



Production scheduling optimization considering ecological costs for open pit metal mines

Xiao-chuan Xu^a, Xiao-wei Gu^a, Qing Wang^{a,*}, Xian-wen Gao^b, Jian-ping Liu^c,
Zong-kang Wang^a, Xun-hong Wang^a

^a College of Resource and Civil Engineering, Northeastern University, Shenyang, 110819, China

^b Automatization Research Institute, Northeastern University, Shenyang, 110819, China

^c Dongmei Foundation Company of Shenyang, Shenyang, 110016, China

ARTICLE INFO

Article history:

Received 6 May 2017

Received in revised form

8 November 2017

Accepted 18 January 2018

Available online 19 January 2018

Keywords:

Open pit mine

Production scheduling

Optimization

Ecological cost

ABSTRACT

In optimizing the production schedule of an open pit operation, ecological costs of mining have been generally treated as externalities and assessed outside the optimization scheme. However, ecological costs may have significant effects on the scheduling outcome and should be internalized in schedule optimization models. This paper presents a method of open pit production scheduling that treats ecological costs as internal cost items. A series of geologically optimum (maximum-metal) push-backs is first generated inside the ultimate pit. These push-backs are then sequenced using a Dynamic Programming (DP) model to obtain the best production schedule, in which the ecological costs are incorporated in the economic evaluation formulations. The ecological costs considered and estimated in the model include carbon emission cost of energy consumption and the costs related to damaged land (ecosystem), such as the lost value of direct ecological services, restoration costs, lost value of indirect ecological services (air purification, oxygen release, soil and water conservation, nutrient cycling). A case study on a large-scale open pit mine is presented to compare the scheduling outcomes with and without internalizing the ecological costs. Results show that ecological costs do have considerable effects on the scheduling outcome: the schedule with internalized ecological costs has lower production rates and a longer mine life than that without ecological costs; the former has a 2.8% reduction in the total present value of ecological costs and a 2.5% gain in the overall net present value over the latter; the mining sequences of the two schedules are also different.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Mining activities cause environmental serious problems, especially in case of open pit mining. On one hand, large areas of land which were used as open pit, waste dump, tailings pond and infrastructure construction have been occupied and destroyed (Dudka and Adriano, 1997; Sahu and Dash, 2011). On the other hand, the waste produced by mine production results in environmental pollution, as well as the destruction of ecosystem and natural landscape (Singh and Singh, 2016; Adushkin et al., 2010; Monjezi et al., 2009). In order to protect the environment, some “End Treatment” methods are required at the end of mining, such

* Corresponding author.

E-mail addresses: guxiaowei@mail.neu.edu.cn (X.-w. Gu), 493212755@qq.com (Q. Wang).

as land reclamation method (Holl, 2012; Kohnke, 1950; Tyner et al., 1948). What's more, it is more important to implement the idea of “Design for Environment” (Chen, 2001; He and Huo, 2012; Ameknassi et al., 2016) during the design stage, accomplishing the goal of “Source Reduction” (Kim et al., 2014; Gunson et al., 2010) for the ecological stress. However, at present, the core objective of mine design is still the maximization of economic benefit but the ecological benefit (Samavati et al., 2015; Alonso-Ayuso et al., 2014). Although the environmental assessment for mine project has been required by the laws in many countries, it still shows the independent of mine design (Lema, 2016; Republic of South Africa Digging for Mining Licenses, 2009; Odell, 2004).

Production scheduling optimization, which is a vital step for mine design, presents the significant impact on the economic benefit and ecological environment. In mine design, production scheduling is a long-range planning and throughout a mine's life. The production rate, mining sequence and mine life are major

elements of production scheduling. The aim of optimizing production scheduling is to determine how many tons of ore and waste should be mined each year, where the zone that should be mined each year, and the total service life of mines to maximize NPV (Ramazan, 2007).

In recent years, research on the production scheduling problem has primarily focused on two aspects. One is reducing the scale of problems, which makes the strict optimization algorithm more efficient and practical (Samavati et al., 2017; Jélvez et al., 2016; Lamghari et al., 2015; Shishvan and Sattarvand, 2015; Sari and Kumral, 2016). The other new progress in researching production scheduling involves the consideration of uncertainties in market prices and resources to obtain the maximum level of balance between investment returns and risks (Chatterjee et al., 2016; Lamghari and Dimitrakopoulos, 2012; Kizilkale and Dimitrakopoulos, 2014; Silva et al., 2015; Gilani and Sattarvand, 2016; Mokhtarian and Sattarvand, 2016; Rahmanpour and Osanloo, 2016). Whether to reduce the scale of problems or to obtain the maximum level of balance between investment returns and risks, the objective function of production scheduling optimization is always to maximize economic benefit while the environmental issues closely related to the production scheduling are ignored.

The production scheduling is directly related to the annual discharge amount of waste rock, tailings, exhaust gas and waste water, the area of land occupation and destruction, as well as the disturbing degree of ecosystem (Rahmanpour and Osanloo, 2017). All of such environmental issues caused by resource exploitation will persist until the completely recovery of ecosystem. Therefore, with the situation of sustainable development, a great deal of studies, such as methodologies of field-site investigation, laboratory analysis and satellite data processing, focus on the environmental protection for mining. The most important research is the ecological remediation, which concentrates on recovering the available land from the disturbed one. Overall, there are two main topics of the present studies. One is the remediation technology (Jacobs, 2005; Kuter et al., 2014; Ebrahimabadi, 2016; Haque et al., 2007; Thavamani et al., 2017; Alvarenga et al., 2009). Another one is the land reclamation schemes (<http://www.sciencedirect.com/science/article/pii/S0959652617319431> Gronhøvd and Scott, 1979; Gorokhovitch et al., 2003). In reality, ecological remediation is an “End Treatment” pattern. In many mines, ecosystem has been destroyed seriously by the pattern of treatment after pollution. Meanwhile, the cost of such treatment cost is expensive.

With the introduction of “Design for Environment” idea to mine, the environmental issues and the sustainability of resource exploitation are evaluated by researchers (Azapagic, 2004; Laurence, 2011; Kommadath et al., 2012; Saini et al., 2016). Sustainability evaluation for resource exploitation is one way of qualitative analysis using index optimization, weight assignment and judgment matrix calculation, which results in the fuzzification results. At the same time, researchers show diverse understanding on the selection of index, the allocation of weight and the sustainability definition, which lead to the altered evaluation criterion. Therefore, some researchers focus on the quantification for the environmental issues caused by mining. Parts of them conducted the collection and calculation about the area of land occupation and destruction, and the quantity for the discharged waste, such as waste rock, tailings, pollution water and exhaust gas (Norgate and Haqu, 2010; Gałaś and Gałaś, 2016; Glaister and Mudd, 2010; Elżbieta et al., 2015; Driussi and Jansz, 2006; Fatah, 2008). Others paid more attention to the classification of the environmental treatment costs resulted from the financial book for various types of mines (U.S. Environmental Protection Agency, 1997). In addition, researchers studied the prediction and optimization for the waste

discharging cost and reclamation cost (Mckay et al., 2006; Pavlidakis et al., 2012; Paricheh and Osanloo, 2017).

It is observed that, whether the ecological remediation, sustainability evaluation or environmental issue quantification mentioned above, the basic idea is “End Treatment”. It is to estimate environmental effect and put forward the treatment measures according to the designed scheme or production status. In other words, mine environmental issues are viewed as an externality in mine design without consideration.

It is important to optimize mine design with environment (Moradi and Osanloo, 2015; Gu et al., 2013a). Researchers attempted to integrate sustainable development concept into the mine design procedure, such as cut-off grade optimization (Osanloo et al., 2008; Rashidinejad et al., 2008; Prasetya and Simatupang, 2012; Rahimi and Ghasemzadeh, 2015; Rahimi et al., 2015), ultimate pit design (Rodriguez, 2007; Xu et al., 2014; Adibi et al., 2015; Rahmanpour and Osanloo, 2017).

For the production scheduling optimization, mine land reclamation is paid more attention by researchers. Badiozamani and Askari-Nasab, 2014 put the reclamation cost of tailings pond into the production scheduling optimization, where the cost is a function of the location of tailings facility and the quantity of interburden and tailings coarse sand material. Neufeld (2015) integrated the progressive land reclamation technique into the mine-planning process for Kearsarge from the beginning of project planning. Based on the value of money, Nehring and Cheng (2016) calculated the reclamation costs (closure costs) for diverse production scheduling scheme and studied the influence of mine closure on the mining life. In the coal mine design, Calvo and Pérez (2016) internalized the environmental and social monetary values into the cost functions of the mine firms. They found that the present private optimal overproduction policy for the terminal phase of the resource extraction program could be reduced, where the environmental costs were just the unpublished statistics data from the Colombia Ministry Environmental (2010). Based on the designed production scheduling, Xu et al., (2017) built ecological cost calculation model and calculated all over NPV. However, the interaction between the production scheduling and environmental issues were not considered.

As mentioned above, in the mine design, some studies about the environmental issues focused on the optimization of cut-off grade, ultimate pit and production scheduling. However, there are two problems about such research. One is the quantization of environmental cost (Gu and Wang, 2011; Gu et al., 2013b; 2013c; Wang et al., 2012). In the previous studies, the environment cost was regarded as the reclamation cost. However, the emission cost of exhaust gas, the lost value of direct ecological services (such as crop economic output), and the lost value of indirect ecological services (such as ecological function value) have not been considered. One reason is the difficulty of the data collection and quantitative model construction. Another is that the dynamic influence of mining on the environment has not been considered for the mine design in real-time (Xu et al., 2014). The different environmental costs can be generated by the various design schemes, which result to the altered quantities of mining and stripping, energy consumption, waste discharge and land damage area each year.

The unit costs of mining, stripping and ore dressing are the basic economic parameters for the production scheduling optimization. Such parameters influence the optimization scheme. Therefore, the choice of production scheduling scheme is also influenced by the annual environmental costs caused by mining. That is to say, various environmental issues in every link of mining should be considered dynamically because of the interaction and inter-affection between production scheduling scheme and mine environmental issue.

Download English Version:

<https://daneshyari.com/en/article/8097882>

Download Persian Version:

<https://daneshyari.com/article/8097882>

[Daneshyari.com](https://daneshyari.com)