Analysis of Characteristic Grades, Daily Production Capacity, and Maximum Limits of Exploitability of Existing Mineral Resources in a Mining Plant

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ABSTRACT

The estimate of mineral resources has had its beginnings with the use of empirical techniques, or what we know today by classical methods used to estimate the amount of mineral in the mineral deposit, and has also used statistics as support to estimate average grade and describe the behavior of the grade.

The values we get from the estimated reserves are only a first approximation the most important issue to consider, that is, the economic viability of mineral resource. During the life of a mine, estimates of reserves are continually being revised to support the development of planning, analysis of efficiencies and costs, quality control and improve methods of extraction and processing. Safe estimates of reserves are also required when a project is funded, in buying or selling a property and for accounting purposes as depreciation and tax calculations. It is also used in determining the value of shares on the stock.

Different alternatives and their impact on economic parameters to optimize the project specifications and the expected value, Sensitivity and Risk Analysis, together with the appreciation of intangible factors non-qualifying are used ultimately to take the managerial decision regarding the economic viability of a mining project.

INTRODUCTION

The complexity and risk involving the definition and implementation of a mining project demands an early and constant evaluation of the expected results of the operation. This process covers from the project evaluation in its exploration phase to the evaluation of the project in its construction phase.

Although each of the stages of evaluation is a crucial step in the development of a mining project, the early stages, that it to say, stages of feasibility studies of the project are of crucial importance because they allow you to define.

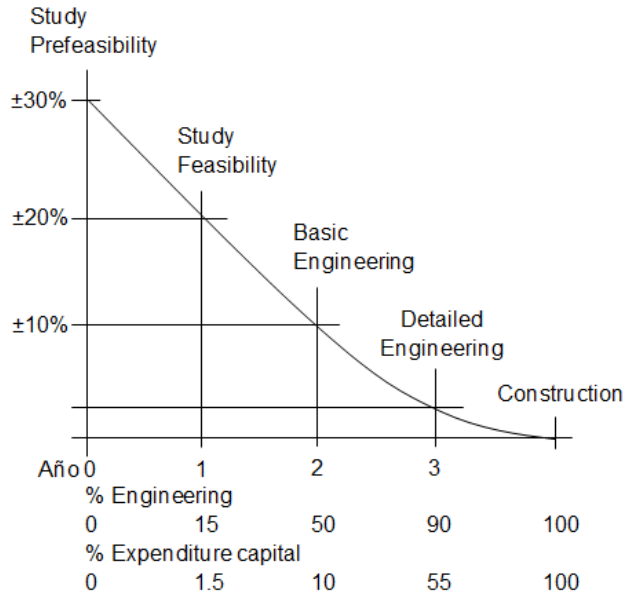

Figure 1) Cost Estimate and Progress of Engineering

- Available reserves.
- Mineralogical / metallurgical characteristics of the ore.
- The basic flow of processing.
- The mining method and design of the mine.
- The sizing of operations.
- The effect of climatic phenomena.
- The effect of the presence of aquifers.
- The effect of the quality from the rock.
- The effect of the operation on the environment.

PRESENTATION OF THE PROBLEM

IDENTIFICATION OF A MATHEMATICAL MODEL

According to the planning and operation associated with the operation of a mine can be considered appropriate to identify and develop a mathematical model to define the technical and economic parameters associated with each of these phases.

During the planning phase it is essentially requires a critical grade allowing geographically define the limits of exploitation of resources in the long term. The cutoff geographically defines the limits of exploitability of the resource in the short term. In the operating phase itself, and with a more complete knowledge of local operating conditions it is required to define the technical and economic parameters for each mineralized sector to define their sequence of extraction and the grade of extraction for each of them (marginal extraction grade).

A mathematical model allows the incorporation of technical and economic parameters and analysis of situations and results. On this basis it is recommended to develop a model that considering the requirements of the two phases mentioned in the preceding paragraph, succeed in its response to the analysis set of grades previously defined characteristics.

GENERAL OBJECTIVE

Orienting the mathematical model to analyze the characteristic grades and the daily production capacity to an embodiment of the parameters that influence the maximum generation of economic benefits (economic plan); as well as the integration of those criteria for defining maximum limits of exploitability of existing mineral resources (technical level).

SPECIFIC OBJECTIVES

According to LaGrange equations, determine and obtain the maximum benefit that can provide a mineral reserve.

Using a mathematical model to estimate the income to be obtained by an ore deposit with an acceptable level of confidence.

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METHODOLOGY

PROCESS DESCRIPTION

RESOURCES AND RESERVES

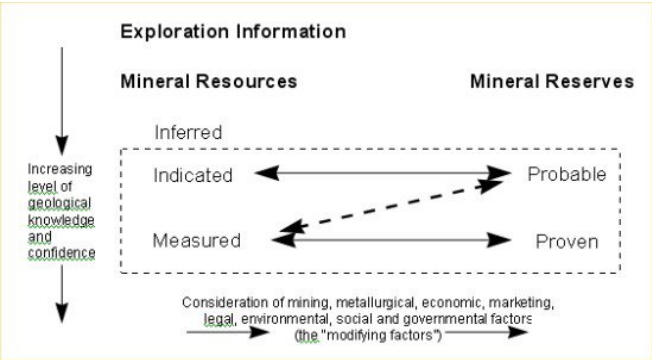


Figure 2. General Relationship between Resources and Mineral Reserves.

Mineral resource

It is a concentration or occurrence of intrinsic economic interest in or out of the earth's crust in the form and quantity as to demonstrate that there are reasonable prospects for eventual economic extraction. The location, quantity, metallic content, geological characteristics and continuity of a mineral resource are known, estimated or interpreted from specific geological evidence and knowledge. Mineral Resources are classified according to geological confidence rising in categories Inferred, Indicated and Measured.

Mineral reserves

It is the economically mineable part of an Indicated or Measured Mineral Resource. It includes dilution factors and allowances for losses that may occur when the mineral is mined. He considers that have carried out appropriate assessments which could include feasibility studies and include take into account mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. At the time of the report these calculations show that the operation could reasonably be justified. Mineral Reserves are subdivided in order of greater confidence in Probable Mineral Reserves and Proved Mineral Reserves.

Interdepencia

Probable reserves - Indicated Resource

A 'Probable Mineral Reserve' is the mineable part of an Indicated Mineral Resource, and in some circumstances a Measured Mineral Resource. It includes diluting materials and allowances for losses that may occur when the material is removed, and have carried out appropriate calculations which may include feasibility studies and take into account factors mining, metallurgical, economic, marketing, legal, environmental, social and governmental. At the time of the report these calculations show that extraction could reasonably be justified.

Proved Reserves - Measured Resource

A 'Proven Mineral Reserve' is the economically mineable part of a Measured Mineral Resource. It includes diluting materials and losses that may occur when the material is extracted and have carried out appropriate calculations which may include feasibility studies and take into account factors mining, metallurgical, economic, marketing, legal, environmental, social and government. At the time of the report these calculations show that extraction could reasonably be justified.

ESTIMATE OF GRADES

Ordinary Kriging equations

For kriging equations must be minimized expression of σ_{E^2}

$$\sigma_{E^2} = 2\sum_{i=1}^{N} \lambda_i \frac{1}{V}\int_V \gamma(x_i, x)dx - \frac{1}{V^2}\iint_V \gamma(x,y)dxdy - \sum_{i=1}^{N}\sum_{j=1}^{N} \lambda_i \lambda_j \gamma(x_i, x_j)$$

but λi should check the condition:

$$\sum_{i=1}^{N} \lambda_i = 1$$

The classic (equal to zero the partial derivatives of σE2 regarding λ1, λ2,... , λN) Method to minimize the expression of σE2 does not ensure that the sum of the λi is 1. In this case we must use the method Lagrange.

Usually the parameter μ no physical significance. In the case of kriging it is necessary to consider the expression: A' = σ_{E^2} + 2μ(λ1 + λ2 + . . . + λN - 1)

It is shown that performing N + 1 system leads the following equation is obtained:

$$\lambda 1\gamma(x1,x1) + \lambda 2\gamma(x1,x2) + \ldots + \lambda N\gamma(x1,xN) + \mu = (1/V)\int v\gamma(x1,x)dx$$

$$\lambda 1\gamma(x2,x1) + \lambda 2\gamma(x2,x2) + \ldots + \lambda N\gamma(x2,xN) + \mu = (1/V)\int v\gamma(x2,x)dx$$

$$\vdots$$

$$\lambda 1\gamma(xN,x1) + \lambda 2\gamma(xN,x2) + \ldots + \lambda N\gamma(xN,xN) + \mu = (1/V)\int v\gamma(xN,x)dx$$

$$\lambda 1 + \lambda 2 + \ldots \qquad \ldots + \lambda N = 1$$

Figura 3. Lineal System of N+1 ecuations with N+1 ecuations with N+1 unknowns (λ1, λ2, . . . , λN, μ)

Which is a linear system of N + 1 equations with N + 1 unknowns (λ1, λ2,..., λ N, μ) it is shown that the system always has a solution (assuming that the model γ (h) is authorized) except in the case where there are two (or more) different samples with the same coordinates: This case should not arise in practice but sometimes occurs, which necessitates a prior review of the database. The method we have presented is known as ordinary kriging and can be applied whenever the regionalized variable not present a drift in the vicinity of estimation.

Error variance

It demonstrated that expression of σE2 is simplified, yielding:

$$\sigma_{E^2} = \sum_{i=1}^{N} \lambda_i \frac{1}{V}\int_V \gamma(x_i, x)dx - \frac{1}{V^2}\iint_V \gamma(x,y)dxdy + \mu$$

REVERSE METHOD TO DISTANCE

Uses: It is an estimation method is not advisable in deposits with very definite limits (step mineralization to net sterile), it is more similar to that classical geostatistical methods.

Methodology: a weighting factor is applied to each sample surrounding the (unknown) center point of a

mineralized block. The weighting factor is the inverse of the distance between the point in question and the known, raised to a power n (2).

$$L = \Sigma\, l / d^m$$

$$\Sigma\, 1/ d^m$$

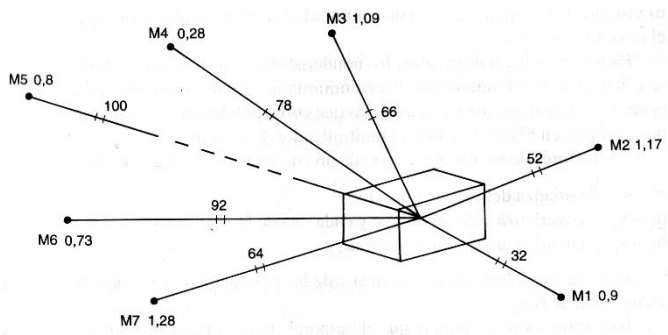


Figure 4. Grade estimation block GBj.

BUILDING BLOCKS MODEL

Usually, the first step is to create a set of perforated sections from the drilling database. These sections are then used to verify the project data and then to establish interpreted geological limits for different types of rock and mineral. The next step is to divide the geological zones into blocks and calculate the tonnage and graduation of each block. The shape of the blocks and calculation methods vary according to the specific requirements of your project. (Anexo 1)

WHAT IS A MODEL OF BLOCKS

The method most used in resource modeling is 3D space discretization in three-dimensional blocks or cells. Each block must contain all the information available on the development phases of a project: lithology-mineralogy, metal content, quality in the case of coal and industrial rocks, contents of pollutants, geomechanical parameters, hydrogeological data, etc.
To define the block model is necessary to set the following parameters:

- Position model is specified from the coordinates of the centroid of the block.
- Extension of the model in different X, Y, Z (must be large enough to frame the region of interest).
- Dimensions cells or blocks by the X, Y and Z.
- Defined model orientation (angle of inclination and azimuth).
- Set of variables to be stored in the model with corresponding formats: grade of different metals, volumetric weight, lithology, ore type technology etc.

METHODOLOGY TO OPTIMIZE

The methodology is presented by G. Matheron y P. Formery.

Each year production will get an annual profit equal BA

$$BA = |\,V(m) - P(t)|.\,t$$

Where:

BA = Annual Benefit

V(m) = Value of a tonne of ore grade

P(t) = Production cost per ton of ore associated with an annual production of t tons.

The balance of the future operation is then presented as the present value of all future benefits those obtained during the N years of mine life, discounting the total investment I (t) that had to be done.

If the update is calculated at an interest rate i, the benefit will be:

$$B(m,t,N) = |V(m) - P(t)|.\,t.\frac{|1 - e^{-iN}}{i} - I(t)$$

If we want to determine the operating conditions for maximum benefit, these conditions would have to meet the relationship.

To optimize a function B, subject to a given ratio, as the following expression, Lagrange formalism is used:

$$\frac{\delta F}{\delta t} = \frac{\delta F}{\delta N} = \frac{\delta F}{\delta m} = 0$$

F = B (m,t.N) λ|N(t) – T(m)|, being λ a parameter system

N = Tonelaje de reservas explotables/Tonelaje anual

Where T(m) = tonnage of mineable reserves with an average grade m.

Thus we get:

$$\frac{\delta F}{\delta t} = \frac{1 - e^{-iN}}{i}\left[I\left[\frac{-\,dp(t)}{dt}\right] + |V(m) - P(t)|\right]\frac{dt(t)}{dt}\lambda N = 0$$

$$\frac{\delta F}{\delta m} = t|V(m) - P(t)|e^{-iN}\,\lambda t = 0$$

$$\frac{\delta F}{\delta m} = t\left[\frac{dV(m)}{dm}\right]\frac{1 - e^{-iN}}{i} + \frac{\lambda dT(m)}{dm} = 0$$

With the last equations are obtained:

$$1)\ \frac{1-e^{-iN}}{i}\left|V(m)-\frac{d}{dt}\big(tp(t)\big)\right| = \lambda N + \frac{dI(t)}{dt}$$

$$2)\ t|V(m)-P(t)|e^{iN} = \lambda t \ \gg\ \lambda = |V(m)-P(t)|e^{iN}$$

And how:

$$\frac{d|V(m)|}{dmt} = b$$

$$3)\ bt\frac{1-e^{-iN}}{i} = \frac{\lambda dT(m)}{dm}$$

With the equation 1) y 2) It is finally obtained:

$$|V(m)-P(t)|\frac{1-e^{-iN}-iNe^{-iN}}{i} = \frac{dI(t)}{dt} + \frac{t(1-e^{-iN})}{i}\frac{dp(t)}{dt}$$

Equation 2) y 3) it is obteined:

$$bt\frac{1-e^{-iN}}{i} = |V(m)-P(t)|e^{-iN}\frac{dT(m)}{dm}$$

However already seen that:

$$\frac{dm}{dT} = \frac{x-m}{T}$$

Then;

$$bt\frac{1-e^{-iN}}{i} = |V(m)-P(t)|e^{-iN}\frac{Nt}{m-x}$$

$$(m-x)\frac{1-e^{-iN}}{i} = mNe^{-iN} - \frac{P(t)}{b}Ne^{-iN}$$

$$(m-x)\frac{1-e^{-iN}}{i} - mNe^{-iN} + \lambda Ne^{-iN} - \lambda Ne^{-iN} = \frac{-P(t)Ne^{-iN}}{b}$$

Then:

$$(m-x)\left[\frac{1-e^{-iN}}{i} - Ne^{-iN}\right] - xNe^{-iN} = \frac{-P(t)Ne^{-iN}}{b}$$

And:

$$x = \frac{P(t)}{b} + (m-x)\frac{1-e^{-iN}-iNe^{-iN}}{iNe^{-iN}}$$

This is the expression of the characteristic grade considering an interest rate “i” during the years of mine life. Interestingly, this expression reflects a cutoff that optimizes the utilization of capital invested over the N years of the life of the operation. This grade does not necessarily have to coincide that which optimizes the use of total extractable reserves (reserves covering its extraction and its benefit).

This situation is shown without much difficulty observing the last relationship that contains two terms. One that matches the expression of critical grade considering a zero interest rate (i = 0), and one that is highly sensitive due to the coefficient e (base of natural logarithms) that affects it. From this observation we can conclude that:

a) When we require optimization relates to the technically extractable reserves that maximize operating or contours (long term reserves), property grade coincides with a critical grade given by

$$x = \frac{P(t)}{b}$$

b) When optimization we require is related to a type of operation defined for a period of time (short term reserves), property grade coincides with a cutoff affects an interest rate “i” over the N years of life of the operation. In this case the analysis of Total Profit Updated at a rate i provide optimum cutting grade.

RESULTS

It is easy to understand that a correct decision in every phase of the assessment will depend on a good measure of reliability to be assigned to the various parameters involved; the degree of variability or "sensitivity" presenting each.

The most appropriate model should interrelate all the benefits-income-cost production-level components. The increase in production capacity allows to incorporate economies of scale that lead to analysis of marginal costs and benefits associated with different production scale increases. So the relationship between production parameters (ie, based on average costs) and optimum production parameters (ie, based on marginal costs) should be identified to determine the maximum limits of exploitability of the resource.

CONCLUSIONS

The evaluation of a mining property must consider the best estimate available of the extractable reserves in the categories of proved and probable in terms of tonnages and grades, the program of annual production in terms of tonnages, ore grades, and destinations of materials extracted from the mine, metallurgical to use process and recoveries to obtain the product or products to sell in terms of quantity, quality and price, capital costs, operating costs, financing costs of investment, cost of working capital and investment program and construction. These elements and others of different category (cost of environmental protection, administrative costs, insurance, taxes, benefits for workers,

communications, among many others) that must eventually be compiled and estimated each year to derive the assessment a mining property.
In order to proceed to estimate the value to pay for a deposit it is always useful to separate the analysis into two parts. One, in which a estimation generates income is made, and one on which an estimate of the maximum value is made to pay for the property.

With the results of the mathematical model, we can estimate the grade and location of the material on the ground (land resources) must meet with an acceptable level of confidence. This applies especially in the case of deposits of large dimensions and a low-grade, whose values are only slightly above the minimum levels of profitability, and in the case of some deposits of precious metals in which only you can exploit a small percentage of mineralized rock profitably.

The three tasks related to the estimation of mineral extraction planning and control of the grade is complementary and is the natural progression of passage from one to the other. The integration of these three challenges is very important, because the control system of the grade must be balanced with ore reserves and the final products of plant operations, and both estimation and control of the grade are influenced by planned operational procedures.

BIBLIOGRAPHIC REFERENCES

[1]Estimación de Recursos Mineros - Marco Antonio Alfaro Sironvalle.
http://www.cg.ensmp.fr/bibliotheque/public/ALFARO_Cours_00606.pdf
[2]Bustillo Revuelta, M. y López Jimeno, C., 1997: Manual de evaluación y diseño de explotaciones mineras. Madrid. ISBN 84-921708-2-4 .
[3]ANNELS, A. E. (1991). Mineral deposit evaluation. A practical approach. Ed. Chapman & Hall, London.
[4]TULCANAZA,E. (1992). Técnicas geoestadísticas y criterios técnico-económicos para la estimación y evaluación de yacimientos mineros.. E.Tulcanaza, Santiago, Chile.
[5]E. García Orche. Madrid 1999. Manual de Evaluación de Yacimientos.
[6] “Estimación de Reservas”- Curso dictado por Roberto Oyarzun.
[7]Código para la Certificación de Prospectos de Exploración (realizado por Comité de Recursos Mineros del I.IM.Ch).

ANEXOS

PROCESS AND DATA FLOW OVERVIEW

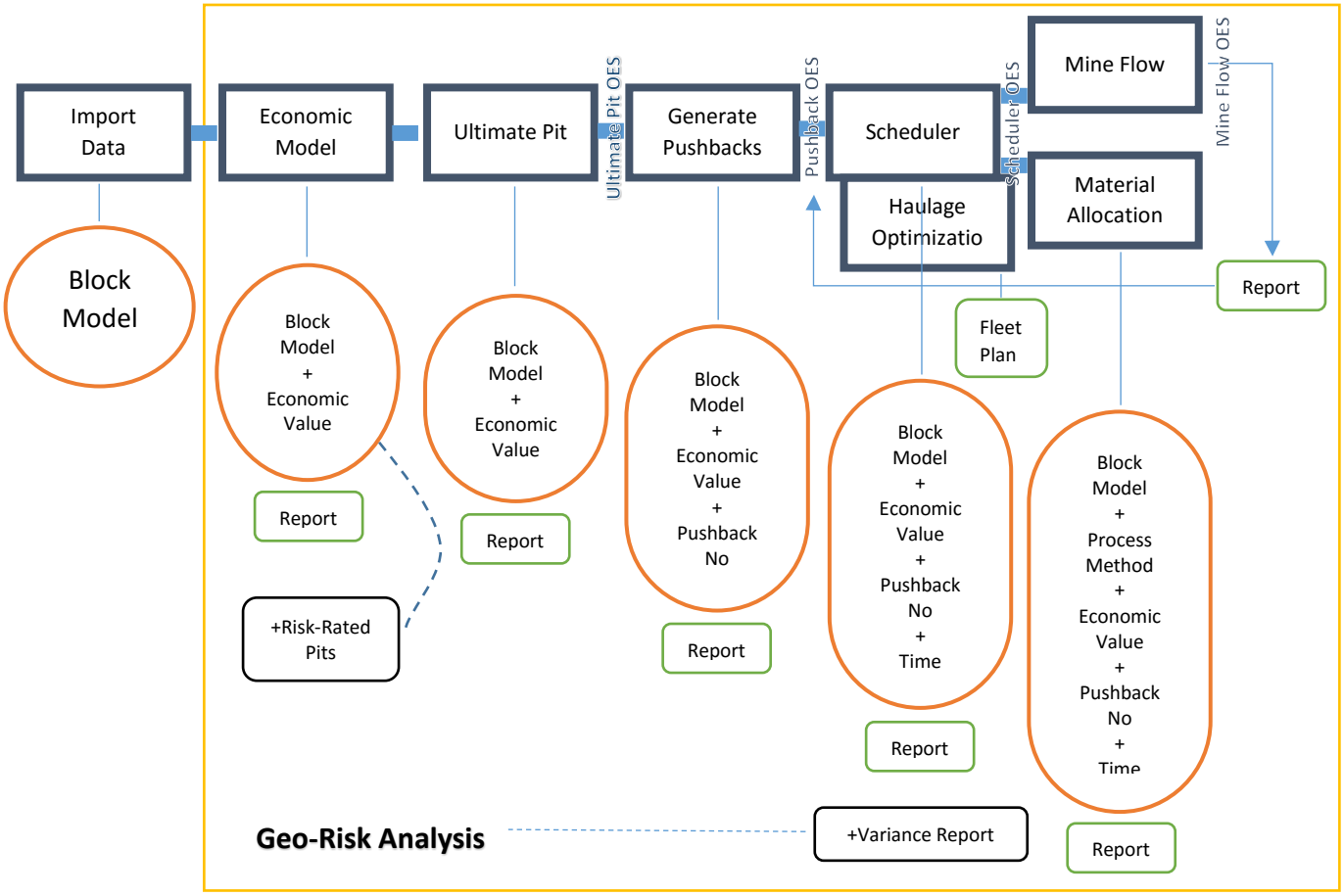
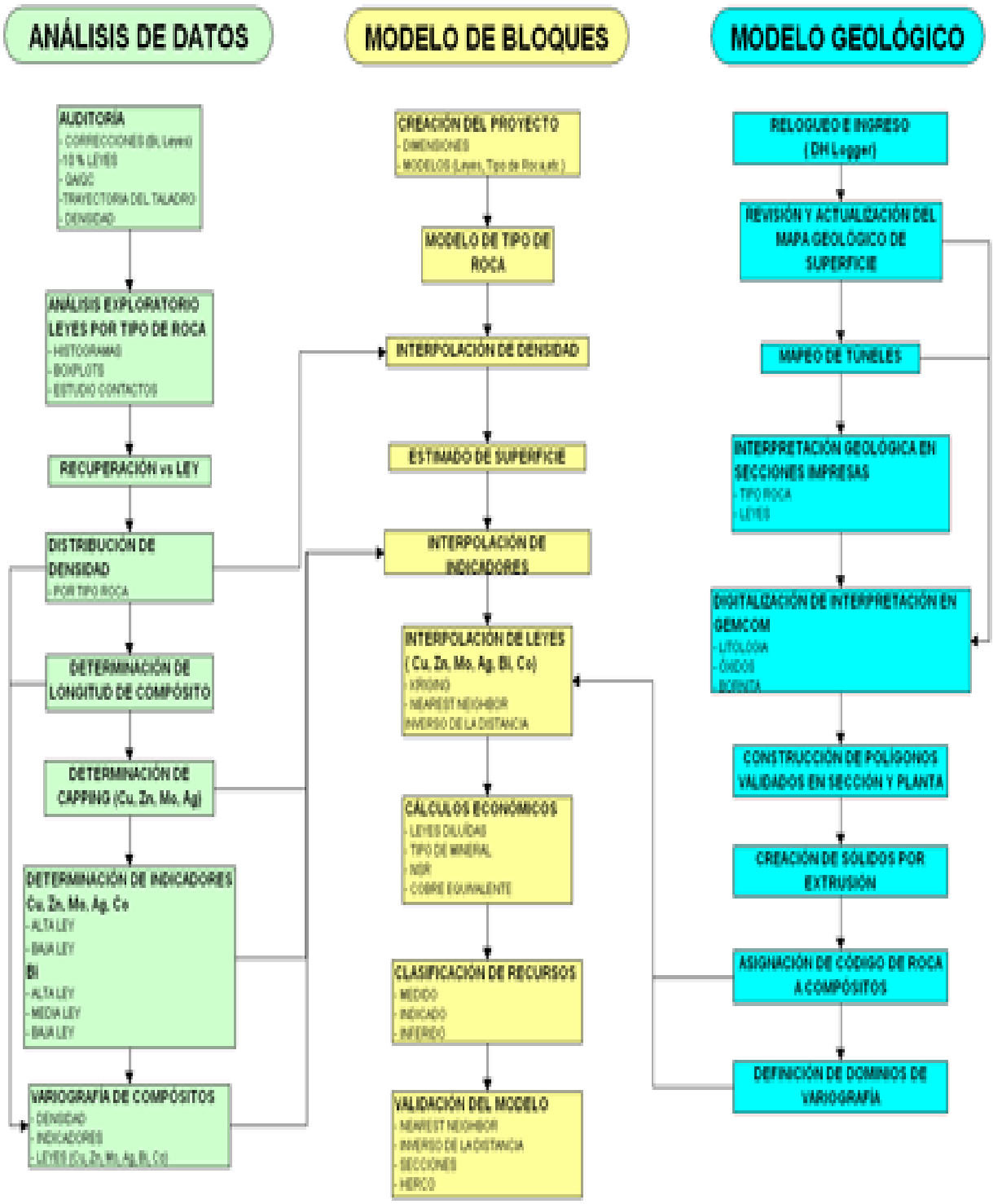


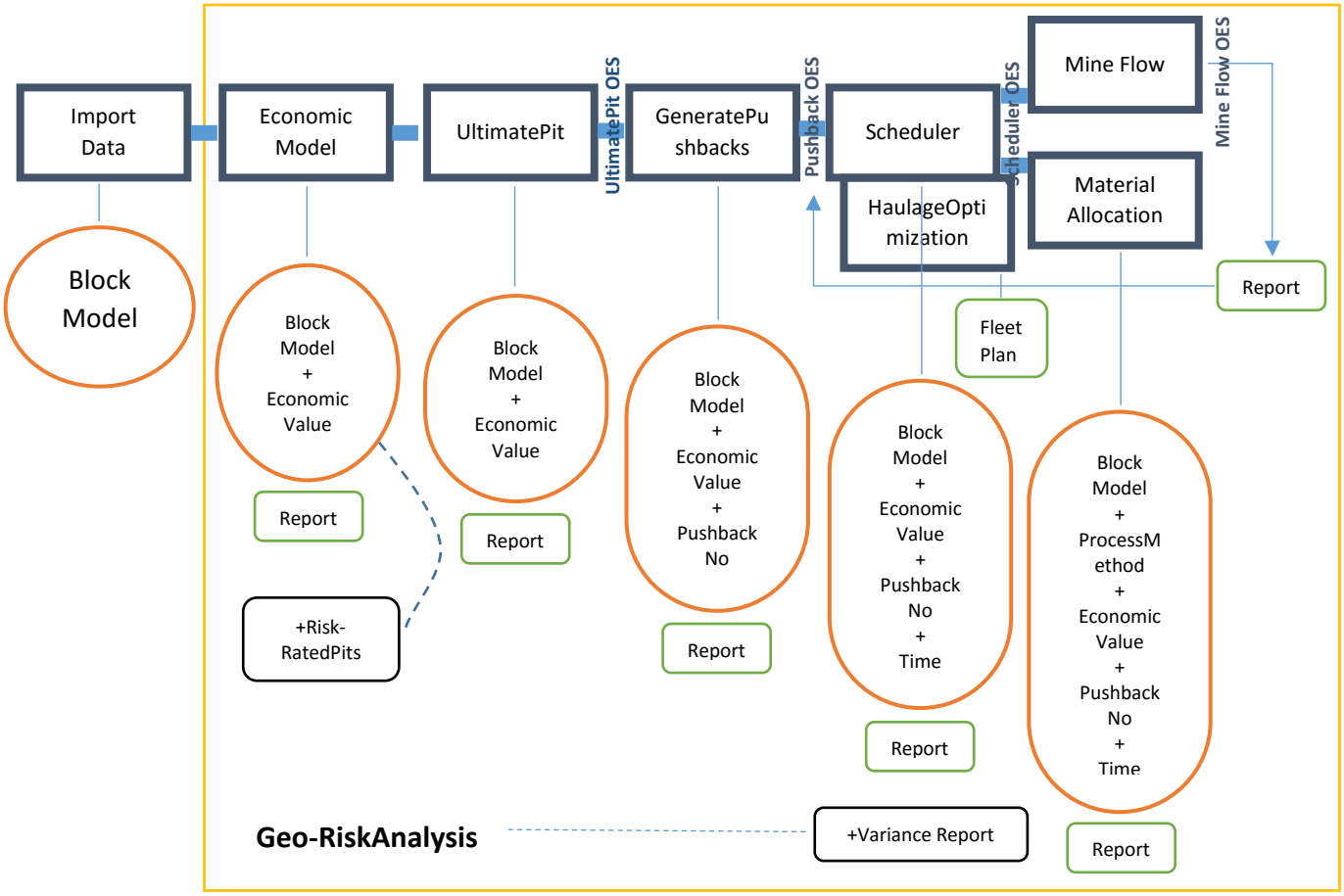
DIAGRAMA DE FLUJO DE RELACIÓN DE ANEXO 1



ELABORACIÓN DE UN MODELO DE BLOQUES

ANEXO 2

PROCESS AND DATA FLOW OVERVIEW



ANEXO 3

DIAGRAMA DE FLUJO DE RELACIÓN DE DIMENSIONAMIENTO MINERO DE LAS ETAPAS DE PLANIFICACIÓN Y OPERACIÓN