Developing Bauxite Projects – Planning for Quality Product

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Abstract

The development of bauxite projects is focused primarily on such important aspects as in-country available infrastructure, logistics, mineral processing, or deposit geology. These disciplines play an important role by having significant impact on project economic viability, technical feasibility or the capacity to raise funds for project development. Nevertheless, when all these important aspects are finally determined, the project still needs to deliver a quality and profit-generating product, therefore a study should be undertaken to incorporate appropriate mine planning techniques to determine the product quality range. It should define the bauxite product quality achieved from the deposit over the Life of Mine period and how this aligns with the project's strategic objectives in terms of project minimum mine life or head grades. Some fundamental factors, known as Mining Modifying Factors, will influence the production profile and should be appropriately incorporated into the study at an early stage. These modifying factors include mining dilution and recovery, processing recovery, cash costs, and their effect on the economic value of a mining block. They are inherently linked to the deposit characteristics, the mining method to be applied, in situ grades, strip ratio, and other technical or economic characteristics influencing the quality of the final product.

Keywords: Bauxite quality; bauxite mining; mine planning; production planning; losses and dilution, margin ranking.

1. Introduction

Progressing a bauxite project through the different study levels without losing focus on the key drivers is fundamental to developing a successful project. Well-developed international best practice and various international reporting codes facilitate progress while maintaining the key features of transparency, materiality and competence. In that process, disciplines such as geology, mining, hydrology and hydrogeology, infrastructure, geotechnics, waste management, environment and social, and logistics are involved and have low to high [1] influences which should be properly assessed. At the end of the day, costs, revenue, and economic outcome determine a project's economic viability.

Usually, and especially in undeveloped countries, project logistics is the primary focus. It is common that more than 60% of the total operational costs over the Life of Mine ("LoM") are related to logistics [1]. It is therefore critically important when paying high rates for transport, that the project can be assured it is of the required quality and satisfies client requirements and will not be subject to penalties which impact revenue. It is consequently important to have an understanding of the deposit in terms of mining and other technical drivers which could impact product quality. To achieve this, it is necessary to identify economic mining blocks and to extract them at the right time and in the right manner. At present, a broad range of methodologies and mining software packages are available which enable the quick and efficient preparation and analysis of mine planning scenarios. Based on experience gained on numerous bauxite projects recently completed by the author, the main limitation in the early (Scoping Study) stages in this process is the availability of input data and a fairly poor level, or utter lack, of marketing studies covering planning horizons beyond the first five years of the LoM. This paper summarises the most appropriate modelling and mine planning techniques and aspects considered by the author as crucial for developing and operating bauxite projects.

2. Mining Modifying Factors

As stated above, mining modifying factors incorporate mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors used to convert Mineral Resources to Ore Reserves [2].

Estimating appropriate mining modifying factors such as mining dilution and recovery can have a significant impact on the Run of Mine ("RoM") qualities. However, mining dilution and recovery tend to be neglected in some mining studies, especially those related to industrial minerals, while they receive much more attention in metal mining. This is perhaps driven by a tendency towards lower grades and higher selling prices for metals. It is arguable however, that RoM grades, and qualities (available alumina, reactive silica, etc.), have a far more important role and greater impact on bauxite projects, especially where the Mineral Resource is not extensive or grades are generally low when compared to the product specification. Furthermore, there is a whole set of other technological and economic factors influencing the production process which are analysed outside of the mining study, but must be included and used in mine planning to make the results realistic. The most common of these are; mining cost, processing/washing recovery and cost (if required), alumina production cost, transportation and logistics costs, royalties, and selling price. These factors, though the most common, are absolutely fundamental and, ideally, should include other aspects of the production process such as, for example, cost of energy required to crush the bauxite, behavior in the Bayer process (dependent of the mineralogy and grades), red mud production levels and treatment costs, or land rehabilitation costs. Possibilities here are practically unlimited and should be defined on a case by case basis, but, from the author's experience, it is usually the case that very little of the required input information is available at the Scoping Study or Preliminary Economic Assessment stage when developing bauxite projects. In such cases it is common to use benchmarked values. This exercise can, however, be successfully implemented in operating mines as part of their long term mine plans. Obviously, different sets of the input parameters will be required for a bauxite export operation than for a bauxite mine with an integrated alumina plant.

2.1. Mining recovery and dilution

It has been assumed that the reader of this paper has basic mining knowledge, so only basic definitions of mining dilution and losses are given, following Bertinshaw and Lipton [3]:

"*Mining Dilution is lower than economic cut-off grade material (waste) that is taken with the ore as part of the mining process (...). Mining loss is that part of the Mineral Resource that is above the economic cut-off grade and was intended to be mined as ore but is not sent to the mill or placed in an ore stockpile, i.e. it is lost to waste*".

Dilution and losses generated from operational errors are harder to predict and much less substantial than those resulting from deposit geometry and applied mining method. This paper focuses on the latter.

While selecting an approach to deal with mining dilution and recovery, some key project related facts are always taken into account:

- the size of the Mineral Resource versus expectation of LoM duration; and
- in situ grades/qualities.

Taking the above into consideration, it may be noted that, having a limited Mineral Resource, the objective of the mining operation may be to reduce mining losses at the expense of increased dilution and lower head grades, if that is accepted by the processing unit and does not cause the ore mined being out of specifications. Conversely, if there is a significant Mineral Resource allowing a potential production period longer than the required LoM period, the objective may be to maximise grades; but again, that depends on the product specification. In this case, the mining operator will decide to minimise dilution (or eliminate it completely), usually by introducing higher losses while maintaining high grades.

Figure 1 represents three possible approaches [4] for dealing with mining dilution and losses for a typical bauxite project, depending on the mining objectives. The exclusive approach assumes only loss with no dilution to maintain better quality, at the expense of product quantity. The inclusive approach assumes no loss but higher dilution, with higher quantities but lower quality RoM material produced. The standard approach assumes equal parts of loss and dilution.

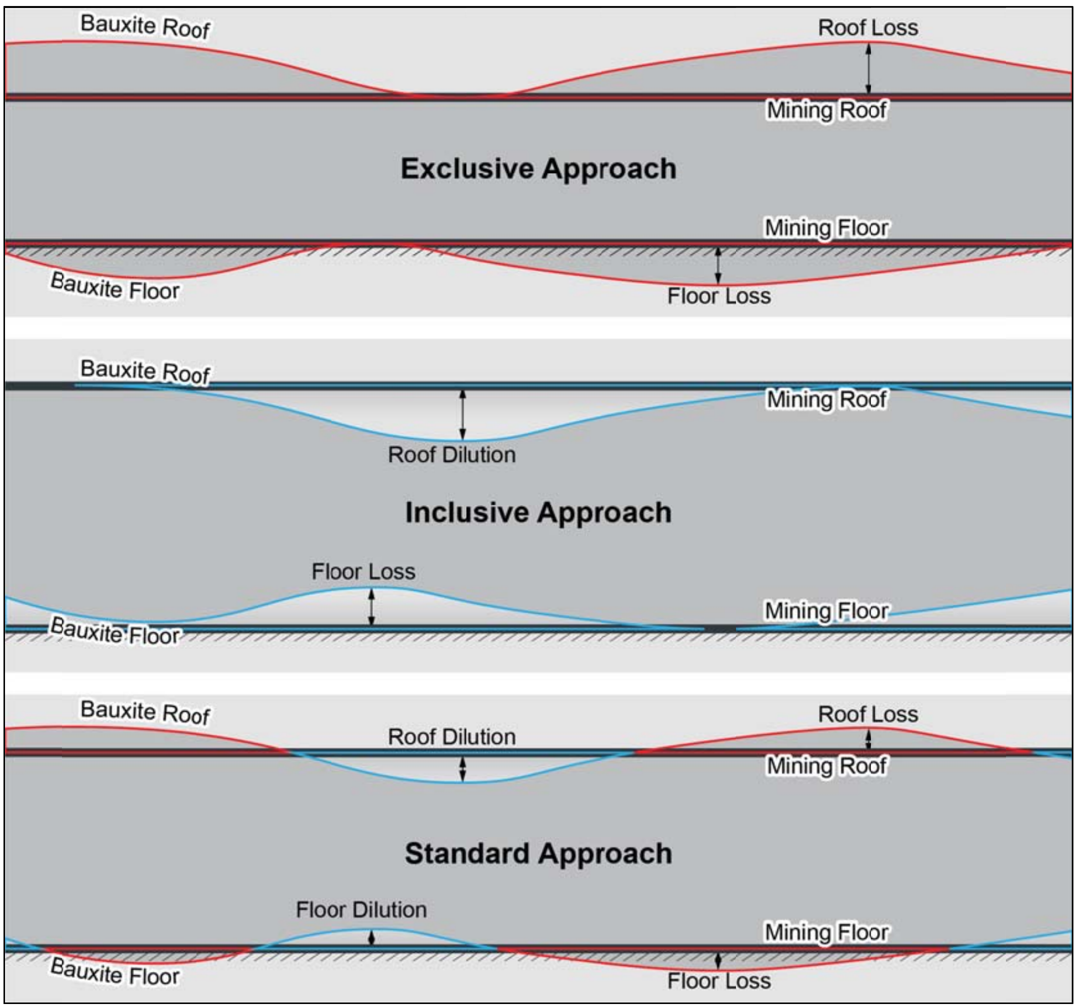

Figure 1. Three Approaches to Mining Dilution and Losses.

Each project should be analysed from this perspective on a case by case basis, taking into account strategic objectives, geological setting, and available mining techniques. Analysis of mining dilution and losses are a starting point for any further strategic planning and all subsequent studies, including both technical and economic aspects, which must be based on RoM diluted mining figures.

2.2. Processing and other technological factors

Mining activity is obviously the start of the entire production process, followed by various technical and technological elements driving and shaping the final product. In the case of bauxite and alumina production, the main elements would be mass yields for various stages of the process, such as ore crushing and finishing, washing and processing recoveries (including/excluding drying), refining, and product handling. The only limitation on the use of these factors in analyses is the availability of the data (see Section 3 of this paper), as current modelling techniques allow for an almost unlimited number of scenarios and possibilities. For example, one could analyse Total Available Alumina ("TAA") content for each considered mining block based on geological information providing gibbsite, goethite, and boehmite contents and accordingly apply an amount of caustic soda required for processing. This would indicate potential variations in the processing costs which could be used as a driver in mine planning. Depending on the study level, different levels of confidence in the input data will exist, but this type of analysis allows planning for not only quality, but also economics, which at the end of the day, is the expected outcome for the enterprise.

2.3. Economics

Similar to the technological factors, almost any kind of economic drivers can be assigned and used for the analysis. These could include: mining costs, which could be split into sub-groups like drilling and blasting (dependent on rock strength and excavatability); haulage (distance from the crusher or dump); crushing cost (use of power related to rock strength); washing and drying costs (moisture); refining process related power and consumables costs (based on modelled temperature requirements linked to geological and mining model); royalties; or marketing costs.

There are a variety of approaches to using this information in business planning. One is a Theory of Constraints [5], which says that the focus should be on the key driver bottle necking the entire production chain, while the main objective would be to maximise Net Present Value ("NPV") of the enterprise. The aim of this paper, however, is simply to bring to the reader's attention the possibility of using these business planning techniques, rather than analysing them in depth. Sections 3 and 4 describe tools and processes, including geological modelling and margin ranking, selected to suit bauxite mine and alumina refining processes which form part of the mine planning process.

3. Methodology

The author has worked on several bauxite projects in the last few years, mainly (but not only) projects in their early stages of development located in Guinea or Saudi Arabia. The practices and methods presented below are based on that experience and are presented as a series of options to achieve the optimal output from the mine planning exercise particularly for bauxite operations.

3.1. Geological modelling

Typical bauxite deposits, especially those in West Africa, usually consist of a series of plateaux, subdivided into smaller mining blocks. It is worth mentioning that this kind of placement is often associated with deposits covering a large surface area and with potentially significant mineral resources. These bauxite deposits frequently form horizons which are fairly flat and thick, between 4 and 6 m, on average. In some circumstances, they can have distinct vertical chemical element profiles that should be considered during selective mining to provide suitable RoM grades. To ensure the most suitable method is chosen, a case by case approach to geological modelling versus study objectives should be taken. Generally, one of the two methods described below should be selected, but for the majority of projects, grid modelling is most applicable for bauxite mine planning requirements.

3.1.1. Grid modelling

Unlike 3D geological models, seam or grid models according to Fardell [6] are

"2D surfaces where the X and Y positions are on a regular mesh (i.e. 25x25m) and the "Z" is the variable (…)."

The grid models are a set of files containing relevant information about geological structures and qualities translated into sets of numbers readable for mine planning tools for three values: X, Y and the Variable. For example, the Variable could be information about structural elevation, thickness, grade, dip, type of ore, etc. This method allows mine planners to analyse and apply mining dilution and losses in an appropriate manner for this type of deposit (for example, a dilution skin). The grid models are draped along the geological surfaces representing the roof and floor of the horizons giving much more flexibility in modelling. More importantly, this approach provides the flexibility of working with surfaces rather than blocks which have pre-defined size and location, potentially inconvenient when working with very thin mineralisations where the block size in the horizontal is far greater than the block size in the Z direction.

The mining model is a geological model which includes mining modifying factors, such as mining dilution and losses. Ideally when developing a mining model, it will ultimately include all of the modifying factors involved in the mine planning process. Not every bauxite deposit is made of various mineralised horizons where compositing is required, but even within one layer some differentiation may be made based on low and high grades. In the compositing process, thin seams or horizons are composited together or eliminated, treated as waste, based on input parameters such as minimum thickness or ratio of waste to ore. This process generates a set of grids (a complete model) with allocated ore and waste locations (compositing) and related qualities which now include mining dilution and losses. These grids can then be used in the mine planning process, having taken into account the required aspects of mining selectivity.

3.1.2. Block modelling

Using solids for mine planning processes is usually considered to be the most suitable and flexible solution. They can be easily interrogated with grids; however, using block models for the same interrogation can be problematic in cases where block sizes do not match or are too large. Although the necessary computing facilities are available, from the author's experience, modelling relatively thin bauxite horizons with sufficient accuracy to maintain best international practice, block sizes (or sub-blocks, if used) would need to be very small, too small for practical modelling and resource estimation and would generate extremely large file sizes. For example, some projects plan for mining dilution at contact zone between bauxite and waste at a level of 10 to 25 cm. On the other hand, applying blocks of inappropriately large size, can lead to situations such as presented in Figure 2, where block models clearly do not match the geological wireframes, extending beyond the geology or not entirely representing the shape of the orebody, especially where some changes in thickness or unit dip take place.

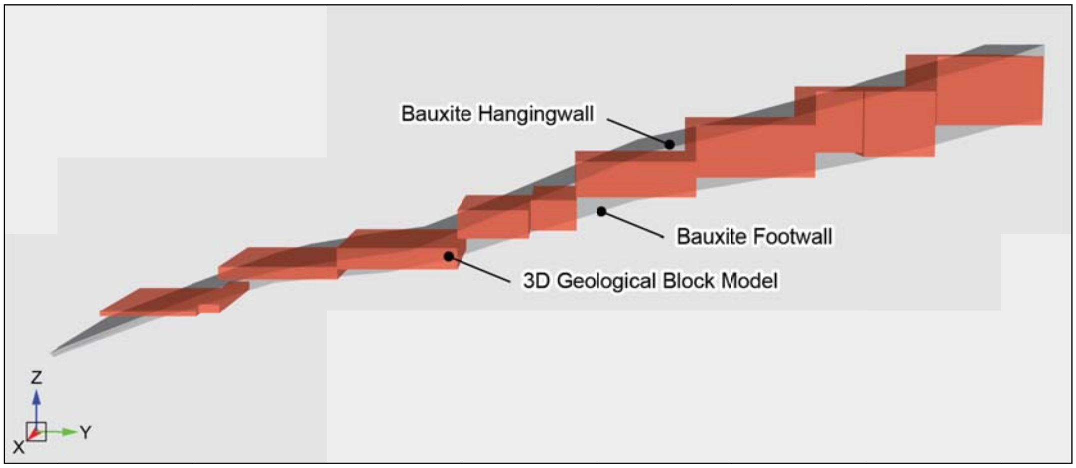

Figure 2. Inappropriate Block Size of the Geological Model.

Seam compositing using block models is potentially possible; it would however be complex and time consuming and has never been attempted by the author. Although there are methods to work around these types of problems, such as when the geological model has been defined using techniques less/unsuitable for the mineralisation type, this paper's objective is to provide support and guidance to best practice, and such methods will not be discussed further. Ultimately, bauxite mining is generally simple, and accordingly, sophisticated workarounds are not generally warranted.

There are, of course, instances where block models may still be appropriate or are still very useful and applicable for bauxite projects. In cases where the deposit is fairly regular in its structure but requires mining selectivity, using a mining method based on blocks may still be suitable or compliment other methods in order to understand grade variability in vertical directions etc.

3.2. Margin ranking

In deep open pit mines it is a common practice to define the pit depth and shape which will limit the planned ore and waste quantities. This process is called pit optimisation, often based on the Lerch-Grossman algorithm, which essentially calculates a value based on input conditions, and generates the maximum economic pit shape at a given metal price. Bauxite deposits however, are of a different nature being mainly horizontal bodies, usually located at shallow depths and covering large surface areas, where slope angles play a largely insignificant role, and the approach to the definition of pit limits is slightly different. An alternative, more appropriate approach is margin ranking. The concept of the method is similar to conventional pit optimisation except that an economic value is calculated for the entire vertical mining column (being a result of using mine planning blocks), including all influencing technical and economic factors, as shown in Figure 3. This way, by looking into one chart representing said value, planners can avoid using multiple maps (thickness of ore, thickness of waste, strip ratio, grades).

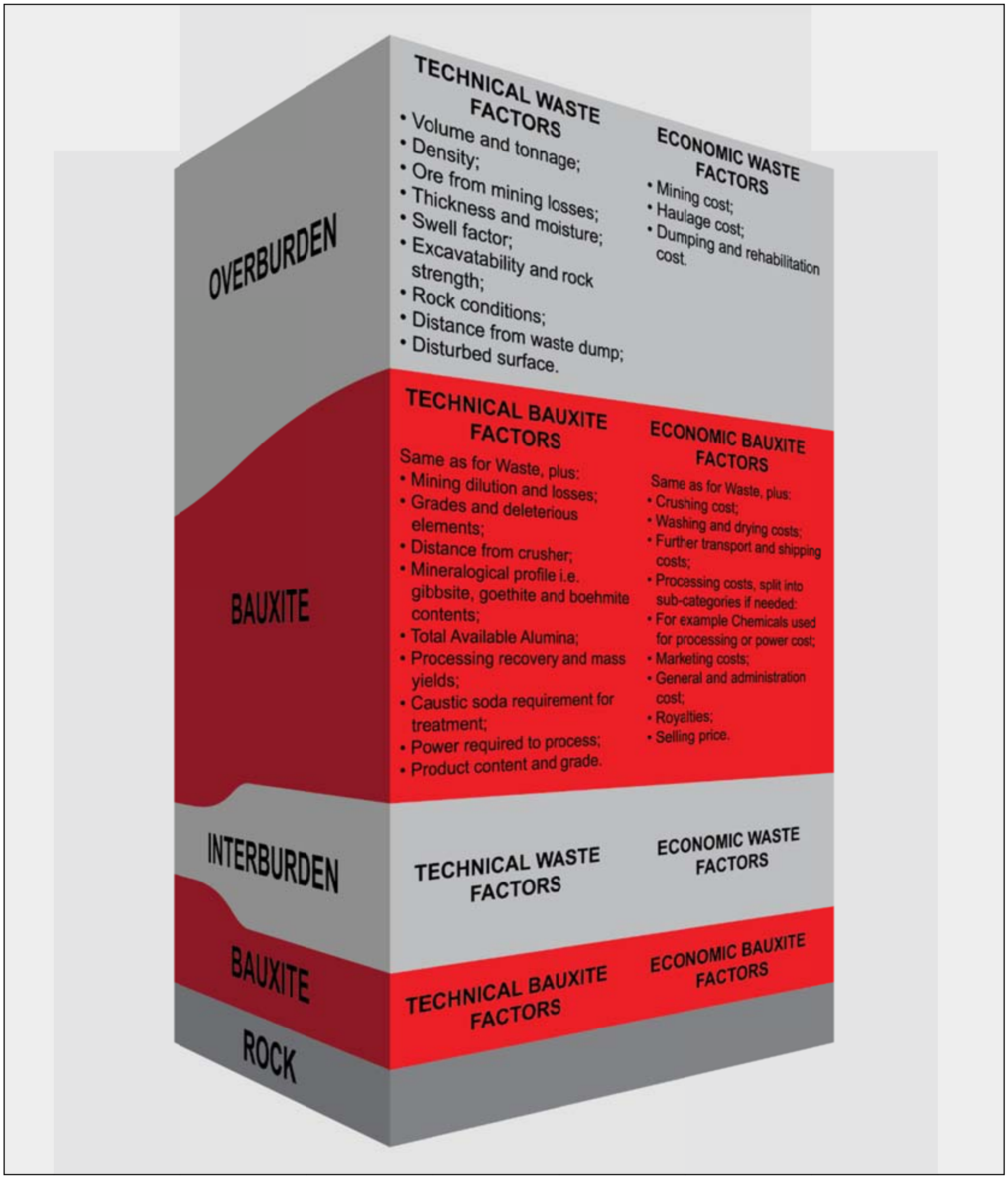

Figure 3. Approach to Margin Ranking.

To calculate the economic value, it is first necessary to define how much of each material type there is per mining block and geological horizon. For example, quantity of waste to be removed, quantity of ore at a given grade, and the resulting product amount that is contained within the block. The next step is to assign related costs to each of the given quantities and qualities. This process should include parameters for the entire production process so that the resulting value is appropriate and is a reliable driving factor to assess pit limits from an economic perspective. The parameters can be split into sub-groups down to a level limited only by the availability of data. Once this is achieved, all other costs occurring post-production are assigned, including shipping costs, royalties, etc, to ultimately define the value of all the costs cumulated for each column and set against revenue from the contained product. This is presented in Figure 4.

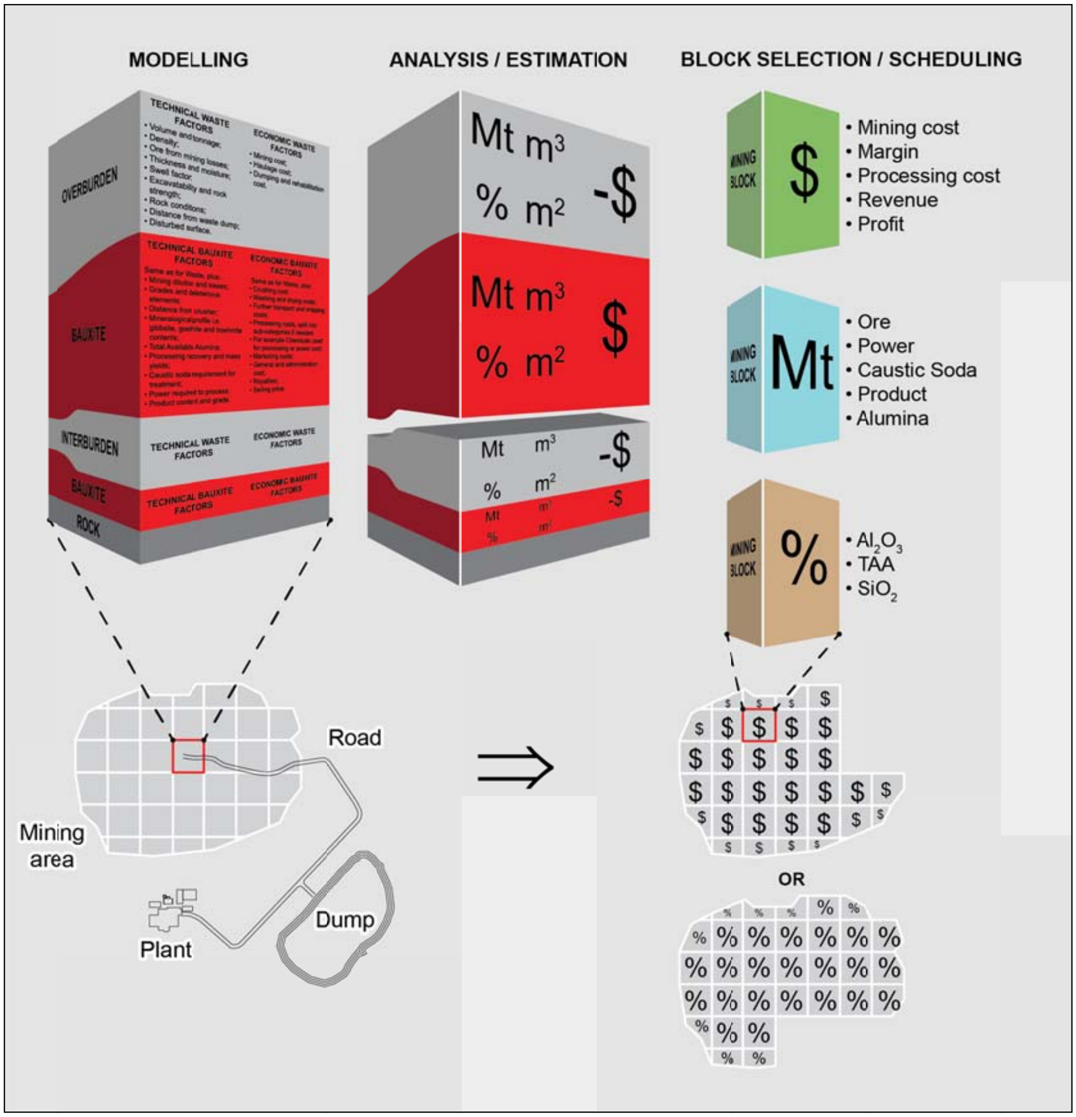

Figure 4. Defining Economic Pit Limits and Scheduling.

By running a margin ranking analysis for each mining block, the mine planner determines which areas or seams in the mine are economic. For example, one may discover that some mining columns should be split vertically for selective mining, or that only the top layers of the orebody are economic. This information is then utilised in optimising the mining sequence/scheduling, identifying the highest value blocks in the deposit.

Traditionally, production scheduling formed part of the mine planning process (especially long term), by taking into account mainly physical properties such as dry and wet tonnes of ore and waste, volumes, grades and deleterious elements, and haulage distances to calculate truck requirements. All these properties are allocated in time and space to create a mining production schedule, usually driven by production targets and cost. It is typically assumed that low costs are achieved by pushing waste stripping to the end of the LoM, while trying to achieve higher grades at the start of the LoM. From the author’s experience, this is the most common approach for bauxite export operations, while for alumina production, the grades would be expected to remain at a constant level. By introducing all the relationships between ore and final product, and between the costs and revenue, the mine planner can include economics beyond the mining process and perhaps determine that delaying waste striping is not necessarily the most economic option, especially if there is much richer ore (more product) in a higher strip ratio area. Whatever the case for a project is, the key conclusion is not to focus on one mine planning driver only, but to take into consideration various parameters and analyse their influence on the project.

4. Conclusions

Bauxite mining is often considered to be fairly straight forward, with relatively small associated mining costs compared to those in subsequent phases of the production chain, including processing, transportation and logistics. Proper mine planning however, enables equally easy control of the economic drivers from the early stages of project development and in an existing operation. It is fundamental for the entire exercise, and before starting any technical work, to define the business objectives. In most cases, the answer to that question is generating profit, but on a case by case basis this may be achievable in different ways. Mining Modifying Factors are always part of the process, regardless of the final saleable product. Two factors, losses and dilution, are used to transition a geological model into a mining model and can be introduced by using appropriate techniques, depending not only on the format of the existing model but, more importantly, what is most suitable for a given geological deposit.

It can be concluded that for planning bauxite operations, grid models have probably the most flexibility in use. There are some very good tools designed to work with these types of deposits and these generally have fewer limitations compared to block models, including margin ranking techniques and seam compositing tools. On the other hand, grid models appear to be less common these days, so identifying those with the skills required to generate grids may not be simple.

Once the model is established, the next step is to define the pit limits based on economic and technological factors. Understanding the profit of each mining block in the project/operation can simplify the mine planning process. However, to make it practical and applicable, a set of good input parameters is required. Typically, this should cover the entire production chain and may be split into sub-groups to the required level of detail. Bringing the mine planning processes to that level is likely to show that the mining process, even though relatively cheap itself, drives the processing costs, which are significantly higher and impacted by RoM quality.

An optimised solution is only achievable when all the key technical and economic input information is used in margin ranking to define the pit limits definition and guide mine production scheduling. It is recommended therefore that the input parameters, modifying factors, and margin ranking factors are reviewed periodically throughout the development and life of the project to incorporate the data which is constantly being generated and react to current technical or market conditions.

5. References

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