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# A spatial mine-to-plan compliance approach to improve alignment of short- and long-term mine planning at open pit mines

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### Synopsis

The objective of any mining company is to sustainably maximize the net present value (NPV) throughout the life-of-mine (LOM). The expected NPV over the LOM is calculated based on a mine plan, yet the actual value realized by the mining company depends greatly on the level of intertemporal execution against the mine plan. Consequently, a major key performance indicator (KPI) that is often overlooked in open pit mining, due to a greater focus on temporal KPIs, is the degree of spatial compliance to the mine plan. Such focus sometimes leads to short-term actions being detrimental to long-term plans. In this paper we describe the development and implementation of a spatial mine-to-plan compliance reconciliation approach for an open pit mine. Application to a case study open pit iron ore mine in South Africa indicated a significant improvement in the spatial mine-to-plan compliance, from 69% to 94% over a three-year period from 2014 to 2016. These results indicate that implementation of the proposed spatial mine-to-plan compliance reconciliation approach can contribute positively to improving the level of spatial execution and assists in improving the alignment between short-term, medium-term, and LOM plans.



### Keywords

intertemporal compliance, spatial compliance, short-term plan, long-term plan, LOM plan.


## Introduction

The objective of any mining company is to maximize the net present value (NPV) throughout the life of mine (LOM). However, this objective needs to be fulfilled in a sustainable manner that considers the needs of various stakeholders, including employees, shareholders, and local communities where the mines operate. The expected NPV is calculated using a mine plan as a basis. Mine planning broadly involves identifying a strategy to exploit the mineral resource in a way that maximizes value at an acceptable level of risk throughout the LOM (Tholana and Neingo, 2016).

The mine planning process is a well-recognized component in the mining value chain of an open pit mine. Figure 1 reflects the relative position of mine planning within a typical open-pit mining value chain from the mineral resource to the market.

The mine planning process begins with a sequence of increasingly detailed feasibility studies and continues throughout the life of the mine through several long-term and short-term planning processes (McCarthy, 2015). According to Steffen (1997), most open pit mining operations follow a systematic and disciplined mine planning process involving three distinct levels of mine planning in developing the Mineral Reserves. These levels are the:

- LOM plan
- Long-term plan (LTP), which follows from the LOM
- Short-term plan (STP), which in turn follows from the LTP.

Each of these stages of planning represents different levels of risk and has different objectives. The planning horizons for the different stages are also broadly referred to as the strategic, tactical, and operational planning levels (Tholana and Neingo, 2016).

Literature on mine planning generally focuses on ways of improving mine plans by incorporating the analysis and evaluation of risk into the planning process, thereby improving the expected NPV and/or risk-adjusted NPV of the mine. The literature deals mainly with the strategic level of mine planning. Various studies have been devoted to improvements in the mine planning process with the aim of developing optimal mine plans. These include advances in mine planning software and related systems that are employed in mine planning (Gurgenli, 2011) and the application of orebody flexibility to ensure maximum mineral asset utilization in underground mining applications (Tholana and Neingo, 2016), as well as the progression of stochastic mine planning techniques. Where stochastic approaches have been applied, they have proven to be able to add higher value in production schedules – in the order of 25%,


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**Figure 1—Mining value chain from resource to market**

with consequent improvements of up to 30% in the NPV compared to conventional approaches to mine planning (Dimitrakopoulos, 2011).

Despite significant improvements in the mine planning process and the resultant mine plans, open pit mining remains a high-risk business (Sabour and Dimitrakopoulos, 2008). There are numerous sources of risk, and these can be grouped as:

- External uncertainties such as volatile commodity prices and exchange rates
- Internal uncertainties such as geology, chemical quality predictions, operational uncertainties, and input cost.

Open pit mines are dynamic environments that are characterized by a continuous displacement of the working faces both in time and space (Halatchev and Dimitrakopoulos, 2003). The existence of risk (and opportunity) in open pit mining is evident when considering the differences between the expected and actual outcomes achieved by mining projects and operating mines. This was noted from benchmark studies considering mainly Australian mining operations. A survey of 48 Australian mining projects showed that the actual tonnages extracted for 46% of these mines were more than 20% higher or lower than those expected (Sabour and Dimitrakopoulos, 2008). Benchmark studies of 21 open pit mines by AMC Consultants evaluating the monthly variability between the mine budget and actual production over a 12-month period showed an average variability of 29% for ore tonnes mined (McCarthy, 2015). Ramazan and Dimitrakopoulos (2004) indicated that about 60% of the mines surveyed had an average rate of production in the early years of operation that was less than 70% of the designed production capacity. The failure to have actual outcomes close to or the same as planned targets is widely acknowledged in the mining industry as a top risk (Musingwini, 2016).

Ultimately, the actual value realized by the mining company (as opposed to the expected value) is not only dependent on the quality and integrity of the mine plans; it also depends greatly on the level of execution against the mine plan. The effective execution of the agreed-upon mine plan is therefore critical to the successful operation of an open pit mine (Hall and Hall, 2006). In order to sustainably operate a large open pit mine two major areas need to be managed; namely the quality and integrity of the mine planning process and the execution of the mine plan. The importance of execution against the mine plan is also highlighted by Musingwini (2016); operations are measured against planned targets in order to evaluate operational performance.

The level of execution or compliance against a mine plan can be measured in two ways – time-based or temporal measurements, and area-based or spatial measurements. The measurement of performance against temporal metrics is common practice in the open pit mining industry and these time-based targets are typically short-term focused. The measurement of performance against spatial metrics is equally important in an open pit mine. These area-based metrics provide insight into the long-term aspects of execution against the mine plan. The development and implementation of a spatial mine-to-plan compliance process is important to ensure:

- Long-term sustainable ore supply
- That key issues adversely impacting on mine production are identified (*e.g.* ramp establishment, dewatering, drill-and-blast quality, pre-split and buffer blocks)
- The achievement of planned mining flexibility.

Previous studies on spatial mine-to-plan compliance have been done in mining environments other than open pit mining and have mainly focused on short-term plans. For example, Angelov and Naidoo (2010) described a two-dimensional (2D) spatial mine-to-plan compliance approach that determines the degree of deviation from the original short-term mine plans in underground coal mines by comparing actual mined areas to initially planned mining areas. Morely and Arvidson (2017) proposed a spatial mine-to-plan compliance approach that determines spatial comparison of volumes measured monthly against the short-term plan. The purpose of this paper is to describe the development and implementation of a standardized spatial mine-to-plan compliance reconciliation approach at an open pit mine by comparing planned and actual tonnages in three dimensions (3D) instead of just comparing volumes and aligning short-term plan execution to long-term plans.

### Why track spatial mine-to-plan compliance?

To achieve the goal of creating long-term value, mining companies (with operational mines) typically develop short-term measures of value against which operational and financial performance are tracked. As a result, many time-based or temporal key performance indicators (KPIs) are developed and tracked by mining companies.

One grouping of KPIs is concerned with reconciling planned activities with what actually happened. Conducting reconciliation across the mining value chain ensures that the mining process occurs in a progressively more predictable manner (Bester *et al*., 2016). Reconciliation in the open pit mining industry is a broad subject and is usually associated with comparing the results of planned *versus* actual activities for temporal KPIs such as the waste production, plant production, and chemical and physical qualities of the product for the specific time period under review. The main reason for undertaking these reconciliations is performance tracking with the purpose of operational improvement. Consequently, a major KPI that is often overlooked in the open pit mining industry is the level of spatial compliance to the mine plan, which measures how well the mine plan is executed spatially. This requires considering not only what is being mined and when, but also where the mining activities are taking place in the open pit. This is important because mining in areas outside of the planned areas can affect future waste stripping or advance into future production areas too early.

Hall and Hall (2015) stated that the major focus of high-performing open pit mines should be on delivering the operational and financial targets according to the tactical mine plan, without compromising the mine's ability to deliver on its future KPIs. The difference (if any) between planned and actual performance should therefore be regularly measured and monitored. The monitoring of compliance with the mine plan should also consider spatial aspects. It is important to identify where material has been mined to ensure that the progress of mine development is adequate to meet long-term strategic targets such as timely access to future ore (Hall and Hall, 2015). An unbalanced focus on short-term temporal KPIs such as productivity improvements or unit cost reduction at the expense of spatial compliance with the mine plan could lead to the prioritization of inappropriate mining activities in the wrong mining areas.

The development and implementation of a spatial mine-to-plan compliance reconciliation approach is of critical importance in an open pit mine, as it ensures that short-term KPIs are achieved by identifying key factors negatively impacting on mine production while giving adequate consideration to long-term KPIs such as sustainable ore supply and the achievement of planned mining flexibility.

An evaluation of the operational performance of an open pit mine that considers only temporal KPIs, such as monthly ore and waste tonnages mined, can provide a false sense of security to mine management as performance against these KPIs could be positive while mining activities are not occurring in the correct spatial areas in the open pit, to the detriment of long-term KPIs such as timely exposure of future ore. Spatial mine-to-plan compliance is therefore a critical KPI as it provides a bridge between the short-term KPIs that mining companies track on a weekly, monthly, quarterly, and annual basis and the long-term value expected by (and often promised to) stakeholders.

### Mine-to-plan compliance model

The spatial mine-to-plan compliance at an open pit mine can be measured effectively when the following major components are in place: a quality mine plan, a process of capturing and analysing actual mining progress spatially, and definitions or categories for reconciling the actual areas mined with the planned mining areas. These aspects are explained in the following sections.

#### *A quality mine plan*

As a start, it is important to define 'the plan' against which spatial mine-to-plan compliance is measured. The tactical horizon of mine planning normally involves the development of annual tactical plans (also referred to as budget plans, business plans, or medium-term plans). These plans are successors of feasibility studies and LOM plans, and predecessors of operation plans (Phillis and Gumede, 2011). These annual production schedules are a critical factor in the planning of open pit mines. They deal with the effective management of a mine's production and cash flows in the order of millions of dollars (Ramazan and Dimitrakopoulos, 2004). The reason for focusing on the tactical mine plan is that this plan is typically the basis for annual budgets and, as such, it sets annual operational and financial performance targets. Management is expected to deliver against annual mine plans – these plans are a form of contract between a mine and its stakeholders (Phillis and Gumede, 2011). The tactical plan provides the bridge between strategic mine planning and operational planning and translates the expected long-term value (often expressed as NPV) into operational and financial targets such as monthly production tonnes, product quality, unit cost, and revenue projections. Importantly, it remains a mining plan and therefore also prescribes the spatial development of the open pit mine.

For these reasons, the annual tactical plan produced for an open pit mine is used as the basis for tracking the spatial mine-to-plan compliance. The minimum output required from the tactical plan is stage plans for the agreed-upon measuring period (typically monthly) per mining area (or pushback) and mining bench. The stage plans are typically provided in the format of a digital terrain model (DTM) indicating the areas planned for mining per month. In addition, ore and waste tonnages for these areas are calculated from the applicable mining model, which contains the appropriate geological information for these areas. These outputs are typically generated using mine scheduling software and a suitable general mining package (GMP).

#### *Actual areas mined*

In an open pit mine the survey department is typically responsible for capturing and analysing actual spatial mining progress. Best practice in data acquisition involves the use of laser scanners to conduct month-end ex-pit production measuring surveys. Riegl and Maptek scanners exceed the minimum requirements for the spatial accuracy of surveyed data-points and are currently considered industry-leading technologies. Scanners and associated global positioning system (GPS) equipment are checked and calibrated on a weekly basis to ensure their spatial accuracy is within 50 mm. Although Total Stations are also still utilized, laser scanning technology is preferred due to its speed, accuracy, density of survey points captured, and the ability to work effortlessly in a 3D environment.

The laser scanning process involves the continuous scanning of open pit working areas during the production month and again at month-end. The working areas are typically scanned in a 'stop-and-go' mode from three positions to ensure accurate spatial registration of the scanned data as well as complete coverage of the working areas. These working area scans are then registered and a report is generated which states the spatial accuracy achieved for the scans. A survey DTM of the pit is then generated by combining all the individual scans. The survey DTM represents the actual pit surface at the time of measurement. By comparing the latest survey DTM with the DTM developed at the start of the measuring period (month), areas where mining took place during the month under evaluation, can be identified.

### *Reconciling actual areas mined with areas planned for mining*

The spatial data can now be analysed in order to reconcile the actual mined areas with the planned areas in 3D space. Actual and planned mining areas are then divided into three categories: 'mined in plan', 'mined out of plan', and the resultant 'planned areas not mined'. The reconciliation is done by considering both the total (or annual) area envisaged in the tactical plan and the incremental (or monthly) areas within the bigger tactical plan. This introduces the concepts of in-sequence and out-of-sequence mining as subsets of mining within the tactical plan. Actual mining is deemed to be in sequence when it took place within the areas indicated in the tactical plan up to the date of measurement. Actual mining is deemed to be out of sequence when it took place within the areas indicated in the tactical plan but after the date of measurement. For example, for the reconciliation process done at the end of month six of a specific year, all actual mining activities that took place in areas planned for months one to six are deemed in sequence, while actual mining activities that took place in areas planned for months seven to twelve are deemed out of sequence. The categories used for reporting spatial mine-to-plan compliance are described in Table I and illustrated in Figure 2.

Compliance measurement per category is calculated as a tonnage compliance and expressed as a percentage of planned tonnes for ore, waste, and total material mined.

## Mine-to-plan compliance reconciliation process

The components of the mine-to-plan compliance model described above provide the basis from which the reconciliation process can be managed. The detailed steps of the reconciliation process are presented in the following sections.

### *Reporting*

The spatial compliance against the tactical mine plan is

*Table I*

**Categories for calculating spatial mine-to-plan compliance**

| Category | Description | Colour code |
|---|---|---|
| Planned and mined in sequence | Areas that were planned to be mined and were mined in sequence. | Green |
| Planned and mined out of sequence | Areas that were planned to be mined but were mined out of sequence. | Yellow |
| Mined out of plan | Areas that were mined completely outside of the tactical plan. | Red |
| Planned not mined | Areas that were planned to be mined but not mined. | Brown |

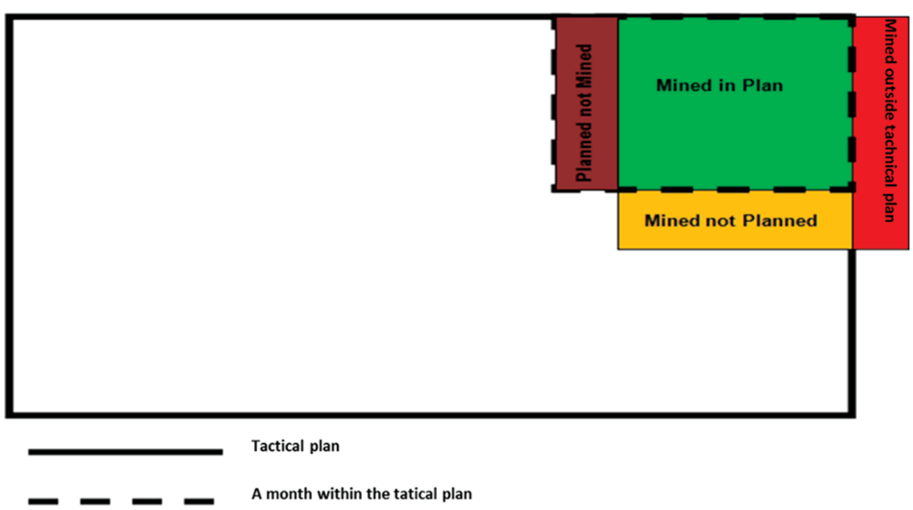


**Figure 2—Categories for calculating spatial mine-to-plan compliance**

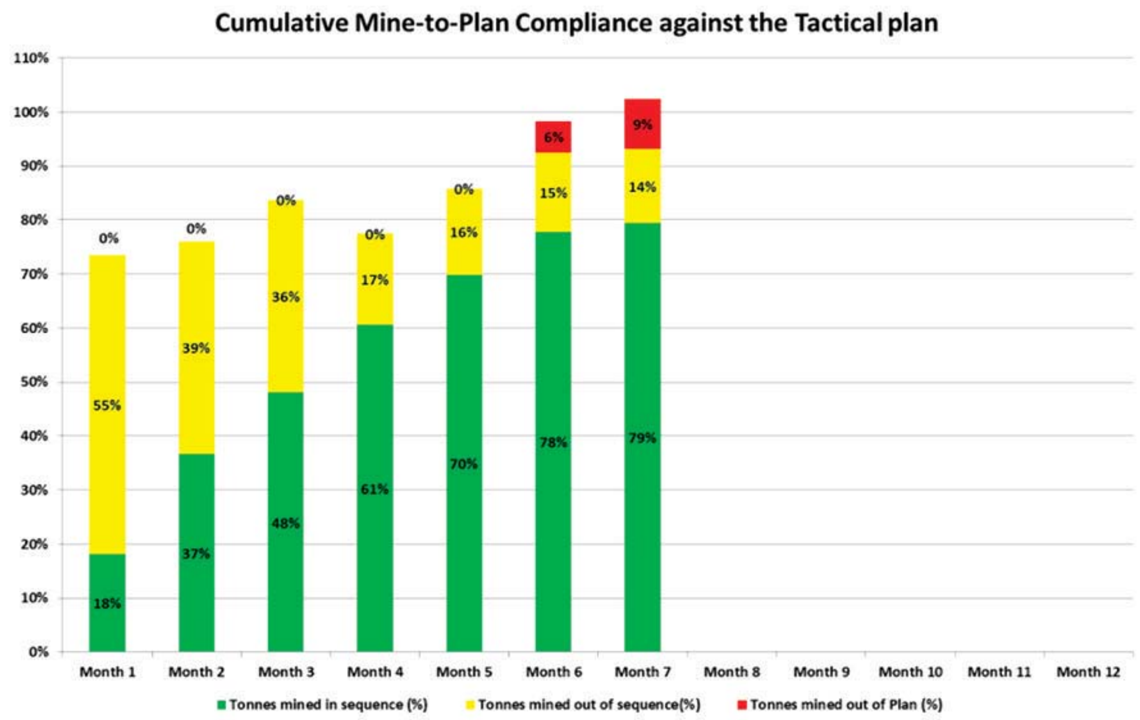


Figure 3—Reporting of cumulative spatial mine-to-plan compliance (Esterhuysen, 2013)

reported on a monthly basis using the categories described in Table I. The reporting format consists of graphs in which the spatial compliance is expressed as a percentage of planned tonnes mined. This allows for evaluation of the year-to-date compliance as well as the assessment of trends in the spatial mine-to-plan compliance over a given period of time. Figure 3 illustrates an example of the reporting of spatial mine-to-plan compliance on a cumulative monthly basis.

From the information provided in Figure 3 the following interpretation can be made using the mine-to-plan compliance data.

1. The actual tonnes mined for the seven month period is 102% of the planned tonnes
2. 79% of the mining took place in the areas planned to date (mined in sequence)
3. 14% of actual mining took place within the areas planned in the tactical plan but after the date of measurement (mined out of sequence)
4. 9% of mining took place outside of the tactical plan (mined out of plan).

In addition, the monthly trend provides further insight into month-on-month changes in compliance to the tactical mine plan. The major implication of below-targeted spatial mine-to-plan compliance is the fact that planned areas are not mined (*i.e.* mining capacity is not applied spatially in line with the tactical plan). This impacts negatively on the open pit mine's ability to achieve operational (production and product quality) and financial targets.

The reporting is further enhanced with plans per mining area illustrating the reconciliation between areas planned and areas where actual mining took place (Figure 4) by using the categories in Figure 2. Although these plans allow for further analysis of the areas actually mined, the real value lies in evaluating the areas that were planned but not mined and considering how these areas should be prioritized in future operational plans. The plans also assist in understanding the reasons for adverse outcomes with the aim to improve future mine-to-plan compliance.

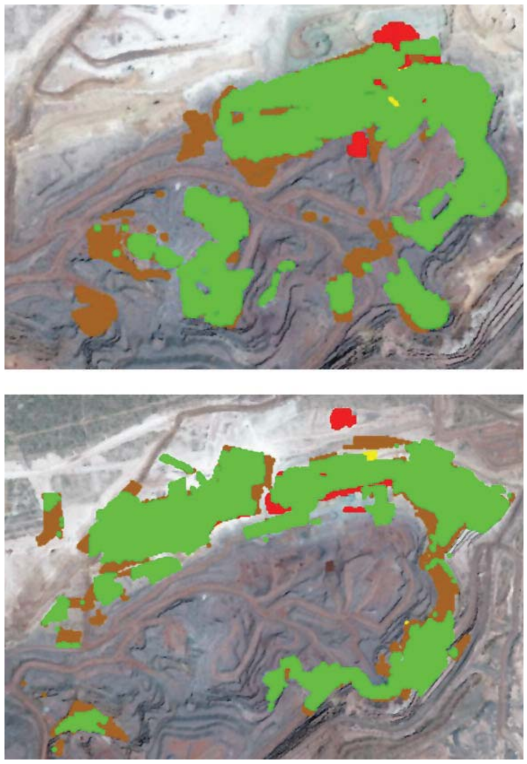

Figure 4—Plans showing spatial mine-to-plan compliance reconciliation results at Sishen iron ore mine (Snyman, 2017)

It is important to note that the mine-to-plan compliance reconciliation results should not be considered in isolation. These results should be included in a consolidated performance dashboard for an open pit mine that provides a holistic view of the mine's technical and financial performance against temporal and spatial short-term and long-term KPIs.

### *Target setting*

Target setting is of paramount importance for the successful management of spatial mine-to-plan compliance. It is important to select targets that reflect industry best practice while taking account of historical performance, levels of flexibility in the open pit mine, as well as practical considerations. For the purpose of explaining the process and based on acceptable results achieved, the target for spatial mine-to-plan compliance against the tactical plan is set at a minimum of 85% in-sequence mining and a maximum of 15% mining outside of the tactical plan. The targets should be refined as the mine-to-plan compliance process is embedded.

### *Understanding the reasons for deviations*

Spatial deviations from the mine plan (positive and negative) occur when either the quality of the mine plan is not on standard or the execution against the mine plan is not adequate. In an open pit mine, spatial deviations from the mine plan typically occur for two main reasons. Firstly, when the assumptions used as input to the development of the tactical mine plan are not achieved in practice (or are incorrect). Examples include assumptions on the vertical rate of advance, loading and hauling equipment productivity, and assumptions regarding equipment allocated to critical secondary tasks. Actual mining therefore remains spatially on plan but takes place at a different rate from the planned rate. This normally manifests as actual in-sequence mining being higher or lower than planned. If not managed, it could lead to actual mining activities taking place out of sequence and out of plan. Secondly, this occurs when short-term technical or financial objectives are prioritized at the expense of the spatial execution of the tactical mine plan. Examples include cutting back on waste stripping to improve short-term unit cost and targeting an unplanned mining area to reduce short-term hauling distances. Here, actual mining is not spatially honouring the tactical plan. If not managed properly, then out-of-sequence and out-of-plan mining takes place and the areas planned and not mined increase as a result.

Adverse outcomes are highlighted as part of the monthly reporting routines and should be viewed as opportunities for improvement of either the quality of the next tactical mine plan or the quality of spatial mining execution against the plan. The operational or short-term planning horizon is utilized to manage improved spatial compliance by directing mining to areas planned and not yet mined.

## Application in an open pit iron ore mine

The spatial mine-to-plan compliance approach discussed above was implemented at the Sishen iron ore mine in the Northern Cape Province of South Africa. Sishen is operated by Anglo American Kumba Iron Ore. At the end of 2017 the iron ore Mineral Reserve was approximately 500 Mt and the LOM stripping ratio approximately four times. The Sishen pit is a conventional open pit, truck-and-shovel operation. In 2017, a total of 162 Mt of waste material was mined at Sishen, making it the single biggest open pit mine in southern Africa on a tonnes per annum basis. Both dense medium separation and jig processing plants are employed and the annual product output in 2017 was 31.1 Mt.

The spatial mine-to-plan compliance methodology was introduced at Sishen during 2013. The focus of the mine-to-plan compliance reconciliation model and process is to track spatial compliance against the annual business plan (tactical plan) agreed upon as part of the annual business planning cycle.

Spatial mine-to-plan compliance reconciliation takes place through a well-established monthly management routine using the model and process discussed in this paper. At Sishen, the mine-to-plan compliance results form part of a technical key success factor (TKSF) dashboard that is used to measure and manage the technical health of the mine.

The effectiveness of the proposed approach is demonstrated in Figure 5, which shows the Sishen spatial mine-to-plan compliance reconciliation results for 2014, 2015, and 2016.

Figure 5 demonstrates that, using the approach discussed in this paper, the spatial mine-to-plan compliance at Sishen improved from 69% to 94% over the three-year period up to 2016. This illustrates the benefits of implementing spatial mine-to-plan compliance reconciliation and incorporating this KPI into the TKSF dashboard of an open pit mine.

## Conclusions

An approach for measuring and managing the spatial mine-to-plan compliance against the tactical mine plan has been presented. The approach incorporates a model providing mine-to-plan reconciliation categories as well as a spatial reconciliation process focusing on reporting, target setting, and analysis of the reasons for deviations. The aim of the approach is to improve the spatial execution against the tactical mine plan in an open pit mine. Application of the approach will contribute to the achievement of an open pit mine's operational and financial targets (derived from the tactical mine plan) while maintaining the mine's ability to deliver on its future KPIs, thereby contributing towards meeting the ultimate objective of maximizing the NPV throughout the LOM in a sustainable way.

A case study at the Sishen iron ore mine, South Africa illustrated how the implementation of the spatial mine-to-plan compliance approach contributed positively to improving the quality of mining plans and to an improved understanding of the major reasons for non-compliance. This led to a significant improvement in the spatial mine-to-plan compliance from 69% to 94% over the three-year period from 2014 to 2016, inclusive.

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**Figure 5—Spatial mine-to-plan compliance performance, Sishen iron ore mine (Snyman, 2017)**

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