Improving spatial mine-to-plan compliance at an open pit mine through enhanced short-term mine planning

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Abstract

The value realised by an open pit mine depends on the quality and integrity of the mine planning process as well as the level of execution against these mine plans. When managing the execution against the mine plan, how well the mine plan is executed spatially, is of critical importance. The short-term mine plan is the plan that is physically executed on most open pit mines. At the same time, the spatial mine-to-plan compliance is typically reconciled against the annual business plan. Short-term mine planning, therefore, plays an important role in the effectiveness of the spatial mine-to-plan compliance reconciliation process by providing operational teams with detailed designs and schedules, while ensuring that mining execution is spatially aligned with the business plan.

The Sishen open pit iron ore mine (Sishen) strives to continuously improve spatial compliance to the business plan. Sishen enhanced the role that short-term mine planning plays in enabling the forward-looking component of the spatial mine-to-plan compliance reconciliation process. The enhanced short-term mine planning process focuses on detailed tactical sequence designs per mining pushback, the health of value chain buffers, spatial plan-to-plan reconciliation, and the associated management routines.

This led to improved spatial mine-to-plan compliance to the business plan from 71% to 94% over the four-year period from 2020 to 2023 inclusive. These results indicate that the application of short-term mine planning as part of an integrated spatial mine-to-plan compliance process at open pit mines can contribute positively to improving the level of spatial execution against the business plan. This paper presents the enhancements made to the short-term mine planning process, which other open pit mining operations can consider to improve spatial mine-to-plan compliance.

Keywords

short-term mine planning, business plan, spatial mine-to-plan compliance, plan-to-plan reconciliation, detailed tactical sequence, management routines

Introduction

The economic objective of mining companies is to maximise the net present value (NPV) throughout the mine life in a sustainable way. The success of open pit mines is often determined by the mine's ability to deliver actual value in line with the expected value that was 'promised' to investors and other stakeholders, based on mine plans. To ensure the sustainable success of a large open pit mine, two major areas need to be effectively managed. These are firstly, the quality and integrity of the mine planning process and secondly, the execution of the mine plan (Otto, 2019). The expected NPV of a mining operation is calculated using a mine plan as the technical basis. The actual value realised by a mining operation, 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 level of execution or compliance against a mine plan can be measured in two ways: time-based (temporal) measurements, and area-based (spatial) measurements (Otto, Musingwini, 2020).

Spatial mine-to-plan compliance

Spatial mine-to-plan compliance can be defined as a measure tracking how well a mine plan is executed spatially. The level of spatial compliance to the mine plan is a key performance indicator (KPI) that is of critical importance to the open pit mining industry when managing the execution against the mine plan. Typical temporal mining reconciliation processes comparing tonnes, grade, and product alone do not adequately address the spatial aspect of open pit mining (Otto, 2019). According to Morley and

Arvidson (2017), the ultimate question to answer is: 'Did we mine where and when we planned to mine?' The effective measurement and management of spatial mine-to-plan compliance reconciliation is critical to answer this question. According to Otto (2019), this requires not only considering what is being mined when, but also where the mining activities are taking place in the open pit. 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 targets (Hall, Hall, 2015). According to Esterhuysen (2013), the measurement and management of spatial mine-to-plan compliance is important to ensure:

- long-term sustainable supply of ore;
- that key issues negatively impacting on mine production are identified;
- the achievement of planned mining flexibility.

Otto and Musingwini (2019) provide insights into the major components and aspects associated with measuring and managing spatial mine-to-plan compliance at an open pit mine. Firstly, it is important to define 'The Plan' against which spatial mine-to-plan compliance is measured. Annual tactical plans (also called Business plans) are proposed as the basis for tracking the spatial mine-to-plan compliance. Secondly, the spatial aspects of the actual areas mined should be determined. By comparing the latest surveyed digital terrain map (DTM) with the DTM developed at the start of the measuring period (month), areas where mining took place during the period under evaluation, can be identified. Thirdly, the spatial data is analysed to reconcile the actual mined areas with the planned areas in 3D space (Otto, Musingwini, 2019).

The actual areas mined, are spatially compared and evaluated to the areas planned in the annual tactical plan and then divided into four categories for reconciliation purposes. These categories are areas planned and not mined, areas mined out of sequence, areas mined out of plan and areas mined in plan. These categories are illustrated in Figure 1. The 'planned not mined areas' are those areas that were planned and not mined (indicated using the brown colour). The 'mined out-of-sequence areas' are those areas that were planned to be mined in the annual tactical plan, but they were mined out of their planned period. These areas are indicated by the yellow colour. The 'mined out of plan areas' are those areas that were not planned within the annual tactical plan but were mined (indicated by the red colour). The 'mined in plan areas' are those areas that were planned and mined. These areas are indicated in green.

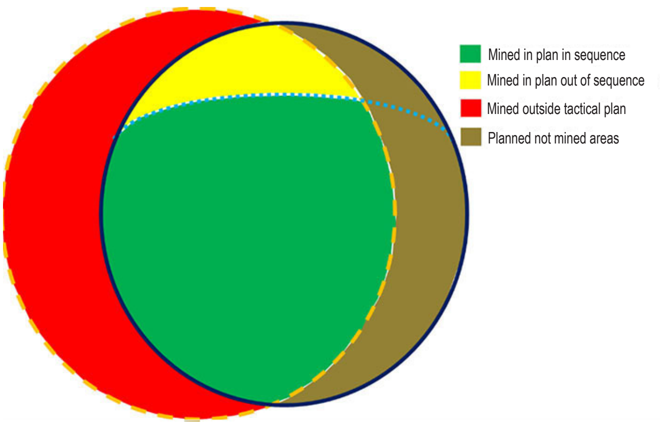

Figure 1—Spatial mine-to-plan compliance categories (Otto, 2019)

Short-term mine planning

Mine planning is a mining engineering process that transforms a mineral resource into the best productive mining business (Morales, Rubio, 2010). The mine planning process is cyclical, and mine plans are regularly updated to incorporate the latest available information and changes in the macro-economic environment (Vivas, Nava, 2014).

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 long-term (strategic), medium-term (tactical), and short-term (operational) mine planning horizons. Each of these horizons of mine planning represent different levels of risk and have different objectives. The planning horizons are nested in each other and the mining plans with a longer timeframe pass down guidance and restrictions in decisions to the shorter-term plans (Otto, Lindeque, 2021).

A mine plan, typically, has a design and a scheduling component. The design component provides the design for the mining activities such as the pit design, waste dump designs, ramp access designs, infrastructure requirements, and the design of mining activities within a mining bench. Developing an optimal mine design is a critical component of each of the mine planning horizons (Otto, Lindeque, 2021). The scheduling component considers the timing of these mining activities. For example, the design component will indicate the location and dimensions of an access ramp, and the scheduling component will indicate when the access ramp should be constructed.

Blom et al. (2019) discussed the major differences between long-term and short-term mine planning at open pit mines. Firstly, short-term plans are more practical and models mining activities at a higher level of detail when compared to long-term plans. Secondly, short-term plans cover a period of up to three months in daily and weekly increments, while long-term plans cover the life-of-mine using quarterly to yearly increments. Thirdly, short-term plans contribute to operational decision making while long-term plans provide inputs to strategic decision-making.

Short-term mine planning (STMP) is important because it links the guidance received from longer-term mining plans, and the execution thereof (Otto, Lindeque, 2021). Upadhyay and Askari-Nasab (2017) stated that the whole planning process at open pit mines is ineffective when STMP is not done well. An STMP is a rolling schedule that is updated weekly, fortnightly, or monthly, depending on the complexity and scale of the open pit mining operation. Short-term mine planning is typically conducted in detail on a day-to-day basis. The mining activities being considered in an STMP include access ramp construction, infrastructure establishment, block preparation, drilling, blasting, loading, and hauling (Otto, Lindeque, 2021).

The four main objectives for STMP are as follows (Blom et al., 2019; Blom et al., 2017; Burt et al., 2015; Upadhyay, Askari-Nasab, 2017; Vivas, Nava, 2014):

- Achieving the production throughput, and quality targets set by the tactical plans;
- The spatial alignment of the STMP to tactical plans;
- Enabling heavy mining equipment (HME) productivity;
- Practical executability.

When an open pit mine has an effective STMP process in place, accurate and detailed mine plans can be produced, communicated, and executed. In summary, STMP aims to ensure a detailed understanding of the critical mining path, that will result in achieving the four objectives of throughput and quality, alignment with tactical plans, HME productivity, and executability (Otto, Lindeque, 2021). When developing an STMP it is critical that a balance should be found between spatial adherence to the tactical plan and the practical short-term realities in the open pit mine. The STMP links the tactical plans and the mining execution activities. The STMP (an output of the operational mine planning horizon) represents the 'sharp end' of the mine planning process as it is this plan that is physically executed (Otto, 2019). This paper explores how a well-developed STMP process supports the implementation of a spatial mine-to-plan compliance framework at an open pit mine. Examples from Sishen mine are included to illustrate the methodology.

Spatial mine-to-plan compliance framework

A high level of spatial compliance to the tactical mine plan is one of the major enablers for open pit mines to consistently, predictably, and sustainably deliver against budget targets and stakeholder expectations. The implementation of a comprehensive and integrated spatial mine-to-plan compliance reconciliation framework contributes to achieving high levels of spatial mine-to-plan compliance. According to Otto and Musingwini (2019), the implementation of such a framework at an open pit mine firstly ensures that short-term KPIs are achieved by identifying key factors negatively impacting on mine production, and secondly, considers long-term KPIs such as sustainable ore supply and the achievement of planned mining flexibility.

Otto (2019) described the development and implementation of a spatial mine-to-plan compliance reconciliation framework at an open pit mine in South Africa. The framework enables mine planning engineers to proactively redirect mining (if required) using the operational mine planning horizon and to improve the executability of future mine plans. Figure 2 illustrates this spatial mine-to-plan compliance framework. It shows the six major components of the framework and the relationships between the components. The different components of the framework serve the following purposes (Otto, 2019):

- Components 1 to 3 provide guidance on defining and collecting data required to measure spatial mine-to-plan compliance.
- Component 4 utilises the value driver tree concept for drilling down of information and root cause analysis.
- Component 5 analyses the impact and consequence of the historic spatial mine-to-plan compliance on future compliance.
- The purpose of Component 6 is to determine the next best actions (NBAs) that are required to improve the spatial mine-to-plan compliance.
- Feedback loops ensure the implementation of agreed corrective actions (also referred to as NBA) to improve the spatial mine-to-plan compliance. The first feedback loop enhances near real time visibility of the spatial progress of open pit mining and the second feedback loop facilitates improved tactical plans in future.

The green block identifies Component 6 where effective STMP (an output of the operational planning horizon referred to in the framework) plays a critical role. The NBA component is about applying the intelligence derived from the previous components of the framework for effective decision making.

The important role that STMP plays to define and implement the correct NBAs and ensure effective decision-making is highlighted by Otto (2019). Firstly, the STMP should actively seek to adhere to the spatial execution guidance provided by the tactical plan and direct mining to the correct spatial areas identified during the mine-to-plan compliance reconciliation process (Component 3 of the framework). Secondly, the STMP should incorporate identifying and actioning of priority tasks (PTs). PTs are focused actions that address the root causes of adverse spatial mine-to-plan compliance performance identified in Component 4 of the framework. These PTs are defined as tasks that will enable the successful execution of the STMP. PTs are typically a list of key actions or key enablers linked to spatial areas of critical importance in the execution of the STMP and to the major inputs into the STMP. Ultimately, a reconciliation process adds value when it results in implementing corrective actions aimed at improving future performance (Morley, Arvidson, 2017).

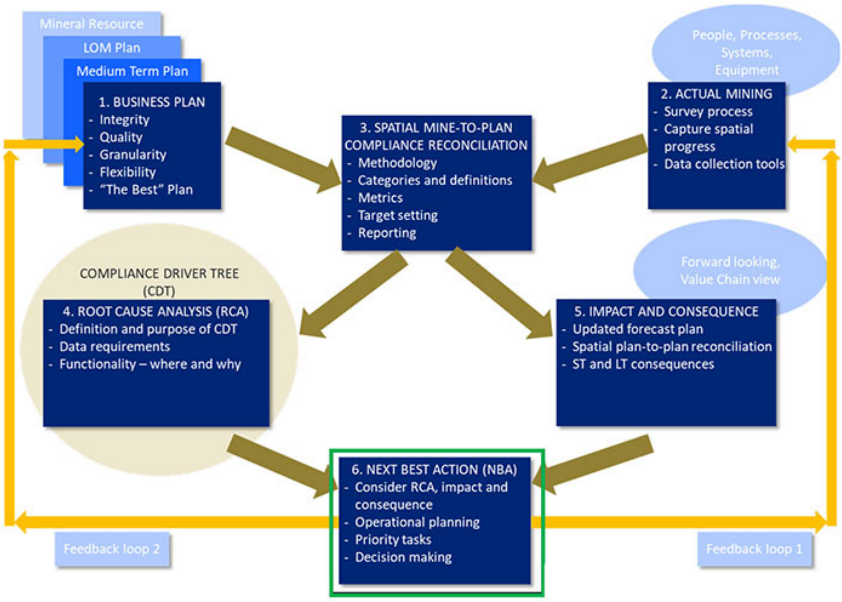

Figure 2—Spatial mine-to-plan compliance framework (Otto, 2019)

Improving spatial mine-to-plan compliance at an open pit mine

Once the spatial alignment to the business plan (BP) is incorporated into the STMP, the open pit mine should seek to mine the blocks scheduled in the STMP and action the PTs. Executing the STMP then implies that the correct NBAs are being conducted. Effective decision making can now occur and will ensure that tactical planning outcomes are achieved in a sustainable manner. Effective STMP, therefore, underpins implementing a spatial mine-to-plan compliance framework at open pit mines. STMP is the tool used to define and guide the implementation of the BP.

Sishen as a case study mine

The Sishen open pit iron ore mine (Sishen), is owned and operated by Anglo American Kumba Iron Ore (Kumba). It is located in the Northern Cape Province of the Republic of South Africa. Sishen is Kumba's flagship mine and one of the largest open pit mines in the world. The mine consists of a single open pit with interconnected pushbacks stretching for approximately 14 km in the north-south direction (Kumba Iron Ore Limited, 2014).

Sishen extracts high-grade iron ore and the associated waste material utilising conventional truck and shovel open pit mining methods. The open pit mining method entails topsoil removal and stockpiling for later use during the waste dump rehabilitation process, followed by drilling and blasting of waste and ore. The waste material is in-pit dumped where such areas are available or hauled to waste rock dumps. The run-of-mine (ROM) iron ore is transported to the beneficiation plants, where it is crushed, screened, and beneficiated. The ROM iron ore is processed through two processing facilities namely a dense media separation (DMS) plant and a jig plant. The final product is transported via a railway line to the Saldanha harbour for subsequent export to various international markets.

The ex-pit material mined at Sishen is classified into iron ore and waste. In the 2023 financial year Sishen produced a total of 202.9 Mt ex-pit mined material comprising 39.1 Mt of ex-pit mined iron ore and 163.8 Mt of ex-pit mined waste material. The ratio of waste material to iron ore that needed to be extracted (stripping ratio) was at 4.2. In the 2023 financial year, Sishen produced a saleable product of 25.4 Mt (Kumba Iron Ore Limited, 2024). On 31 December 2023, Sishen declared an ore reserve of 599 Mt at an average quality of 54.1% Fe. The ore reserve was declared at a cut-off grade of 40% Fe and resulted in a reserve life of 15 years at the estimated production rate. The saleable product equated to 380 Mt at an average quality of 64.1% Fe (Moolman, Esterhuysen, 2023). The 2023 Sishen reserve report has been prepared in accordance with the guidelines of the SAMREC Code.

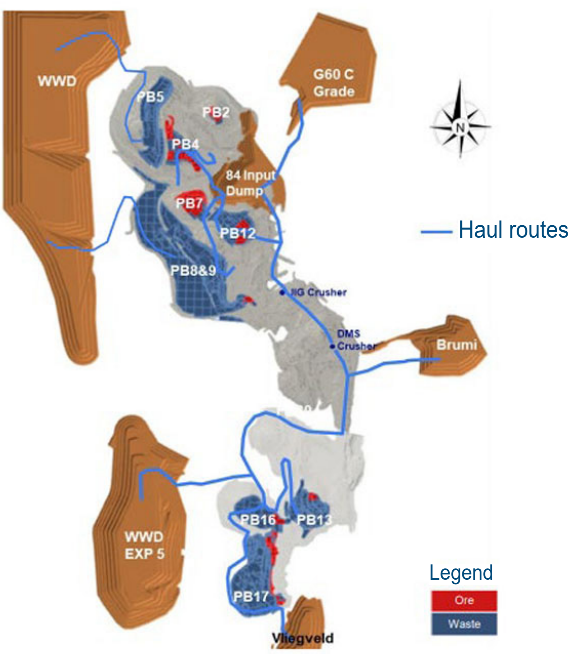

Figure 3—An overview of Sishen mine (Mashala, 2023)

Sishen typically operates in 10 active pushbacks, mining approximately 600 kt of ex-pit material per day. Figure 3 is a plan view showing Sishen's active pushbacks targeted for ore and waste extraction and major waste dumps (WWD). Mining activities within the pushbacks are conducted using 12.5 m high mining benches. These activities are well coordinated to ensure safe execution and operational stability. The primary equipment deployed at Sishen includes primary blasthole drills (18 Pit viper 351D drills), rope shovels (3 P&H 4100 and 3 P&H 2800), hydraulic shovels (6 Liebherr R996), and trucks (36 Komatsu 960E haul trucks and 63 Komatsu 860E haul trucks). The P&H 4100 rope shovels are dedicated to loading pre-strip waste material to increase the capacity of waste material moved. The P&H 2800 rope shovels load internal waste and iron ore. The hydraulic shovels are assigned to loading buffer blocks, ramp establishment, and supporting the rope shovels (Mashala, 2023).

Sishen makes a substantial contribution to the operational and financial performance of Kumba, hence it is a significant operation to Kumba. The mine strives to consistently achieve budgeted production and financial targets while ensuring long-term sustainable iron ore supply. This objective is supported by implementing a spatial mine-to-plan compliance reconciliation process that ensures high levels of spatial compliance to the tactical mine plan. Effective STMP is a key enabler for successfully implementing the spatial mine-to-plan compliance reconciliation process in the open pit mining operations at Sishen. Therefore, STMP is key in improving the spatial mine-to-plan compliance reconciliation performance at Sishen.

Short-term mine planning at Sishen

The STMP process at Sishen is an established and structured mine planning process, which generates mine plans that are detailed, practically executable and, at the same time, aligned with the guidance provided from the BP, which is an output of the tactical planning horizon. Figure 4 is an overview of the mine planning process flow at Sishen. It illustrates how each planning horizon links to the next. It shows that the STMP (referred to as short-term production strategy) plays a critical role in linking the BP or medium-term production strategy to work execution. The figure also indicates that the STMP comprises a mine design and a mine scheduling component (Gentle, 2021).

The STMP, at Sishen, covers a rolling period of three months or 12 weeks. The 12-week window provides clear visibility on the required mining production activities for that period, ensuring all the stakeholders are prepared in advance and aligned regarding priorities. The outputs of the STMP include the mining activities per bench, daily production deliverables such as ex-pit mining tonnages, ROM iron ore feed to the processing plants, and chemical qualities as well as PTs to be executed in support of the plan. The STMP is presented visually, which enables the different stakeholders to fully understand the interactions between mining activities captured in the plan. To continuously improve the quality and integrity of the mine plans and the alignment between the planning horizons, learnings from the STMP process are used as feedback or inputs into the next tactical planning cycle.

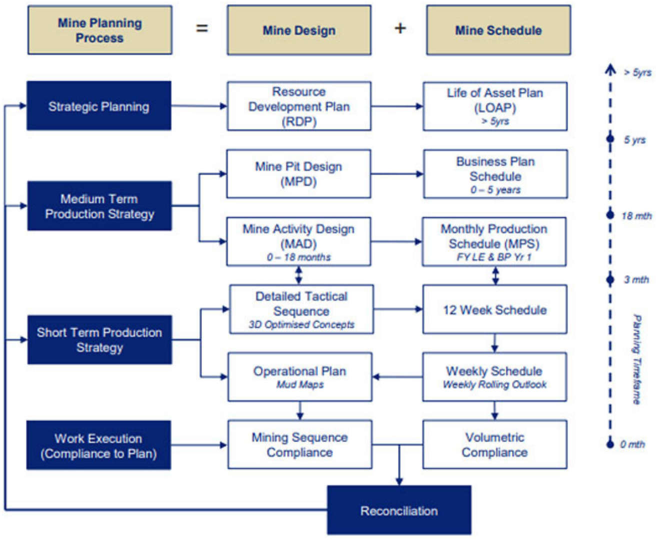

Figure 4—Overview of the mine planning process at Sishen (Gentle, 2021)

One of the main objectives of the STMP at Sishen is to bridge the gap between the BP and the daily operational mining activities. Thus, ensuring that mining execution aligns with the BP, both from a temporal and a spatial perspective. The STMP provides the operational teams with detailed guidance on how the annual tactical plan should be executed. This includes specifying the blocks to be mined, allocation of resources, timelines allocated per activity, and the requirements for all the supporting priority tasks. The STMP, therefore, plays a critical role in directing the execution teams to the correct spatial mining areas and highlighting PTs that require operational focus, such as infrastructure placement, haulage ramp requirements, loading of sumps for water management, creation of drill accesses, and extension of power lines.

To support the role that STMP plays as a key enabler of spatial alignment between the BP and the daily mining activities, Sishen enhanced its STMP process during 2021 and 2022. The enhancements focused on improving four critical aspects of the STMP process namely STMP design, STMP scheduling, Plan-to-Plan reconciliation, and the associated management routines.

In the STMP horizon at Sishen, the mine design component is referred to as the detailed tactical sequence (DTS). The DTS spans a period of three months and is updated quarterly. The main objective of a DTS is to design the mining sequence per pushback, HME interaction, infrastructure considerations, access routes, and PTs prior to conducting the SMTP scheduling. The DTS aims to define the mining sequence and related short-term designs in such a way that it facilitates spatial compliance to the BP, optimises HME productivity, and ensures practical executability. Figure 5 shows an example of a DTS for Pushback 16 at Sishen. From the figure, the mining sequence design for Benches 14 and 13 can be seen. Firstly, the figure indicates the mining sequence and related HME interaction, including blocks to be drilled, blasted, and loaded. Secondly, it indicates infrastructure requirements such as electrical infrastructure, permanent ramp systems, and water infrastructure – critical enablers for the successful execution of the STMP. The visual nature of the DTS allows all relevant stakeholders to effectively understand and adhere to it.

The DTS provides highly visual 3D representations of how to effectively extract the required ex-pit material from a particular pushback by outlining the mining sequence and the interaction between different mining activities. It covers critical HME paths, including the access paths for drilling, loading, and hauling activities. It includes considerations for the interaction between the loading activities and other mining activities such as drilling, charging, blasting, highwall scaling, etc. Additionally, the DTS incorporates PTs that support the execution of the STMP such as infrastructure placement, access ramp requirements, and surface water management. Sishen introduced the concept of rain readiness per pushback as a PT, thereby formalising and prioritising surface water management as a critical component of the DTS designs. Figure 6 is a visual representation of the key aspects associated with rain readiness in the Pushback 16 area. The figure identifies the positioning of sumps and surface waste pipe infrastructure and facilitates discussion around the establishment of the rain readiness infrastructure and the impact on other mining activities in the pushback.

Developing DTS designs improves the practical executability of the STMP, leading to improved spatial compliance to the BP because risks and opportunities associated with the mining design per pushback have been identified prior to the STMP scheduling process. The DTS serves as an essential input into the scheduling portion of the STMP process. At Sishen, this is referred to as the 12-week schedule.

The 12-week schedule is a time-based component of the STMP. It transforms the DTS designs into a time-based sequence of interrelated and interdependent mining activities and ensures that

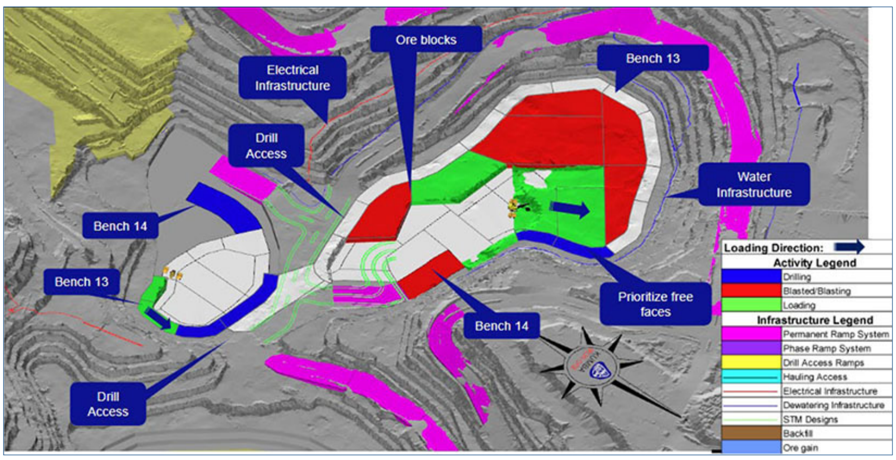

Figure 5—Detailed tactical sequence of Pushback 16 at Sishen (Mantsena, 2023)

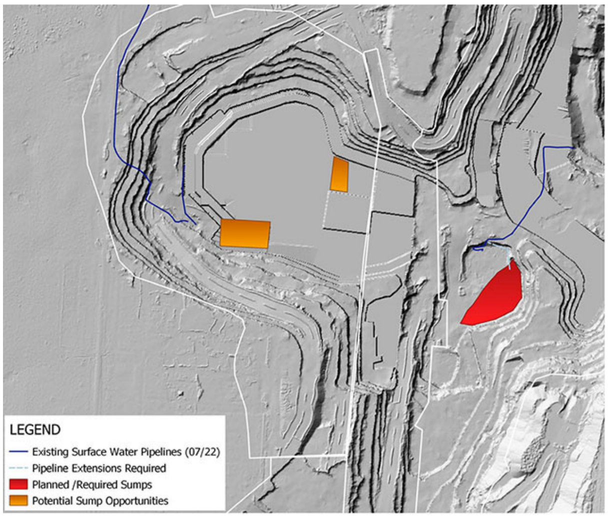

Figure 6—Key components of rain readiness planning in Pushback 16 (Cloete, 2022)

the tonnage and ROM iron ore quality results from the different pushbacks effectively combine to produce the required ex-pit mining output at a mine level. In addition to the DTS designs, the 12-week schedule incorporates cross-functional inputs such as HME maintenance considerations, HME performance assumptions, and processing plant inputs.

To ensure stability within the mining operation at Sishen, the 12-week schedule actively targets and effectively manages the health of mining value chain buffers, such as the number of blocks staked, the number of blocks being drilled, and the amount of blasted material. ROM stockpiles (another buffer in the mining value chain) are also managed through the STMP to ensure that the feed to the processing plants is aligned with BP expectations. Having these buffers in place enables the mine to effectively deal with short-term variability without the need to deviate from the 12-week schedule, thus, improving spatial mine-to-plan compliance. Figure 7 illustrates how the drilled and blasted floor stock, high-grade run-of-mine (ROM) iron ore stockpile level, and finished product stockpile levels are tracked on a monthly basis to ensure that these buffers stay at levels above the planned levels required.

PTs, identified and agreed for execution as part of the DTS designs, are incorporated in the 12-week schedule. This process ensures that the PTs are assigned (with due dates and KPIs to measure successful completion) to the responsible team members for the mining areas where actions are required. The incorporation of PTs in the 12-week schedule leads to improved spatial mine-to-plan compliance because these enablers to the spatial deployment of the open pit mine are actively managed.

The outputs of the 12-week schedule are a visual representation of mining activities. An example is shown in Figure 8. The figure shows the timing of mining activities such as block preparation, drilling, and loading. Utilising 3D visualisations to represent the 12-week schedule output, enables stakeholders to visualise the mining sequence and associated HME interactions, allowing them to fully understand risks, such as maintaining adequate blasted stock, and contribute towards optimising the final agreed schedule (Gentle, 2021).

As indicated before, the STMP is the mining plan that is physically executed by the mining operations team. It is, therefore, critical that the spatial mining areas targeted by the STMP align with the mining areas targeted by the BP. At Sishen, this alignment is validated through the introduction of a spatial plan-to-plan reconciliation process, which compares how well the STMP aligns with the tactical plan spatially.

Having a detailed, well-designed, and highly executable STMP is only one half of the requirement. For the STMP to be effective and ensure that "the right things are done right", the STMP has to also align spatially to the BP. At Sishen, the STMP actively seeks to align spatial deployment priorities with the BP and actively limits the mining of areas outside of the footprint defined by the BP. To validate that the STMP consistently aligns spatially to the BP per pushback, the period progress plots (or stage plans) of the STMP are compared to the stage plans of the BP monthly. This process is referred to as spatial plan-to-plan reconciliation. The objective of this spatial reconciliation is to ensure that the mining areas targeted by the STMP, and therefore executed by the mining operations team, are aligned with the spatial deployment guidance from the BP. The process also highlights the areas that are scheduled to be mined in the BP but have not been scheduled in the STMP. Should these yet unmined areas require additional focus, they are then assigned to the PT list. According to Otto and Musingwini (2020), measuring the spatial plan-to-plan reconciliation gives the operation a forward-looking view on the likelihood of achieving their spatial mine-to-plan targets against the BP.

Figure 9 is a view of the output from a plan-to-plan reconciliation conducted for Pushbacks 16 at Sishen. The figure visually compares the areas planned in the STMP with the areas planned in the BP. The colours used to represent the spatial reconciliation categories are aligned with the categories discussed earlier in the paper and illustrated by Figure 1. It can be seen from the figure that there are areas that are spatially aligning with the BP (areas indicated in green), there are areas that are planned to be mined in the annual tactical plan but not yet scheduled in the STMP (areas indicated in brown), and there are areas that are scheduled to be mined in the STMP, which are outside of the annual tactical plan (areas indicated in red).

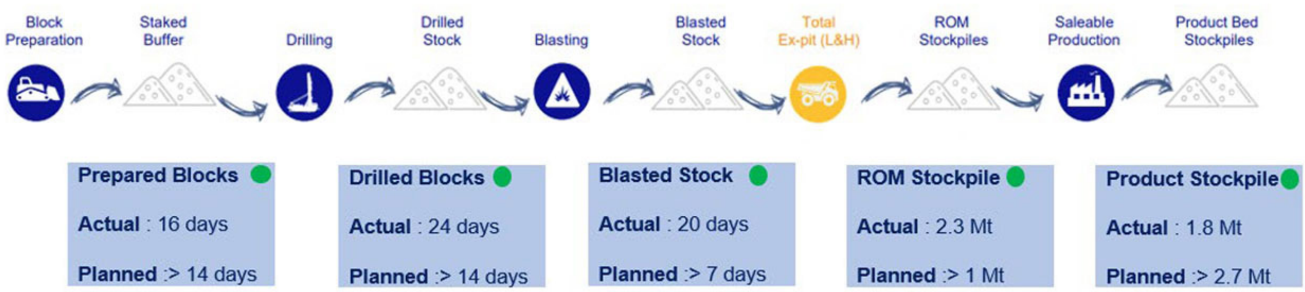

Figure 7—Mine value chain buffers (Mashala, 2023)

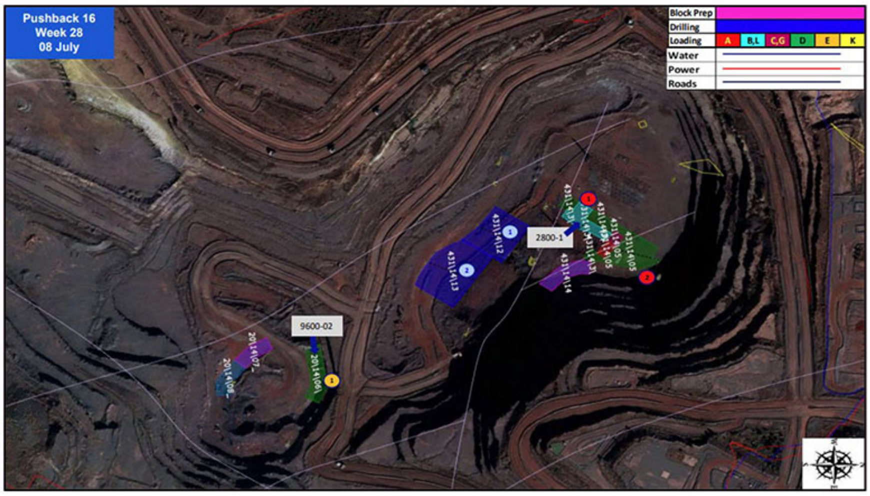

Figure 8—12-Week schedule output of Pushback 16 at Sishen (Moeng, 2023)

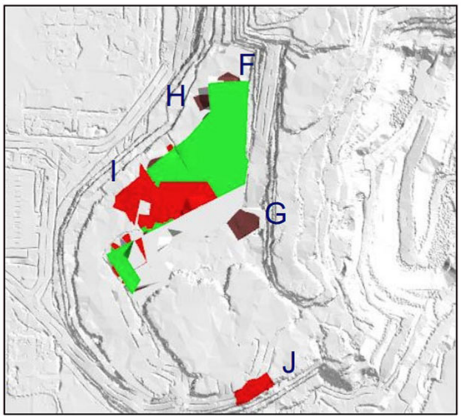

Figure 9—STMP versus BP plan-to-plan compliance for Pushback 16 at Sishen (Pilane, 2023)

The results from this reconciliation are used as inputs into the next STMP cycle. Mining is directed to the 'brown areas' and PTs required to enable mining in these areas, if any are identified, while the necessity of mining in the 'red areas' is debated and escalated for approval as required. This feedback loop continuously improves the quality of the STMP.

At the core of a successful STMP process lies integration, collaboration, and alignment (Otto, Lindeque, 2021). Sishen has improved the collaboration between the mining operations and mine technical services (MTS) teams by introducing formalised management routines supporting the development and approval of the monthly STMP. These routines are embedded through four formalised meetings, namely a monthly STMP inputs meeting, a monthly STMP review meeting, a monthly STMP sign-off meeting, and weekly pit visits meetings. These management routines ensure the planning process is predictable, repeatable and effective, and improve the quality of the STMP.

The STMP inputs meeting is held during the first week of every month and kicks off the monthly process that leads to the sign-off of the next STMP for execution. The purpose of this meeting is to agree on the terms of reference (or major input assumptions) that will form the basis of the next cycle of the STMP process. The meeting ensures that all key inputs are adequately analysed, discussed, and agreed by process owners prior to them being included into the STMP scheduling process. Importantly, the inputs are also evaluated against the BP to ensure alignment.

The agenda of the meeting typically covers the following: a review of the previous month's spatial mine-to-plan reconciliation performance, key input assumptions regarding HME performance, haul route and waste dumping inputs, grade control, product quality and processing plant assumptions, geotechnical considerations, and rain readiness aspects such as the position of sumps and areas of anticipated water accumulation. The DTS designs and PTs are also reviewed per mining pushback.

The meeting is chaired by the MTS manager, whilst representatives from the mining operations teams are led by the Manager Mining. The involvement of senior mine leadership enforces the importance of the meeting, creates a sense of discipline in terms of attendance, and ensures that quality decisions are taken to provide clear direction to the team developing the STMP. All relevant stakeholders involved in mining operations and MTS disciplines attend this meeting.

All risks and opportunities associated with the STMP, as well as ways to mitigate those risks and capitalise on the opportunities, are discussed in this meeting. If a topic is not raised in the STMP inputs meeting it is unlikely to form part of the STMP. Ultimately, the meeting provides clear direction to the team developing the STMP and prevents re-work. The STMP team can now effectively and efficiently complete the STMP schedule, which is then reviewed in the second meeting, namely the STMP review meeting.

The STMP review meeting occurs in the second week of the month. The objective of this meeting is to review the temporal and spatial outputs from the STMP schedule with the aim of firstly, ensuring alignment with the BP expectations and secondly, ensuring that the STMP schedule is effectively enabling the execution of the DTS designs and PTs per mining pushback. The meeting requires critical analysis of the 12-week schedule by all key stakeholders and process owners to adequately assess, challenge, and optimise the schedule prior to execution. As a part of the discussion, the following key questions are evaluated (Gentle, 2021):

- ➤ Does the schedule meet temporal and spatial annual BP targets?
- ➤ Does the sequence follow the DTS?
- ➤ How are drilling and blasting activities and the associated interaction with HME addressed?
- ➤ Have haul route, waste dump, and ROM stockpile options been adequately considered and incorporated in the 12-week schedule?

- ➤ What is the status of agreed mining value chain buffers?
- ➤ Does the 12-week schedule incorporate the agreed PTs, including assigning responsibilities and due dates for completion?

The collaborative nature of the meeting ensures that the STMP is rigorously evaluated and optimised. It provides a high degree of confidence in the execution of the STMP to all stakeholders, thus, ensuring practical executability of the STMP leading to improved spatial compliance to the BP. Following the STMP review meeting, the 12-week schedule is finalised for formal sign-off and communication.

The third management routine is the STMP sign-off meeting, which occurs in the third week of the month. In the sign-off meeting the STMP is physically signed off by the relevant stakeholders as a formal way of officially approving the monthly STMP and committing to achieving the requirements.

To ensure continuous alignment between the MTS team and the mining operational team, the STMP is discussed every Monday in the pit during a weekly pit visit meeting. This is the fourth meeting to complete the STMP management routines. The focus of the discussion is progress against the planned mining activities (including block preparation, drilling, blasting, loading, and hauling) for the current week and the following week. Progress with PTs is also tracked and discussed. The value of conducting this meeting face to face and in the pit is that team members have the same context of unforeseen risks and opportunities experienced on a day-to-day basis by the mining operational team. Now the teams can directly compare the planned versus actual mining activities. Being in the pit, the team members can visually inspect the mining progress, allowing for real-time assessment of how closely actual mining activities align with the STMP. Deviations that are picked up can be immediately addressed, allowing the mining operations to maintain their compliance to the STMP plan. These meetings solidify alignment between the mining operations team and the MTS team. Learnings from these meetings are also fed into the inputs meeting of the next STMP cycle.

In summary, the management routines followed at Sishen create a platform for collaboration between the teams developing the STMP and the teams executing the STMP. These interactions improve the quality of the STMP as well as the level of spatial execution of the STMP. The enhancements of the other components of the STMP process at Sishen enable and validate the spatial alignment between the STMP and the BP. In combination, these positively impacted on Sishen's spatial mine-to-plan compliance reconciliation performance.

Impact on spatial mine-to-plan compliance

At Sishen, the spatial alignment between mining execution and the BP is measured through a spatial mine-to-plan compliance reconciliation process. Otto and Musingwini (2019) discussed the implementation of spatial mine-to-plan compliance reconciliation at Sishen in the period between 2014 and 2016 and highlighted that the approach incorporated 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. At the time, the application of STMP as a tool to define and guide the spatial implementation of the BP (by bridging the gap between the BP and the daily operational mining activities and ensuring that spatial mining execution aligns with the BP) was not adequately incorporated in the spatial reconciliation process at Sishen. This contributed to a regression in the spatial mine-to-plan compliance reconciliation results after 2016. This paper provides insights into how the incorporation of effective STMP, in the spatial mine-to-plan compliance reconciliation process at Sishen during 2019 and 2020, led to the mine regaining the targeted spatial mine-to-plan compliance reconciliation results at the end of 2022 and sustaining these results into 2023.

Spatial mine-to-plan compliance against the BP is measured, reconciled, and reported monthly. The reporting format includes graphs in which the spatial mine-to-plan compliance is expressed as a percentage of planned tonnes mined using the categories suggested by Otto and Musingwini (2019). 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. The spatial mine-to-plan reconciliation results are compiled and expressed cumulatively over a 12-month period. Figure 10 is an example of a graph used to report the spatial mine-to-plan compliance at Sishen for the open pit mine as a whole. The figure illustrates that the cumulative spatial mine-to-plan compliance, for the year featured in the graph, was 82% at the end of May and increased to 94% by the end of December. This is relative to a target of 85% at Sishen.

Sishen also reports the spatial mine-to-plan compliance reconciliation results per pushback. This additional level of reporting provides visibility on the spatial reconciliation performance per individual mining area. Using these insights into the spatial reconciliation 'health' of the pushbacks assists in defining which pushbacks should receive more focused attention during the development of the next STMP, with the aim of improving the spatial mine-to-plan compliance performance of that pushback. Figure 11 is a graph indicating how the spatial mine-to-plan compliance is reported per pushback. From the graph it can be seen that Pushbacks 1, 8.1, 8.2, and 13 have significant (higher than 5%) planned areas that were not mined. Pushbacks 1 and 8.2 also present a high percentage of areas mined out-of-sequence. To address this, during the development of the next STMP, focus should be given to prioritise inputs, which will mitigate the challenges encountered in these pushbacks with the aim of improving the spatial compliance going forward. This could include redirecting mining capacity from mining areas ahead of plan towards mining the planned not mined areas. For the other pushbacks it is important to maintain the performance while ensuring adherence to the BP.

As discussed before, the results from the spatial mine-to-plan compliance reconciliation process are incorporated into the STMP routines. The reconciliation results are discussed and thoroughly analysed during the monthly STMP inputs meeting. The focus is firstly, on understanding the reasons for not mining the planned areas and for mining the areas outside of the annual BP (if any) and secondly, on identifying those pushbacks requiring specific interventions to address unsatisfactory spatial mine-to-plan compliance performance. These discussions ensure that the STMP directs mining activities to the correct spatial areas and incorporates the identified PTs.

The enhanced STMP process at Sishen has positively impacted the spatial mine-to-plan compliance performance against the BP. Figure 12 shows the end-of-year (December) spatial mine-to-plan compliance graphs from 2020 to 2023 inclusive. From the information presented in Figure 12, the spatial compliance at Sishen improved from 2020 to 2023. At the end of 2020 the spatial mine-to-plan compliance, measured against the approved BP at Sishen, was at 71%. At the end of 2022 the spatial mine-to-plan compliance had improved to 94% against a target of 85%. This performance was

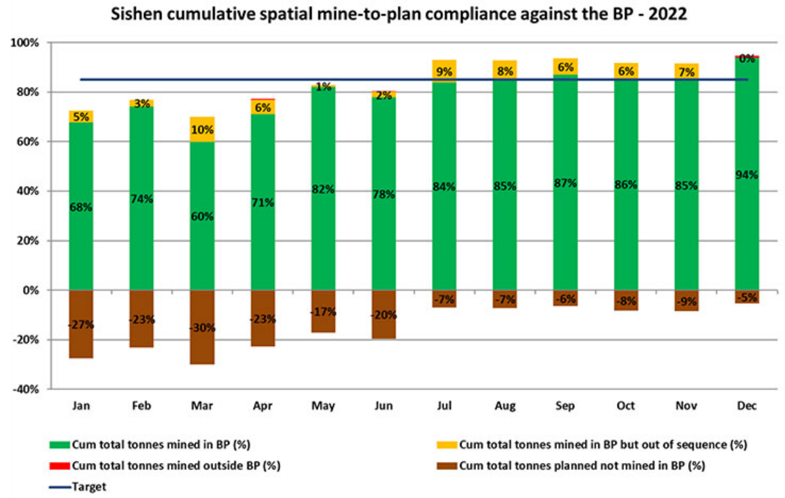

Figure 10—Spatial mine-to-plan compliance, Sishen performance (Pilane, 2022)

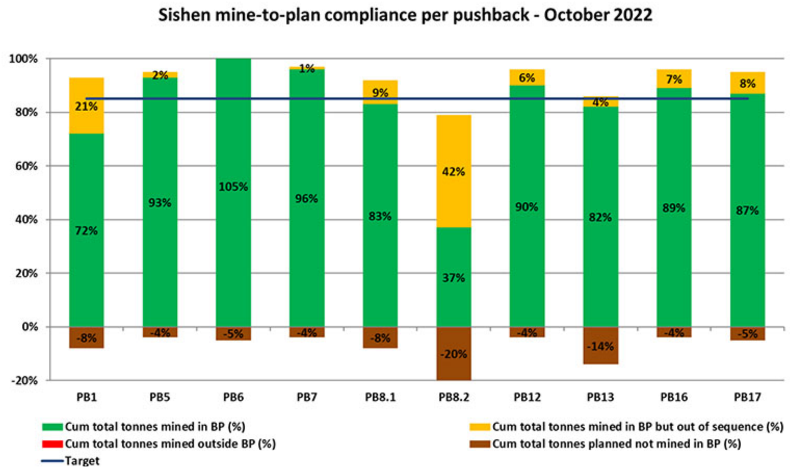

Figure 11—Spatial mine-to-plan compliance per pushback, Sishen (Pilane, 2022)

repeated in 2023, illustrating the sustainability of the results. The figure also indicates a reduction in the areas planned and not mined from 25% in 2020 to 6% in 2023, and a reduction in the areas mined outside of the annual BP, from 4% in 2020 to 0% (no mining outside of the annual BP) in 2023.

Conclusion

This paper presented the role that STMP plays in ensuring the effectiveness of the spatial mine-to-plan compliance reconciliation process at an open pit mine. A well-developed STMP process improves the alignment between mining execution and the BP, both from a temporal and a spatial perspective. An effective STMP process bridges the gap between the BP and the daily operational mining activities. The STMP is the plan that is physically executed and thus, provides the operational teams with detailed guidance needed to ensure mining execution is aligned with the BP requirements.

STMP is the ideal tool to use to facilitate and enable the forward-looking component of the spatial mine-to-plan compliance reconciliation process at an open pit mine. At Sishen, it is used to define and implement the corrective actions resulting from this reconciliation process, thus ensuring effective decision making.

Enhancements were made to the STMP process at Sishen, aimed at supporting the spatial mine-to-plan compliance reconciliation process. Firstly, introducing the DTS designs improved the practical executability of the STMP, which led to improved spatial compliance with the BP. The sequence per pushback, HME interaction, infrastructure considerations, access routes, and PTs are evaluated prior to the STMP scheduling process. Secondly, the STMP targets and effectively manages the health of mining value chain buffers. Focusing on these buffers enables the mine to effectively deal with short-term variability without the need to deviate from the STMP, thus, improving spatial mine-to-plan compliance. Thirdly, the introduction of a spatial plan-to-plan reconciliation, which compares the areas planned for mining in the STMP with those targeted in the BP confirms spatial alignment between the mine planning horizons. Finally, formal management routines, supported by senior mine leadership, are used to improve the collaboration between the mining operations and MTS teams. These management routines ensure that the STMP process is effective and improve the quality of the STMP.

These enhancements in the STMP process contributed to an improvement in the spatial mine-to-plan compliance reconciliation performance at Sishen in the period between 2020 and 2023 inclusive. The spatial areas mined within the approved annual BP increased from 71% at the end of 2020 to 94% at the end of 2022 and this performance was repeated in 2023, illustrating the sustainability of the results. In addition to the improved spatial mine-to-plan compliance reconciliation results, the increased alignment between the BP and mining execution contributed

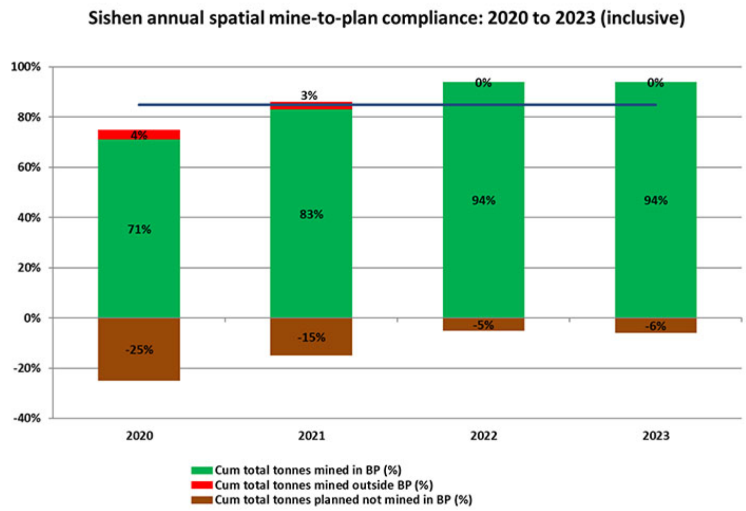

Figure 12—Sishen end-of-year spatial mine-to-plan compliance reconciliation results

positively to the mine safely achieving production targets in line with the BP expectations. Effective STMP supported the implementation of a spatial mine-to-plan compliance reconciliation process at Sishen and is a key contributor to the mine delivering and improving spatial mine-to-plan compliance to the BP. The approach presented in this paper can be adapted by other open pit mining operations to improve alignment between mining execution and the BP.

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