Applied Soft Computing 32 (2015) 1–12

Contents lists available at ScienceDirect

Applied Soft Computing

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

Decision support system of unplanned dilution and ore-loss in underground stoping operations using a neuro-fuzzy system

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ARTICLE INFO

Article history:
Received 27 May 2014
Received in revised form 13 March 2015
Accepted 18 March 2015
Available online 28 March 2015

Keywords:
Neuro-fuzzy system
Underground metalliferous mining
Unplanned dilution
Ore-loss

ABSTRACT

Unplanned dilution and ore-loss are the most critical challenges in underground stoping operations. These problems are the main cause behind a mine closure and directly influencing the productivity of the underground stope mining and the profitability of the entire operation. Despite being aware of the significance of unplanned dilution and ore-loss, prediction of these phenomena is still unexplained as they occur through complex mechanisms and causative factors. Current management practices primarily rely on similar stope reconciliation data and the intuition of expert mining engineers. In this study, an innovative unplanned dilution and ore-loss (uneven break: *UB*) management system is established using a neuro-fuzzy system. The aim of the proposed decision support system is to overcome the *UB* phenomenon in underground stope blasting which provides quantitative prediction of unplanned dilution and ore-loss with practical recommendations simultaneously. To achieve the method proposed, an uneven break (*UB*) prediction system was developed by an artificial neural network (*ANN*) considering 1076 datasets covering 10 major *UB* causative factors collected from three underground stoping mines in Western Australia. In succession, the *UB* consultation system was established via a fuzzy expert system (*FES*) in reference to surveyed results of fifteen underground-mining experts. The *UB* prediction and consultation system were combined as one concurrent neuro-fuzzy system that is named the 'uneven break optimiser'. Because the current *UB* prediction systems in investigated mines were highly unsatisfactory with correlation coefficient (*R*) of 0.088 and limited to only unplanned dilution, the performance of the proposed *UB* prediction system (*R* of 0.719) is a remarkable achievement. The uneven break optimiser can be directly employed to improve underground stoping production, and this tool will be beneficial not only for underground stope planning and design but also for production management.

1. Introduction

The goal of underground mining is to extract ore as economically as possible while ensuring the safety of the workforce and machinery. To achieve this goal, numerous mining methods have been developed and employed that are based on the geological formations and conditions of ore bodies, e.g., the shape, size, depth, orientation, and surrounding waste rock [1]. Among many metalliferous underground mining methods, various stoping methods, e.g., sublevel, cut and fill, shrinkage, open long-hole, etc., are prevalently applied based on the technical and economical consideration of the orebody and geology conditions of the region. Prevalence of stoping methods was reported by many researches. For instance, 51% of underground metalliferous production in Canada relies on open-stoping methods [2]. In addition, surveying eight major underground metalliferous mines in Australia reveals that seven out of eight mines are employing various stoping methods.

The productivity of stoping methods can be evaluated by the excavation of the planned stope with a marginal amount of unplanned dilution and ore-loss [3]. Because the stope is primarily extracted by drilling and blasting, unplanned dilution and ore-loss are inevitable phenomena that affect not only the safety of the workforce and machineries but also seriously deteriorate the overall mining processes. In other words, the most effective way to increase the productivity of the mine is to reduce the unplanned dilution and ore-loss [4].

The definition of dilution is "the contamination of ore stream with lower grade ore and/or waste material". Dilution and ore-loss are generally categorised into planned and unplanned. This study focuses on unplanned dilution (the lower grade material exterior to the planned ore-reserve block that deteriorates the value of

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http://dx.doi.org/10.1016/j.asoc.2015.03.043
1568-4946/

the ore stream) and unplanned ore-loss (the remaining valuable material after production blasting). In addition, through different engineering perspectives, these phenomena can be described as dynamic and quasi-static types; the dynamic type occurs immediately, whereas, the quasi-static type occurs within an interval of time after blasting [5]. This study deals with the dynamic type of unplanned dilution and ore-loss. Moreover, a new term 'uneven break' (*UB*) has been introduced to define them. Fig. 1 demonstrates a schematic view of typical underground stoping method with reconciliation of unplanned dilution and ore-loss.

Fig. 1a is an overview of a typical metalliferous mine and Fig. 1b depicts 3D view of a planned underground stope, which will be excavated by drilling and blasting. After the production, the planned stope will be reconciled with the actual mined volume of stope, which can be captured by cavity monitoring system (CMS) [6]. 3D reconcile model and its section view are demonstrated in Fig. 1c and d, respectively.

Despite being aware of the importance of controlling unplanned dilution and ore-loss, numerous underground mines experience these negative effects that are prominent in the causes of mine closure. However, current unplanned dilution and ore-loss (uneven break: *UB*) management still relies on historical reconciliation data of similar stopes and the intuition of engineers. According to a survey from Pakalnis [7], 47% of the open stoping mines had more than 20% dilution in Canada. Likewise, Henning and Mitri [8] reported that approximately 40% of open-stoping operations in Canada suffered 10–20% dilution.

In this study, to successfully manage the potential *UB*, a new uneven break (*UB*) prediction and consultation systems were established with the help of soft computing technologies. An uneven break (*UB*) prediction system was established by using an artificial neural network (*ANN*). The proposed *ANN* model was trained adopting 1076 datasets of 10 major *UB* causative factors, which had been selected via thorough investigations of field documents from three underground stoping mines in Western Australia. The selected 10 *UB* causative factors are composed of two geological, five blasting, and three stope design factors and details of these factors are explained in Section 2. In succession, an uneven break (*UB*) consultation system was designed using a fuzzy expert system (*FES*) in reference to surveying fifteen underground mining experts. The proposed decision support tool is established based on Mamdani fuzzy inference system [8] composing of two inputs and two outputs. A predicted *UB* percentage (*PUB*) from the proposed *UB* perdition *ANN* model and a representative geological factor, i.e., *Q*-value [9] are adopted as input parameters. For output parameters of *FES*, two new criteria, powder factor (*Pf*) and ground support (*GS*) control rates (*PFCR* and *GSCR*) are introduced. Detailed information of these parameters is explained in Section 4. Ultimately, these two systems were combined as a neuro-fuzzy system to support not only underground stope planning and design but the production management of the mine also.

As presented in the following section, even though various studies have been established to manage and control unplanned dilution and ore-loss in underground blasting, these studies failed to explain this complex phenomenon as they just consider few causative parameters using unsatisfactory methodology. The significance of the proposed decision support system is that it is the first successful application of *ANN* and *FES* in underground stope management providing quantitative value of potential *UB* and its controlling criteria prior to actual stope production. Furthermore, it is the unique model can cover both unplanned dilution and ore-loss at the same time.

In the following Section 2, previous studies on unplanned dilution and ore-loss (uneven break: *UB*) are presented emphasising on their causative factors. Section 3 expounds the data management of this study. The proposed *UB* prediction *ANN* model, *UB* consultation *FES* model, and their integrated concurrent neuro-fuzzy system are demonstrated in Section 4. Subsequently in Section 5, the paper concluded with explaining the significance of the proposed system for managing uneven break.

2. Investigations of the unplanned dilution and ore-loss

Numerous studies have been conducted on the control of unplanned dilution and ore-loss in underground blasting. Unplanned dilution and ore-loss are still not clearly defined because they occur through complex mechanisms and causative factors; most of the previous studies focused on a few particular causative parameters.

The stability graph method [9,10] has been recognised as an adequate method to estimate stope dilution, and this method has been accepted by both industry and academia [2,11]. The stability graph plots a stability number (*N*) against a hydraulic radius (HR: area/perimeter of the stope wall) of a stope wall, where *N* is calculated from the modified *Q* (*Q′*), stress, joint orientation, and gravity factors. The stability graph method has been modified and improved by various authors. For instance, dilution lines were proposed by Scoble and Moss [12], and cable bolt effects on the stability of the stope wall were introduced by Nickson [13]. Subsequently, [14] proposed an empirical stope design approach

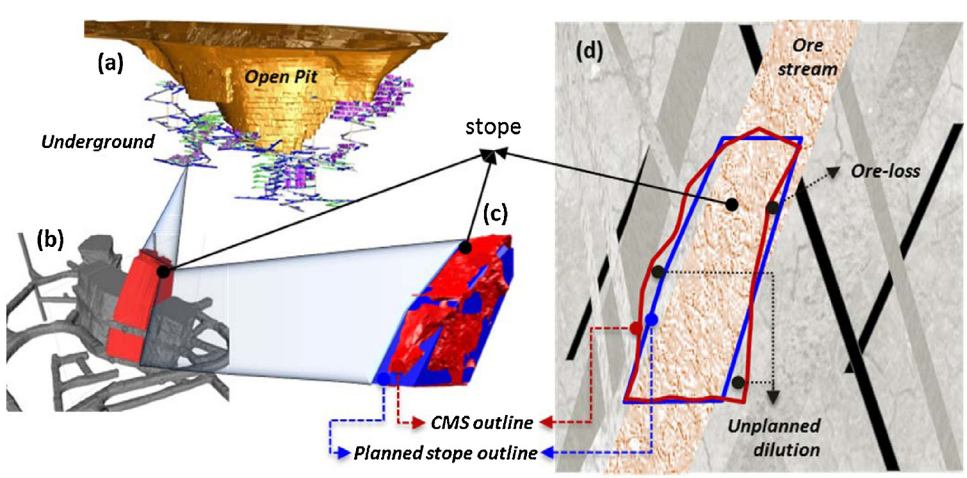

Fig. 1. A schematic view of underground stoping with unplanned dilution and ore-loss. (a) Overview of typical metalliferous mine, (b) 3D view of a planned stope, (c) 3D model of the stope after production captured by cavity monitoring system (CMS), (d) section view of the stope.