MINERAL MINING TECHNOLOGY

MULTI-PERIOD QUARRY PRODUCTION PLANNING THROUGH SEQUENCING TECHNIQUES AND SEQUENCING ALGORITHM

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This paper presents a new methodology in form of three sequencing techniques for the development of alternative quarry plans using cement quarry production-sequencing algorithm. The algorithm generates multi-period quarry plans, satisfying geometric (slope) and cement plant production capacity constraints. The benefits of the approach are demonstrated through application on an existing cement manufacturing operation in Midwestern USA.

Optimization, mine planning and design, production sequencing algorithms, cement raw mix

INTRODUCTION

In cement quarry operations, the quality of the limestone mined at a given period is the key to the efficiency of cement production. Once the blasted rock from the quarry enters the crushing system in a cement plant it cannot be removed. Therefore, if poor quality rock is placed in the system, an unmarketable product is the result [1].

A cement plant consists of a series of processes connected by material conveying systems, literally “garbage in, garbage out”. Usually, a few rock units in a quarry contain suitable constituents to run alone. Therefore, the normal process requires blending of high and low-grade material in the quarry and, if required, with the additives from the market. In order to reduce the cost incurred on the purchase of additives from the market, limestone mined in a given period must meet the quality/raw mixing constraints such that the required percent content of SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, LOI (loss of ignition), SO₃, K₂O, Na₂O, TiO₂, P₂O₅, and Cl in the raw materials is achieved [2].

Currently, both quarry production sequencing and blending of raw materials are achieved through manual interaction, by trial and error, using Computer Aided Design (CAD) programs [3, 4]. One major downside of trial and error method is its inadequacy for analyzing alternative plans and selection of the optimum. Another disadvantage is its inability to perform optimum long-term quarry planning [5, 6].

Cement industry has witnessed approximately 75% worldwide growth from 1995 to 2006 [7]. The industry produced 2.50 billion tons of cement in 2006 as compared to 1.421 billion tons in 1995. Growing demand has ensured an enormous investment towards the improvement of processing technology to produce low cost product. Currently, the industry has realized the potential impact of cost savings in producing raw materials from the quarry operations. Therefore, it is focusing on the means towards the development of most favorable alternatives to plan and operate limestone quarries.

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Keeping in view the possibility of a contribution to the industry, a production sequencing algorithm is developed that exclusively addresses the needs of a cement manufacturing operation. The algorithm generates multi-period alternative feasible quarry plans through implementation of three quarry sequencing techniques. The unique aspect of these techniques is that the production sequence is achieved by defining the starting point (base block) and the preferred direction of mining depending upon the knowledge of the chemical composition of the exposed area on a given bench.

**QUARRY SEQUENCING TECHNIQUES**

The objective of quarry planning is to determine the suitability of the resource for subsequent processing by the cement plant [8]. Once the geologic model and operational plan are established, which define the structural domains and stratigraphy chemistry, long-term reserves, average chemical composition and its variability, mineable resource boundaries, haul road layout, and long-term reclamation requirements, the quarry production sequencing issue needs to be addressed [3, 4].

The solution to cement quarry production sequencing is different from metallic ore deposits as the objective is the provision of a proper blend of raw materials to the cement plant [5]. Even if a block is low in CaO, it could be high enough in SiO₂ or Al₂O₃, hence, becomes a candidate for mining and processing in the plant. Furthermore, a block located in the overburden benches could still be processed in the plant, if it consists of clay, which is a source of SiO₂, Al₂O₃, and other raw materials. However, like the sequencing of metallic ore deposits or open pit mining operations, the determination of optimum quarry production sequencing involves two distinct and important decisions, including, what is the best order in which to mine blocks and when to mine a given block? And, if a block is mined, should it be crushed for cement production or not [9]?

These two decisions must be made in a manner so as to minimize the overall cost of cement production while still ensuring that raw materials quality requirements are met [8, 9]. Keeping in view the objectives and other related issues as described, three sequencing techniques are developed. These techniques require the following inputs for the development of feasible mining sequences: deposit matrix (block model); tons of limestone to be produced (bench-by-bench capacity or bench proportions); preferred direction of mining; starting point of mining (base block); scheduling horizon (number of periods or years).

The sequencing techniques differ from one another based on the direction of mining; i.e. for the same starting point (base block) each technique will follow a different preferred direction, and hence, gives a different raw mix quality due to difference in chemical composition of the exposed area on bench. Following are the techniques: Directional Sequencing Technique (North, South, East, and West Weights); Axis Sequencing Technique (Positive Y-axis, Negative Y-axis, Positive X-axis, and Negative X-axis Weights); Slanted Sequencing Technique (Northeast, Northwest, Southeast, and Southwest Weights).

**Directional Sequencing Technique.** The directional sequencing technique accepts the directional weights, i.e., the number of blocks to be considered for mining in the north, south, east, and west direction of the base block or the starting point. Also required is the definition of preference - to honor the east or the west direction first, while mining away from the base block. The algorithm considers mining blocks in east of the base block first and then west, or blocks in west of the base block first and then east. This preference provides an additional flexibility for quarry planning, because the blocks in either direction have different chemistries/quality of limestone. In this technique, the general direction of mining is either north or south.

Consider the block matrix given in Fig. 1, which consists of 15 blocks. Assuming that north is the general direction of mining, the following weights are assigned: North — 2; South — 0; East — 2; West — 2; Preference — East first (Fig. 1).