expansion can affect supply and demand stability for mineral products. Technology factors such as advances in exploration, development, production, and processing, can affect the production cost of ore extraction and furthermore price of the commodity. In most cases, advances in technology
implement a decrease in the production cost while optimizing overall mining operation. Advances in technology also means improvement in exploration, production, processing, and extractive metallurgy. For example, lower grade ore can be mined economically with new mining methods such as SX/EW (Solvent Extraction / Electrowinning). New equipments such as larger and more dependable haul truck will increase productivity. Increase in commodity price and reduction of production cost will result to higher revenue, and furthermore will generate the economic attractiveness of an ore deposit, or overall mining activities.

Figure 1.1. Mineral supply process. (Hustrulid, 1993)
In general, mining operation itself consists of three major stages: planning, implementation, and production. The planning stage consists of three basic evaluation processes: concept study, preliminary study, and feasibility study. The implementation stage consists of two activities: design and construction, and commissioning. The production phase consists two activities: start up and operation. Each major stage has a level of relative ability to influencing incurred cost until production startup and operation stages initiated (see Figure 1.2).

![Figure 1.2. Three stages of mining activities with regard to their relative ability to influence cost. (Hustrulid, 1993)](image)

Figure 1.2 shows that the planning stage has the highest relative ability to influence cost, followed by the implementation and production stages. Each mine has its own characteristics to influence cost based on nature of the ore deposit, and other factors. For example, let us analyze how cost involved in Bougainville mine, Papua...
New Guinea (Figure 1.3). It shows how cost can significantly increase during the planning and implementation phases. It also shows that it is relatively easier to do cost control during planning and implementation phases than during the production or exploitation phase. Cost control can become more complicated as soon as the production or exploitation phase initiated.

Figure 1.3. Stages in the life of a mine. Relationship between planning steps during exploration, development, and expenditures preparatory to mining a large copper open pit - Bougainville mine, Papua New Guinea. (SME Mining Engineering Handbook, 2nd Edition, Vol.1,p.30)

Activities in each phase can be ramified into sub-activities due to their complexity and dependability. For example, planning phase can be broken down into
three activities: concept, preliminary, and feasibility study. Feasibility study can be broken down into sub-activities with regards to each related activity. Appendix-A shows an example of activity network for feasibility study by Northwest Mining Association (Mineral Industry Costs, p.13). Furthermore, each sub-activity can be broken down into more detailed activities. It is very important to consider all related activities which can affect the overall operation, and group it as a sub-activity for project control.

Open pit mining project basically deals with many of earth removal activities. Long term planning and scheduling of materials movement is a frequently neglected aspect in most mine planning activity. This can result for a mine to face periods of extraordinarily high strip-ratios which should be avoided. Continuous planning, scheduling, and monitoring are necessary to keep mining activities in optimal and profitable operations. A mine planner should be aware that continuous pit planning and design are two activities that executed with the operation and are very critical with regard to the economic maximization of overall mining activities.

Figure 1.4 shows the open pit mine design process which has to be iteratively done during the planning stage. It also shows that the process is rather iterative than linear. There are iterations which simply explain continuous process and outputs process in the evaluation stage. These iterations are generated due to the requirement for better and accurate database for evaluation purposes. There are possibilities where factors such as reliability of the reserve calculation and the mine optimization process reveals areas of uncertainty or lack of data. This is a situation where an evaluation process needs to be iterative. Therefore, conceptualization and mine optimization can be continuously
supported with more detailed information. Consequently, the additional information results in a new mine optimization.

Figure 1.4. Open pit mine design process. (D.J. Charbonneau, 1991)

Figure 1.5 shows parameters of mine design which are common to most open pit mining operations.
Mine design parameters can be classified into two main groups: **human** and **non-human factors**. Human factors consist of all human-related factors including economic uncertainty which is dynamic and constantly changing. Human factors determine economic parameters such as discount rates, mining costs, processing and overhead costs, as well as commodity prices. Non-human factors consist of all nature-related factors including geological uncertainty which constantly changes the more information is obtained from the deposit. Non-human factors determine technical parameters such as grade models, dilution, mine recovery, mill recovery, slope angles, densities, rock type
models, and bench heights. These parameters continuously change and dynamically affect the open pit mine design process during mine life.

Evaluation of a mining property or mining operation for purchase or financing purposes often requires quick result. Also, optimization has become an important tool in assessing risks for a new or an existing mining project. Bankers, investors and developers as well as mining engineers are recognising the importance of being able in assessing factors such as costs, prices, grades or recoveries which can affect the overall mining operation. Manual evaluation will be no longer representative although final decision making is still manually done by executives. Continuous pit design tends to be more sophisticated especially with rapid development of computer application in open pit planning and design which facilitate faster calculation using continuously updated database.

The following paragraphs discuss how professionals who are involved in mining activities perceive the business in broader perspective, starting from the importance of pit optimization in assessing risks for new and existing open pit mining projects to alternative optimization methods which can be applied for initiating the ultimate pit limit.

Pit optimization has became an important tool in assessing risks in new and existing open pit mining projects. Bankers, investors and developers as well as mine managers and mine planners realize the importance of being able to analyze the effects of changes which several factors such as costs, prices, grades or recoveries will have on the location and size of open pits. Figure 1.6 shows an example of considerations which
generally come from professionals who are involved in open pit mining activities.

**BANKERS/AUDITORS/DEVELOPERS:**
- If the reserves vary up or down by 15% how will affect minable reserves and property value?
- What if my pit slopes were 5 degrees steeper. How much should I invest in a geotechnical program?
- What if metal prices fall by 5 percent?
- How much can I invest in metallurgical studies which may improve recoveries by 3 percent?
- If I improve oxide ore recovery and final sulphide ore recovery is poorer than expected, how will this affect my cashflow and how will it affect economic pit limits.
- Will changing cutoff grades improve my property values and if so by how much?
- Could run of mine heap leaching substantially affect the life of the property or the profitability - if so by how much?

**MINE MANAGERS:**
- Can I defer any waste mining until later?
- Should I install cable bolts or flatten the slopes?
- Is my mine being extracted in its optimum sequence?
- Is the long term material’s movement schedule developed in detail on a flitch by flitch basis?
- It will cost $1.3 million to move that road and pipeline to expose more ore - is it worth it?

**MINE PLANNERS:**
- Is my sequence of mining practical?
- Where will I be mining 4 months from now and what will my pit look like?
- Can I meet my targets with current equipment or do I need to change the fleet size?
- Are my temporary ramps well sited?
- What if my ramps were 1 in 8, how much waste mining would this save?

Figure 1.6. Professionals’ considerations while conducting an open pit mining business. (adapted from Stewart, D.H. in Vogely, 1991)

Ideally, an open pit operation should fulfil all professionals’ needs and considerations. In reality, this situation is rarely attained although approaches can be done. It is very important to understand that the basic concept of an open pit mining activity is similar to other businesses which is maximizing economic value of the property or maximizing net present value (NPV) of the property.

Figure 1.6 also shows that these considerations come from all factors and actors within an open pit mining property. For example, changes in reserve is a result of an exploration activity and economic activity such as changes in prices and costs. The more active an exploration activity is, the more precise reserve calculation is, which will
also affect the design and life of the mine.

This context will be more complicated if we view an open pit mine operation in more macroeconomic perspective. Figure 1.7 shows the big picture of mineral model used by most econometrician to assess relationship between all factors within mining activities which we can also use for our purpose in open pit mining.

![Diagram of basic econometric mineral model](image)

Figure 1.7. Basic econometric mineral model. (adapted from Labys, W.C., et.al. in Vogely, 1985)

The most important aspect that we have to consider to approach open pit design
from Figure 1.7 is the commodity price. According to Figure 1.7, prices have interdependency relations to world’s demand, supply, and inventories. We will not assess Figure 1.7 in detail since we are not focusing an open pit mine from econometrician’s point of view. It is important for a mine planner to understand this concept, because commodity price fluctuations are real and will affect the open pit design process significantly. Forecasted commodity price ranges are important to be considered in mine planning and design.

Interactive relations between professionals who are involved in open pit mining activities are important. Professionals should realized that everybody is important to be involved in mine planning and design: technical and non-technical. For example, engineers with technical view conduct the open pit mine design while financial people support them with price forecasting of the commodities. Ideally, this interaction should be a continuous process to gain optimization and to fulfil everybody’s needs.

This situation shows that professionals who are involved in mining activity has to consider how the big picture works instead of scrutinizing it based on their own interests. For example, an open pit mine planner has to realize that a mine planning is a dynamic and continuous processes with regard to changes and the need for maximum net present value. Figure 1.8 shows how mine planner can establish alternatives for final pit limits based on various price scenarios.
Each price scenario gives an impact to how revenues, capital and operating costs, and risks will be involved in the property. Higher commodity price will give opportunity for a mining company to mine bigger pit size and access to deeper orebody. Mining expansion will result to higher capital and operating cost. Otherwise, mining expansion will result to higher revenues and profits. Lower commodity price may result a cutback in production, or in worst case is to close the mining operation or to sell the property to other party who will take the risk. Again, mine planner has to be aware of all aspects which might affect mining operation and know how to put them in long term project planning although simplifications have to be done in order to effectively establish a pit design.

Another example, professionals also have to consider mining sequences in order to gain more detail and accurate design for practical purposes. This will also support the
need to maximize Net Present Value of the property, because the dollar we have today is different from the dollar that we are going to receive or spend in a year’s time.

There are many financial aspects which have to be considered when scheduling an open pit operation. For example, it is critical to understand how delays can affect the overall operation, and furthermore the value of the mine. Delayed revenue may increase our need to borrow funds and pay interest, while delayed expenditure may reduce our need to borrow funds and pay interest. This situation will result to ineffective revenue and expenditure which may increase another risk factor of the overall mining operation.

It is clear that ultimate pit design is the most important activity in the planning and implementation stage with regard to open pit mining activities (see Figure 1.5). The pit design process itself is an complicated task. There are many methods and approach to establish an ultimate pit design with objective of maximizing the economic value of overall mining activities. The most common algorithm which are currently used to define the ultimate pit limits by mining industry is Moving Cone and Lerchs-Grossmann techniques. These methods define the limits of an open pit mine by maximizing the undiscounted profits while ensuring slope stabilities.

This engineering report compares Moving Cone and Lerchs-Grossmann optimization methods for an ultimate pit limit design. The ultimate pit limit of a gold deposit is determined by the two different methods to show what impact each method can make on the overall economics of the project.

Two open pit design software packages that are common in the mining industry are used for the purpose of this report: Moving Cone (M720V1) and Lerchs-Grossmann
(M720V3) programs of Medsystem developed by Mintec, Inc. of Tucson, Arizona, and the Three-D Whittle Open Pit Optimization Software (Three-D) from Whittle Programming Pty. Ltd. of Melbourne, Australia.

This engineering report consists of six chapters: *Introduction, Background, The Application of Moving Cone Optimization Method, The Application of Lerchs-Grossmann Optimization Method, Comparative Analysis of Moving Cone and Lerchs-Grossmann Optimization Methods, and Conclusions*. Chapter two explains the background theory for open pit optimization, Moving Cone method, and Lerchs-Grossmann method. Chapter three explains the application of Medsystem (M720V1) for Moving Cone method; the results and analysis for an existing mine data. Chapter four explains the application of Three-D (LG3D) and Medsystem (M720V3) for Lerchs-Grossmann method; the result and analysis for an existing mine data. Chapter five consists the comparisons between results and analysis using Moving Cone and Lerchs-Grossmann techniques for similar existing mine data. Chapter six concludes the results and analysis of Lerchs-Grossmann optimization techniques, comparisons to Moving Cone technique, and how mining companies can utilize Lerchs-Grossmann technique to support better open pit planning and design.
CHAPTER 2
BACKGROUND

The task for a mining engineer who works on mine planning and design, after a mineral deposit with a significant economic potential has been discovered is how to mine and process that orebody in a way that maximizes the net present value (NPV) or economic value within a practical operating format, or within economical and technical limitations.

In general, the biggest challenge facing mine planners who must recommend mine plant size, equipment selection, and long-range scheduling is how to optimize and maximize a property not only in terms of technical efficiency but also along the project life. The above statement refers to a condition that mine planning and design is a continuous process along the mine life.

There are lots of data which can be assessed with regards to open pit mine planning and design. To simplify the discussion on pit optimization theories, assume that the data are acceptable and provide at least the following categories of information and guidelines:

- detailed drillhole data
- mineral and waste inventory
- geology, hydrology, and geotechnical criteria
- topographic layout, including property boundaries
- metallurgical flowsheet, recovery, and design criteria
- access, water and power information
- environmental baseline data, and
- financial criteria (minimum rate of return, payback period, etc.).

These data are common in mining database. Most mining companies gather and update these data continuously. Updated data is very important for mine planning because it affect calculation, and furthermore the final design.

A basic understanding of open pit geometry has to be understood before accessing a pit design. Figure 2.1 shows the basic geometry of a pit. An active pit consists of several working benches and several ramps and roads to bring equipment in and take the ore out of the pit.

Figure 2.1. Section through an open pit design. (adapted from Fourie and Dohm, in Hartman, 1992)

The main purpose of pit design optimization with respect to open pit geometry is to construct the best possible pit within a mineral inventory (see Figure 2.2). The best
possible pit means the most economical, safe and minable pit with extractive activities such as drilling, blasting, loading, and hauling within technology and economic limitation, or a practical operating format.

Figure 2.2. Mineral inventory, minable material, and pit limit. (Hustrulid, 1993)

2.1. Open Pit Limit Design

A typical approach in open pit design is to model the pit shape similar to the shape of frustum (see Figure 2.3). The shape of frustum is common to pit design due to the importance of accessibility to get into the ore and transport it throughout the pit. This shape is not fixed since a final design should included the most profitable alternative.
designs based on physical occurrence of the ore deposit. Symmetrical or asymmetrical shape of frustum approach can be found in pit design, and basically depends on the best economics value (see Figure 2.4).

![Figure 2.4. Symmetric(a) and asymmetric(b) frustums.](image)

A block model to analyze the economic value of an ore deposit is very important. The block model approaches the orebody by dividing the orebody into blocks; each block has its own economic value. The economic value of an ore deposit is generally evaluated using a monetary or dollar value rather than a technical value. A block's value represents the economic value of a block if it is mined or extracted. Figure 2.5 shows the block model approach to determining the value of an ore deposit using block model.

Block model is very common in the mining industry, and a very important tool to evaluate economic value of the ore and the extraction or production process. A grid of blocks is assigned to an ore and waste for open pit design purposes. Figure 2.6 shows frustum shape design when imposed to the block model.
A frustum shape is commonly used to analyze the block model and define the ultimate pit. This shape is considered to be a good way to approach open pit mining operation because it considers the basic open pit framework for accessing ore from the surface.

This frustum shape basically represents top and bottom pit and overall pit slope. An overall pit slope is calculated by using geological and geotechnical analysis of rock, waste, and ore properties. Also, a symmetrical frustum is commonly used due to its simplicity and compatibility for further analysis, calculation, and computer application.
Economic evaluation of the orebody starts from calculating value of future working area which also includes waste and overburden removal activities. Common economic calculation to measure the economic value of an activity is:

\[
\text{Profit} = \text{Revenue} - \text{Cost} \quad \ldots \quad (2.1.)
\]

Maximizing the total undiscounted value of the blocks mined is the main consideration of decision making process in open pit design.

Revenues come from commodity’s quantity sold in at market price. Costs come from all aspects of mining activities such as production costs (mining, milling, and general and administration), amortization and depreciation, treatment, refining, selling, smelting, and shipment or delivery. These costs vary by location, time and mining method. A mine planner should be aware of including all necessary costs which can affect the whole project.

Maximizing profit along the project lifetime is very important for a mining engineer who is working with mine plan and design since economy, technology and the market tend to change continuously. Economic changes might mean an increase or a decrease of fund availability, while technological changes mean new invention in technology can develop more effective methods of mining. Market changes generally mean increases, decreases, or fluctuations of demand and supply, commodity price, trade policy and barrier. Revenues and costs are together calculated together and translate into one economic value which can be used to analyze the block model in order to establish
the ultimate pit design. Generally, the economic value of a block expresses the monetary value consequences if mining initiated. A positive block value means economic profit, and negative value means economic loss. A mine planner assigns this economic value to each block; then analyzes and evaluates the block model to establish the ultimate pit for the minable area (see Figure 2.7).

Figure 2.7 shows the first stage of evaluating a block model of an ore reserve for the open pit mine design purpose. Based on ore deposit condition, the observation area divided into two major areas: ore and waste. Let us assume that the value of ore is +16 and waste is 0, and cost of mining a block is -4.

\[
\text{ORE: } (+16 - 4) = +12 \\
\text{WASTE: } (-4)
\]

Figure 2.7. Valuing ore and waste in the economic block model.

The value of waste basically equal to zero since there is no economic value of it. The (−4) is the cost of mining a block. The ore value is (+16)+(-4) or +12 because the mining cost of a block is (-4). Figure 2.8 shows 2-D economic block model for the section.
Another representation of a block model is three dimensional economic model. The three dimensional model basically similar to the two dimensional except is more complicated in calculation, analysis and optimization (see Figure 2.9). Computer application is strongly recommended for three dimensional economic block model.
Most pit optimization software uses three dimensional block model. Blocks are identified by ID# or specific formulas so it can be located within model framework. Two open pit optimization software which will be used in this report; Medsystem Open Pit Optimization Software from Mintec, Inc. and Three-D Whittle Open Pit Optimization from Whittle Programming Pty. Ltd. uses 3-D economic block models.

The following discussions will focus on how pit optimization processes done on a 3-D block model by using Moving Cone and Lerchs-Grossmann algorithms.

2.2. The Moving Cone Method

Mathematically, the block model analysis to construct the ultimate economic pit limit is done under the objective of undiscounted profit maximization. The optimal pit limit when determined has the maximum undiscounted economic value.

The first and still acceptable pit optimization method using computer is the moving cone or floating cone. The algorithm was developed to float or move a fixed frustum within the block model framework. The shape of the frustum based on the assumptions for slope angle and minimum pit bottom width.

This frustum moves or floats within the block model framework from left to right, and begins from top row down to bottom. The floating process stops when reaching positive block value and calculate the total value of the frustum. If the summation of blocks within frustum is positive, these blocks will be mined. Otherwise, the frustum will move to the following blocks until it reach positive value. This repeated process will be done after reaching the bottom row of the block model.
An easy example to explain how the ultimate economic pit limit design done by moving cone is by taking an example of a simple two dimensional block model.

Figure 2.10 shows an example of moving a fixed frustum along blocks. Figure 2.11 shows an example of changing size of a frustum within valued block model, and Figure 2.12 is the combination of changing sizes and moving the frustum.

![Cone Movement Diagram]

Figure 2.10. Moving a fixed cone along blocks to reach the ultimate pit limit.

The theory associated with the moving cone technique consists of three basic principles: economic block evaluation, removal increment selection, and pit limit generation (Suriel, 1984).
Figure 2.11. Changing sizes of a cone within blocks to reach the ultimate pit limit.

Figure 2.12. Combining movement and changing sizes of a cone to reach the ultimate pit limit.

2.2.1. Moving Cone Method: Example #1

Figure 2.8 shows the economic block model which will be used as an example of moving or floating cone application to a two-dimensional section of an economic
block model to define the ultimate pit limit. This block model will be used for explaining the three optimization theories to find the ultimate economic pit limit design in the paper.

A frustum shape should be considered to apply the moving or floating cone method in order to generate the ultimate pit limit. Another important consideration is realizing the open pit mining sequences which starts from the surface through the bottom of the pit. There has to be some blocks extraction chosen to initiate the open pit mining operation. The best blocks removal that initiate open pit mining activities is the most total economic value of some blocks configuration.

Open pit mining activities can not avoid the extraction activities of ore or waste. It is very important to consider the concept that to extract a certain block in open pit mining, accessibility of all equipment and operation has to be properly designed and planned. This condition means that activities of moving other blocks has to be done in order to extract the targeted block. Economic and technical feasibility study and analysis is very important to be done with respect to the necessity of maximizing economic profit of overall open pit mining operation.

The first step is to establish a frustum along the surface to obtain maximum economic results. Figure 2.13 shows the best possible pit to extract the first two rows. The total economic value of this pit is (-4)+(+12)+(+12)+(+12)+(+12)+(-4)+(-4)+(+12)+(+12)+(+12)+(-4)+(+12)+(+12)+(-4) or +68. Therefore, open pit mining activities can be done for the first row because they will result in a profit of +68.

The next step is to expand the first pit outline based on providing the maximum
economic value (see Figure 2.14). Figure 2.14 shows the best possible pit to extract the first three rows. Total economic value of this pit is 

\((-4) + (-4) + (12) + (12) + (12) + (-4) + (12) + (-4) + (12) + (12) + (-4) + (12) + (-4) + (12) + (12) + (-4) + (12) + (12)\) or +84.

Another possibility is expanding the first pit to a best possible following pit. Then, the total economic value is 

\((-4) + (-4) + (12) + (12) + (12) + (12) + (12)\) or +16.

Open pit mining activities can be done to extract ore from row-3 at economic value profit.

The floating or moving process of a frustum or a cone along the block model to find maximum economic value of a pit outline is the basic approach of the moving or floating cone method. This process will stop if there is no more possible way to find any positive value. The floating cone method of open pit mine design helps the mining engineer on detecting the general open pit design.

Figure 2.15 shows the final ultimate pit design using the moving cone method. The total economic value of the final outline is +124. A symmetrical frustum or cone shape of final pit outline shows the result of the whole moving or floating processes. The final pit outline is based on constant economic value; assuming that there will be no internal or external forces which can change the block value.
An example of external force which can change the economic block value is changes in commodity price. An example of internal force is changes of managerial decision. These two forces basically affect the economic block values of the block model. Changes in economic value can affect the whole mining process, and in particular the design of ultimate pit.
Although it is difficult to follow all changes which can affect the block’s economic value, a decision has to be made based at the time the block analysis is analyzed. A mine planner has to put a range of value which can be tolerated due to possible changes.

Figure 2.15. Moving cone method after floating six rows. (Hustrulid, 1993)

2.2.2. Moving Cone Method: Example #2

The first row shows that the only positive economic values are in column-6 with a value of +2 (see Figure 2.16). A pit can be generated in order to extract this block from the model since it will give a positive value to the mining operation (Figure 2.17). There is no requirement to move other blocks to get this block, so this block can be moved without any other economic value influence. Column-7 can be put aside because there is no positive value in the column and will also be easier to analyze following rows.
Row-2 will be the next step because there are no more positive economic value in row-1 (see Figure 2.18). There is one positive value in row-2 and column-4 which is +6. In order to access this block, overburden blocks in column 3, 4, and 5 on row-1 have to be removed first (see Figure 2.19). These blocks are the only access way to reach and extract the block in column-4, row-2.

The removal of overburden and effect of waste gives a big impact to the economic value of the ore and all the mining activities. The total value to mine and
extract this positive block in row-2 will be \((-1)+(-1)+(-1)+(6)\), or equal to +3. This means that mining activities to extract the block in column-4 of row-2 can be done because it has a positive economic value. A positive value is important for every decision to mine a valuable block. A positive value means a positive economic result of extracting a valuable block. It also means that to reach a +3 of economic value, the mining activities of removing -3 of overburden and +6 of ore economic values has to be done.

<table>
<thead>
<tr>
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<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>+8</td>
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</table>

Figure 2.18. Extraction of positive block in row-1.

<table>
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<td>2</td>
<td>-2</td>
<td>-2</td>
<td>+6</td>
<td>-2</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>+8</td>
<td>+2</td>
<td>-2</td>
<td></td>
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</table>

Figure 2.19. Possible pit in row-2.
The extraction of block in row-2, column-4 gives a positive economic value and is profitable. Therefore, mining activities will result in economic profit result. Figure 2.20 shows the extraction of block in row-2, column-4 which also lead to the next possible pit generation (row-2)

![Diagram of extraction](image)

Figure 2.20. Extraction of row-2, column-4.

There are two positive economic values in row-3, which are +8 and +2. In order to extract these two blocks, it is a requirement to remove two blocks in row-1 (column-1 and 2) and three blocks in row-2 (column-2, 3, and 5). The extraction of column-4 in row-3 will not give any positive value since to extract this block will only give (+2)+(-2), or 0 in economic value (see Figure 2.21).
Therefore, the development of the next possible pit can be established by summing the economic value of every block which will involve mining activities to extract column-3 row-3. The economic result of developing the next possible pit for extracting this block is $(-1)+(-1)+(-2)+(-2)+(+8)$ or $+2$ (see Figure 2.22).

The pit design for extracting profitable block in row-3 will give overall pit after extracting all profitable blocks (see Figure 2.23). This overall pit is also known as the
final pit (see Figure 2.24) after extracting column-3 in row-3. This final pit can also be used as a tool to trace the whole operation from the beginning which also express the ultimate pit limit design.

Figure 2.23. The final pit after extracting block in row-3.

The final pit will not be the final design for the whole mining operation. The initial pit limit design is based on current technology and economic situation and limitation. Improvement in technology will reduce extracting cost and increase production and efficiency. Economic improvement will generate more capital and possible new mining investment. Mining engineer who works with mine plan and design has to be aware of external and internal forces which can change the initial plan and design since it will affect the operation profitability. An example is shown by calculating and analyzing the simple two dimensional block model below. Some variation of economic block value will result in some variation of the final pit limit.

The total economic value of the whole pit is (-1)+(-1)+(-1)+(-1)+(-1)+(+2)+(-
2) +(-2) +(+6) +(+8), or +7. This means that the whole operation can be done with +7 in economic value after extracting the last block in row-3.

\[
\begin{array}{ccccccc}
1 & 2 & 3 & 4 & 5 & 6 & 7 \\
\hline
(1) & -1 & -1 & -1 & -1 & +2 & -1 \\
(2) & -2 & -2 & +6 & -2 & -2 & \\
(3) & +8 & +2 & -2 & & \\
\end{array}
\]

Figure 2.24. The ultimate pit limit.

2.2.3. **Shortcomings to Moving Cone Method**

There are positive and negative considerations in Moving Cone technique. One of the positive considerations of Moving Cone technique is its simplicity which account of its widespread use and popularity (Hustrulid, 1993). Development and implementation of a moving cones computer program does not require sophisticated knowledge in operations research or computer science. The moving cone technique can be used with generalized pit slopes. This method also provides highly useable and sufficiently accurate results for engineering planning (Barnes, 1982).

There are however two major problems with the Moving Cone method. It may miss profitable combinations of blocks, and it may overextend the ultimate pit beyond
optimal limits (Barnes, 1982).

The first consideration is the problem of missed positive blocks within the model. This situation occurs when ore blocks which are investigated individually can not justify the removal of the necessary overburden. Instead, combinations of these ore blocks with overlapping cones are profitable. We will use Figure 2.25 as an example to discussing this problem.

Figure 2.25. Two dimensional block model.

There are two possible pits which can be generated. Figure 2.26 shows these possibilities. Total value of each scenario is -1 which means that the configuration can not be mined at profit. Consequently, no mining can be conducted for this block model. Actually, a combination of overlapping cones will make this block model minable (see Figure 2.27).
The second consideration is an overextending blocks configuration beyond the optimal pit tends to include non-profitable configuration into the pit design. Figure 2.28 shows problem which arise from the above situation.
The most complicated consideration is when both problems occur simultaneously. Figure 2.29 shows steps for generating pit limit; starting from block model until it reached the third incremental cone with a total value of +1. Apparently there is one possible configuration which generate more value. Figure 2.30 shows the ultimate pit limit with a total value of +2.

The above considerations put the moving cone open pit optimization method in a situation which more development in computer coding to reduce its occurrences. The following discussion will focus on the application of Lerchs-Grossmann 3-D dynamic programming approach for open pit mining optimization.
Figure 2.29. Steps for moving cone optimization method.

Figure 2.30. The ultimate pit limit (value = +2).
2.3. The Lerchs-Grossmann 3-D Method

Lerchs-Grossmann algorithm is one of methods that overcomes the shortcomings of Moving Cone Method. Other optimization techniques will not be discussed in this report since Lerchs-Grossmann method is the most widely used algorithm in the industry.

The following is an overview of Lerchs-Grossmann optimization method. The algorithm first proposed by Helmut Lerchs and Ingo F. Grossmann in their paper titled "Optimum Design of Open-Pit Mines" in 1965. This method is based on three assumptions: the type of material, its mine value and its extraction cost is given for each point, restrictions on the geometry of the pit are specified (surface boundaries and maximum allowable wall slopes), and the objective is to maximize total profits which is total value minus total extraction costs. Figure 2.31 shows the idea proposed by Lerchs-Grossmann in graphical representation.

![Figure 2.31](image)

\[
\begin{align*}
    v(x,y,z) &= \text{value of ore per unit volume} \\
    c(x,y,z) &= \text{extraction costs per unit volume} \\
    m(x,y,z) &= v(x,y,z) - c(x,y,z) = \text{profit per unit volume}
\end{align*}
\]

Figure 2.31. Specified point with economic value.
The maximizing problem is approached by a mathematical method which basically the integration of the whole profit per unit volume values within a specified area of observation. A mathematical approach to this problem is:

\[ \int_{V} m(x,y,z) \, dx dy dz \]

where \( V \) is the family of volumes corresponding to the family \( S \) of surface.

The objective of Lerchs-Grossmann approach to open pit mine design is to explore alternatives in pit design, given a real or a hypothetical economical environment (market situation, plant configuration, etc.) by simulating a block model of an area of observation. This approach also uses the basic of dynamic programming for two dimensional pit analysis and graph algorithm for three dimensional pit analysis.

Computer simulation to open pit mine design and optimization is needed to conduct more complex calculation and analysis. There are few open pit limit optimization programs in the market using the Lerchs-Grossmann approach. An optimization program called the Three-D Whittle Open Pit Optimization Software by Whittle Programming Proprietary Limited will be used to representing Lerchs-Grossmann optimization for this report. Data gathering, processing, calculation, simulation, and analysis will be formatted to accommodate this software configuration and method.

This method approaches a block model by realizing that there are two basic geometry of interest for approximating an open pit on an orthogonal set of blocks. These
are: the 1-9 pattern (see Figure 2.32) and the 1-5 pattern (see Figure 2.33). The 1-9 pattern means that 9 blocks have to be removed to gain access to one block on the level below. The 1-5 pattern means that 5 blocks have to be removed to gain access to one block on the level below.

Figure 2.32. The 1-9 pattern.

It is common to define a block as a node with regards to simplification for mathematical and graphical approach and explanations.

Figure 2.33. The 1-5 pattern.
The important process in Lerchs-Grossmann 3-D is the development of network between nodes based on the above patterns. Generation of network starts from bottoms toward up in three dimensional framework. Computer application for arc generation basically controlled by determined overall slope, number of benches to be considered, and economic value of blocks.

2.3.1. **Steps of the Lerchs-Grossmann Method**

First, it is important to understand the arc definition. Dagdelen (1994) simplifies the definition of arc as follows:

- An arc is a "p" arc if it is going away from the root.
- An arc is a "m'" arc if it is going towards the root.
- A "p" arc is strong (s) if it supports a positive mass, and weak (w) it supports a null or negative mass.
- A "m" arc is strong (s) if it supports a null or negative mass, and weak (w) if it supports a positive mass.

The mass of a "p" arc is the sum of all nodes that a given "p" arc is pointing to. The mass of a "m" arc is the sum of all nodes that a given "m" arc is leaving behind.

A general algorithm of Lerchs-Grossmann method can be given as follows (Dagdelen, 1994):

- **Step-0** Initialization process, which includes the process of connecting all nodes to the root and label the arcs.
- **Step-1** Connect nodes which are related to the root by strong arc to other
nodes that must be removed in order to mine this strong block. When the connection is made, eliminate the strong arc going to the root for this node.

Step-2 Re-label the arcs.

Step-3 Normalize the tree. Root \( x_0 \) must be common to all strong edges. If not, then:

- Replace the strong p-edge \( (x_k - x_L) \) with a dummy arc \( (x_0 - x_L) \).
- Replace the strong m-edge \( (x_Q - x_R) \) with a dummy arc \( (x_0 - x_Q) \).

Step-4 Go to step-1 if there is a node that overlying a node which connected to the root by a strong arc. Otherwise stop.
2.3.2. **An example to Lerchs-Grossmann Algorithm**

Following is an example of Lerchs-Grossmann algorithm using Figure 2.25 as a 2-D representation of a block model. Assuming 45° slope angles, this example will show how Lerchs-Grossmann algorithm overcomes the multiple support problem of Moving Cone algorithm.

Lerchs-Grossmann algorithm uses nodes to represent the blocks of the economic block model (see Figure 2.34). There are three strong nodes which are \( x_1 (+9) \), \( x_6 (+1) \), and \( x_3 (+9) \) to be evaluated in this example.

![Figure 2.34. The economic block model as nodes.](image-url)
The development of arc structure starts by connecting each node to the root, and labelling all arcs as discussed previously (see Figure 2.35).

Following are steps of finding the ultimate pit limit, that gives the maximum economic value subject to slope constraints. The process starts by connecting strong nodes to weak nodes, which represent waste blocks to be mined in order to extract ore blocks, and labelling the arcs. The process stops when all the ore block are evaluated. Figures 2.36 to 2.50 show step by step arc development and labelling process in reaching the optimum ultimate pit limit solution.
Figure 2.36. Arc generation from $x_6$ to $x_{11}$. The process stopped since connection to the root is weak (p-w) with a value of 0.

Figure 2.37. Arc generation from $x_1$ to $x_4$. Connection to the root is strong (p-s) with a value of +7.
Figure 2.38. Arc generation from $x_1$ to $x_9$. Connection to the root is strong (p-s) with a value of +5.

Figure 2.39. Arc generation from $x_1$ to $x_9$. Connection to the root is strong (p-s) with a value of +4.
Figure 2.40. Arc generation from $x_i$ to $x_{10}$. Connection to the root is strong (p-s) with a value of +2.

Figure 2.41. Arc generation from $x_i$ to $x_{11}$. Connection to the root is strong (p-s) with a value of +1.
Figure 2.42. Arc generation from $x_6$ to $x_i$'s closure. Connection to the root is strong (p-s) with a value of +2.

Figure 2.43. Arc generation from $x_1$ to $x_{12}$. The process is stopped since connection to the root is weak (p-w) with a value of 0.
Figure 2.44. Arc generation from $x_3$ to $x_8$. Connection to the root is strong (p-s) with a value of +7.

Figure 2.45. Arc generation from $x_3$ to $x_7$. Connection to the root is strong (p-s) with a value of +5.
Figure 2.46. Arc generation from $x_3$ to $x_{15}$. Connection to the root is strong (p-s) with a value of +4.

Figure 2.47. Arc generation from $x_3$ to $x_{14}$. Connection to the root is strong (p-s) with a value of +2.
Figure 2.48. Arc generation from $x_3$ to $x_{13}$. Connection to the root is strong (p-s) with a value of +1.

Figure 2.49. Arc generation from $x_3$ to $x_{12}$. Connection to the root is strong (p-s) with a value of +1.
Figure 2.49 concludes the optimization process since there are no more nodes within the block model. The ultimate pit limit is generated with a cumulative weight of +1 (see Figure 2.50).

Figure 2.50 shows the ultimate pit limit outline of the economic block model, which is also the maximum closure. This figure also shows the evidence that Lerchs-Grossmann overcomes the multiple support problem in Moving Cone.

A similar process also used for three dimensional block model which make Lerchs-Grossmann algorithm become more complicated. Tedious process of Lerchs-Grossmann algorithm results in a more difficult task of computer programming and significantly longer computer time.
2.3.3. Three-D Implementation of Lerchs-Grossmann Method

As discussed in previous chapters, we will be focusing more on Three-D Whittle Open Pit Optimization Software. It means that we will only consider Lerchs-Grossmann pit optimization method for our economic block model. Three-D Whittle Open Pit Optimization Software uses Lerchs-Grossmann method to optimizing the block model. The processes involving two important inputs: the required mining slopes and the value in monetary units (dollars) of each block once it has been uncovered.

The required mining slopes will give the information of the overall mining outline through orebody which projected open pit mining operation will be conducted. Practically, we are considering the overall pit slope. Lerchs-Grossmann method analyzes each block details, identify what other blocks must be removed to uncover it, and construct list of pairs of block known as structure arcs. Structure arcs show that if the first block in the pair is to be mined, then the second must be mined to uncover it. The value in monetary units (dollars) of each block gives the information of the economic value for each block in the model.

Lerchs-Grossmann method construct a list of related blocks in the form of branches of a tree. "Strong" branch shows if the total of their block values is positive, while other is "weak" branch. The process continues from a strong branch to a weak branch until it reach the maximum value of structure arcs combination. This condition means that blocks in all the strong branches taken together to establish the optimum pit.

Following is graphical explanation of the way Three-D Whittle Open Pit Optimization Software does the optimization. Figure 2.51 shows the concept that
wherever a block is mined, the three immediate blocks above it also mined.

Figure 2.51. Basic approach for extracting a block in open pit mining.

Figure 2.52 shows an example of a block model for which will be optimized by Three-D. We will use two dimensional block model for the purpose on explaining how Three-D works. There are three positive blocks on the bottom of the model framework. Assume that the assign values for this three blocks are 23.9, 6.9, 23.9. Other blocks are negative with assigned value of -1.

Let us start the arcs construction process with the right positive block. There are three immediate blocks above this block which has to be removed in order to extract it. Next is, we flag these four blocks by connecting it with a straight line. Consequently, the value of the positive block is not 23.9 but 23.9+(-1)+(-1)+(-1) or 20.9.
It will be the similar way for the centre and right positive block. New values for these arcs are 3.9 and 20.9 (see Figure 2.53).

We will continue with the left positive block by adding another three arc starting from three possible starting blocks. There will be no arc toward up left developed from the centre and right starting point because there is nothing to resolved. The new value is 20.9+(-1)+(-1)+(-1)+(-1)+(-1) or 15.9 (see Figure 2.54).
Figure 2.54. Arc development for left positive block. (Whittle Programming Pty., 1992)

The centre positive block has two possible arc which can be initiated from upper left and one from upper centre blocks. The new value is $3.9 + (-1) + (-1) + (-1)$ or 0.9 (see Figure 2.55).

Figure 2.55. Arc development for centre positive block. (Whittle Programming Pty., 1992).

There is an interesting arc development which can be seen in this scenario. It is a possibility of grouping centre and right positive blocks. Both can be work together as one system. Problem is, right positive block will end of paying more when the centre
positive block starts to develop another arc (see Figure 2.56). It will be better if both not grouped, so right positive block can expand more toward the top level. Also the centre positive block will stop on expanding arcs after it reach negative value of -0.1 (see Figure 2.57).

After grouping, arc development will cost -1 for the new group which basically paid by the right positive block.

If grouped, new value for right positive block is $20.9 + 0.9 + (-1)$ or 20.8.

Figure 2.56. Possible grouping situation.
Figure 2.57. Arc development for left, centre, and right positive blocks.

The expansion of centre positive block stop since it already reached negative value without reaching the top level. The left positive block will have problem if it expand. It will reach the final value of 8.9+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1) or -0.1. This left arc structure needs a grouping from other structure in order to keep exist. It looks like the right arc structure will be a good counterpart for grouping. The right arc structure will have final value of 8.9+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1) or -0.1. If we group these two arc structure, the right arc structure will have a final value of 8.9+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-1)+(-0.1) or 0.8 which is also the final value for the block model after Lerchs-Grossmann optimization (see Figure 2.58).
The completion of optimization identified after no additional arc can be done within the block model. In computer application, the process of labelling (flag) will repeated for another section until it reached that there are no more additional arc for the block model.

For the purposes of assessing the value of a block, some of the technical and economic factors mentioned earlier are added together as a total cost. The economic value of a block generally represent value in unit of currency of the block once it has been uncovered, and consists of the return obtainable from any ore in the block less the cost of mining and processing the block. Following is the approach and calculation to establish economic block value used by the Whittle Three-D and Four-D Pit Optimization software. Figure 2.59 shows the block model approach for an open pit design.

An economic block model includes ore, waste, and air blocks. Figure 3-4 also shows that property’s topography can control the block model. The Three-D Whittle
Open Pit Optimization Software approaches the economic value of a block through the monetary unit which result can be understood by all professionals involved in the activities. A mathematical approach for the economic value of a block is:

\[(\text{METAL} \times \text{RECOVERY} \times \text{PRICE}) - (\text{ORE} \times \text{COSTP}) - (\text{ROCK} \times \text{COSTM}) \] \quad (2.4)

*Note: the expression in brackets is omitted if it is negative.*

where:
- **METAL** = the units of product in the block.
- **RECOVERY** = the fraction of the product which can be obtained from the ore.
- **PRICE** = the price obtainable for a unit of product less any delivery costs.
- **COSTM** = the cost of mining and removing a ton of ore.
- **COSTP** = the extra cost of processing a ton of ore.

All available overhead costs must be included in COSTM, while COSTP should not carry all the overheads on the basis that "ore pays for the mine". Fixed overhead costs should not be included for the purposes of optimization and has to be subtracted from any value obtained for the pit. For example, nonrecoverable upfront costs such as access roads, permits, etc. should not be included in the costs used for pit optimization purposes. These costs may be exist as a loan which has to be repaid over a number of years whether mining continues or not. If the value of the optimized pit is less than the nonrecoverable upfront costs, then the mine should not be proceeded with.

The values of ORE, METAL, and ROCK for each block will be treated as fixed, unless there are other supporting information to some acceptable degree of accuracy which can be considered to explain that these values are changeable. Also, these values
will be treated as fixed if there are no further evaluation of the deposit.

Figure 2.59. Block model approach for pit design.

PRICE, COSTM, and COSTP for each block mostly varies with the likely range of value for more sensitive pit design. COSTM can be expanded to the cost of mining and removing a ton of waste, while COSTP can be expanded not just as the processing cost but what it could cost to mine and process a ton of ore over and above what it could cost to mine it as waste.

There has to be assumptions to simplify massive computing task and calculation, quantity of data to be assessed, and processing time which basically not-practical to
apply in actual mining operation. For example, simplification to formula (2.4):

\[ \text{METAL} \times \text{RECOVERY} \times \left( \frac{\text{PRICE}}{\text{COSTM}} \right) - \text{ORE} \times \left( \frac{\text{COSTP}}{\text{COSTM}} \right) \right] - \text{ROCK} \ldots \quad (2.5) \]

, and

\[ \text{METAL} \times \text{RECOVERY} \times \left( \frac{\text{MCOSTM}}{\text{COSTP}/\text{COSTM}} \right) - \text{ORE} \times \left( \frac{\text{CRATIO}}{\text{COSTP}/\text{COSTM}} \right) \right] - \text{ROCK} \ldots \quad (2.6) \]

where: \( \frac{\text{COSTP}}{\text{COSTM}} \) or \( \text{CRATIO} \) = technology factor.
\( \frac{\text{COSTM}}{\text{PRICE}} \) or \( \text{MCOSTM} \) = metal cost of mining.

\( \frac{\text{COSTP}}{\text{COSTM}} \) or CRATIO likely to change significantly with time if new mining or processing methods are introduced, or if there is a very significant change in a particular cost component. \( \frac{\text{COSTM}}{\text{PRICE}} \) or MCOSTM likely to change if there are very significant change in price obtainable for a unit of product less any delivery costs or change in a particular cost of mining and removing a ton of ore.
CHAPTER 3
ECONOMIC BLOCK MODEL DESCRIPTIONS

The application of Moving Cone and Lerchs-Grossmann open pit optimization method will be discussed more in detail in the next two chapters. Chapter three will discuss the application of Moving Cone method using Medsystem. Chapter four will discuss the application of Lerchs-Grossmann method using Medsystem and Three-D.

The economic block model which will be used for the application of both methods consists of 129,500 or 70x74x25 blocks in X, Y, and Z direction respectively representing an orebody of 3,930 ore, 125,561 waste, and 9 air blocks. The size of each block is 50 ft. in X direction, 100 ft. in Y direction, and 40 ft. in Z direction. Each block weighs 14,815 tons with assumed tonnage factor of 13.5\text{ft}^3/\text{ton}. Total tonnage of the ore blocks is 58,222,950 tons. Total tonnage of the waste blocks is 1,860,186,215 tons.

The economic block model for Three-D is contained in an ASCII file named "er4466r.eco". For the Medsystem, the economic block model DAT610IA is a reformatted file from "er4466r.eco". Both files are similar except each formatted for the purpose to accommodate the software data format requirements.

There are assumptions made to avoid massive calculation and complexity for the optimization such as:

a. Topographic feature of the property are flat.

b. Overall pit slope is set at 45°.

c. Commodity price (gold) is constant at US$400.00/tr.oz.
d. General default waste value is constant at US$0.0972/ton of waste block.

e. Tonnage factor is constant at 13.5ft³/ton.

f. There is only one mining phase for the model framework

g. There are no further aspects to be put in the open pit design such as roads, etc.

Three-D and Medsystem are used for Lerchs-Grossmann optimization method in order to establishing better comparison to Moving Cone method. Three-D is used because it is very specific software that apply Lerchs-Grossmann optimization technique. It is also easy to use, run with relatively small computer memory, and provide good result.

Three-D’s block print program (LGPR) will be used to analyze results from both software and optimization methods. A Fortran program developed in order to convert Medsystem result into Three-D format so it can be plotted by LGPR.
CHAPTER 4
THE APPLICATION OF MOVING CONE
OPTIMIZATION METHOD

The application of moving cone optimization method for the economic block model will be exercised by Medsystem software. Medsystem consists of routines which each conduct specific task. These routines are grouped into nine series programs consisting project initialization, graphics, drillhole data operations, geostatistical analysis, classical statistics for drillholes and composites, composite data operations, mine model operations, variable block model operations, mine planning operations, gridded seam model, production scheduling, financial analysis system, and the menu system (see Figure 4.1).

Each routines group has a group or series number such as 100, 120, 200, etc. Each routine has specific number in which we can identify the task. Appendix B shows the routine identification and tasks for each group.

Routines in Medsystem can be either operated in interactive screen or typed manually. Figure 4.2 shows the menu screen of Medsystem version 1.10 at SUN/Unix workstation. This interactive screen follows similar logic as if typed manually. It will be advisable if we can work with this program interchangeably using interactive screen and manual.
Group 700: Mine Planning Operations will be used to conduct the task for the purpose of this report. Specifically, program M720V1 (Economic Pit Limits for constant pit wall slope) will do the Moving Cone optimization process. M720V1 is a DIPPER (Dynamic Interactive Pit Planning Evaluation Routine) program in the Medsystem for designing economic pits using the moving cone technique.

Figure 4.3 shows the flow diagram of program M720V1. This program reads a condensed block model created by M718V1 which consists a block file (B-file) and a surface file (S-file). There are three types of economic block value which can be stored in the condensed model: total, net, and value per ton.
Medsystem calculates the net economic cone value as follows:

\[
\text{Net Value} = (\text{Gross Value}) - (\text{Total Costs}) \quad \ldots \quad (4.1.)
\]

where total costs is

\[
\text{Total Cost} = (\text{Waste Cost/Ton} \times \text{Tons/Block} \times \text{Number of Waste Blocks}) + \\
(\text{Ore Cost/Ton} \times \text{Tons/Block} \times \text{Number of Ore Blocks}) + \\
(\text{Overburden Cost/Ton} \times \text{Tons/Block} \times \text{Number of Overburden Blocks}) \quad \ldots \quad (4.2.)
\]

The block value in the condensed model may be in grade (average mineral...
content as a percent), units (ounces/ton, grams/ton), dollar value, or %ore. Dollar value is used for the purpose of this report with regard to the consistency to the economic block model framework which will be used by Three-D for Lerchs-Grossmann method. The economic block model DAT610.IA is an ASCII dollar economic model in Medsystem format generated from another ASCII file (er4466r.eco). Appendix E shows the FORTRAN code used for this conversion.

Figure 4.3. Program flow diagram of M720V1.

The following section discusses steps and parameters which been used to run the Moving/Floating Cone optimization. First of all, we initialize the economic block data
by running M601V1 or 3D DEPOSIT MODELLING - INITIALIZE - Initialize Model File at the menu screen (see Figure 4.4). It will bring us to the option for labelling and initializing items to the economic block model (see Figure 4.5 and 4.6).

---

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MIN. VALUE</th>
<th>MAX. VALUE</th>
<th>ITEM VALUE</th>
<th>PRECISION</th>
<th>(SUGGESTED) ITEM DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TOPO</td>
<td>0.0</td>
<td>100.0</td>
<td>0.1</td>
<td></td>
<td>BLOCK % BELOW TOPOG</td>
</tr>
<tr>
<td>2. $AU</td>
<td>-9999</td>
<td>999999</td>
<td>1.0</td>
<td></td>
<td>2ND MODEL ITEM</td>
</tr>
<tr>
<td>3. SURF 1</td>
<td>-9999</td>
<td>999999</td>
<td>1.0</td>
<td></td>
<td>3RD</td>
</tr>
<tr>
<td>4. SURF 2</td>
<td>0.0</td>
<td>40.0</td>
<td>1.0</td>
<td></td>
<td>4TH</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5TH</td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6TH</td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7TH</td>
</tr>
<tr>
<td>8.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8TH</td>
</tr>
<tr>
<td>9.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9TH</td>
</tr>
</tbody>
</table>

---

Figure 4.4. Model file initialization: specifying items for the 3-D model.
**INITIALIZE VALUES IN THE 3-D MODEL**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>INITIAL</th>
<th>VALUE</th>
<th>(SUGGESTED)</th>
<th>ITEM DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TOPO</td>
<td>100</td>
<td></td>
<td>BLOCK % BELOW TOPOG</td>
<td></td>
</tr>
<tr>
<td>2. SAU</td>
<td>-1</td>
<td></td>
<td>2ND MODEL ITEM</td>
<td></td>
</tr>
<tr>
<td>3. SURF1</td>
<td>0.</td>
<td></td>
<td>3RD</td>
<td></td>
</tr>
<tr>
<td>4. SURF2</td>
<td>0.</td>
<td></td>
<td>4TH</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td>5TH</td>
<td></td>
</tr>
</tbody>
</table>

**YOU DO NOT HAVE TO ENTER ANY OF THE ITEMS AFTER TOPO. BUT ANY ITEMS ENTERED ABOVE WILL BE SET TO THE INITIAL VALUE.**

---

**Figure 4.5.** Model file initialization: initializing values in the 3-D model.

```
BEGIN MODEL INITIALIZATION
* BEGIN EXECUTION OF PROGRAM M601V1 *
RUN FILE = RUN601.A RUN102.F
REPORT FILE = RPT601.LA RPT102.LF
```

---

**Figure 4.6.** Model file initialization: beginning model initialization.
The model file initialization is performed by executing program M601V1. Run files for this program are run601.a and run102.f. Report files are rpt610.la and rpt102.lf. The following discussion describes the run files that are built for running the routines to determine the ultimate pit limits by the moving cone algorithm. Program M601V1 has the task for initializing the model files prior to entry of numerical values. Program run601.a includes parameters which required in initialization process (see Figure 4.7).

**INITIALIZE THE 3-D MINE MODEL**

Date

RUN = INITIALIZE

IOP2 = 1 25. / LEVELS TO INITIALIZE

PUT15= TOPO $AU SURF1 SURF2

PAR1 = 100. -1. -1. -1.

END

Items to be initialized:

- TOPO - topography
- $AU - dollar value of each block
- SURF1 - output for M720V1
- SURF2 - output for M720V3

Figure 4.7. The structure of run601.a

Medsystem approaches the economic block model from top to bottom. It is a
reverse approach compared to Whittle’s Three-D. Therefore, a FORTRAN program is written to convert an economic block model which used in Whittle’s format to the Medsystem’s format (see Appendix F).

The next step is to run the M610V2 program which loads real data representing dollar values of the blocks into initialized Medsystem block model file (file 15). Run file for this program is run610.a1 (see Figure 4.8).

```
Name of program
Project Control File
Mine Model File
Input File
Report File

MEDS-610V2  10=lgpo10.DAT 15=lgpo15.DAT 19=dat610u.ia 3=RPT610.LA
** LOAD ASCII DATA TO THE BLOCK MODEL **

USR = kd / 08-28-94 19:56:17

COM ----------------------------------------------
COM LOAD 3-D ASCII DATA
COM ----------------------------------------------

IOP3 = 1 25 / 1ST & LAST MODEL BENCHES
IOP5 = 1 70 / 1ST & LAST MODEL COLUMNS
IOP7 = 1 74 / 1ST & LAST MODEL ROWS
IOP9 = 1 / 1=INPUT DATA IS IN FILE 19=dat610u.ia
IOP10= 0 / # = BENCH OFFSET ADDED TO INPUT IZ
IOP11= 0 / # = BENCH OFFSET ADDED TO INPUT IX
IOP12= 0 / # = BENCH OFFSET ADDED TO INPUT IY

PUT15= $AU / FILE 15 ITEMS                      Labels of items to be loaded

FMT1 = ( 3i4,f15.0)                          Optional format for input data in FORTRAN
END

Figure 4.8. The structure of run610.a1.
It is important to understand how each run program has specific task in Medsystem. For example, run610.a1 and run610.b has different tasks. Run610.a1 is used for entering real data, and run610.b is used for entering integer data. Run610.a1 is used for M610V2, and run610.b is used for M610V1. This condition reflects the complexities of Medsystem.

Following M610V2 is M717V1 which is the initialization of DIPPER (Dynamic Interactive Pit Planning Evaluation Routine) Model Descriptors. M717V1 sets up the PCF (Project Control File) for the files required by the Medsystem DIPPER series program and must be run prior to any other DIPPER program. The run file for this program is run717.a (see Figure 4.9).

<table>
<thead>
<tr>
<th>Name of program</th>
<th>Project Control File</th>
<th>Condensed Mine Model File (B-file)</th>
<th>Primary Surface File (S-file)</th>
<th>Report File</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEDS-717V1</td>
<td>10=lgpo10.DAT</td>
<td>21=LGPODP.P00</td>
<td>22=LGPODP.BLK</td>
<td>3=RPT717.LA</td>
</tr>
<tr>
<td>** SET UP DIPPER SET LGPODP.BLK **</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

USR = kd / 10-21-94 16:06:15

ALF1 = $AU / GRADE LABEL  ➔ Condensed Model Item

PAR2 = 0. / VMIN ➔ Minimum Value of Condensed Model Item
PAR3 = 2850000. / VMAX ➔ Maximum Value of Condensed Model Item
PAR4 = 1. / PRECISION ➔ Precision of Item

PAR6 = 13.5 13.5 / TONNAGE FACTORS FOR ORE AND WASTE
PAR8 = 0. / OPTIONAL TONNAGE FACTOR FOR OVERBURDEN

PAR9 = 25 / NUMBER OF BENCHES, DEFAULT FROM PCF
PAR10 = 1. / 1 = V-SERIES, 2- X-SERIES

END

Figure 4.9. The structure of run717.a.
M718V1 follows M717V1 for reading the 3-D Mine Model File, the 2-D Surface File, and condenses them. The condensed files will be the DIPPER B-file and S-file. M718V1 will read all data in ASCII Files 13 and 15 which not include overburden. The run file is run718.a (see Figure 4.10).

**Figure 4.10.** The structure of run718.a.
M720V1 run the Moving/Floating Cone optimization of the economic block model. Run file for M720V1 is run720.a (see Figure 4.11).

** DIPPER ECONOMIC PIT LIMITS **

USR = kd / 10-03-94 08:50:04

IOP1 = 1 1 1 / INCREMENT BETWEEN COL, ROWS, LEV IN SEARCH
IOP4 = 1 / TIMES TO REPEAT SEARCH OVER AREA
IOP5 = 1 / SET # OF ASSUMPTIONS BELOW
IOP11= 0 / 0=NO VARIABLE COSTS, 1=USE VARIABLE COSTS BY BENCH
IOP12= 0 / 0=SINGLE PAR6 SLOPE; 1=VARIABLE SLOPES
IOP14= 1 / 1=MEASURE BLOCK AT CENTER

PAR1 = -1438 / MILL CUT OFF GRADE (USED IN ECONOMIC CALCULATIONS)
PAR2 = 0.1 / MINE CUT-OFF GRADE (BASE BLOCK CUTOFF USED IN CONE SEARCHING)
PAR3 = 0.0972 / MINING COST PER UNIT OF WASTE MATERIAL
PAR4 = 0 / TOTAL OPERATING COST PER UNIT OF ORE
PAR5 = 0 / NET VALUE PER UNIT OF PRODUCT ($/# OR $/OZ)
PAR6 = 45. / MINIMUM PIT SLOPE (TANGENT IF <10; DEGREES IF >10)
PAR7 = 0.0001 / RADIUS OF CONE BASE
PAR15 = -1500.0 / CONSTANT TO BE ADDED TO B-FILE ENTRIES

ITM1 = BLOCK VALUE IS NET$$
ITM2 = FEED UNITS ARE TONS
ITM3 = WASTE UNITS ARE TONS

END

Area specification lines:
- column 1=0 —> for Economic Cone Calculations
- column 2=1 —> Examine all cones with base blocks greater than PAR2
- column 3=0 —> Used when column-2=1
- column 4 and 5 —> Range of bench numbers to search (Z direction)
- column 6 and 7 —> Range of columns to search for base of cone (X direction)
- column 7 and 8 —> Range of rows to search (Y direction)
- column 9 —> New S-file name when all cones have been searched

Figure 4.11. The structure of run720.a.
The area specification lines at Figure 4.11 shows that there are eight passes when running for optimization. First pass done by floating the simulated cone from the lowest number of each direction. Second pass done by floating the simulated cone from the highest number to the lowest number in X direction. Third pass done by floating the simulated cone from the highest number to the lowest number in X and Y directions, and so on. The floating process is constant at Z direction.

The following step is to dump the result into ASCII file for conversion into Three-D format. We can use the interactive screen to dump the result by choosing 3D DEPOSIT MODELING - DUMP - DUMP MODEL TO ASCII (see Figure 4.12)
Figure 4.12 followed by three interactive screens to establishing variables for the conversion file in ASCII format. First page asks about file for the 3-D mine model, file extension, name of output file, labels to be dumped, minimum value of base item, and maximum value of base item. Second page asks about optional data selection for value selection such as actual item label, keyword, and selection limits if item specified. The last page asks about model limits for selection of data.

The dumped ASCII file has to be converted into DOS file by using unix2dos option in Unix operating system. Then, a FORTRAN code is wrote for converting this dumped DOS file into Three-D format (see Appendix E). The Whittle's Three-D LGPR program is used to generate block print of Medsystem's result.

A contouring and 3D surface mapping program called Surfer for Windows from Golden Software, Inc. is used for generating the contours of the ultimate pit limits mined by the Moving Cone technique (see Figure 4.14). Three-D’s LGPR is used for block print purpose. The M720V1’s Three-D format is MC.OUT, and the M720V3 is LG.OUT. Figures 4.13 shows the summary of mc_out.prp generated by LGPR for xy-plan (z direction).

The pit outline obtained from Moving Cone algorithms is shown on Figure 4.14. The result of Moving Cone M720V1 optimization program summarized as follows:

- 13,002 blocks representing 192,535,740 tons were read with 2,518 blocks or 37,304,170 tons of ore, 10,478 blocks or 155,231,570 tons of waste, and 6 blocks of air.

- 2,518 blocks or 37,304,170 tons mined from the total of 3,930 blocks or
58,222,950 tons ore within the economic block model.

- Total undiscounted net profit within the ultimate pit defined by the Moving Cone method is US$49,965,088.

Figure 4.13. Summary of mc_out.prp.

Table 4.1 shows bench by bench summary of the Moving Cone method. Following are figures showing pit outline (Figure 4.14), and how the Moving Cone method mined at bench 2,260 (Figure 4.15), 1,980 (Figure 4.16), 1,780 (Figure 4.17), and
1,580 (Figure 4.18). The Moving Cone method mined 178 blocks or 2,637,070 tons from 197 blocks or 2,918,555 tons of ore in reserve at bench 1,980. It mined 229 blocks or 3,392,635 tons from 330 blocks or 4,888,950 tons of ore in reserve at bench 1,780. It also mined 39 blocks or 577,785 tons from 197 blocks or 2,918,555 tons of ore in reserve at bench 1,580. At bench 2,260, Moving Cone mined all ore blocks in reserve.

<table>
<thead>
<tr>
<th>Bench (ft.)</th>
<th>Ore blocks in reserve</th>
<th>MOVING CONE (M720V1)</th>
<th>Ore blocks mined</th>
<th>Ore blocks unmined</th>
<th>Ore blocks cumulative mined</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,260</td>
<td>37</td>
<td></td>
<td>37</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>2,220</td>
<td>46</td>
<td></td>
<td>46</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>2,180</td>
<td>49</td>
<td></td>
<td>49</td>
<td>0</td>
<td>132</td>
</tr>
<tr>
<td>2,140</td>
<td>72</td>
<td></td>
<td>70</td>
<td>2</td>
<td>202</td>
</tr>
<tr>
<td>2,100</td>
<td>113</td>
<td></td>
<td>109</td>
<td>4</td>
<td>311</td>
</tr>
<tr>
<td>2,060</td>
<td>141</td>
<td></td>
<td>135</td>
<td>6</td>
<td>446</td>
</tr>
<tr>
<td>2,020</td>
<td>156</td>
<td></td>
<td>147</td>
<td>9</td>
<td>593</td>
</tr>
<tr>
<td>1,980</td>
<td>197</td>
<td></td>
<td>178</td>
<td>19</td>
<td>771</td>
</tr>
<tr>
<td>1,940</td>
<td>205</td>
<td></td>
<td>182</td>
<td>23</td>
<td>953</td>
</tr>
<tr>
<td>1,900</td>
<td>281</td>
<td></td>
<td>230</td>
<td>51</td>
<td>1183</td>
</tr>
<tr>
<td>1,860</td>
<td>335</td>
<td></td>
<td>256</td>
<td>79</td>
<td>1439</td>
</tr>
<tr>
<td>1,820</td>
<td>319</td>
<td></td>
<td>240</td>
<td>79</td>
<td>1679</td>
</tr>
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<td>1,780</td>
<td>330</td>
<td></td>
<td>229</td>
<td>101</td>
<td>1908</td>
</tr>
<tr>
<td>1,740</td>
<td>350</td>
<td></td>
<td>213</td>
<td>137</td>
<td>2121</td>
</tr>
<tr>
<td>1,700</td>
<td>381</td>
<td></td>
<td>165</td>
<td>216</td>
<td>2286</td>
</tr>
<tr>
<td>1,660</td>
<td>291</td>
<td></td>
<td>112</td>
<td>179</td>
<td>2398</td>
</tr>
<tr>
<td>1,620</td>
<td>254</td>
<td></td>
<td>77</td>
<td>177</td>
<td>2475</td>
</tr>
<tr>
<td>1,580</td>
<td>197</td>
<td></td>
<td>39</td>
<td>158</td>
<td>2514</td>
</tr>
<tr>
<td>1,540</td>
<td>95</td>
<td></td>
<td>4</td>
<td>91</td>
<td>2518</td>
</tr>
<tr>
<td>1,500</td>
<td>41</td>
<td></td>
<td>0</td>
<td>41</td>
<td>2518</td>
</tr>
<tr>
<td>1,460</td>
<td>28</td>
<td></td>
<td>0</td>
<td>28</td>
<td>2518</td>
</tr>
<tr>
<td>1,420</td>
<td>10</td>
<td></td>
<td>0</td>
<td>10</td>
<td>2518</td>
</tr>
<tr>
<td>1,380</td>
<td>2</td>
<td></td>
<td>0</td>
<td>2</td>
<td>2518</td>
</tr>
<tr>
<td>1,340</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
<td>2518</td>
</tr>
<tr>
<td>1,300</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
<td>2518</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3,930</td>
<td></td>
<td>2,518</td>
<td>1,412</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1. Moving Cone (M720V1) summary by benches.
Figure 4.14. The Medsystem (M720V1) Moving Cone ultimate pit limit outline.
XY plane for Z = 25 facing in the direction of negative Z
Symbols: '.' is air, '*' could be processed, '-' is waste

Figure 4.15. Bench 2,260 (+=ore, -=waste, .=air).
XY plane for $z = 18$ facing in the direction of negative $z$
Symbols: '.' is air, '"' could be processed, '"' is waste

Figure 4.16. Bench 1980 (+=ore, -=waste, .=air)
XY plane for \( z = 13 \) facing in the direction of negative \( z \)

Symbols: \( * \) is air, \( .+ \) could be processed, \( -. \) is waste

\[
\text{Figure 4.17. Bench 1,780 (+=ore, -=waste, .=air)}
\]
XY plane for Z = 8 facing in the direction of negative Z
Symbols: '.' is air, '+' could be processed, '-' is waste

Figure 4.18. Bench 1,580 (+=ore, -=waste, .=air)
CHAPTER 5
THE APPLICATION OF LERCHS-GROSSMANN OPTIMIZATION METHOD

5.1. Three-D: Overview

Three-D identifies each block in the model framework by block’s ID number. Each block has its identity number (ID number) which represent the location in X, Y, and Z axis. Figure 5.1 shows an ID number of a block which represent it location in the block model. Values can be either integer (I) or real (R), depend on the context of the data in optimization processes.

![Figure 5.1. Block position using ID number.](image)

Three-D consists of five separate programs and run on a wide range of computers:

a. LGED, which is a program for editing Model Parameter Files.
b. LGRB, which is a program for manipulating Economic Files.

c. LGST, which is a program for pre-calculating the slope requirements.

d. LG3D, which is a program to do the optimizing.

e. LGPR, which is a program for printing simple plans and sections of the pits.

It is also very important to understand the file structure used by Three-D. This report use Three-D in the DOS operating system which recognize the file structure as follows:

<table>
<thead>
<tr>
<th>File Type</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Parameter Files</td>
<td>.MPA</td>
</tr>
<tr>
<td>Economic Files</td>
<td>.ECO</td>
</tr>
<tr>
<td>Structure Files</td>
<td>.STU</td>
</tr>
<tr>
<td>Work Files</td>
<td>.WRK</td>
</tr>
<tr>
<td>Results Files</td>
<td>.RES</td>
</tr>
<tr>
<td>Additional Arcs Files</td>
<td>.ADD</td>
</tr>
<tr>
<td>Print Files for LGRB</td>
<td>.PRR</td>
</tr>
<tr>
<td>Print Files for LGST</td>
<td>.PRS</td>
</tr>
<tr>
<td>Print Files for LG3D</td>
<td>.PR3</td>
</tr>
<tr>
<td>Print Files for LGPR</td>
<td>.PRP</td>
</tr>
</tbody>
</table>

Table 5.1. Three-D's file structures.

These files written in DOS operating system and controlled by rows and columns format.

Model Parameter File (.MPA) checks input values for the block model and validate it as a whole. It consists nine different line types, and must be arranged in the following sequence:
Figure 5.2. Model Parameter File (.MPA) format.

Line type-1 determines block dimensions and origin. Line type-1 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'1'</td>
</tr>
<tr>
<td>6 - 15</td>
<td>R</td>
<td>Block size in the 'X' or east-west direction.</td>
</tr>
<tr>
<td>16 - 25</td>
<td>R</td>
<td>Block size in the 'Y' or north-south direction.</td>
</tr>
<tr>
<td>26 - 35</td>
<td>R</td>
<td>Block size in the 'Z' or vertical direction.</td>
</tr>
<tr>
<td>36 - 45</td>
<td>R</td>
<td>Model framework origin coordinate in the 'X' or east-west direction (optional).</td>
</tr>
<tr>
<td>46 - 55</td>
<td>R</td>
<td>Model framework origin coordinate in the 'Y' or north-south direction (optional).</td>
</tr>
<tr>
<td>56 - 65</td>
<td>R</td>
<td>Model framework origin coordinate in the 'Z' or vertical direction (optional).</td>
</tr>
</tbody>
</table>

Table 5.2. Line type-1.

Line type-2 determines model framework size, or number of blocks in the block model. Line type-2 written and controlled by the following format:
### Table 5.3. Line type-2.

Line type-3 determines active blocks indicator, air flags and restart interval. Line type-3 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'3'</td>
</tr>
</tbody>
</table>
| 6-15   | I    | Active block indicator:  
         |       | 1 = All blocks in the model framework are considered.  
         |       | 2 = Only blocks within the defined sub-regions are considered.  
         |       | 3 = Only blocks that appear in the Economic File are considered.  
| 16-20  | I    | Air flag A:  
         |       | 1 = Air blocks are considered in the optimization.  
         |       | 2 = Air blocks are not considered in the optimization.  
| 21-25  | I    | Air flag B:  
         |       | 1 = Air blocks are not included in the Result File.  
         |       | 2 = Those air blocks that would fall within the pit wall if it were extended into the air, are included in the Result File. *Air flag B must be 2.*  
| 26-35  | R    | The restart interval in hours. *2.0 is used if this blank.* |

### Table 5.4. Line type-3.
Line type-4 determines the general default waste value. This value can be put manually or calculated by LGRB. LGRB can calculate the general default waste value if we do reblocking process to the model. Line type-4 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'4'</td>
</tr>
<tr>
<td>6 - 15</td>
<td>R</td>
<td>Default value for a waste block. This should be blank, or less than or equal to zero.</td>
</tr>
</tbody>
</table>

Table 5.5. Line type-4.

Line type-5 determines number of sub-regions projected in the block model. Line type-5 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'5'</td>
</tr>
<tr>
<td>6 - 15</td>
<td>I</td>
<td>Number of sub-regions within the block model. Sub-regions must not overlap, and if the active blocks indicator is 1 they must completely fill the model framework.</td>
</tr>
</tbody>
</table>

Table 5.6. Line type-5.

Line type-6 determines limits of a sub-region within the block model. The limit
value will be the lowest and the highest value where each sub-region contained within the block model. Line type-6 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'6'</td>
</tr>
<tr>
<td>6-15</td>
<td>I</td>
<td>Lowest X coordinate in terms of blocks.</td>
</tr>
<tr>
<td>16-25</td>
<td>I</td>
<td>Highest X coordinate in terms of blocks.</td>
</tr>
<tr>
<td>26-35</td>
<td>I</td>
<td>Lowest Y coordinate in terms of blocks.</td>
</tr>
<tr>
<td>36-45</td>
<td>I</td>
<td>Highest Y coordinate in terms of blocks.</td>
</tr>
<tr>
<td>46-55</td>
<td>I</td>
<td>Lowest Z coordinate in terms of blocks.</td>
</tr>
<tr>
<td>56-65</td>
<td>I</td>
<td>Highest Z coordinate in terms of blocks.</td>
</tr>
</tbody>
</table>

Table 5.7. Line type-6.

Line type-7 determines slope angles, planes and default waste for each sub-region. Line type-7 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'7'</td>
</tr>
<tr>
<td>6-15</td>
<td>I</td>
<td>Number of slope angles for this sub-region.</td>
</tr>
<tr>
<td>16-25</td>
<td>I</td>
<td>The maximum number of benches to consider when calculating the structure vectors. Generally, this must be 2 or greater.</td>
</tr>
<tr>
<td>26-35</td>
<td>I</td>
<td>The default value for a waste block in this sub-region. This should be blank, or less than or equal to zero.</td>
</tr>
</tbody>
</table>

Table 5.8. Line type-7.

Line type-8 determines slope bearing and angle for each sub-region within the
block model. Line type-8 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'8'</td>
</tr>
<tr>
<td>6 - 15</td>
<td>R</td>
<td>Bearing clockwise in degrees from the positive Y direction. <em>There will be no effect if only one slope.</em></td>
</tr>
<tr>
<td>16 - 25</td>
<td>R</td>
<td>Required pit slope in degrees from the horizontal.</td>
</tr>
</tbody>
</table>

Table 5.9. Line type-8.

Line type-9 determines the details of mining phases for the block model. Line type-9 written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I</td>
<td>'9'</td>
</tr>
<tr>
<td>6 - 8</td>
<td>I</td>
<td>Number of mining phases - that is, the number of sub-optimizations to be carried out by LG3D.</td>
</tr>
<tr>
<td>9 - 11</td>
<td>I</td>
<td>Z index of the lowest bench for first phase.</td>
</tr>
<tr>
<td>12 - 14</td>
<td>I</td>
<td>Z index of the lowest bench for second phase.</td>
</tr>
<tr>
<td>15 - 17</td>
<td>I</td>
<td>Z index of the lowest bench for third phase.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>:</td>
</tr>
<tr>
<td>66 - 68</td>
<td>I</td>
<td>Z index of the lowest bench for twentieth phase.</td>
</tr>
</tbody>
</table>

Table 5.10. Line type-9.
It is also very important to recognize how the Economic File (.ECO) formatted in Three-D. This file consists of lines of text that each contain a block identification number, a block value in monetary unit and, optionally, an orebody identification number. The block identification number is approached by the following formula:

\[ ID = IX + (IY-1) \times NX + (IZ-1) \times NX \times NY \ldots (7.1) \]

where:  
ID = Block ID#.  
IX = Block-i position in the 'X' or east-west direction.  
IY = Block-i position in the 'Y' or north-south direction.  
IZ = Block-i position in the 'Z' or vertical direction, started from the bottom of the model.  
NX = Block-n or the highest/farthest block in the 'X' or east-west direction.  
NY = Block-n or the highest/farthest block in the 'Y' or north-south direction.  
NZ = Block-n or the highest/farthest block in the 'Z' or vertical direction.

The Economic File (.ECO) written and controlled by the following format:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>I</td>
<td>ID of the block.</td>
</tr>
<tr>
<td>11 - 30</td>
<td>R</td>
<td>Value of the block in monetary unit.</td>
</tr>
<tr>
<td>31 - 40</td>
<td>I</td>
<td>Orebody identification number. <em>(optional)</em></td>
</tr>
</tbody>
</table>

Table 5.11. The Economic File (.ECO) format.

Proper format is very important in order to run Three-D properly. Programming
sub-routines for converting data to the right format is necessary. Three-D is a stand alone software which need some programming work in order to be compatible with other system. There are two programs in FORTRAN have been developed in order to convert block model data into Economic File (.ECO) format, and from Result File (.RES) format into X, Y, and Z format so programs such Surfer or AutoCad can interpret easily.

5.2. Three-D: LGED, LGRB, LGST, LG3D

LGED is a program built in Three-D system for editing Model Parameter Files. This program facilitates changing in .MPA files and validates interrelationships between data within the file. LGED accommodates Model Parameter File format, and structured as follows:

![Diagram of LGED structure]

Figure 5.3. LGED structure.
LGRB is a program built in Three-D system for manipulating Economic Files (.ECO). This program facilitates changing the .ECO files: combining blocks into bigger blocks and/or splitting blocks into smaller blocks. LGRB requires structured inputs as follows:

Figure 5.4. LGRB structure.

LGRB also accommodate changes in .MPA file by developing new block
dimension, model framework, active block indicator, general default waste value for each block and sub-region.

LGST is a program built in Three-D system for preparing "structure arcs" file based on given block model and pit slope into a format which is suitable for optimization purposes. LGST takes the dimensions of the blocks and the required pit slopes to the model framework, and generate a generic set of arcs which accommodate blocks for each sub-region. This program requires information from Model Parameter File (.MPA) such as dimensions of block and framework, and block limit, number of benches, bearing, and slope for each sub-region in order to generating structure arcs. LGST has a straightforward structure since inputs are Model Parameter (.MPA) files and optional Additional Arcs File (.ADD).

LG3D is a program built in Three-D system for carrying out the optimization using the Structure File (.STU) and the Economic File (.ECO). The following is the structure of LG3D:

Figure 5.5. LG3D structure.
LG3D runs in five consecutive stages:

1. Sets initial data structures and read the Economic File.

2. Preliminary scans of Structure File (only if active block indicators 1 and 2).

3. Detail scans of Structure Files.

4. Optimization for each mining phase from the highest bench to the lowest.

5. Write the Result File (.RES).

LGPR is a program built in Three-D system for printing out simple plans and sections of the blocks to be mined. In order to run this program properly, LGPR requires information such as:

- Name of the Print File.
- Model Parameter File.
- Planes to be printed.
- Maximum phase number to be printed (optional).
- How blocks to be displayed.

Programs in Three-D are interdependent. Each program relates and depends to others. There has to be a good filing system because changes in inputs for each program can change input in other programs. For example, changes in LGRB inputs will change .MPA files unless we specify the new .MPA or decline the option.

The following is the application of Three-D for given data which also used by the Moving Cone software. This application will basically focus in the model optimization without considering aspects such as roads, etc. Therefore, it is just for the purpose of representing Lerchs-Grossmann method of pit optimization.
5.3. **Three-D: The Application of LG3D on er4466r.eco**

We will now discuss the application of Three-D for given Economic File called er4466r.eco, and Model Parameter File called ersr1mp1.mpa. The Model Parameter File input as follows:

Dimension of each block is 50.00ft*100.00ft*40.00ft. Total blocks in the model is 70*74*25 or 129,500 blocks. The default waste value is -14.40 (in hundreds). There is one sub-region within the model (from bench 1 through 25). Overall pit slope is 45°.
with bearing of 0.0°. The model has one mining phase with lowest level XY-plane=1.

Figure 5.7. Sub-regions in the model framework.

LGST calculation shows that with twenty five benches for one sub-region, each block has 81 possible arcs per block with minimum, average, and maximum slope errors are 0.0°, 0.2°, and 0.7° respectively. The total arcs output within the model framework is 6,117,108. The structure output called er4466r3.stu. Three-D approaches the model from bottom moving upward.

Figure 5.9 shows the final mined Lerchs-Grossmann pit limit outline using Three-D Whittle Open Pit Optimization Software. The result of Whittle's LG3D program (er4466r3.res) summarizes the model framework as follows:

- 15,792 blocks representing 233,884,405 tons were read with 2,835 blocks or 42,000,525 tons of ore, 12,952 blocks or 191,883,880 tons of waste, and 5 blocks of air.
- 2,835 blocks or 42,000,525 tons mined from the total of 3,930 blocks or
58,222,950 tons ore within the economic block model.

- Total undiscounted net profit within the ultimate pit defined by the Lerchs-Grossmann method is US$50,671,500.
Table 5.12 shows bench by bench summary of the Lerchs-Grossmann method. Following are figures showing pit outline (Figure 5.9), and how the Lerchs-Grossmann method mined at bench 2,260 (Figure 5.10), 1,980 (Figure 5.11), 1,780 (Figure 5.12), and 1,580 (Figure 5.13). The Lerchs-Grossmann method mined 193 blocks or 2,859,295 tons from 197 blocks or 2,918,555 tons of ore in reserve at bench 1,980. It mined 268 blocks or 3,970,420 tons from 330 blocks or 4,888,950 tons of ore in reserve at bench 1,780. It also mined 50 blocks or 740,750 tons from 197 block or 2,918,555 tons of ore in reserve at bench 1,580. At bench 2,260, Lerchs-Grossmann mined all ore blocks in reserve.

<table>
<thead>
<tr>
<th>Bench (ft.)</th>
<th>Ore blocks in reserve</th>
<th>Lerchs-Grossmann (LG3D)</th>
<th>Ore blocks mined</th>
<th>Ore blocks unmined</th>
<th>Ore blocks cumulative mined</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,260</td>
<td>37</td>
<td>37</td>
<td>0</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>2,220</td>
<td>46</td>
<td>46</td>
<td>0</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>2,180</td>
<td>49</td>
<td>49</td>
<td>0</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>2,140</td>
<td>72</td>
<td>70</td>
<td>2</td>
<td>202</td>
<td></td>
</tr>
<tr>
<td>2,100</td>
<td>113</td>
<td>109</td>
<td>4</td>
<td>311</td>
<td></td>
</tr>
<tr>
<td>2,060</td>
<td>141</td>
<td>135</td>
<td>6</td>
<td>446</td>
<td></td>
</tr>
<tr>
<td>2,020</td>
<td>156</td>
<td>151</td>
<td>5</td>
<td>597</td>
<td></td>
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Table 5.12. Lerchs-Grossmann (LG3D) summary by benches.
Figure 5.9. The Three-D (LG3D) Lerchs-Grossmann ultimate pit limit outline.
XY plane for Z = 25 facing in the direction of negative Z
Symbols: '.' is air, '+' could be processed, '-' is waste

Figure 5.10. Bench 2,260 (+=ore, -=waste, -=air).
Figure 5.11. Bench 1980 (+=ore, -=waste, .=air).
XY plane for Z = 13 facing in the direction of negative Z
Symbols: '.' is air, '*' could be processed, '+' is waste

Figure 5.12. Bench 1,780 (+=ore, -=waste, .=air).
XY plane for Z = 8 facing in the direction of negative Z
Symbols: '•' is air, '+' could be processed, '-' is waste

Figure 5.13. Bench 1,580 (+=ore, -=waste, .=air).
5.4. Medsystem: The Application of M720V3 on DAT610.IA

Program M720V3 is used for the purpose of Lerchs-Grossmann optimization on the economic block model. As we discussed in the previous chapter, steps in Medsystem is similar. M720V3 or the Optimum Economic Pit Limits program utilizes Lerchs-Grossmann method for optimization. Likewise the M720V1, it uses cost data, model boundaries (rows, columns, benches), prices, and pit slope to generate optimum economic pit limit (see Figure 5.14). M720V3 is recently added to the Medsystem as a DIPPER (Lerchs-Grossmann) program.

![Program flow diagram of M720V3.](image)

Figure 5.14. Program flow diagram of M720V3.
The calculations process in M720V3 has similar approach with LG3D in the Three-D. The run file for M720V3 is run720.b. This run file has similar structure with M720V1’s run file (run720.a). There are differences in the run options such as no IOP1 (increment between columns during search) and IOP2 (increment between rows during search). M720V3 only use IOP3 (increment between benches during search) with a default value of 2. The report file for M720V3 is rpt720.lb.

M720V3 runs significantly faster than LG3D because it is under SUN/Unix operating system. It took only 15 minutes compare to 150 minutes by LG3D. Otherwise, it is more complicated in its application than LG3D.

The result of M720V3 is put together with M720V1’s result and dumped to ASCII format. This ASCII file is converted to Three-D format so we can generate block print of the result for better comparisons. Three-D’s LGPR is used for block print purpose. The M720V1’s Three-D format is MC.OUT, and the M720V3 is LG.OUT.

Figure 5.16 shows the final mined Lerchs-Grossmann pit limit outline using Medsystm. Lerchs-Grossmann’s M720V3 optimization program shows a summarized result as follows:

- 16,497 blocks representing 244,328,980 tons were read with 2,860 blocks or 42,370,900 tons of ore, 13,631 blocks or 201,943,265 tons of waste, and 6 blocks of air.
- 2,860 blocks or 42,370,900 tons mined from the total of 3,930 blocks or 58,222,950 tons ore within the economic block model.
- Total undiscounted net profit within the ultimate pit defined by the Lerchs-
Großmann method is US$50,787,904.

Figures 5.15 shows the summary of lg_out.prp generated by LGPR for xy-plan (z direction).

Figure 5.15. Summary of lg_out.prp.
Table 5.13 shows bench by bench summary of the Lerchs-Grossmann method. Following are figures showing pit outline (Figure 5.16), and how the Lerchs-Grossmann method mined at bench 2,260 (Figure 5.17), 1,980 (Figure 5.18), 1,780 (Figure 5.19), and 1,580 (Figure 5.20). The Lerchs-Grossmann method mined 196 blocks or 2,903,740 tons from 197 blocks or 2,918,555 tons of ore in reserve at bench 1,980. It mined 272 blocks or 4,029,680 tons from 330 blocks or 4,888,950 tons of ore in reserve at bench 1,780. It also mined 47 blocks or 696,305 tons from 197 block or 2,918,555 tons of ore in reserve at bench 1,580. At bench 2,260, Lerchs-Grossmann mined all ore blocks in reserve.

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Table 5.13. Lerchs-Grossmann (M720V3) summary by benches.
Figure 5.16. The Medsystem (M720V3) Lerchs-Grossmann ultimate pit limit outline.
Figure 5.17. Bench 2,260 (+=ore, -=waste, .=air).
XY plane for $Z = 18$ facing in the direction of negative $Z$
Symbols: '.' is air, '*' could be processed, '*' is waste

Figure 5.18. Bench 1,980 (+=ore, -=waste, .=air).
XY plane for Z = 13 facing in the direction of negative Z
Symbols: '.' is air, '+' could be processed, '-' is waste

Figure 5.19. Bench 1,780 (+=ore, -=waste, .=air).
XY plane for $z = 0$ facing in the direction of negative $z$

Symbols: '.' is air, '+' could be processed, '-' is waste

Figure 5.20. Bench 1,580 (+=ore, -=waste, .=air).
CHAPTER 6
COMPARATIVE ANALYSIS OF MOVING CONE AND LERCHS-GROSSMANN OPTIMIZATION METHODS

As we discussed in the previous chapters, there are differences in results between Moving Cone and Lerchs-Grossmann pit optimization methods. 13,002 blocks mined by Moving Cone method, while 15,792 and 16,497 blocks mined using Lerchs-Grossmann method.

The following sections discuss differences on the application between Moving Cone and Lerchs-Grossmann methods by benches. Likewise, the final pit limit outlines between both methods will be compared in this chapter. The economic block model will be used to show ore blocks mined by each methods. Medsystem's M720V1 program is used to generate Moving Cone results. Whittle Three-D's LG3D and Medsystem's M720V3 program are used to generate Lerchs-Grossmann pit outlines.

For comparisons, both Moving Cone and Lerchs-Grossmann pit outlines are printed bench by bench using Three-D's LGPR block print option. There are modifications made in LGPR program to list the statistic of each bench with regard to ore blocks in reserve, ore blocks mined, ore blocks unmined, cumulative ore blocks mined, and bench level. Figure 6.3 to 6.6 and Figure 6.9 to 6.12 show comparisons between both methods at bench 2,260, 1,980, 1,780, and 1,580. Figure 6.1, 6.2, 6.7, and 6.8 show the ultimate pit limit outline from each method and it comparison at Bench 2,260.
6.1. Moving Cone (M720V1) and Lerchs-Grossmann (LG3D)

Medsystem M720V1 and Three-D LG3D are used for this purpose. The Medsystem ran by Sun/Unix workstation, and Three-D ran by PC/DOS Intel 486DX2/66MHz workstation.

The economic block model are DAT610.IA and er4466r.eco for Medsystem and Three-D respectively. There are 129,500 blocks within the economic block model with 3,930 ore, 9 air, and 125,561 waste blocks.

There is significant difference of computer time for running Medsystem and Three-D software. Medsystem took 5 minutes of computer time for the optimization. Three-D took 2 hours and 32 minutes of computer time for optimization.

Some difficulties are found while using Medsystem because of its complexities especially on defining variables, precision, calculation procedures, and entering the economic block model data. Three-D is more user friendly and does all the optimization processes with a very straightforward steps.

Figure 6.1 shows the comparison of the contours of the ultimate pit outline between Moving Cone (M720V1) and Lerchs-Grossmann (LG3D) optimization methods. Figure 6.2 shows the difference between the two outlines.

Moving Cone method read 13,002 possible blocks to be mined within the economic block model. This includes 2,518 ore, 6 air, and 10,478 waste blocks. Lerchs-Grossmann method read 15,792 possible blocks to be mined within the economic block model. This includes 2,835 ore, 5 air, and 12,952 waste blocks.

Moving Cone and Lerchs-Grossmann optimization method mined for same
amount with a total cumulative number of 446 ore blocks until Bench 2,060. The differences started from Bench 2,020 until Bench 1,540. Both methods did not mine ore blocks below Bench 1,540. Table 6.1 shows the comparisons between both methods for each bench.

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Table 6.1. The comparisons between Moving/Floating Cone (M720V1) and Lerchs-Grossmann (LG3D) by benches.

The undiscounted net profit for Moving Cone method is US$49,965,088. The undiscounted net profit for Lerchs-Grossmann method is US$50,671,500. The difference between both methods is US$706,412.
Figure 6.1. The comparison between Moving Cone's (M720V1) and Lerchs-Grossmann's (LG3D) ultimate pit outline.
The ultimate pit limit outline difference between Moving Cone (M720V1) and Lerchs-Grossmann (LG3D).
Figure 6.3. Comparisons at Bench 2,260.
Figure 6.4. Comparisons at Bench 1,980.
Figure 6.5. Comparisons at Bench 1,780.
Figure 6.6. Comparisons at Bench 1,580.
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<th>Lerchs-Grossmann (LG3D)</th>
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<tr>
<td>TOTAL</td>
<td>3,930</td>
<td>2,518</td>
<td>1,412</td>
<td>2,835</td>
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</table>

Table 6.2. The differences between Moving Cone (M720V1) and Lerchs-Grossmann (LG3D) by benches.
6.2. **Moving Cone (M720V1) and Lerchs-Grossmann (M720V3)**

Medsystem M720V1 and M720V3 are used for this purpose. M720V1 used to representing Moving Cone optimization. M720V3 used to representing Lerchs-Grossmann optimization.

The economic block model is DAT610.IA. There are 129,500 blocks within the economic block model with 3,930 ore, 9 air, and 125,561 waste blocks.

There is difference of computer time for running Medsystem M720V1 and M720V3. Medsystem M720V1 took 5 minutes of computer time for the optimization. Medsystem M720V3 took 15 minutes of computer time for optimization.

Figure 6.7 shows the comparison of the contours of the ultimate pit outline between Moving Cone (M720V1) and Lerchs-Grossmann (M720V3) optimization methods. Figure 6.8 shows the difference between the two outlines.

Moving Cone method read 13,002 possible blocks to be mined within the economic block model. This includes 2,518 ore, 6 air, and 10,478 waste blocks. Lerchs-Grossmann method read 16,497 possible blocks to be mined within the economic block model. This includes 2,860 ore, 6 air, and 13,631 waste blocks.

Moving Cone and Lerchs-Grossmann optimization method mined for same amount with a total cumulative number of 446 ore blocks until Bench 2,060. The differences started from Bench 2,020 until Bench 1,540. Both methods did not mine ore blocks below Bench 1,540.
### Table 6.3: The comparisons between Moving Cone (M720V1) and Lerchs-Grossmann (M720V3) by benches.

The undiscounted net profit for Moving Cone method is US$49,965,088. The undiscounted net profit for Lerchs-Grossmann method is US$50,787,904. The difference between both methods is US$822,816.
Figure 6.7. The comparison between Moving Cone's (M720V1) and Lerchs-Grossmann's (M720V3) ultimate pit outline.
Figure 6.8. The ultimate pit limit outline difference between Moving Cone (M720V1) and Lerchs-Grossmann (M720V3).
Figure 6.9. Comparisons at Bench 2,260.
Figure 6.10. Comparisons at Bench 1,980.
Figure 6.11. Comparisons at Bench 1,780.
Figure 6.12. Comparisons at Bench 1,580.
<table>
<thead>
<tr>
<th>Bench (ft.)</th>
<th>Ore blocks in reserve</th>
<th>MOVING CONE (M720V1)</th>
<th>LERCHS-GROSSMANN (M720V3)</th>
<th>M720V1 vs M720V3</th>
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</thead>
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<tr>
<td></td>
<td>Ore blocks</td>
<td>Ore blocks</td>
<td>Ore blocks</td>
<td>Ore blocks</td>
</tr>
<tr>
<td></td>
<td>mined</td>
<td>unmined</td>
<td>cumulative</td>
<td>mined</td>
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<td>2,200</td>
<td>37</td>
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<td>37</td>
<td>37</td>
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<td>2,140</td>
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<td>70</td>
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<tr>
<td>2,100</td>
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<td>4</td>
<td>117</td>
<td>109</td>
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<tr>
<td>2,060</td>
<td>141</td>
<td>6</td>
<td>147</td>
<td>135</td>
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<td>147</td>
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<tr>
<td>1,980</td>
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<td>19</td>
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<td>1,540</td>
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<td>91</td>
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<td>1,380</td>
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<td>0</td>
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<td>1,340</td>
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<td>0</td>
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<td>1,300</td>
<td>0</td>
<td>0</td>
<td>258</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3,930</td>
<td>1,412</td>
<td></td>
<td>2,960</td>
</tr>
</tbody>
</table>

Table 6.4. The differences between Moving Cone (M720V1) and Lerch-Grossmann (M720V3) by benches.
6.3. **Lerchs-Grossmann’s solutions to Moving Cone’s problems**

As we discussed earlier, Moving Cone has two major problems: it may miss profitable combinations of blocks (mutual support problem), it may overextend the ultimate pit beyond the ultimate limits (overmining problem). Figure 6.13 and 6.14 shows the evidence that Lerchs-Grossmann algorithm solves these two problems.

![Figure 6.13. Lerchs-Grossmann’s solution to mutual support problem.](image)

![Figure 6.14. Lerchs-Grossmann’s solution to overmining problem.](image)
CHAPTER 7

CONCLUSIONS

Computer application in open pit design demands more innovation in methods, techniques, and software that is advantageous for the industry. Nowadays, open pit optimization, planning, and design are faster than it used to be. Bigger and faster computer, sophisticated and efficient software, and the intention to gaining maximum net present value put mine planning and design work more interesting for a mining engineer.

There are various open pit optimization methods and software which can be used in the mining industry. The Moving Cone method is still the most popular method for open pit optimization followed by Lerchs-Grossmann method.

Two open pit optimization software are used in this report for the purpose of understanding the difference between Moving Cone and Lerchs-Grossmann methods: *Three-D Whittle Open Pit Optimization Software* and *Medsystem*. The Moving Cone optimization method represented by Medsystem's M720V1 program. The Lerchs-Grossmann optimization method represented by Three-D's LG3D and Medsystem's M720V3 programs.

The case study for this report is an economic block model named er4466r.eco (Three-D’s format) and DAT610.IA (Medsystem’s format) which consists of 129,500 or 70x74x25 blocks in X, Y, and Z direction respectively representing an orebody of 3,930 ore, 125,561 waste, and 9 air blocks. The size of each block is 50 ft. in X direction, 100 ft. in Y direction, and 40 ft. in Z direction. Each block weighs 14,815 tons
with assumed tonnage factor of 13.5 ft³/ton. Total tonnage of the ore blocks is 58,222,950 tons. Total tonnage of the waste blocks is 1,860,186,215 tons.

The Moving Cone method mined 13,002 blocks or 192,535,740 tons consist of 2,518 blocks or 37,304,170 tons of ore, 10,478 blocks or 155,231,570 tons of waste, and 6 blocks of air. The total undiscounted net profit within the ultimate pit defined by the Moving Cone method is US$49,965,088.

The Lerchs-Grossmann (LG3D) mined 15,792 blocks or 233,884,405 tons consist of 2,835 blocks or 42,000,525 tons of ore, 12,952 blocks or 191,883,880 tons of waste, and 5 blocks of air. The total undiscounted net profit within the ultimate pit defined by the Lerchs-Grossmann method is US$50,671,500.

The Lerchs-Grossmann (M720V3) mined 16,497 blocks or 244,328,980 tons consist of 2,860 blocks or 42,370,900 tons of ore, 13,631 blocks or 201,943,265 tons of waste, and 6 blocks of air. The total undiscounted net profit within the ultimate pit defined by the Lerchs-Grossmann method is US$50,787,904.

There are differences in results between both methods. Lerchs-Grossmann (LG3D and M720V3) mined more blocks than Moving Cone (M720V1). Lerchs-Grossmann (LG3D) mined 317 blocks or 4,696,355 tons or 12.6% more ore than Moving Cone (M720V1). The undiscounted net profit of Lerchs-Grossmann (LG3D) is US$50,671,500 or 1.41% more than Moving Cone (M720V1). Stripping ratio of Lerchs-Grossmann (LG3D) is 4.57 compared to 4.16 of Moving Cone (M720V1).

Lerchs-Grossmann (M720V3) mined 342 blocks or 5,066,730 tons or 13.6% more than Moving Cone (M720V1). The undiscounted net profit of Lerchs-Grossmann...
(M720V3) is US$50,787,904 or 1.65% more than Moving Cone (M720V1). Stripping ratio of Lerchs-Grossmann is 4.77 compares to 4.16 of Moving Cone (M720V1).

Lerchs-Grossmann method (LG3D and M720V3) started to mine more ore blocks from Bench 2,020 down to Bench 1,540. There are no more ore blocks mined after Bench 1,540. Table 7.1 shows the summary of the above discussion.

```
<table>
<thead>
<tr>
<th>Blocks mined:</th>
<th>MOVING CONE</th>
<th>LERCHS-GROSSMANN</th>
<th>LG - MC</th>
</tr>
</thead>
<tbody>
<tr>
<td># of blocks</td>
<td>M720V1</td>
<td>LG3D</td>
<td>M720V3</td>
</tr>
<tr>
<td>Ore</td>
<td>2,518</td>
<td>2,835</td>
<td>317</td>
</tr>
<tr>
<td>tonnage</td>
<td>37,304,170</td>
<td>42,000,525</td>
<td>4,696,355</td>
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<tr>
<td>Waste</td>
<td>10,478</td>
<td>12,952</td>
<td>2,474</td>
</tr>
<tr>
<td>tonnage</td>
<td>155,231,570</td>
<td>191,863,880</td>
<td>46,711,695</td>
</tr>
<tr>
<td>Total*</td>
<td>12,996</td>
<td>15,494</td>
<td>4,16</td>
</tr>
<tr>
<td>tonnage</td>
<td>192,535,740</td>
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<tr>
<td>Stripping ratio</td>
<td>4.16</td>
<td>4.57</td>
<td>4.77</td>
</tr>
<tr>
<td>Undiscounted net profits (US$):</td>
<td>49,965,088</td>
<td>50,671,500</td>
<td>706,412</td>
</tr>
<tr>
<td>Computer time (minutes)**</td>
<td>5</td>
<td>150</td>
<td>145</td>
</tr>
</tbody>
</table>

Note: * Total figures exclude air blocks.
** Medsystem ran on Sun/Unix workstation. Three-O ran on IBM PC-Compatibles (Model 486DX2/66).
```

Table 7.1. Summary of results of Moving Cone and Lerchs-Grossmann.

The above discussion brought us to a conclusion that Lerchs-Grossmann optimization method can generate more profitable pit than Moving Cone. Lerchs-Grossmann optimization method is also a very good comparison to the existing Moving Cone method for the purpose of open pit mine planning and design.
SELECTED REFERENCES AND BIBLIOGRAPHY


APPENDIX A

ACTIVITY NETWORK FOR FEASIBILITY STUDY
APPENDIX B

MEDSYSTEM'S PROGRAM IDENTIFICATION AND TASKS
Medsystem structure.

**PROJECT INITIALIZATION (100)**
- Interactive creation of project control and history files (M100TS)
- Add, update, or list project data table (M101V1)
- Interactive creation of Medsystem data file descriptors (M102TS)
- Creation of Medsystem data file descriptors (M102V1)
- Interactive list and edit of the PCF file table (M104TS)
- Interactive list of the PCF file descriptors (M105TS)
- Interactive edit of Medsystem file passwords (M106TS)
- Transfer data between permanent files (M110V1)

**Group 100: Project initialization.**

**GRAPHICS (120)**
- Interactive graphics utility (M121V1)
- General purpose graphics program (M122V1)
- Binary conversion of M122 files (M123TS)
- Coordinate conversion of M122 files (M124TS)
- Create M122 commands with digitizer (M125TS)
- View metafiles (EMPC/Unix workstation versions only - M126MF)
- Convert AutoCAD DXF format to VBM format (M130TS)

**Group 120: Graphics.**
DRILLHOLE DATA OPERATIONS (200)

- DRILLHOLE ENTRY UTILITY (DHUTIL)
- SCAN INPUT DRILLHOLE DATA FOR LIMITS AND ERRORS (M200V1)
- LOAD DRILLHOLE DATA TO MEDSYSTEM DATA FILES (M201V1)
- INTERACTIVE DRILLHOLE DATA FILE EDITING (M202FS)
- DRILLHOLE DATA FILE EDITING (M202V1)
- LIST DRILLHOLE ASSAY FILE (M203V1)
- LIST DRILLHOLE ASSAY FILE AND GEOLOGIC BOUNDARY POINTS (M203V2)
- LIST DRILLHOLE SURVEY FILE (Standard Format - M204V1)
- LIST DRILLHOLE SURVEY FILE (Special Format - M204V2)
- INTERACTIVE ADDITION OF CODES TO THE ASSAY FILE (M205TS)
- ADDITION OF CODES TO THE ASSAY FILE (M205V1)
- COLLAR PLOT (M122) OF DRILLHOLE SURVEY FILE (M206V1)
- COLLAR PLOT (Printer) OF DRILLHOLE ASSAY AND SURVEY FILES (M206V2)
- EXTRACT DATA FROM THE DRILLHOLE ASSAY AND SURVEY FILES (M207V1)
- SPECIAL PROJECT CALCULATIONS (Reverse Polish Notation - M208RP)
- USER INTERFACE FOR DRILLHOLE DATA FILES (M208V1)
- DRILLHOLE INTERSECTION COORDINATE CALCULATIONS (M209V1)
- COORDINATE ROTATION BETWEEN COORDINATE SYSTEMS (M210V1)
- SORT DRILLHOLE SURVEY FILE (M212V1)
- STRIP LOGPLOT (M122) OF DRILLHOLE DATA (M215V1)
- CROSS-SECTION PLOT WITH SEAM JOINING (M122 - M216SM)
- CROSS-SECTION PLOT (M122) OF DRILLHOLE DATA (M216V1)
- PLAN PLOT (M122) OF DRILLHOLE DATA (M216V2)
- CONVERT DRILLHOLE INTO 3-D COORDINATE (EMPC/Unix workstation versions only - M219V1)
- EXTRACT DRILLHOLE LOCATIONS FOR POLYGON CALCULATIONS (M234V1)
- GENERATE DRILLHOLE POLYGONS AND AREAS (M236V2)
- PLOT POLYGON OUTLINES (M122 - M237V1)

Group 200: Drillhole data operations.

GEOSTATISTICAL ANALYSIS (300)

- INTERACTIVE MODEL AND PLOT OF VARIOGRAMS (M300TS)
- INTERACTIVE MODEL AND PLOT OF VARIOGRAMS (EMPC/Unix workstation versions only - M300V1)
- COMPUTE EXPERIMENTAL VARIOGRAMS FOR ASSAY DATA (M301V1)
- COMPUTE EXPERIMENTAL VARIOGRAMS FOR COMPOSITE DATA (M303V1)
- COMPUTE EXPERIMENTAL VARIOGRAMS (up to 50 - M303V2)

Group 300: Geostatistical analysis.
CLASSICAL STATISTICS FOR DRILLHOLES AND COMPOSITES (400)

- Statistical Analysis of Assay Data (M401V1)
- Statistical Analysis of Composite Data (M402V1)
- In-situ Statistical Analysis of Assay or Composite Data (M403V1)
- Dip/Strike Analysis of Drillhole Data (M404V1)
- Correlation Analysis of Assay or Composite Data (M411V1)
- Generate Scatter Graph, Histogram and Simple Statistics (M411V2)
- Cumulative Distribution Analysis of Assay or Composite Data (M412V1)

Group 400: Classical statistics for drillholes and composites.

COMPOSITE DATA OPERATIONS (500)

- Load Composites into Medsystem Data Files (M500V1)
- Compute Seam Composites from Drillhole Data (M501SM)
- Compute Bench Composites from Drillhole Data (M501V1)
- Interactive Composite Data File Editing (M502TS)
- Update Composite Using Batch Run (M502V1)
- List Composite Files (M503V1)
- Bench Plan (M122) of Composite Data (M504V1)
- Bench Plan (Printer) of Composite Data (M504V2)
- Addition of Codes to Composite Files (M505V1)
- Sort Composite Data File (M506V1)
- Extract Composite Data (M507V1)
- Special Project Calculations (Reverse Polish Notation - M508RP)
- User Interface for Composite Files (M508V1)
- Cross-Section of Composite Data (M122, MM516V1)
- Cross-Section of Composite Data (M122, without dh traces - M516V2)
- Decluster Composite Data (M523V1)
- Point Validation for Interpolation Techniques (M524V1)
- Interactive Evaluation of Point Validation (M525TS)

Group 500: Composite data operations.
MINE MODEL OPERATIONS (600)

- Initialize a Mine Model File (M601V1)
- Create a Compressed Format Model File (M601V2)
- Interactive Mine Model File Editing (M602TS)
- List Specified Data Items from the Mine Model File (M603V1)
- Line Printer Map of Composite vs. Mine Model Values (M605V1)
- Plan Map (M122) of Mine Model Data (M606V1)
- Plan Map (Printer) of Mine Model Data (M606V2)
- Contour Plot (M122) of Mine Model Data (M607V1)
- Contour Plot (Printer) of Mine Model Data (M607V2)
- Generate a Perspective View Plot (M607V3)
- Create Contour Data Using Triangulation (M607V4)
- Interactive Surface Data Display (EMPC/Unix workstation versions only - M607V5)
- Classical Statistical Analysis of Model Data (M608V1)
- Cross-Section (M122) of Mine Model Data (M609V1)
- Cross-Section (Printer) of Mine Model Data (M609V2)
- Enter Integer Data Into a Mine Model File (M610V1)
- Enter Real Data Into a Mine Model File (M610V2)
- Determine Mine Model Codes from 3-D Planes (M611V1)
- Special Project Calculations for Mine Model Files (M612RP)
- Surface Generation (M612SM)
- User Interface for Mine Model Files (Benches - M612V1)
- User Interface for Mine Model Files (Sections - M612V2)
- Calculate Project Coordinates from Digitized Outlines (M613V1)
- Interactive Entry of Mine Model Block Codes (M615TS)
- Compute Block Codes from Digitized Plan Boundaries (M615V1)
- Compute Block Codes from Digitized Section Boundaries (M615V2)
- Plot (M122) Exposed Block Below Surface (M616V1)
- Add Mine Model Codes to Composite Data (M617V1)
- Inverse Distance Weighting Interpolation (Standard Version - M620V1)
- Inverse Distance Weighting Interpolation (Octant Version - M620V2)
- Trend Plane Search Interpolation (M621V1)
- Kriging Interpolation Technique (M624V1)
- Gradient Interpolation Technique (M625V1)
- Load 2-D Surface File (File 13 - M630V1)
- Add Topography Percent to the Mine Model (M633V1)
- Create a Digital Terrain Model (M635V1)
- Calculate Elevations at Grid Point in a D.T.M. (M636V1)
- Dump File 13 into M607V5 Format (EMPC/Unix workstation versions only - M638V1)
- Generate Block Partials Between Two Surfaces (M639V1)

Group 600: Mine model operations.
VARIABLE BLOCK MODEL OPERATIONS (VBM)

- DIGITIZED DATA ENTRY UTILITY (DIGED)
- INTERPOLATE SEAM THICKNESS INTO A VBM FILE (M640V1)
- LOAD DIGITIZED DATA TO A VBM FILE (M649V1)
- INTERACTIVE VBM FILE EDITING (M649TS)
- OUTLINE AND AVERAGE RESERVES (EMPC/Unix workstation versions only - M650AR)
- DRAGLINE (EMPC/Unix workstation versions only - M650DL)
- INTERACTIVE VBM EDITOR (EMPC/Unix workstation versions only - M650ED)
- INTERACTIVE GRAPHICS PLANNER (EMPC/Unix workstation versions only - M650IP)
- SURVEY EDITING (EMPC/Unix workstation versions only - M650SV)
- NORMALIZE NODE POINTS OF VBM DATA (M651V1)
- COMBINE/ADD VBM FEATURES (M651V2)
- UPDATE LINE SEGMENTS IN THE VBM (M651V4)
- LIST A VBM MODEL INDEX (M652V1)
- CONVERT VBM DATA TO AUTOCAD DXF FORMAT (M653AC)
- EXTRACT VBM DATA (M653V0)
- LIST VBM DATA IN REPORT FORMAT (M653V1)
- LIST VBM DATA AND UTILITY FUNCTIONS (M653V2)
- PLOT VBM CONTOUR DATA IN PLAN OR SECTION (M122 - M654V0)
- PLOT VBM POINT DATA IN PLAN OR SECTION (M122 - M654V1)
- PLOT VBM PITS MERGED WITH VBM TOPO (M122 - M654V2)
- PLOT VBM PITS CLIPPED BY FILE 13 TOPOGRAPHY (M122 - M654V3)
- PLOT CLIPPED VBM DATA (M122 - M654V5)
- CALCULATE PLANE INTERSECTIONS FROM VBM DATA (M655V1)
- CALCULATE SECTION INTERSECTIONS FROM VBM DATA (M655V2)
- COMPUTE 3-D MODEL CODES FROM VBM PLAN DATA (M656V1)
- COMPUTE 3-D MODEL CODES FROM VBM CROSS-SECTION DATA (M656V2)
- COMPUTE 3-D MODEL PERCENTAGES FROM VBM PLAN DATA (M656V3)
- COMPUTE 3-D MODEL PERCENTAGES FROM VBM SECTION DATA (M656V4)
- EXTRACT INTERSECTIONS OF VBM DATA WITH A GRID (M657V1)
- CREATE GRIDDED DATA FROM INTERSECTIONS (M657V2)
- PLOT CROSS-SECTIONS FROM VBM (M122 - M658V1)
- PLOT PIT CROSS-SECTIONS FROM VBM (M122 - M658V1)
- EXTRACT FEATURES FROM VBM (M658V3)
- REFORMAT M658V3 POINTS (M658V4)
- SLICE FEATURES FROM SECTION VBM (M658V5)
- COMPUTE BLOCK PARTIALS FROM VBM FEATURES (M659V1)
- CALCULATE "WASTE DUMP" VOLUMES FROM VBM DATA (M659V2)
- INTERPOLATE INTERMEDIATE VBM PLANES (M661V1)
- TRUNCATE MINING CUTS STORED IN THE VBM (M662V1)
- COMPUTE SEAM LENGTH FOR 3-D BLOCKS FROM VBM DATA (M663V1)
- COMPUTE OUTCROP INTERSECTIONS FOR VBM DATA (M664V1)
- VBM CUT GENERATOR (M665V1)
- INTERACTIVE SOLIDS MODELER (EMPC/Unix workstation versions only - M670V1)
- INTERACTIVE VBM EDITOR (VBMED)

Group VBM: Variable block model operations.
MINE PLANNING OPERATIONS (700)

- Geometric Expansion of Pit Outlines (M701V1)
- Plot M701V1 Pit Outlines in Plan (M122 - M703V1)
- Calculate Block Partial from Pit Outlines (M705V1)
- User Interface for Reserve Calculations (M708V1)
- Set up or List the Reserve Summary File Logic (M710V1)
- Calculate 3-D Mine Model Reserves (M711V1)
- Reserve Summary Report Generation (M712V1)
- Interactive Initialization of Dipper Model Descriptors (M717V1)
- Initialization of Dipper Model Descriptors (M717V1)
- Create the Dipper Model from the Block Model (M718V1)
- Economic Pit Limits (Constant Pit Wall Slope - M720V1)
- Optimum Economic Pit Limits (EMPC/Unix workstation versions only - M720V3)
- Plan Plot of Dipper Pits (Printer - M721V1)
- Plan Plot of Dipper Pits (M122 - M721V2)
- Section Plot of Dipper Pits (M122 - M721V3)
- Printer Maps of Condensed Model Data (M722V1)
- Dipper Reserve Calculations (M723V1)
- List Condensed Model Values (M724V1)
- Summarize Reserves for Intermediate and Final Pit Outlines (M727V1)
- Calculate Block Partial from Dipper Pits (M728V1)
- Edit Surface Files or Add Mining Restrictions (M729V1)

Group 700: Mine planning operations.

GRIDDED SEAM MODEL (GSM)

- Cut Outline Generation/Propagation (M701SM)
- Digitize Cut Boundaries and Create Cut Outlines (M702SM)
- Plot Cut Outlines (M703SM)
- Determine Mining Limits from the GSM (M706SM)
- GSM Reserve Calculations (M708SM)
- Create an Auxiliary Schedule File (M708S0)
- Reserve Targeting (M709SM)
- Plot End of Target Periods (M709S1)
- GSM Reserve Summary (M712SM)
- Merge M708SM Reserves Summary Output (M713SM)
- Report Merged M708SM Reserves Summary Files (M714SM)

Group GSM: Gridded seam model.
PRODUCTION SCHEDULING (800)

- Long Range Scheduling for Open Pit Mines (M805v1)
- Long Range Scheduling from Dipper Designs (M806v1)
- Equipment Requirement Calculations (M807v1)
- Extract Assay Slice Files for Outline and Average (M819v1)
- Extract Composite Slice Files for Outline and Average (M819v2)
- Extract Composite Slice Files for M820v1 (File 9 only - M819v3)
- Outline and Average Reserves (M820v1)
- Extract Plan Slice Files for IGP (M829v1)
- Extract EW Section Slice Files for IGP (M829v2)
- Interactive Graphics Planner (M830v1)
- Plot M830v1 Cuts (M831v1)
- Convert M830v1 Cuts to VBM Format (M832v1)
- Summarize Reserves from M830v1 Cuts (M833v1)

Group 800: Production scheduling.

FINANCIAL ANALYSIS SYSTEM (900)

- M901TS
- M901TS Operation
  Calculation Subroutine

Group 900: Financial analysis system

THE MENU SYSTEM (MINER)

- MENU3 / MINER2 / EDMNU3
- MEDTOOL
- PROCMP

Group Miner: Menu system
APPENDIX C

LEVEL MAPS COMPARISONS OF

MOVING CONE (M720V1) AND LERCHS-GROSSMANN (LG3D)
**Economic Block Model** - Mixed by Moving/Plating Cone (MT2DF1):

### Input Modal Parameters File: `c:\3D\art4466\phasel\er4466r3.mpa`

<table>
<thead>
<tr>
<th>Contents of Modal Parameters File</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 50.00 150.00 40.00 8000.00 7800.00 1300.00</td>
</tr>
<tr>
<td>2 70 74 75 25</td>
</tr>
<tr>
<td>3 3 3 3</td>
</tr>
<tr>
<td>4 -14.40</td>
</tr>
<tr>
<td>5 1</td>
</tr>
<tr>
<td>6 1 79 1 74 1 25</td>
</tr>
<tr>
<td>7 1 20 -14.40</td>
</tr>
<tr>
<td>8 0.00 45.00</td>
</tr>
<tr>
<td>9 1</td>
</tr>
</tbody>
</table>

01/14/94 21:45 -- Thirdyanto

**Results File: `c:\3D\art4466\convert\MC.OUT`**

13982 Blocks were read
5 were air (zero)
2516 were ore (+ve)
12552 were waste (-ve)

---

**Economic Block Model** - Mixed by Larche-Grosensm (LQ2D):

### Input Modal Parameters File: `c:\3D\art4466\phasel\er4466r3.mpa`

<table>
<thead>
<tr>
<th>Contents of Modal Parameters File</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 50.00 150.00 40.00 8000.00 7800.00 1300.00</td>
</tr>
<tr>
<td>2 70 74 75 25</td>
</tr>
<tr>
<td>3 3 3 3</td>
</tr>
<tr>
<td>4 -14.40</td>
</tr>
<tr>
<td>5 1</td>
</tr>
<tr>
<td>6 1 79 1 74 1 25</td>
</tr>
<tr>
<td>7 1 20 -14.40</td>
</tr>
<tr>
<td>8 0.00 45.00</td>
</tr>
<tr>
<td>9 1</td>
</tr>
</tbody>
</table>

01/14/94 21:45 -- Thirdyanto

**Results File: `c:\3D\art4466\convert\MC.OUT`**

15792 Blocks were read
5 were air (zero)
2851 were ore (+ve)
13952 were waste (-ve)
Economic Block Model - Mixed by Working/Placing Cone (M720V1)

XY plane for X = 25 facing in the direction of negative Z (March 2, 2001)

Ore blocks in reserve = 37, Ore blocks mined = 37
Ore blocks unmine = 0, Cumulative ore blocks mined = 37
Symbols: '•' is air, '+' ore mined, 'o' ore unmine, '-' is waste

Economic Block Model - Mixed by Lerche-Grossman (LOGD)

XY plane for X = 25 facing in the direction of negative Z (March 2, 2001)

Ore blocks in reserve = 37, Ore blocks mined = 37
Ore blocks unmine = 0, Cumulative ore blocks mined = 37
Symbols: '•' is air, '+' ore mined, 'o' ore unmine, '-' is waste

---

Whittle Programming Pty. Ltd. - Melbourne, AUSTRALIA

27-DEC-94 Block print for Medsystem Pit Optimization 07.01 25-DEC-94 Block print for Three-D Pit Optimization 05.23

---

Whittle Programming Pty. Ltd. - Melbourne, AUSTRALIA
XY plane for I = 24 facing in the direction of negative Z (March 2, 220)
Ore blocks in reserve = 46. Ore blocks mined = 46
Ore blocks unmined = 3. Cumulative ore blocks mined = 93
Symbol: ' ' is air. '+' ore mined. '-' ore unmined. ' -' is waste

XY plane for I = 24 facing in the direction of negative Z (March 2, 220)
Ore blocks in reserve = 46. Ore blocks mined = 46
Ore blocks unmined = 3. Cumulative ore blocks mined = 93
Symbol: ' ' is air. '+' ore mined. '-' ore unmined. ' -' is waste
Economic Block Model - Mixed by Norming/Floating Cone (K720V)

XY plane for Z = 21 facing in the direction of negative Z (March 2, 1981)

- Ore blocks in reserve = 49
- Ore blocks mined = 49
- Ore blocks unmined = 5
- Cumulative ore blocks mined = 132

Symbols: ** is air, * is mined, o is unmined, - is waste

Economic Block Model - Mixed by Leach-Oreswap (LG3D)

XY plane for Z = 21 facing in the direction of negative Z (March 2, 1981)

- Ore blocks in reserve = 49
- Ore blocks mined = 49
- Ore blocks unmined = 5
- Cumulative ore blocks mined = 132

Symbols: ** is air, * is mined, o is unmined, - is waste
XY plane for Z = 22 facing in the direction of negative Z (Bench 2,149)

- Ore blocks in reserve = 72
- Ore blocks mined = 72
- Ore blocks unmined = 3
- Cumulative ore blocks mined = 302

Symbols: 
- ' ' is air, ' ' ore mined, ' ' ore unmined, ' ' is waste

---

XY plane for Z = 22 facing in the direction of negative Z (Bench 2,149)

- Ore blocks in reserve = 72
- Ore blocks mined = 72
- Ore blocks unmined = 3
- Cumulative ore blocks mined = 302

Symbols: 
- ' ' is air, ' ' ore mined, ' ' ore unmined, ' ' is waste

---
Economic Block Model - Mined by Moving/Plating Cone (M720V1)

XY plane for I = 21 facing in the direction of negative Z (March 2, 1991)
- Ore blocks in reserve = 133, Ore blocks mined = 109
- Ore blocks unmined = 4, Cumulative ore blocks mined = 311

Symbols: '!' is air, '+' ore mined, '-' ore unmined, '•' is waste

Economic Block Model - Mined by Leach-Drostmann (GQ0)

XY plane for I = 21 facing in the direction of negative Z (March 2, 1991)
- Ore blocks in reserve = 133, Ore blocks mined = 109
- Ore blocks unmined = 4, Cumulative ore blocks mined = 311

Symbols: '!' is air, '+' ore mined, '-' ore unmined, '•' is waste
Economic Block Model - Mixed by Lehman-Greenman (LGD)

XY plane for Z - 20 facing in the direction of negative Z (Bench 2,040)

Ore blocks in reserve = 141, Ore blocks mined = 135
Ore blocks unmined = 6, Cumulative ore blocks mined = 446

Symbols: "-" is air, "*" ore mined, "o" ore unmined, "-" is waste

Ore blocks in reserve = 141, Ore blocks mined = 135
Ore blocks unmined = 6, Cumulative ore blocks mined = 446

Symbols: "-" is air, "*" ore mined, "o" ore unmined, "-" is waste
XY plane for Z facing in the direction of negative Z (March 2.025)

Ore blocks in reserve = 156. Ore blocks mined = 187
Ore blocks untaken = 9. Cumulative ore blocks mined = 597
Symbols: '*' is air, '+' ore mined, '-' ore untaken, '*' in waste.

XY plane for Z facing in the direction of positive Z (March 2.025)

Ore blocks in reserve = 156. Ore blocks mined = 151
Ore blocks untaken = 9. Cumulative ore blocks mined = 597
Symbols: '*' is air, '+' ore mined, '-' ore untaken, '*' in waste.
Economic Block Model - Mixed by Moving/Floatin Cone (M720V1)

XY plane for X - 18 facing in the direction of positive Z (Bench 1,980)
Ore blocks in reserve = 197, Ore blocks mined = 178
Cumulative ore blocks mined = 771
Symbols: 'O' are air, 'X' are mined, '-' are unmined, '---' are waste

Economic Block Model - Mixed by Lauck-Grossman (M720V3)

XY plane for X - 18 facing in the direction of positive Z (Bench 1,980)
Ore blocks in reserve = 197, Ore blocks mined = 178
Cumulative ore blocks mined = 771
Symbols: 'O' are air, 'X' are mined, '-' are unmined, '---' are waste

---
Economic Block Model - Mixed by Mowing (Floating Cone)

XY plane for X = 17 facing in the direction of negative Z (Bench 1, 93)
One blocks in reserve = 205, one blocks mined = 182
One blocks unused = 23, cumulative ore blocks mined = 253
Symptoms: "*" is air, "-" ore mined, "o" ore unused, "-" in wets

Economic Block Model - Mixed by Lectra-Graeseman (H409)

XY plane for X = 17 facing in the direction of negative Z (Bench 1, 94)
One blocks in reserve = 205, one blocks mined = 195
One blocks unused = 19, cumulative ore blocks mined = 253
Symbols: "*" is air, "*" ore mined, "o" ore unused, "-" in wets
XY plane for $x = 16$ facing in the direction of negative $z$ (Bench 1,900)
One block in reserve = 281, One block mined = 253
One block unmined = 26, Cumulative ore blocks mined = 1,239
Symbols: '*' in air, '+' ore mined, 'o' ore unmined, '-' is waste

XY plane for $x = 16$ facing in the direction of negative $z$ (Bench 1,900)
One block in reserve = 281, One block mined = 253
One block unmined = 26, Cumulative ore blocks mined = 1,239
Symbols: '*' in air, '+' ore mined, 'o' ore unmined, '-' is waste
Economic Block Model - Mined by Moving/Placing Cone (M205P)

XY Plan for X - 14 facing in the direction of negative Z (Bench 1,820)
- Ore blocks in reserve = 153
- Ore blocks mined = 240
- Ore blocks mined = 79
- Cumulative ore blocks mined = 1,479

Symbols: '.' is air, '+' ore mined, 'o' ore unmined, '*' is waste

XY Plan for X - 14 facing in the direction of negative Z (Bench 1,820)
- Ore blocks in reserve = 153
- Ore blocks mined = 240
- Ore blocks mined = 79
- Cumulative ore blocks mined = 1,479

Symbols: '.' is air, '+' ore mined, 'o' ore unmined, '*' is waste
### XY plan for 13 facing in the direction of negative Z

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.</code></td>
<td>air</td>
</tr>
<tr>
<td><code>o</code></td>
<td>ore</td>
</tr>
<tr>
<td><code>u</code></td>
<td>unused</td>
</tr>
<tr>
<td><code>-</code></td>
<td>waste</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore blocks in reserve: 330</td>
</tr>
<tr>
<td>Ore blocks mined: 229</td>
</tr>
<tr>
<td>Ore blocks unused: 101</td>
</tr>
<tr>
<td>Cumulative ore blocks mined: 1,909</td>
</tr>
</tbody>
</table>

### XY plan for 13 facing in the direction of positive Z

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>.</code></td>
<td>air</td>
</tr>
<tr>
<td><code>o</code></td>
<td>ore</td>
</tr>
<tr>
<td><code>u</code></td>
<td>unused</td>
</tr>
<tr>
<td><code>-</code></td>
<td>waste</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore blocks in reserve: 250</td>
</tr>
<tr>
<td>Ore blocks mined: 268</td>
</tr>
<tr>
<td>Ore blocks unused: 62</td>
</tr>
<tr>
<td>Cumulative ore blocks mined: 2,046</td>
</tr>
</tbody>
</table>

---

**Economic Block Model - Mixed by Morsh/Flooding One (M7205V)**

**Economic Block Model - Mixed by Lachne-Rawman (LG3D)**

---

**Note:** The diagrams and tables above represent the plan for 13 facing in the direction of negative Z. The symbols and data provided are used to illustrate the mining and block distribution.
ECONOMIC BLOCK MODEL - MIXED BY MOVING/FLOTTING CONE (M20VE)

XY plans for 2 = 11 facing in the direction of negative Z (bench 1,700)
Ore blocks in reserve = 261, ore blocks mined = 169
Ore blocks unmined = 219. Cumulative ore blocks mined = 3,286
Symbols: '.' is air, '•' ore mined, 'x' ore unmined, '••' is waste

XY plans for 2 = 11 facing in the direction of negative Z (bench 1,700)
Ore blocks in reserve = 91. Ore blocks mined = 222
Ore blocks unmined = 69. Cumulative ore blocks mined = 2,952
Symbols: '.' is air, '•' ore mined, 'x' ore unmined, '••' is waste
<table>
<thead>
<tr>
<th>XY Plan for Z facing in the direction of negative Z (March 1, 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore blocks in reserve = 291, ore blocks mined = 119</td>
</tr>
<tr>
<td>Ore blocks unlined = 179, cumulative ore blocks mined = 2,398</td>
</tr>
<tr>
<td>Symbols: &quot;-&quot; is air, &quot;<em>&quot; ore mixed, &quot;</em>&quot; ore unlined, &quot;*&quot; waste</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XY Plan for Z facing in the direction of negative Z (March 1, 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore blocks in reserve = 391, ore blocks mined = 139</td>
</tr>
<tr>
<td>Ore blocks unlined = 167, cumulative ore blocks mined = 2,446</td>
</tr>
<tr>
<td>Symbols: &quot;-&quot; is air, &quot;<em>&quot; ore mixed, &quot;</em>&quot; ore unlined, &quot;*&quot; waste</td>
</tr>
</tbody>
</table>

---
XY plans for 2 - 9 facing in the direction of negative Z (March 1, 2020)
Ore blocks in reserve = 254. Ore blocks mined = 97
Ore blocks unmined = 177. Cumulative ore blocks mined = 2.4%
Symbols: '-' is air. '*' ore mined. '+' ore unmined. '*' is waste

XY plans for 2 - 9 facing in the direction of negative Z (March 1, 2020)
Ore blocks in reserve = 254. Ore blocks mined = 97
Ore blocks unmined = 177. Cumulative ore blocks mined = 2.4%
Symbols: '-' is air. '*' ore mined. '+' ore unmined. '*' is waste
BY plans for X = 6 facing in the direction of negative Z (March 1, 1989)
 ore blocks in reserve = 397, ore blocks mined = 39
 ore blocks unused = 158, cumulative ore blocks mined = 2,145
 symbols: "•" is air, "•••" ore mined, "•" ore unused, "••" in waste.

BY plans for X = 6 facing in the direction of negative Z (March 1, 1989)
 ore blocks in reserve = 397, ore blocks mined = 50
 ore blocks unused = 147, cumulative ore blocks mined = 2,925
 symbols: "•" is air, "••" ore mined, "•••" ore unused, "••••" in waste.
Economic Block Model - Mixed by Moving/Placing Cone (MTPS)

XY plane for X = 3 facing in the direction of negative Z (March 1,500)
Ore blocks in reserve = 41; Ore blocks mined = 0
Ore blocks unmined = 41; Cumulative ore blocks mined = 2,518
Symbols: '.' is air, '+' are mined, 'o' are unmined, '.' is waste

Economic Block Model - Mixed by Leach-Overmann (ALSO)

XY plane for X = 3 facing in the direction of negative Z (March 1,500)
Ore blocks in reserve = 41; Ore blocks mined = 0
Ore blocks unmined = 41; Cumulative ore blocks mined = 2,935
Symbols: '.' is air, '+' are mined, 'o' are unmined, '.' is waste
### Economic Block Model - Mined by Mining/Planning Cone (MT2092)

**XY plane for Z = 4 facing in the direction of negative Z (Bench 1,420)**

<table>
<thead>
<tr>
<th>Ore blocks in reserve</th>
<th>Ore blocks mined</th>
<th>Cumulative ore blocks mined</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>2,518</td>
</tr>
</tbody>
</table>

Symbols:
- ' ' is air
- '+' is mined
- 'o' is unmined
- '-' is waste

---

### Economic Block Model - Mined by Leach-Grosmann (LG3D)

**XY plane for Z = 4 facing in the direction of negative Z (Bench 1,420)**

<table>
<thead>
<tr>
<th>Ore blocks in reserve</th>
<th>Ore blocks mined</th>
<th>Cumulative ore blocks mined</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>2,835</td>
</tr>
</tbody>
</table>

Symbols:
- ' ' is air
- '+' is mined
- 'o' is unmined
- '-' is waste

---

---
Economic Block Model - Mixed By Horting/Placing cone (H720V1)

XY plan for Z = 2 facing in the direction of negative $ (bench 1,340)
Ore blocks in reserve = 0, Ore blocks mined = 0
Ore blocks unmined = 0, Cumulative ore blocks mined = 2,029
Symbols: "." is air, "*" ore mined, "O" ore unmined, "*" in waste

Economic Block Model - Mixed By Leach-overflow (LG3D)

XY plan for Z = 2 facing in the direction of negative $ (bench 1,340)
Ore blocks in reserve = 0, Ore blocks mined = 0
Ore blocks unmined = 0, Cumulative ore blocks mined = 2,029
Symbols: "." is air, "*" ore mined, "O" ore unmined, "*" in waste
### Economic Block Model - Mined By Moving/Firefighting Cone (M720V1)

**XY Plan for Z = 1 facing in the direction of negative X (Bench 1,300)**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Air</td>
</tr>
<tr>
<td>*</td>
<td>Ore mined</td>
</tr>
<tr>
<td><em>-</em></td>
<td>Ore unused</td>
</tr>
<tr>
<td><em>-</em></td>
<td>Waste</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Ore Blocks In Reserve</th>
<th>Ore Blocks Mined</th>
<th>Ore Blocks Unused</th>
<th>Cumulative Ore Blocks Mined</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>2,516</td>
</tr>
</tbody>
</table>

### Economic Block Model - Mined By Larc-Grassi (LG3D)

**XY Plan for Z = 1 facing in the direction of negative X (Bench 1,300)**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Air</td>
</tr>
<tr>
<td>*</td>
<td>Ore mined</td>
</tr>
<tr>
<td>*</td>
<td>Ore unused</td>
</tr>
<tr>
<td><em>-</em></td>
<td>Waste</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Ore Blocks In Reserve</th>
<th>Ore Blocks Mined</th>
<th>Ore Blocks Unused</th>
<th>Cumulative Ore Blocks Mined</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>2,635</td>
</tr>
</tbody>
</table>
APPENDIX D

LEVEL MAPS COMPARISONS OF

MOVING CONE (M720V1) AND LERCHS-GROSSMANN (M720V3)
**27-Dec-94**

Economic Block Model - Mined by Moving/Floating Cone (NT2005)

Revised: 01

- Licensed for use by Colorado School of Mines
- Licensed for educational usage only
- Not licensed for use in commercial projects

Contents of Model Parameters File -

| 1 | 50.00 | 100.00 | 40.00 | 8800.00 | 7000.00 | 1300.00 |
| 2 | 70.00 | 74.00 | 25.00 |
| 3 | 3.00 | 3.00 |
| 4 | -14.40 |
| 5 | 1 |
| 6 | 1 | 70 | 1 | 74 | 1 | 25 |
| 7 | 1 | 20 | -14.40 |
| 8 | 0.00 | 45.00 |
| 9 | 1 |

Input Model Parameters File: `c:\3d\er4466\mphases\erimpl.mps`

Data File: `c:\10\er4466\environ\environ.mpc`

Results File: `c:\10\er4466\environ\environ.out`

19001 Blocks were read
4 were air (zero)
2158 were ore (cume)
10478 were waste (cum)

---

**27-Dec-94**

Economic Block Model - Mined by Larche-Graeme (NT2005)

Revised: 01

- Licensed for use by Colorado School of Mines
- Licensed for educational usage only
- Not licensed for use in commercial projects

Contents of Model Parameters File -

| 1 | 50.00 | 100.00 | 40.00 | 8800.00 | 7000.00 | 1300.00 |
| 2 | 70.00 | 74.00 | 25.00 |
| 3 | 3.00 | 3.00 |
| 4 | -14.40 |
| 5 | 1 |
| 6 | 1 | 70 | 1 | 74 | 1 | 25 |
| 7 | 1 | 20 | -14.40 |
| 8 | 0.00 | 45.00 |
| 9 | 1 |

Input Model Parameters File: `c:\3d\er4466\mphases\erimpl.mps`

Data File: `c:\10\er4466\environ\environ.mpc`

Results File: `c:\10\er4466\environ\environ.out`

14497 Blocks were read
4 were air (zero)
2160 were ore (cume)
13651 were waste (cum)
XY plane for Z = 25 facing in the direction of negative Z (March 2, 260)

- Ore blocks in reserve = 37
- Ore blocks mixed = 37
- Ore blocks unmixed = 0
- Cumulative ore blocks mined = 37

Symbols:
- 'o' is air
- 'x' is ore mixed
- 'x' is ore unmixed
- '-' is waste

XY plane for Z = 25 facing in the direction of negative Z (March 2, 260)

- Ore blocks in reserve = 37
- Ore blocks mixed = 37
- Ore blocks unmixed = 0
- Cumulative ore blocks mined = 37

Symbols:
- 'o' is air
- 'x' is ore mixed
- 'x' is ore unmixed
- '-' is waste
XY plans for Z - 24 facing in the direction of negative Z
Ore blocks in reserve = 46, Ore blocks mixed = 46
Ore blocks unmined = 0, Cumulative ore blocks mined = 83
Symbols: '.' is air, '*' ore mined, 'o' ore unmined, '.' is waste
<table>
<thead>
<tr>
<th>XY plane for S = 23 facing in the direction of negative Z (Bench 2,180)</th>
<th>XY plane for S = 23 facing in the direction of negative Z (Bench 2,180)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore blocks in reserve = 49, Ore blocks mined = 49</td>
<td>Ore blocks in reserve = 49, Ore blocks mined = 49</td>
</tr>
<tr>
<td>Ore blocks unmined = 5, Cumulative ore blocks mined = 132</td>
<td>Ore blocks unmined = 5, Cumulative ore blocks mined = 132</td>
</tr>
</tbody>
</table>

Symbols: 'x' is air, '+' ore mined, 'o' ore unmined, '-' is waste
Economic Block Model - Mixed by Lerchs-Grossmann (M720V3)

XY plan for Z = 22 facing in the direction of negative (Bench 2,140)

Ore blocks in reserve = 72, Ore blocks mined = 70
Ore blocks wanted = 2, Cumulative ore blocks mined = 202
Symbols: 'o' is air, '+' ore mined, '-' ore wanted, '**' is waste

Economic Block Model - Mixed by Moving/Flipping Cone (M720V1)

XY plan for Z = 22 facing in the direction of negative (Bench 2,140)

Ore blocks in reserve = 72, Ore blocks mined = 70
Ore blocks wanted = 2, Cumulative ore blocks mined = 202
Symbols: 'o' is air, '+' ore mined, '-' ore wanted, '**' is waste
Economic Block Model - mined by Moving/Floating cone (M720V1)

XY plane for Z = 21 facing in the direction of negative Z
Ore blocks in reserve - 113, Ore blocks mined - 109
Ore blocks unmined - 4, Cumulative ore blocks mined - 311
Symbols: '*' is air, '+' are mined, '*' are unmined, '-' is waste

Economic Block Model - Mixed by Leach-Greenspan (M720V2)

XY plane for Z = 21 facing in the direction of negative Z
Ore blocks in reserve - 113, Ore blocks mined - 109
Ore blocks unmined - 4, Cumulative ore blocks mined - 311
Symbols: '*' is air, '+' are mined, '*' are unmined, '-' is waste
Economic Block Model - Mixed by Moving/Placing Cone (M720V1)

XY plane for Z = 20 facing in the direction of negative Z (Bench 2,040)
Ore blocks in reserve = 141, Ore blocks mined = 135
Ore blocks unmined = 6, Cumulative ore blocks mined = 446
Symbols: '.' is air, '*' ore mined, 'o' ore unmined, 'w' is waste

Economic Block Model - Mixed by Larcha-Greenspan (M720V3)

XY plane for Z = 20 facing in the direction of negative Z (Bench 2,040)
Ore blocks in reserve = 141, Ore blocks mined = 135
Ore blocks unmined = 6, Cumulative ore blocks mined = 446
Symbols: '.' is air, '*' ore mined, 'o' ore unmined, 'w' is waste
XY plane for Z = 18 facing in the direction of negative Z (March 1, 1991)
Ore blocks in reserve = 157, Ore blocks mined = 159
Ore blocks mined = 157, Cumulative ore blocks mined = 771
Symbols: "•" is air, "•" ore mined, "•" ore unmined, "•" is waste

XY plane for Z = 18 facing in the direction of negative Z (March 1, 1991)
Ore blocks in reserve = 157, Ore blocks mined = 159
Ore blocks mined = 157, Cumulative ore blocks mined = 771
Symbols: "•" is air, "•" ore mined, "•" ore unmined, "•" is waste
### Economic Block Model - Mixed by Moving/Floating Cone (K720V1)

**XY plane for X - 17 facing in the direction of negative Z (March 1994)**

<table>
<thead>
<tr>
<th>Symbol:</th>
<th>Ore blocks in reserve</th>
<th>Ore blocks mined</th>
<th>Ore blocks unlined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>192</td>
<td>192</td>
<td>23</td>
</tr>
</tbody>
</table>

Cumulative ore blocks mined: 953

### Economic Block Model - Mixed by Leitch-Grossman (K720V7)

**XY plane for X - 17 facing in the direction of negative Z (March 1994)**

<table>
<thead>
<tr>
<th>Symbol:</th>
<th>Ore blocks in reserve</th>
<th>Ore blocks mined</th>
<th>Ore blocks unlined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>197</td>
<td>197</td>
<td>3</td>
</tr>
</tbody>
</table>

Cumulative ore blocks mined: 991

Symbols: 
- "x" is air, 
- "*" are mined, 
- "-" are unlined, 
- "*" is waste
Economic Block Model - Mixed by Lecce-Graham (M720V1)

XY plan for X = 10 facing in the direction of negative Y (March 1, 1900)

- Ore blocks in reserve = 281
- Ore blocks mined = 230
- Ore blocks unmined = 50
- Cumulative ore blocks mined = 1,183
- Symbol: * is air, + is ore mined, * is ore unmined, . is waste

Symbology: * is air, + is ore mined, * is ore unmined, . is waste

Economic Block Model - Mixed by Lecce-Graham (M720V1)

XY plan for X = 10 facing in the direction of negative Y (March 1, 1900)

- Ore blocks in reserve = 261
- Ore blocks mined = 253
- Ore blocks unmined = 29
- Cumulative ore blocks mined = 1,244
- Symbol: * is air, + is ore mined, * is ore unmined, . is waste

Symbology: * is air, + is ore mined, * is ore unmined, . is waste


**Economic Block Model - Mixed by Moving/Floatong Ceiling (M720V1)**

XY plane for Z = 15 facing in the direction of negative X (bench 1.860)

- Ore blocks in reserve: 179, ore blocks mined: 256
- Ore blocks unmined: 79, cumulative ore blocks mined: 1,419

**Economic Block Model - Mixed by Layer-Grossmann (M720V2)**

XY plane for Z = 15 facing in the direction of negative X (bench 1.860)

- Ore blocks in reserve: 135, ore blocks mined: 297
- Ore blocks unmined: 44, cumulative ore blocks mined: 1,511

Symbols:
- '•' is air, 'o' is ore, 'x' is unmined, '•••' is waste

Symbols:
- '•' is air, 'o' is ore, 'x' is unmined.
XY plane for Z = 13 facing in the direction of negative Z (March 1, 1981)
Ore blocks in reserve = 1,581, Ore blocks mined = 1,239
Ore blocks unmined = 101, Cumulative ore blocks mined = 1,958

Symbols: ' ' is air, '*' ore mined, 'o' ore unmined, '-' in waste

XY plane for Z = 13 facing in the direction of negative Z (March 1, 1981)
Ore blocks in reserve = 195, Ore blocks mined = 272
Ore blocks unmined = 56, Cumulative ore blocks mined = 3,974

Symbols: ' ' is air, '*' ore mined, 'o' ore unmined, '-' in waste
Economic Block Model - Mixed by Moving/Flooding Case (MT749)

XY plane for X = 12 facing in the direction of negative Z (Bench 1,740)

Ore blocks in reserve = 350, Ore blocks mined = 213, Ore blocks unmined = 137, Cumulative ore blocks mined = 2,121

Symbols: '*' is air, '+' ore mined, '-' ore unmined, '•' waste

Economic Block Model - Mixed by Larcher-Grovesman (MT749)

XY plane for X = 12 facing in the direction of negative Z (Bench 1,740)

Ore blocks in reserve = 350, Ore blocks mined = 275, Ore blocks unmined = 75, Cumulative ore blocks mined = 2,349

Symbols: '*' is air, '+' ore mined, '-' ore unmined, '•' waste
Economic Block Model - Mixed by Legehr-Grossmann (MT3PU)
XY plane for Z = 10 facing in the direction of negative Z (Bench 1, 640)
Ore blocks in reserve = 291, Ore blocks mined = 112
Cumulative ore blocks mined = 2,196
Symbols: "" is air, "*" is mixed, "-" is unmined, "-" is waste

XY plane for Z = 10 facing in the direction of negative Z (Bench 1, 640)
Ore blocks in reserve = 391, Ore blocks mined = 132
Cumulative ore blocks mined = 1,712
Symbols: "" is air, "*" is mixed, "-" is unmined, "-" is waste
Economic Block Model - Mixed by Leaching-Flotation (M720V1)

XY plan for Z facing in the direction of negative Z (Bench 1,620)
Ore blocks in reserve = 254, Ore blocks mined = 177
Ore blocks unmined = 177, Cumulative ore blocks mined = 2,475


Economic Block Model - Mixed by Leaching-Flotation (M720V3)

XY plan for Z facing in the direction of negative Z (Bench 1,620)
Ore blocks in reserve = 254, Ore blocks mined = 90
Ore blocks unmined = 164, Cumulative ore blocks mined = 2,803

XY plane for Z = 0 facing in the direction of negative Z (Bench 1,580)

Ore blocks in reserve = 157, ore blocks mined = 39
Ore blocks unmined = 118, cumulative ore blocks mined = 2,314
Symbols: '.' is air, '+' ore mined, '*' ore unmined, '-' is waste

---

XY plane for Z = 0 facing in the direction of negative Z (Bench 1,580)

Ore blocks in reserve = 157, ore blocks mined = 47
Ore blocks unmined = 150, cumulative ore blocks mined = 2,950
Symbols: '.' is air, '+' ore mined, '*' ore unmined, '-' is waste

---

Economic Block Model - Mixed by Minter/Flooding Cone (M720V1)
economic block model - mixed by moving/placing core (m720v1)

xy plane for y = 7 facing in the direction of negative (bench 1.54)

- ore blocks in reserve = 95
- ore blocks mined = -4
- ore blocks unmined = 91
- cumulative ore blocks mined = 2,125

symbols: '•' in air, '•' are mined, 'x' are unmined, '-' in waste

---

economic block model - mixed by leacher-grasemann (m720v3)

xy plane for z = 7 facing in the direction of negative (bench 1.54)

- ore blocks in reserve = 95
- ore blocks mined = -10
- ore blocks unmined = 91
- cumulative ore blocks mined = 2,965

symbols: '•' in air, '•' are mined, 'x' are unmined, '-' in waste

---
Economic Block Model - Mixed by Leachage (M720V1)

XY plane for Y = 4 facing in the direction of negative Z (March 1, 1990)

Ore blocks in reserve = 19, Ore blocks mined = 8
Ore blocks missed = 10, Cumulative ore blocks mined = 2,518

Symbols: '*' is air, '+' is mined, '-' is unmined, 'x' is waste

Economic Block Model - Mixed by Leachage (M720V3)

XY plane for Y = 4 facing in the direction of negative Z (March 1, 1990)

Ore blocks in reserve = 19, Ore blocks mined = 8
Ore blocks missed = 10, Cumulative ore blocks mined = 2,568

Symbols: '*' is air, '+' is mined, '-' is unmined, 'x' is waste
XY plans for 3 facing in the direction of negative X (Level 1,384)
Ore blocks in reserve = 2, ore blocks mined = 0
Ore blocks mined = 2, cumulative ore blocks mined = 2,324
Symbols: 'X' are air, 'o' ore mined, '-' is waste

XY plans for 1 facing in the direction of negative X (Level 1,384)
Ore blocks in reserve = 2, ore blocks mined = 0
Ore blocks mined = 2, cumulative ore blocks mined = 2,845
Symbols: 'X' are air, 'o' ore mined, '-' is waste
Economic Block Model - Mixed by Moving/Placing Cone (M720V1)

XY plane for Z = 1 facing in the direction of negative Z (Block 1,500)
- Ore blocks in reserve = 0
- Ore blocks mined = 0
- Ore blocks unmined = 0
- Cumulative ore blocks mined = 2,108

Symbols: 'x' is air, '+' ore mined, '-' ore unmined, '*' is waste

Economic Block Model - Mixed by Larch-Grossmann (M720V3)

XY plane for Z = 1 facing in the direction of negative Z (Block 1,500)
- Ore blocks in reserve = 0
- Ore blocks mined = 0
- Ore blocks unmined = 0
- Cumulative ore blocks mined = 2,860

Symbols: 'x' is air, '+' ore mined, '-' ore unmined, '*' is waste
APPENDIX E

SECTION MAPS COMPARISONS OF

MOVING CONE (M720V1) AND LERCHS-GROSSMANN (LG3D)
### Input Model Parameters File: \textcolor{red}{c:\3d\er4466\er4466\pln01.trs}

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>50.00</td>
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<tr>
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<td>1.00</td>
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<td>-14.40</td>
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<td>5</td>
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<tr>
<td>6</td>
<td>30.00</td>
</tr>
<tr>
<td>7</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Results File: \textcolor{red}{c:\3d\er4466\er4466\r13002.txt}

- Blocks were read: 13002
- Air were read: 0
- Ore were read: 2835
- Waste were read: 12952

### Input Model Parameters File: \textcolor{red}{c:\3d\er4466\er4466\pln02.trs}

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50.00</td>
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<tr>
<td>2</td>
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<tr>
<td>4</td>
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<td>5</td>
<td>70.00</td>
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<tr>
<td>6</td>
<td>30.00</td>
</tr>
<tr>
<td>7</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Results File: \textcolor{red}{c:\3d\er4466\er4466\r15792.txt}

- Blocks were read: 15792
- Air were read: 0
- Ore were read: 5
- Waste were read: 15792
XZ plane for Y = 4 facing in the direction of positive Y
Symbols: '*' is air, '+' could be processed, '-' is waste

XZ plane for Y = 5 facing in the direction of positive Y
Symbols: '*' is air, '+' could be processed, '-' is waste
XX plane for Y = 6 facing in the direction of positive Y

Symbols: '.' is air, '+' could be processed, '-' is waste

```
   +------------+------------+------------+------------+------------+
   |            |            |            |            |            |
   |            |            |            |            |            |
   |            |            |            |            |            |
   |            |            |            |            |            |
   +------------+------------+------------+------------+------------+
```

XX plane for Y = 1 facing in the direction of positive Y

Symbols: '.' is air, '+' could be processed, '-' is waste

```
   +------------+------------+------------+------------+------------+
   |            |            |            |            |            |
   |            |            |            |            |            |
   |            |            |            |            |            |
   |            |            |            |            |            |
   +------------+------------+------------+------------+------------+
```
ZE plane for Y = 0 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste

```

```

ZE plane for Y = 0 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste

```

```
XZ plane for Y = 12 facing in the direction of positive Y
Symbols: '*' is air, '*' could be processed, '*' is waste

XZ plane for Y = 13 facing in the direction of positive Y
Symbols: '*' is air, '*' could be processed, '*' is waste

XZ plane for Y = 13 facing in the direction of positive Y
Symbols: '*' is air, '*' could be processed, '*' is waste

XZ plane for Y = 13 facing in the direction of positive Y
Symbols: '*' is air, '*' could be processed, '*' is waste
XX plane for Y = 14 facing in the direction of positive X

Symbols: '.' is air, '+' could be processed, '-' is waste

XX plane for Y = 14 facing in the direction of positive X
Symbols: '.' is air, '+' could be processed, '-' is waste

XX plane for X = 15 facing in the direction of positive X

Symbols: '.' is air, '+' could be processed, '-' is waste

XX plane for X = 15 facing in the direction of positive X
Symbols: '.' is air, '+' could be processed, '-' is waste
XX plane for Y = 16 facing in the direction of positive Y

Symbols: '.' is air, '+' could be processed, '-' is waste

---

XX plane for Y = 16 facing in the direction of positive Y

Symbols: '.' is air, '+' could be processed, '-' is waste

---

XX plane for Y = 17 facing in the direction of positive Y

Symbols: '.' is air, '+' could be processed, '-' is waste

---

XX plane for Y = 17 facing in the direction of positive Y

Symbols: '.' is air, '+' could be processed, '-' is waste

---
**XZ plane for Y = 18 facing in the direction of positive Y**

Symbols: "*" is air, "-" could be processed, "*" is waste

---

**XZ plane for Y = 18 facing in the direction of negative Y**

Symbols: "*" is air, "-" could be processed, "*" is waste
XZ plane for Y = 20 facing in the direction of positive Y
Symbols: '-' is air, '+' could be processed, '-' is waste

XZ plane for Y = 31 facing in the direction of positive Y
Symbols: '-' is air, '+' could be processed, '-' is waste
XZ plane for Y = 24 facing in the direction of positive Y
Symbols: '•' is air, '+' could be processed, '-' is waste

XZ plane for Y = 25 facing in the direction of positive Y
Symbols: '•' is air, '+' could be processed, '-' is waste
XZ plane for Y = 24 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste

XZ plane for Y = 27 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste
XZ plan for Y = 28 facing in the direction of positive Y
Symbols: ‘.’ is air, ‘*’ could be processed, ‘-’ is waste

XZ plan for Y = 28 facing in the direction of positive Y
Symbols: ‘.’ is air, ‘*’ could be processed, ‘-’ is waste
XX plane for Y = 32 facing in the direction of positive Y
Symbols: '-' is air, '+' could be processed, '-' is waste

XZ plane for Y = 33 facing in the direction of positive Y
Symbols: '-' is air, '+' could be processed, '-' is waste
XX plane for Y = 34 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste

XX plane for Y = 35 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste
XZ plane for Y = 45 facing in the direction of positive Y
Symbols: '*' is air, '+' could be processed, '-' is waste

XZ plane for Y = 44 facing in the direction of positive Y
Symbols: '*' is air, '+' could be processed, '-' is waste

Symbols: '*' is air, '+' could be processed, '-' is waste
### XZ Plane for Y = 46 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tbody>
</table>

### XZ Plane for Y = 47 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
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</thead>
<tbody>
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### XZ Plane for Y = 46 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
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</thead>
<tbody>
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### XZ Plane for Y = 47 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
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<tbody>
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### XZ Plane for Y = 46 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
</tr>
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<tbody>
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### XZ Plane for Y = 47 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
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### XZ Plane for Y = 46 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
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<tbody>
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### XZ Plane for Y = 47 Facing in the Direction of Positive Y

<table>
<thead>
<tr>
<th>Symbols: * - is air, + - could be processed, - - is waste</th>
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<tbody>
<tr>
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</tbody>
</table>
XI plane for Y = 52 facing in the direction of positive Y

Symbols: '*' is air. '+' could be processed. '-' is waste

```
```

XI plane for Y = 52 facing in the direction of positive Y

Symbols: '*' is air. '+' could be processed. '-' is waste

```
```

XI plane for Y = 52 facing in the direction of positive Y

Symbols: '*' is air. '+' could be processed. '-' is waste

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XI plane for Y = 52 facing in the direction of positive Y

Symbols: '*' is air. '+' could be processed. '-' is waste

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```

XI plane for Y = 52 facing in the direction of positive Y

Symbols: '*' is air. '+' could be processed. '-' is waste

```
```

XI plane for Y = 52 facing in the direction of positive Y

Symbols: '*' is air. '+' could be processed. '-' is waste

```
```
XZ plan for Y = 54 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste

XZ plan for Y = 55 facing in the direction of positive Y
Symbols: '.' is air, '+' could be processed, '-' is waste
XY plane for Y = 56 facing in the direction of positive Y

Symbols: 
- '.' is air, '+' could be processed, '--' is waste

<table>
<thead>
<tr>
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<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
<th>X7</th>
<th>X8</th>
<th>X9</th>
<th>X10</th>
<th>X11</th>
<th>X12</th>
<th>X13</th>
<th>X14</th>
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XY plane for Y = 57 facing in the direction of positive Y

Symbols: 
- '.' is air, '+' could be processed, '--' is waste

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**Diagram 1:**

- **Plan for Y = 59 facing in the direction of positive Y**
- Symbols: 
  - '.' is air, '+' could be processed, '-' is waste

---

**Diagram 2:**

- **Plan for Y = 59 facing in the direction of positive Y**
- Symbols: 
  - '.' is air, '+' could be processed, '-' is waste

---

**Diagram 3:**

- **Plan for Y = 59 facing in the direction of positive Y**
- Symbols: 
  - '.' is air, '+' could be processed, '-' is waste
XZ plane for Y = 40 facing in the direction of positive Y
Symbols: ' ' is air, '+' could be processed, '-' is waste

---

XZ plane for Y = 40 facing in the direction of positive Y
Symbols: ' ' is air, '+' could be processed, '-' is waste

---
APPENDIX F

COMPUTER CODES
C PROGRAM M610V2.FOR: CONVERTS *.ECO (THREE-D) TO DAT610.IA (MEDSYSTEM)
C-----------------------------------------------------------------------------------------------
C Tino Ardhyanto
C Mining Engineering Department
C Colorado School of Mines
C October 1994
C-----------------------------------------------------------------------------------------------
C Three-D files : ER4466R.ECO (Economic File)
C ERSR1MP1.MPA (Model Parameter File)
C Medsystem file: DAT610.IA (input for M610V2 routine)
C-----------------------------------------------------------------------------------------------
OPEN (5,FILE='ER4466R.ECO',STATUS='OLD')
OPEN (7,FILE='ERSR1MP1.MPA',STATUS='OLD')
OPEN (6,FILE='DAT610.IA',STATUS='NEW')
C
WRITE (*,2040)
READ (*,*) IDNUM
READ (7, 2020) DX, DY, DZ
READ (7, 2030) NX, NY, NZ
NXNY=NX*NY
C
C CONVERSION FORMULA
C Three-D to X,Y,Z and Medsystem format
C
DO 1000 I=1,IDNUM
    READ (5,*) ID, VALUE
    WRITE(*,*) ID, VALUE
    RID=FLOAT(ID)
    RIDM1=RID-1
    IZM1=IFIX(RIDM1/NXNY)
    RIXIY=RIDM1-IZM1*NXNY
    IYM1=IFIX(RIXIY/NX)
    IX=RIXIY-IYM1*NX+1
    IY=IYM1+1
    IZ=IZM1+1
    IZ=25-IZ+1
    WRITE (6,2010) IX, IY, IZ, VALUE
    WRITE (*,*) IX,' IY, IZ, VALUE
1000 CONTINUE
1010 STOP
2010 FORMAT (3I4,F8.2)
2020 FORMAT (5X,3F10.2)
2030 FORMAT (5X,3I10)
2040 FORMAT (\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\nC END
C PROGRAM CONTOUR.FOR: CONVERTS *.RES (THREE-D) TO CONTOUR.DAT (ASCII)

C Note: This program is to convert Three-D Whittle Open Pit Optimization Result File to X,Y,Z (ASCII) format.

C Tino Ardhyanto A.R.
Minining Engineering Department
Colorado School of Mines

C OPEN FILES
C Whittle files : LG.OUT (Result File)
ERSR1MP1.MPA (Model Parameter File)
C ASCII file : LG_CONTR.DAT (input for contour)

DIMENSION IZ1(70,74)

OPEN (5,FILE='LG.OUT',STATUS='OLD')
OPEN (7,FILE='ERSR1MP1.MPA',STATUS='OLD')
OPEN (11,FILE='LG_CONTR.DAT',STATUS='NEW')

WRITE (*,2040)
READ (7,2020) DX, DY, DZ
WRITE (*,*) DX, DY, DZ
READ (7,2030) NX, NY, NZ
WRITE (*,*) NX,NY,NZ

NXNY=NX*NY

C CONVERSION FORMULA
C Whittle to X,Y,Z and ASCII format

DO 20 IY=1,NY
   DO 10 IX=1, NX
      IZ1(IX,IY)=25
   10 CONTINUE
20 CONTINUE

NB=75000

DO 1000 I=1,NB
   READ (5,*,END=1010) ID, VALUE
   RID=FLOAT(ID)
   RIDM1=RID-1
   IZM1=IFIX(RIDM1/NXNY)
   RIXIY=RIDM1-IZM1*NXNY
   IYM1=IFIX(RIXIY/NX)
   IX=RIXIY-IYM1*NX+1
   IY=IYM1+1
   IF(IZ1(IX,IY).GT.IZ)THEN
      IZ1(IX,IY)=IZ
   ENDFI
   WRITE(*,*) IX,IY,IZ1(IX,IY)
1000 CONTINUE

1010 DO 40 IY=1,NY
   DO 30 IX=1, NX
      WRITE (11,*) IX, IY, IZ1(IX,IY)
30 CONTINUE
40 CONTINUE

2010 FORMAT (5X,3I4)
2040 FORMAT (5X,'INPUT NUMBERS OF ID TO BE CONVERTED:')
2020 FORMAT (5X,3F10.2)
2030 FORMAT (5X,3H0)
2050 FORMAT (5X,3F10.2)
2060 FORMAT (5X,3H0)
2070 STOP
END
C PROGRAM MEDTO3D: CONVERTS MEDSYSTEM TO THREE-D FORMAT
C -------------------------------------------------------------
C By: Tino Ardhyanto A.R.
C Mining Engineering Department
C Colorado School of Mines
C December 1994
C -------------------------------
C Medsystem format: TINO15D.OUT - Moving Cone (M720V1)
C Three-D format: MC.OUT - Moving Cone
C LG.OUT - Lerchs-Grossmann
C -------------------------------
C
INTEGER NX,NY,NZ,X,Y,Z,I,J,K
REAL MC,LG,RVAL
C
NX = 70
NY = 74
NZ = 25
C
OPEN (5,FILE='TINO15D.OUT',STATUS='OLD')
OPEN (7,FILE='MC.OUT',STATUS='NEW')
OPEN (11,FILE='LG.OUT',STATUS='NEW')
C
DO 20 K=NZ,1,-1
   DO 15 J=1, NY
      RECN=(K-1)*NY+J
      DO 5  I=1,NX
         READ(5,*) X,Y,Z,RVAL,MC,LG
         IDN=I+(J-1)*NX+(K-1)*NX*NY
         IF (MC .EQ. 1.) WRITE(7,100)IDN,RVAL
         IF (LG .EQ. 1.) WRITE(11,200) IDN,RVAL
      5    CONTINUE
   15 CONTINUE
20 CONTINUE
C
100 FORMAT (I10,F20.3)
200 FORMAT (I10,F20.3)
STOP
END