Journal of Cleaner Production 141 (2017) 1249–1258

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A decision support system for determination of a sustainable pit limit

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ARTICLE INFO

Article history:
Received 11 April 2016
Received in revised form
26 September 2016
Accepted 27 September 2016
Available online 29 September 2016

Keywords:
Open pit mining
Sustainable development
Decision support system
Ultimate pit limit

ABSTRACT

There is an increasing interest among practitioners to incorporate sustainability issues in evaluating the projects. However, it is a complex task to deal with the conflicting aspects of sustainable development. Nowadays, most of the minerals are produced by surface mining methods; where the economic, social and environmental impacts of these operations are closely related to Ultimate Pit Limit (UPL). UPL actuates the amount of mineable reserves, stripping ratio, location of waste dump and tailings dam, and the area of lands that will be disturbed at the end of a mining operation. Therefore, it has a significant contribution on the sustainability of the mining community. UPL determination is a strategic decision and it requires a Decision Support System (DSS) to evaluate and understand the outcome of each design alternative for optimal decision-making. In this DSS, after recognizing the indicators, it benefits from a matrix method to assess and measure the sustainability of different UPL alternatives based on subjective judgments. Moreover, some future information is unavailable and imprecise. In that regard, fuzzy logic is used to resolve uncertainties. Sungun Copper Mine data is used to show the effect of considering sustainability issues in UPL determination. The selected UPL changes net present value (NPV) and the mine life by 7% and 13 years respectively compared to the case where just economic issues are considered. The system shows to be efficient in assessing the sustainability issues of design alternatives during the feasibility studies.

1. Introduction

Sustainable Development (SD) is ‘the development that meets the needs of the present generations without compromising the future generations to meet their own needs, and it consists of environmental, economic, and social components’ (Nathorial and Bardos, 2004; Galvic and Lukman, 2007; Merad et al., 2013; Buys et al., 2014). The concept of SD gained its interest among miners from the United Nation's Earth Summit Conference in Rio de Janeiro, Brazil in 1992. From resource depletion point of view, mining is a temporary and not sustainable use of land, where the operating life of a mine normally lasts from a few years to several decades. However, it should be noted that mining industry is a part of SD; since raw material is essential to improve life quality (Newbold, 2003; and Villas-Boas et al., 2005). In that regard, in order to improve life quality and protect the environment, it is necessary to integrate environmental policies and development strategies into the mine design procedure (Villas-Boas et al., 2005; Mascarenhas et al., 2010; Moldan et al., 2012; Agol et al., 2014).

Considering the fact that mines are exploiting non-renewable resources, a mine plan especially for large deposits, should support the issues of SD in the mining community. In these communities, generation of wealth and social welfare depends upon the mining activities. In addition, the mining company is the leading source of municipal revenue. Thus, in the long-term, mining communities with weak economic strength are not economically and socially secure. Because when the mineral resource is depleted, the primary means of wealth generation is lost. Besides, mining activities are always accompanied with some negative impacts on the environment. Therefore, those companies who work on large mines are responsible for generating long-term economic opportunities without causing any irreversible environmental problems (Wasylycia-Leis et al., 2014). Hence, in the future, mining activities must be a practice of Green Mining as a prerequisite for a sustainable mining and SD (Osanloo, 2012). A sustainable mine plan has the social licence to operate. All these maters explain the need to consider and evaluate the sustainability requirements in mine design and planning (Fig. 1).

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http://dx.doi.org/10.1016/j.jclepro.2016.09.205
0959-6526/

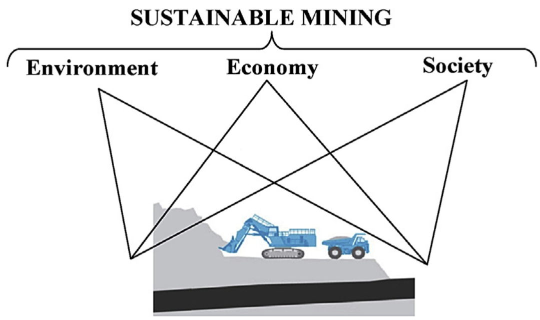

Fig. 1. Triple bottom line of economy, environment, and social issues in mining.

Nowadays, most of the minerals are produced by surface mining methods. In these operations, the economic, social and environmental impacts are closely related to their Ultimate Pit Limit (UPL). Traditionally, UPL determination is a profit maximization problem (Lerchs and Grossmann, 1965; Picard and Smith, 2004; Hochbaum and Chen, 2000; Muir, 2007; Newman et al., 2010; and Meagher et al., 2014). UPL determines the economic excavation limits beyond which the commodity value will not support the costs. Based on the selected UPL, mine facilities are located and the sequence of mining operations is planned. It substantially governs the long-term plan and economy of the entire operation. It actuates the amount of mineable reserves, stripping ratio, location of waste dump and tailings dam, and the area of lands that will be disturbed at the end of a mining operation (Hustrulid et al., 2013; Juarez et al., 2014; Senecal and Dimitrakopoulos, 2014; King, 2014; and Meagher et al., 2014). Therefore, it has a significant contribution on the sustainability of a mining community. In addition, it should be noted that social and the environmental issues are the main reasons of premature mine closures in 22% of the cases (Laurence, 2011). Different UPLs have different impacts on the environment based on their size and amount of waste that is going to be produced. This means that UPL optimization is not just a matter of traditional mining engineering for achieving a maximum revenue (Craynon et al., 2011; Osanloo and Rahmanpour, 2013; Badiozamani and Askari-Nasab, 2014; Adibi et al., 2015).

SD is a multi-discipline concept. To convert SD from just a concept into practice, there should be a method to assess and measure it. Many researchers have been working to define some tools and methods to facilitate the assessment of sustainability. There are more than 700 methods for sustainability assessment in the literature (Walton et al., 2005). Though there are many researches in this area, such a comprehensive tool is not yet available for practitioners (Leopold et al., 1971; Glasson et al., 2005; Li et al., 2002; Azapagic, 2004; Olivieri et al., 2006; Kommadath et al., 2012). Several other approaches are also available to quantify the environmental impact of mining activities such as Multi Attribute Decision Making (MADM) techniques and some heuristics (Hilson and Basu, 2003; Folchi, 2003; Soltanmohammadi et al., 2009; Mirmohammadi et al., 2009; Jahan et al., 2012; Betrie et al., 2013; Merad et al., 2013; Phillips, 2013; Buys et al., 2014). There are some attempts to integrate SD concept into the mine design procedure. For instance, Craynon et al. (2011) discussed the importance of incorporating SD issues in the design of surface coal mines. Rashidinejad et al. (2008), and Narrei and Osanloo (2011) investigated the environmental impacts of mining in cut-off grade determination. Xu et al. (2014) considered ecological costs of a mining operation in determination of the ultimate pit limit. Adibi et al. (2015) applied TOPSIS to rank the pit design alternatives with regard to sustainability indexes.

This paper considers the impacts of different UPL alternatives on the sustainability of a mining community. Determination of a sustainable UPL is a strategic decision and it requires a Decision Support System (DSS) to evaluate and understand the outcome of each alternative for optimal decision-making. This system requires some indicators that could represent the long-term behaviour of a mining operation. Then, with respect to the severity of impacts on sustainability indicators, it is possible to select a sustainable UPL. In that regard, at first, a procedure is established to define and quantify the sustainability of UPL alternative. Then, based on the inferred scores, the alternatives are ranked. It should be noted that during feasibility studies all the alternatives and their impacts on sustainability are inherited with a degree of uncertainty. Because, it is somehow impossible to gather all the data, there is always a probability of impreciseness, incomplete information and uncertainty about SD issues. Therefore, fuzzy logic - first introduced by Zadeh (1965) - is the best mathematical tool for dealing with such an uncertainty.

In the next sections, the concepts of a decision support system for implementation of a sustainable mining practice will be explained. Then, the procedure of incorporating SD issues in UPL optimization is introduced. Finally, the procedure is applied in a case study and the results are reported.

2. Mining and sustainable development - the hypothesis

Mines produce raw material for the industry and create wealth and welfare in the form of taxes, royalties, and employment that would improve the living standards in the mine region (Newbold, 2003). Mineral extraction is confined within a limit beyond which the commodity value will not support the costs. In order to get access to the valuable mineral, overburden is mined from the pit limit and it is hauled to waste dumps. The shape of the mined-out area is like an inverted truncated cone. Open pits can be very large, and the dimension of some of the largest pits is about 4500 m in diameter with a depth of about 1200 m. It means that considerable amount of material is extracted by open-pit mines. This will cause significant disturbances in a large area of land.

It is clear that mining projects are normally involved within a setting of governmental and social policies. Participation of social groups in a project means that the public should have the opportunity to question or at least be aware of the decisions. In order to assure the society that a mining operation is sustainable especially at the local community, a decision support system is required to generate a comprehensive or an integrated mine plan. This system must judge the current and future possible impacts of the mining operation in the region (Fig. 2). Following the steps required in a comprehensive mine plan is somehow time-consuming and will affect the capital and operational costs. However, it will provide sustainable and long-term benefits including greater support from the stakeholders, low closure risks, and easier funding of the operation (Logan et al., 2007; James, 1999; Garcia, 2010; Laurence, 2011). Mines with a comprehensive and sustainable mine plan has the social licence to operate.

3. Methodology

The objective of a comprehensive mine plan is to conduct a sustainable mining operation. For this purpose, one should select an optimal pit limit based on sustainability issues. To do so, a DSS is established to quantify the sustainability of each mining alternative, in order to nominate the most sustainable option (Fig. 3). In brief, at first, the existing environmental condition should be conferred. Then, all the feasible mine plans should be identified. After that, these plans are evaluated based on sustainability issues. Finally, the proper mine design will be nominated based on the result of the assessments.