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A comparison of three production rate estimation methods on South African platinum mines

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ABSTRACT

Mining is a capital intensive business that requires a large amount of upfront capital to cover development and infrastructure costs. Major infrastructure and development required to access the orebody must last for the life of mine. Net present value is commonly used to determine the economic viability of a project and it is driven by production rate among other parameters. This paper tested variation as well as correlation between production rates estimated (based on rules of thumb) and actual production rates reported by mines. Visual observations and correlation coefficients were used to test the rules of thumb and production rate. Data from the blue chip platinum mining companies was used to determine and test variability of production rates estimated using three rules of thumb. The paper established variations of up to 218% among the three rules of thumb tested on production rate as well as weak correlations (average correlation coefficient of −0.02) between production rates reported by mines and rules of thumb. Therefore, this paper concludes that the size and geometry of a deposit cannot be used independently for all deposits to estimate production rate. Authors recommend research into both size and geometry under changing conditions and formulation of mathematical models to estimate production rates.

1. Introduction

South Africa hosts numerous mineral resources including three common geological formations and settings namely, the Witwatersrand Basin, the Bushveld Complex and the Karoo Basin (Statistics South Africa, 2016). Coal, platinum group metals (PGMs), iron ore and gold contributed 77% to mineral sales in 2014, in particular, coal and PGMs contributed 27% and 21%, respectively (Statistics South Africa, 2015). Furthermore, Statistics South Africa (2015) stated that, PGMs, gold and coal made up 82% of the total employment in the mining industry in 2012 with the PGM sector leading at 38%. Chamber of Mines of South Africa (2015) mentions that among others, the South African mining sector contributed 7.6% and 26% to gross domestic product and merchandise exports, respectively. However, the South African mining industry faces global and local challenges including but not limited to, volatile commodity prices, access to funding, industrial actions, erratic and costly supply of electricity and Department of Mineral Resources' Section 54 safety related stoppages (Deloitte, 2014; Chamber of Mines of South Africa, 2015; Neingo and Tholana, 2016).

Although the South African mining sector is faced with numerous challenges, the sector's contribution to the national economy remains significant. The optimal extraction of the minerals therefore is of high importance to the South African economy. Optimization is the maximization and/or minimization of inputs and/or outputs such as the net present value (NPV), costs, ore and waste tonnages against a given set of constraints. In mining, optimization aims to derive economic value from the mineral reserve using minimal possible input resources. Economic value addition is measured using different metrics depending on whether it is short, medium or long term value. Economic value in mining is driven by revenue that is based on production rate among other factors. Wellmer et al. (2007) stressed the need to determine optimal production rate in order to evaluate the viability of a deposit.

Underground mine planning optimization has been focused on the following areas; development and infrastructure placement, stope envelopes, production scheduling and equipment selection and utilization (Little et al., 2013; Musingwini, 2016). These areas either affect or are affected by production rate. For example, a mine can only meet its planned production if the equipment that may be accommodated within the geotechnical constraints have the capacity to move the material (tonnages) out of the mine. Similarly, development and infrastructure placement should be done to enable movement of rock, personnel and material required to meet production rate within various constraints for the life of mine. Thus, determining an optimal production rate helps in optimizing development and infrastructure

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placement. An optimal production rate is defined as mined and milled production rate that minimizes costs and maximizes the NPV. Some authors define an optimal production rate in terms of the annual vertical drop but the objective function remains to maximize NPV.

Several formulae to estimate production rate have been developed by Hotelling, Taylor, Wilson, Gray, Smith, Mosher and others. Although some work has been done in developing formulae (rules of thumbs) that estimate production rate, the optimality of these rules of thumbs remains contested. This is because these formulae apply to deposits with specific orientation, mining method, commodity or even location in terms of the host country. Therefore, it is important to test these rules of thumbs on production rates reported by mining companies.

South Africa hosts the most known platinum reserves than any other country in the world. It accounts for 11% and 96% of the world's gold and platinum group metals reserves, respectively (Republic of South Africa, 2017). However, the long term viability of the two sectors has been affected by weaknesses in the global economy (Statistics South Africa, 2016). According to Statistics South Africa (2016:21), "*in 2013 the Department of Mineral Resources developed a plan to address the long-term sustainability of platinum and gold" sectors.* Unlike gold, some platinum reserves especially in the northern limb of the Bushveld complex are not yet mined so there is potential for new platinum mines to be developed. It is against this background that the South African platinum sector was selected as a proxy for the mining industry to test variability of production rates estimated from selected formulae as well as correlation between estimated production rates and reported production rates.

2. Economic value creation and optimization

Mining in South Africa started over a century ago, such that near surface as well as high grade deposits have mostly been exhausted (Neingo and Tholana, 2016). Therefore, innovation and optimization is not optional if mining companies are to derive optimal value from the remaining marginal low-grade and deep-lying deposits (Musingwini, 2014). Chamber of Mines of South Africa (2015) noted that some mines in the gold, platinum and coal sectors are faced with viability challenges. Viability, in particular economic viability is assessed using different methods/techniques, with the Discounted Cash Flow (DCF) being the popular technique in mining. Napier (1981) viewed net present value to be the most suitable objective for maximization when estimating optimum production rate. While the DCF provides the net present value of a project or range of values, it is highly reliant on the quality and nature of input parameters under given circumstances.

Optimization in general involves either maximizing or minimizing an objective function against a given set of constraints. The objective can be minimizing inputs into a process because they are scarce, minimizing undesired outputs such as waste or maximizing desired outputs such as Net Present Value (NPV) (Musingwini, 2016). Irrespective of the objective, the basis of optimization is a mathematical model that represents the problem that is then solved using an algorithm. Napier (1981) stated that the choice of the economic criterion as the required objective determines optimum production capacity.

Musingwini (2016) further described a system as being made of interdependent components to accomplish desired objectives. This interdependence is confirmed by several authors including O'hara who used production rates to estimate costs. While the mining value chain is the bigger system, mine planning involves establishing where, how, how much and when to mine, but optimization should be an integral part of mine planning (McCarthy, 2006).

There are different ways of creating economic value such as optimizing the production schedule but McCarthy (2006) argued that, key levers of optimum value are mining rate and cut-off grade. Hajdasihski (1988) stated that the problem of optimizing mine size and mine life did not receive much attention and has been a subjective managerial judgement. Little et al. (2013) reiterated this point and stated that plant configuration and production rate have been static as they formed part of managerial early decisions.

3. Production rate

Mine planning is an iterative process that sets corporate objectives and is affected by the decision-making behavior of the company. Kok and Lane (2012) described mine planning as the optimal allocation of resources to appropriate places within the shift cycle. They further define the ultimate objective as maximizing production within infrastructure constraints. Defining an optimum production rate is critical in evaluation of a mineral deposit and consequently decision-making (Smith, 1997; Changsheng and Youdi, 2000). Mining companies are price takers which means to increase profits the only variables within their control are production rate and costs. Therefore, the determination of an optimum production rate is important as it affects the viability/non-viability of a mining project. An optimum production rate may translate into economies of scale consequently lowering unit costs and improving profitability. Other essential parameters and/or infrastructure are a function of production rate. These parameters include, capital costs, operating costs, size of the processing plant, infrastructure and life of mine (Smith, 1997; Changsheng and Youdi, 2000).

Cavender (1992) defined an optimum production rate as the rate at which the net present value (NPV) or internal rate of return (IRR) of a project is maximized. Though critical, often production rate is decided arbitrarily and as a result, incorrect sizing of both underground and surface infrastructure occurs (Smith, 1997).

Tatman (2001) mentioned that there are three methods used to determine production rate namely; general input requirements, economic optimization and empirical formulae. He further stated that general input requirements include work by Ward (1981); Bullock (1982) while economic optimization include work by Carlisle (1955) and Tessaro (1960). In this paper, work done in estimating production rates is grouped into three categories, namely; economic rent, minimum life of mine and empirical formulae. These categories are discussed in detail in the following subsections.

3.1. Economic rent

Economic rent is the extra amount of money earned by an investor from the present use of a natural resource such as land. In this category, production rate is based on the notion of earning a return for the present and/or future use of natural resources in particular, minerals. Hotelling (1931) argued that the price of a mineral commodity is based on the scarcity of the commodity and should grow at a rate equal to the interest rate. On that basis, he formulated the relationship between the net profit after paying for the cost of extraction, initial price and interest rate as shown by Eq. (1). In the equation, p and p_0 are commodity prices at time t = t and t = 0, respectively whereas γ denotes interest rate and t denotes time. Based on this argument, Hotelling (1931) then defined production rate, q, at time, t, as a function of price and time as shown by Eq. (2). The life of mine was determined as the time of final exhaustion, which is the upper limit in the integration of the function, q with respect to time (Eq. (2)).

$$p = p_0 e^{\gamma t} \tag{1}$$

$$\int_o^T q\, dt = \int_o^T f(p_0 e^{\gamma t}, t)\, dt = a, \tag{2}$$

Hotelling's model is similar to earlier work of determining economic rent from exhaustible resources by Gray (1914). With specific reference to coal deposits, Gray (1914) defined an optimum production rate based on the minimum expense required to remove 100t of coal. While both Gray and Hotelling use the price of the commodity as the basis to determine production rate, Gray's work ignored the time value of money and the possibility of fluctuations in both commodity prices and